









water & forestry

Department:
Water Affairs and Forestry
REPUBLIC OF SOUTH AFRICA

BERG RIVER BASELINE MONITORING PROGRAMME

FINAL REPORT - VOLUME 3:

ESTUARY AND FLOODPLAIN ENVIRONMENT

DWAF Report No. P WMA 19/G10/00/1907

Edited by:

BARRY CLARK

October 2007

ANCHOR ENVIRONMENTAL

The Freshwater Consulting Group

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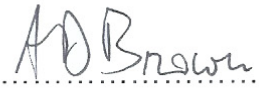


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CHAPTER 1 - INTRODUCTION

1.1 BACKGROUND

The overall objectives of the Berg River Baseline Monitoring Programme (BRBMP) are presented in Volume 1 of this report series. Briefly, the aims of the programme were to describe the natural and present state, including the natural variability, of those chemical, physical and biological characteristics of the river and its hydraulically linked systems (i.e. estuary, floodplains and groundwater) that are most likely to be affected by changes imposed after the construction of the Berg River Dam.

The overall approach to the baseline monitoring programme, for both river and estuarine components was the initial sourcing and collation of a considerable volume of data and information already existing for the Berg River System, previously collected as part of other programmes and/or projects. Each specialist involved on the project was required to collate all available data within his/her field of expertise. The data were then used by the specialists to provide a series of situation assessments, each dealing with a different component of the Berg River or estuary. These assessments included an outline of the present ecological condition of the Berg River, as well as a description based on present knowledge of the structure and functioning of the ecosystem, both historically and in the present day. This was augmented by a field study component.

1.2 ESTUARINE MONITORING PROGRAMME

As part of the development of conceptual relationships between different ecosystem components and the hydraulic / hydrological environment, specialist studies were undertaken over the three-year monitoring programme. The design of the surveys was a) to provide detailed information for the description of ecosystem functioning, but also b) to provide baseline data of variables that would be important to monitor in the long term, to measure predicted or identify undesirable change, to facilitate adaptive management of the Berg River Estuary.

The focus of data analysis was to refine current understanding of links between the various ecosystem components and the flow regime. A two-dimensional hydrodynamic and sediment transport model, integrating flow, channel hydraulics and sediment transport, provided depth and velocity data over the estuary and floodplain that served as a basis for other specialists to describe hydraulic and hydrological drivers of their component – water chemistry, riparian and floodplain vegetation, micro- and macro-algae, invertebrates, fish and birds. A summary of the main components of the riverine monitoring programme, and the focus of the field studies is presented in Table 1.1. All specialists were required to provide a list or description of the key processes affecting their particular component, and to make predictions of the kinds of changes that might be expected as a result of changes in the flow regime of the river following construction of the Berg River Dam. Future monitoring requirements are also provided in each specialist report.

The ultimate aim of such an exercise was to synthesise the key aspects of each specialist report, to describe in conceptual terms the physical and biological dynamics of the ecosystem. This is provided in the synthesis statements in Volume 5 of this report series.

1.3 SELECTION AND LOCATION OF ESTUARINE/ FLOODPLAIN MONITORING SITES

Site selection was based on a different set of criteria for each discipline, and the monitoring sites are indicated on maps within each of the relevant chapters. Estuarine sampling sites were selected for channel topography survey for the hydrodynamic and sediment transport modelling; for water quality measurement; nutrient data collection; estuarine algae; estuarine and floodplain vegetation; macroinvertebrate; fish and bird data collections

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Table 1.1 Terms of reference forfield data collection and analysis for each specialist component of the estuary and floodplain monitoring programme.

BRBMP study component	Sampling details
Topographic surveys of estuary	Survey 40 cross sections along the 40 km estuary, each transect extending from above the high water mark on one bank to the same position on the opposite bank and is to cover a width of 20 m, as input data to hydraulics studies and hydrodynamic model. Repeat sampling of 12-15 cross sections annually for monitoring of channel changes.
DTM of the Berg River floodplain	Digital terrain model (DTM) and orthoimagery for the Berg River Estuary and surrounding flood plain area at a 1:10 000 scale, with ground pixel size 0.25 m and RMS 0.167 m as input data to hydrodynamic model. Interpolation of the river bed terrain model, as determined from the cross-section and mid-stream survey data.
Hydraulics and sediment transport model	Set up a hydraulic model and calibrate based on tidal and flood data, with channel network and floodplains, vegetation, cohesive sediment, water losses and wind effects; investigate flood attenuation and hydraulics of floodplains. Develop a conceptual model of sediment dynamics and mass balance simulation, considering: existing data, tidal effects, floods, non-cohesive and cohesive sediment, historical changes (man-made), long-term dynamics of the main channel and floodplains. Undertake bed and suspended sediment sampling, identification of sediment sources, and spring tide and flood monitoring to calibrate the model, for calibrating the model Provide outputs of future changes in depth and velocity distributions over the estuary and floodplain, and sediment changes, with the Berg River Dam in place.
Water quality	Measure key water quality variables (temperature, salinity, depth, DO and pH) at the 40 surveyed cross sections (0.25 m depth intervals) under spring high, spring low, neap high and neap low tide conditions at quarterly intervals, and source concurrent weather data. Quantify key hydrological and biochemical processes influencing water quality in the estuary, particularly the plug of slow moving water that develops in the middle reaches of the estuary during summer as a result of low river inflow.
Nutrient dynamics	Collect and interpret data on water quality (nutrient) measurements at spring high + low tide at the 40 survey cross sections, measured on a quarterly basis in 2005.
Microalgae	Collect and interpret data on microalgae species composition and abundance at the 40 survey cross sections, on a quarterly basis in 2005.
Macroalgae	Assess the extent (coverage) and biomass (wet biomass of an area of 100% coverage) of *Cladophora* on mud banks at six sites on the estuary at weekly intervals from September through January of each year; interpret patterns in relation to hydrological and water chemistry patterns.
Macrophytes	Once-off mapping of the locations and extent of submerged vegetation (Zostera) in 2005, assessed in relation to flow and water chemistry.
Vegetation	Re-map the floodplain vegetation, including the provision of digitised maps and descriptions of plant communities, and a description of changes relative to existing maps of floodplain vegetation. Collect cross-section data on changes in vegetation or species assemblages at three of the surveyed estuarine sites, on an annual basis. Monitor vegetation change along transects within the floodplain, selected after initial mapping to cover areas of potential change (vegetation unit boundaries), on an annual basis.
Invertebrates	Seasonal (winter and summer) survey of the intertidal, benthic subtidal and zooplankton invertebrate fauna of the estuary and flood plain areas. A minimum of 12 stations should be sampled each including replicate core (intertidal), grab (subtidal) and hyperbenthic sled (subtidal) and zooplankton samples. At least two of these stations should be located in temporary/semi-permanent/permanent pans on the flood plain. Identify diversity, distribution, abundance, biomass habitat use by these specie and appropriate indicator species.

BRBMP study component	Sampling details
Fish	Seasonal (winter and summer) survey of the fish fauna of the estuary and flood plain areas. Identify distribution, abundance, and habitat use by fish specie over the full extent of the estuary, and potential floodplain use in winter. Identify species of regional or national importance.
Birds	Establish diversity, distribution, abundance and biomass of bird populations in the Berg River estuary and surrounding flood plain, based on historic and current (i.e. for the duration of the monitoring period) Collected Waterbird Count (CWAC) data. Augment CWAC data by undertaking two comprehensive bird counts over the whole estuary. Identify species of regional, national and international importance (breeding/non-breeding populations). Establish diversity, distribution, abundance and biomass of bird populations; habitat use, important breeding and feeding areas/habitats within the estuary and assess breeding productivity of component species. Classify foraging guild structures within the different habitats and assess whether/how these change along the estuary.

1.3.1 Cross-sectional survey sites on the estuary/floodplain

For the initial phase of the programme, 43 sites were selected by the hydraulics team, with input from the water quality specialist. These were required to span the length of the estuary, to tie in with the DTM of the floodplain, both of which fed into the development of the hydrodynamic model for sediment transport. Twelve of these were surveyed annually, as the basis for an ongoing monitoring programme extending beyond this project. Water quality (temperature and salinity) data were monitored at 25 of the 43 survey sites, spanning the length of the estuary.

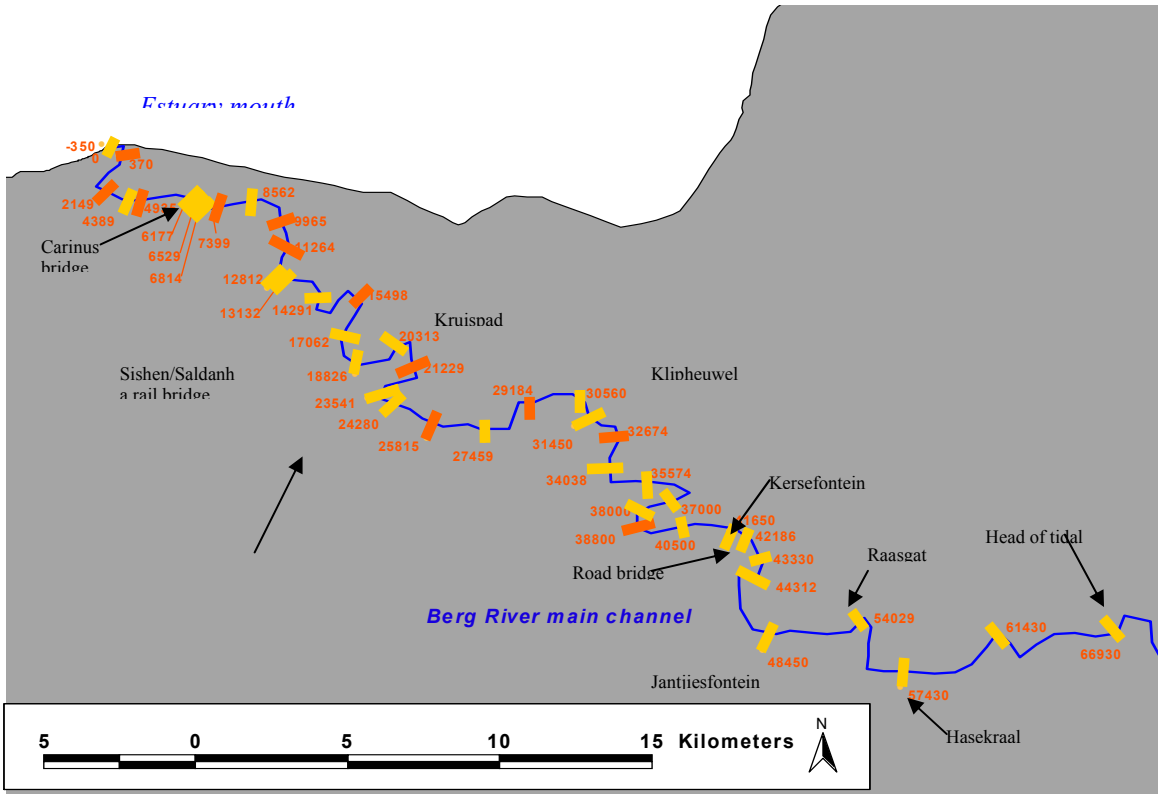


Figure 1.1 Location of bathymetric survey transects along the length of the estuary, established in 2003. Each transect label reflects the chainage (distance upstream in kilometres) from the estuary mouth. All transects were surveyed in 2003. Those indicated in orange were re-surveyed in 2004 and 2005.

1.3.2 Biological monitoring sites on the estuary/floodplain

Algal data were collected at five of the water quality monitoring sites, located near sites where historical data were available.

Vegetation sampling transects were selected after the compilation of the detailed floodplain vegetation map in 2003, and monitored from 2004 onward. Thirteen sites were selected for long-term monitoring of plant community changes. Five of these were surveyed to provide elevation data alongside the plant community zonation patterns whilst plant community records (no height data) were collected from a further eight transects on the floodplain.

Fish and invertebrate sampling sites were selected to coincide where possible with sampling points from previous studies, to incorporate the length of the estuary, to include seasonally inundated areas in winter, and to tie-in with each other and some of the water chemistry sites to assist in interpretation of data and development of conceptual linkages between ecosystem components. Fifteen subtidal invertebrate sampling sites were located along the estuary. A further four intertidal sites and four floodplain pan sites representing the floodplain sampling sites were sampled in winter field trips.

Fish were sampled during summer and winter at 41 and 45 sites, respectively. Sites were arranged from the mouth upstream for a distance of 64 km. The three additional sites during winter were located in floodplain lakes immediately adjacent to the main channel.

Birds were counted during mid-summer (February) and mid-winter (July) 2004 in 13 sections of the Berg River Estuary, as part of the ongoing Co-ordinated Waterfowl Counts (CWAC) programme. Additional monthly counts were undertaken from September to November 2005, to further elaborate seasonal variations in use of the estuary and floodplain by migratory bird species.

1.3.3 Photographic record

High resolution digital aerial photographs were taken of the entire estuary/flood plain for the purposes of compiling a Digital Terrain Model (DTM) for hydrodynamic modelling studies. These photographs also serve as a record of the state of the estuary in 2003. These photographs are presented in Figure 1.2 – Figure 1.11. Additional photographs were taken at key localities down the length of the estuary for the purposes of recording socioeconomic activities. Locations at which the photographs were taken are indicated in Figure 1.12 and the photographs themselves are reproduced in Figure 1.13.

1.4 CONTENT OF THIS REPORT VOLUME

This volume provides detailed descriptions of each of the physicochemical and ecological components of the Berg River Estuary studied as part of the Berg River Baseline Monitoring Programme. This includes the following components:

- Hydraulics and Fluvial Morphology (Chapter 2).
- Water chemistry - Salinity, Temperature, Oxygen and Turbidity (Chapter 3).
- Water chemistry – Nutrients (Chapter 4).
- Microalgae (Chapter 5)
- Submerged macrophytes and macroalgae (Chapter 6)
- Berg River Estuarine and Floodplain Vegetation (Chapter 7).
- Invertebrates (Chapter 8)
- Estuarine Fish (Chapter 9)
- Birds (Chapter 10)

Each chapter provides a detailed description of the current state of the system as revealed by survey activities conducted as part of the programme as well as a summary of any historic information available on the system. Each chapter also includes conclusions and statements from the various experts (authors) regarding the natural variability observed in the system during the baseline monitoring period and from historical data, its relevance to ecological sustainability, key processes that affect the physical or biotic component(s) in question, as well as key parameters that could be used as indicators to measure future changes in the system.



Figure 1.2 Mosaic of aerial photographs of the Berg River estuary. Detailed views of the areas within the boxes 1-9 are reproduced in Figure 1.2 – Figure 1.11



Figure 1.3 Mosaic of aerial photographs of the Berg River estuary. Box 1 from Figure 1.2.



Figure 1.4 Mosaic of aerial photographs of the Berg River estuary. Box 2 from Figure 1.2



Figure 1.5 Mosaic of aerial photographs of the Berg River estuary. Box 3 from Figure 1.2.



Figure 1.6 Mosaic of aerial photographs of the Berg River estuary. Box 4 from Figure 1.2..



Figure 1.7 Mosaic of aerial photographs of the Berg River estuary. Box 5 from Figure 1.2.

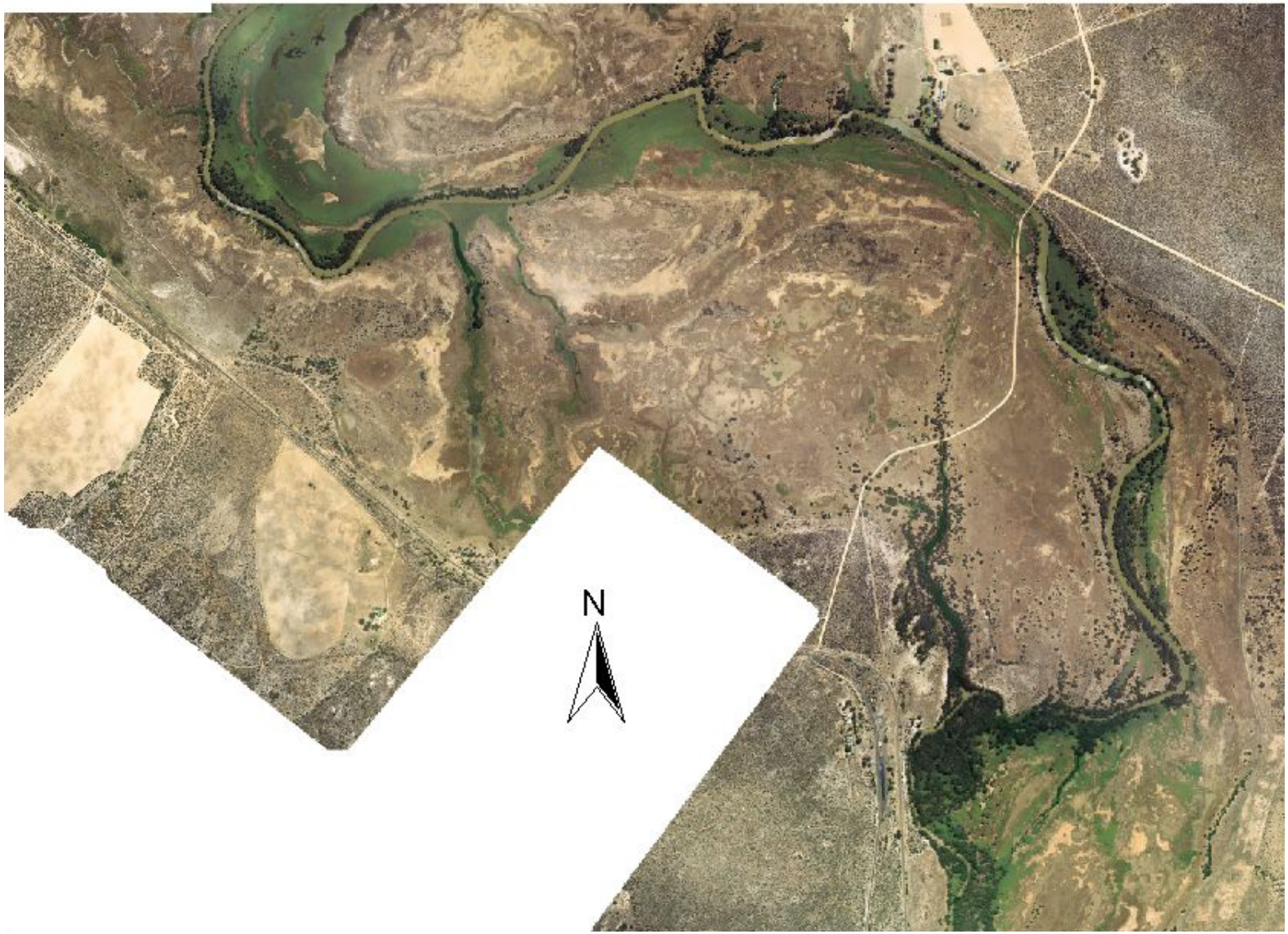


Figure 1.8 Mosaic of aerial photographs of the Berg River estuary. Box 6 from Figure 1.2.



Figure 1.9 Mosaic of aerial photographs of the Berg River estuary. Box 7 from Figure 1.2.



Figure 1.10 Mosaic of aerial photographs of the Berg River estuary. Box 8 from Figure 1.2.

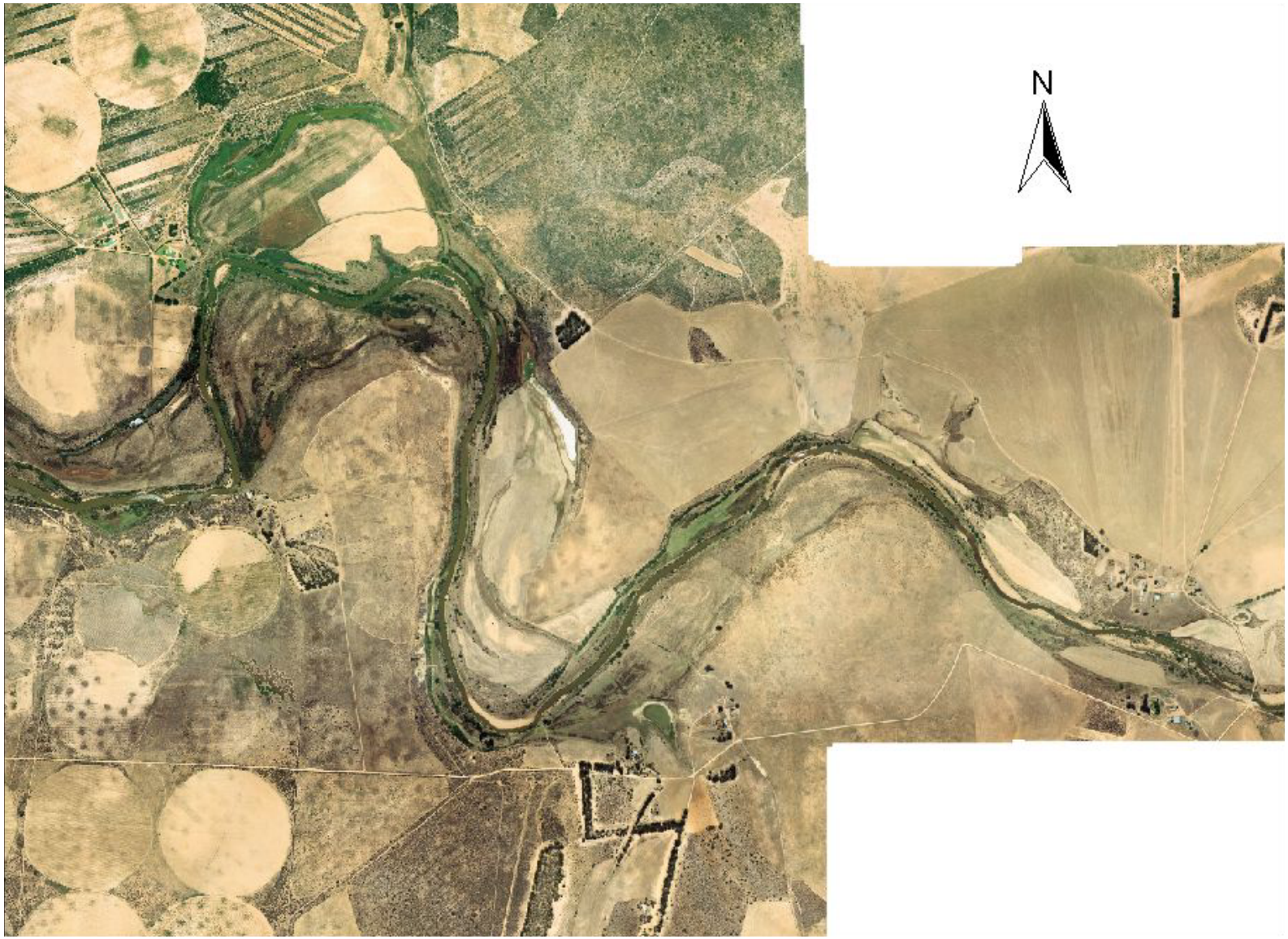


Figure 1.11 Mosaic of aerial photographs of the Berg River estuary. Box 9 from Figure 1.2.

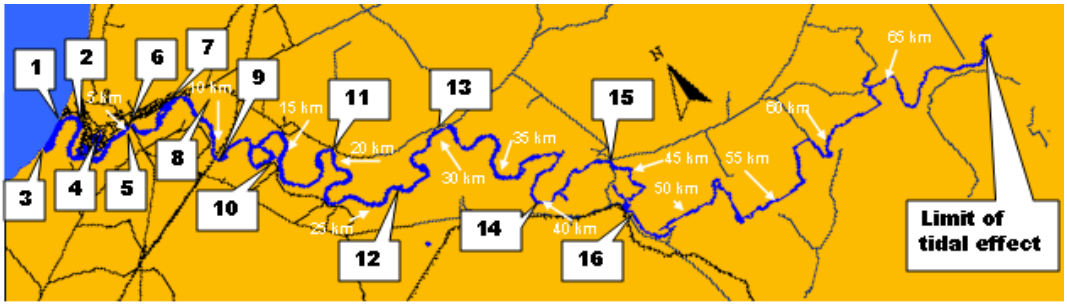


Figure 1.12 Berg River estuary, showing 5 km divisions and the locations of the photographs presented in Figure 1.13.



Figure 1.13 Berg River estuary, photographs of selected sites as indicated in 1.12.

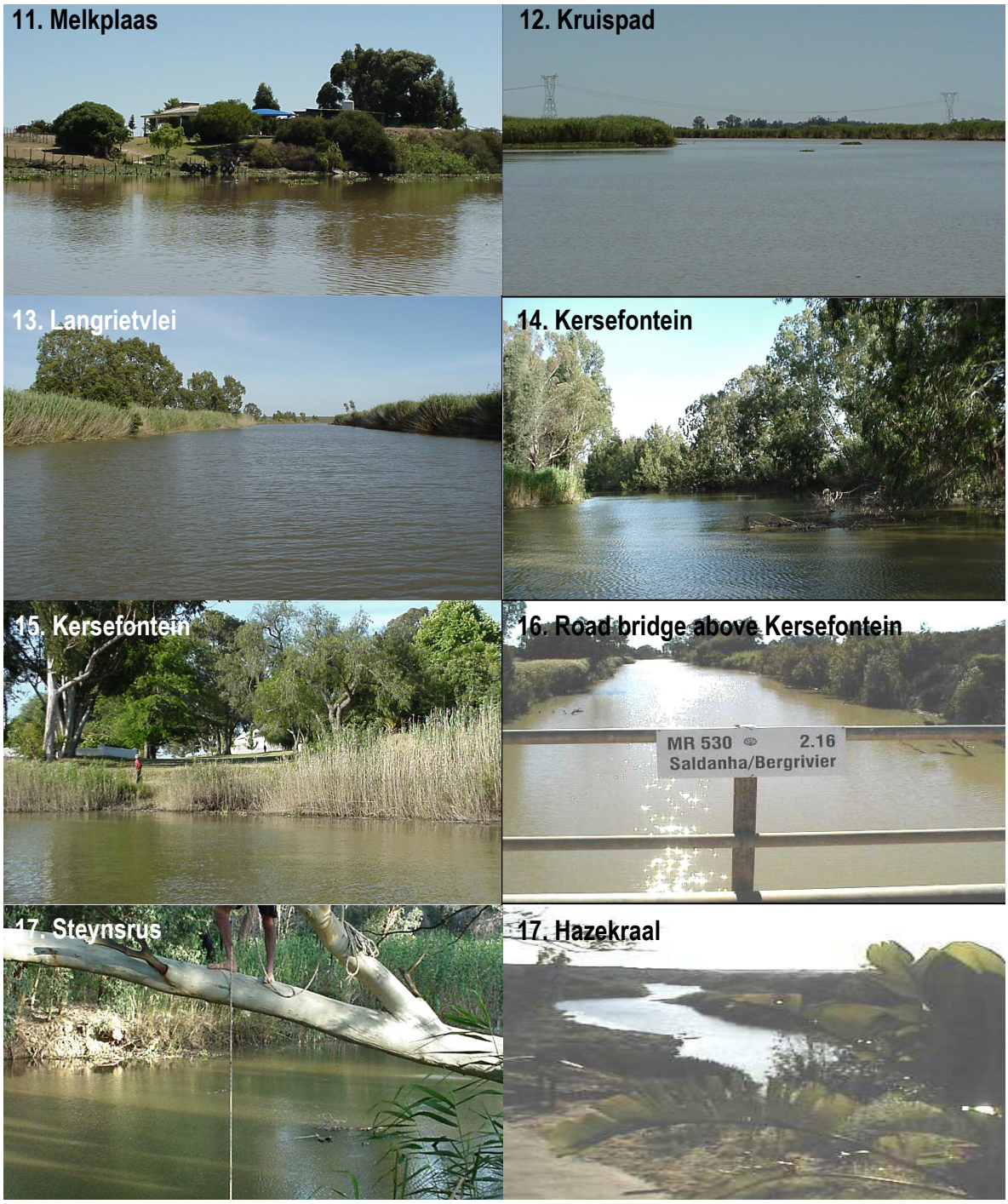


Figure 1.13 Continued. Berg River estuary, photographs of selected sites in the upper portion of the estuary, as indicated in 1.12.

CHAPTER 2 - HYDRAULICS AND FLUVIAL MORPHOLOGY

J.S Beck & G.R Basson

2.1 INTRODUCTION

The Berg River estuary is located 140 km north of Cape Town on the R27. It is one of the largest estuaries in South Africa and only one of four perennial estuaries on the arid west coast of Southern Africa. The estuary is about 33 km long (in a straight line) and consists of a highly sinuous main channel that's tide dominated in the lower reaches, ephemeral pans, salt marshes, and intertidal mud flats.

This study was carried out for the Department of Water Affairs and Forestry and provides hydraulic baseline information on the Berg River Estuary, Western Cape. The study was carried out during the period 2003 to 2006. The scope of work included an assessment of historical changes of the estuary through aerial photos and three surveys carried out during the study. A comprehensive survey was also carried out of the floodplain areas of the estuary to create a detailed Digital Terrain Model (DTM) with xyz data at a spacing of 7 m.

In order to understand the hydrodynamic functioning of the estuary a detailed mathematical model of the estuary was compiled to simulate the flow patterns including tides, low flow and floods. The simulation results can be used to determine flow depth and velocity duration curves in the estuary, and to establish flood inundation areas for different flood peaks, volumes, and starting water level conditions. By using this data a conceptual model can be established to determine the decrease in flooded area caused by the Berg River Dam, in future.

2.2 HISTORICAL INFORMATION

This chapter provides an overview of historical data pertaining to the hydraulics and fluvial morphology of the Berg Estuary, obtained mainly from a literature survey and through the analysis of historical aerial photographs. The aerial photographs were used to identify changes in the morphology of the estuary.

A literature review of historical data has shown that very little information is available on the hydraulics and sediment transport dynamics of the Berg Estuary. The available information is discussed here.

2.2.1 Documentation

The following is a list of some of the documents on which this review is based and the data available therein:

Anon. (1963): Bathymetric surveys between Velddrif and mouth; Depth soundings in the ocean at the mouth, and in the lower river; Sand samples; Measurements of: wind, waves, tides, ocean currents, water levels in the river and sea, current measurements in the river, silt transport in river.

Coetsee & Grobbelaar (1969). Model study of new estuary mouth.

Day (1981): Description of Berg River estuary.

Van Wyk (1983): Effects of dredging on the estuary.

Van der Merwe (1988): Bathymetric survey 1986 and 1987 and sand sample analysis.

Anderson (1991): Historical changes in the estuary.

Whitfield (1995): Description of available scientific information on South African estuaries.

Anon. (1996): An attempt to determine whether the pumping of the dredged material from the Port Owen marina into the river during ebb spring tide and river flood conditions would negative affect the fishing harbour.

Sediment gradings and current measurements are available. Investigation by Ninham Shand for later dredging of the marina channel.

Vonk (1996): Tables and graphs of velocity variations between Port Owen and the river mouth during outflowing water.

2.2.2 Dredging

Dredging was undertaken at the Port Owen Marina and the estuary mouth to facilitate the movement of sailing and fishing vessels in and out of the estuary and the marina. Several environmental studies were undertaken before dredging was carried out at the marina. In May to September 2000 and 2001, 79 000 m^3 were dredged from the marina (Dawid van Wyk, pers comm. Ninham Shand, 2004). Dredging only took place during the winter months to ensure that the fine sediment would be flushed out to sea, and not accumulate in the estuary.

2.3 ANALYSIS OF AERIAL PHOTOGRAPHS OF THE ESTUARY AND SURVEY DATA

Several historical aerial photographs were analysed in this study.

1930's: At this time, the terminal part of the Berg Estuary channel ran parallel to the coastline before it opened into the ocean at the southwest end of an extended berm. Some development existed along the lower estuary, but as yet there were no structures affecting the flow of the river. The main river channel was clearly visible, but there were large floodplain areas which appeared to be permanently inundated, and there were several smaller channels that ran across these areas. The Carinus Bridge had not been built, and a pont was still in use at the time (Figure 2.1).

1940's: The mouth was in the same position as in 1938 (Figure 2.2). Note the two sandbars stretching outward on each side of the mouth.

1960's: The R 399 downstream of Jantjiesfontein had been reconstructed much closer to the river than it was in the 1940's and 50's. Some channels in the upper reaches of the estuary close to Steenboksfontein were a lot more defined in the 1960's than they are now. At Steenboksfontein cultivated areas were observed on the floodplain. The river upstream of Steenboksfontein was about 75 m wide. The floodplain of the estuary at Lang Riet Vlei farm about 21 km from the mouth was about 5.5 km wide.

The mouth was slightly narrower than in 1942 and the outer sandbars had disappeared (Figure 2.3), having been replaced by a single sandbar extending into the estuary on the right side of the mouth. Development along the lower estuary had increased and the Carinus Bridge (R27) had been built across the estuary at Velddrif.

1970's: In 1969 the mouth was artificially shifted to the northeast end of the berm, the new mouth being less than half the size of the original mouth in 1960 (Figure 2.4). Salt mining had commenced on the floodplain area inside the first bend upstream of the mouth, opposite Laaiplek, as well as opposite the future Port Owen development.

The now redundant channel to the old mouth was starting to silt up. Salt mining was now also taking place upstream of the R27 road bridge close to Die Plaat, and roads had been built across the floodplain in some places in the lower estuary. No significant changes had been observed in the upper estuary up to now. The railway bridge upstream of Die Plaat was by completed in the early 1970's.



Figure 2.1 Velddrif in 1938

1980's: The River upstream of Steenboksfontein was about 50 m wide. The floodplain of the estuary at Lang Riet Vlei farm about 21 km from the mouth was about 4.8 km wide (down from 5.5 km in 1960's).

A secondary channel was clearly visible cutting across the floodplain between the Berg River pump station and downstream of the Aurora Road bridge. It is barely visible now.

The old river channel to the old mouth had filled up significantly since 1977, becoming narrower and shallower. The Port Owen development was clearly visible and the floodplain area on both sides of the R27 road bridge was now also being used extensively for salt mining. The river bend just upstream of the Carinus Bridge had moved closer to the left bridge approach (Figure 2.5).

1990's: The river channel upstream of the Carinus Bridge at Velddrif was around 150 m wide in 1998, compared to only 100 m at the start of the 1990's. The reason for this is not clear, but could be as a result of a recent flood. More recent photos would show if a trend could be observed. The old river channel to the original mouth was almost completely silted up and extensive salt mining was taking place on the floodplain along the lower estuary up to Die Plaat (Figure 2.6). By the end of the 1990's flood embankments had been built on the floodplain upstream of the Carinus Bridge and the Railway Bridge where salt mining was being carried out. The river was confined almost exclusively to the main channel in that area and had moved even closer to the left R27 bridge approach.

Further upstream very little development had taken place on the floodplains close to the river and the estuary retained much the same size and course than in 1938. The railway bridge had not affected the flow to Die Plaat.



Figure 2.2 Berg River estuary mouth in 1942



Figure 2.3 Berg River estuary mouth in 1960



Figure 2.4 Berg River estuary in 1971



Figure 2.5 Berg River estuary in 1986

Summary

The main channel has become narrower in places, which may be the result of reduced inflow from the catchment or floodplain developments in the estuary, but may also be the result of the natural dynamics of the estuary. The changes that have occurred have not been drastic, and since the estuary is a very large system, these do not seem to have had a significant effect on the hydraulics and sediment transport in the estuary. The greatest changes have occurred in the mouth region, and the effects of those are clearly visible.

The construction of a new mouth may have reduced tidal flux in and out of the estuary to some degree, disrupting sediment transport processes in the mouth region. This could be the reason for the ongoing dredging that has had to be carried out in that region.

The salt mining on the floodplain has probably led to a reduction in floodplain area. This could have resulted in higher water levels and higher flow velocities in the estuary during floods, but this would probably not be very significant, as the salt mining is not very widespread.

Apart from the R27 (Carinus) road bridge, the other bridges do not seem to have had a noticeable effect on the river hydraulics. The R27 road bridge has caused local scouring of the bank at the left river bend recently.



Figure 2.6 Berg River estuary in 1998

2.3.1 Analysis of recent cross-section surveys

Surveys of the main channel of the estuary were carried out during this study in January 2003, June 2004 and March 2006, and are attached in Appendix 1.1. Bed elevation changes over this three year period were relatively small, within the survey vertical accuracy. Survey data obtained from the CSIR of the 1990's could not be used since the data were not georeferenced.

2.4 HYDRODYNAMIC AND MORPHOLOGICAL MODEL SETUP

2.4.1 Numerical model background

For the computational modelling, the two-dimensional model MIKE 21, developed by the Danish Hydraulics Institute (DHI, 2003), was used. MIKE 21 is a software package for simulating free-surface flows, water quality, sediment transport and waves in rivers, lakes, estuaries, bays, coastal seas and other water bodies. In particular MIKE 21C, a special module developed to simulate river morphology, was used. MIKE 21C is based on a curvilinear grid, and hydrodynamics, sediment transport and river morphology can be simulated, with modules to describe:

- Flow hydrodynamics – water levels and flow velocities over a curvilinear or rectangular grid are computed and the model is fully hydrodynamic.
- Helical flow (secondary currents).
- Sediment transport – based on various model types, capable of graded sediment transport computations.
- Alluvial resistance due to bed material and bed forms.
- Scour and deposition – large-scale movement of bed material is computed and the effect of supply limited sediment layers can be incorporated.
- Bank erosion and planform changes – bank lines as well as the curvilinear grid can be updated.
- The 2D model integrates velocity and sediment profiles in the vertical, but caters for the vertical sediment distribution in sediment transport by profile functions and is therefore a pseudo 3D model.

The modules can run interactively, incorporating feedback from variations in the alluvial resistance, bed topography and bank line geometry to the hydrodynamics and sediment transport.

2.4.2 Scenarios

Flood hydrographs were simulated (hydrodynamics and sediment transport) for both the present as well as post-dam flood releases scenarios, in order to determine the effect that the Berg River Dam may have on estuarine dynamics (see Beck *et al.* 2004 for details on the two scenarios). Table 2.1 lists the floods that were simulated by the MIKE 11 model routed from the Berg River Dam to the head of the estuary, with the inclusion of tributary flows along the length of the river. The floods were selected randomly to include a range of small to large floods. It should be noted that the attenuation in the pre- and post-dam flood peaks are not always the same as this depends on the initial flow conditions in the river and tributary flow.

Longer term simulations were carried out on the winter flows of 1998 to 2003 to establish a relationship between inflow, flood volume, initial water levels and inundated area.

Table 2.1 Simulated floods[1]

Date	Present Peak [m^3/s]	Post-Dam Peak [m^3/s]	Comment
1999/06/19	90	90	100 m^3/s artificial flood at the dam
2002/07/30	284	274	220 m^3/s artificial flood at the dam
1996/07/04	457	403	Approx. 1:5-year flood (pre-dam)
1997/06/29	622	525	Approx. 1:10-year flood (pre-dam)
2001/07/20	890	833	Approx. 1:100-year flood (pre-dam)

2.4.3 Model setup

Two different models were set up, one for the tidal action, and one for the flood simulations. The model for the tidal simulations only was set up from the head of the estuary at Steenboksfontein to the sea (see Figure 2.7). Downstream of the mouth an area was added onto the surveyed points to represent the sea for the tidal action simulations.

A curvilinear grid with 910 grid cells in the flow direction and 174 grid cells across the flow direction was used for the hydrodynamic simulations of the tidal action, with a cell size of approximately 30 m x 15 m. The model bathymetry was based on the 2003 aerial survey (Digital Terrain Model) of the estuary and floodplain. As the DTM did not include points in the main river channel (these were under water), this (the river channel) was added on later. This was done by extracting the outline of the main river channel from the DTM and creating the bathymetry by interpolation from a series of cross section across the estuary channel taken in 2004 as well as a longitudinal profile along the length of the main channel.

The model for the flood simulations was set up from just downstream of Kersefontein to the mouth of the estuary (see Figure 2.8). The region upstream of Kersefontein could not be included in the model, as the main channel in that area was so narrow in places that the chosen grid could not pick up the main channel at all points. This resulted in the main channel being interrupted at many points, leading not only to inaccurately simulated flow conditions, but also causing the model to become highly unstable. However, the floodplain in the area upstream of Kersefontein is relatively narrow, flow is confined to a small area, and tidal variation at this point is very small (according to the data from G1H023 at Jantjiesfontein). This implies that the impact of omitting this section of the estuary would not have significantly affected the accuracy of the simulations.

A curvilinear grid with 1485 grid cells in the flow direction and 350 grid cells across the flow direction was used for the hydrodynamic and morphological simulations of the floods, with a cell size of approximately 15 m x 15 m. For the tidal simulations a larger grid was used than for the flood simulations, mainly to reduce the time it takes to run the simulations. A smaller grid size was required for the flood simulations, as significant morphological changes and high velocities that occur during these floods, can better be resolved with a smaller grid.

For the tidal model an inflow time series was specified at the upstream boundary. This time series consisted of simulated flows extracted from the one-dimensional hydrodynamic and morphological model of the Berg River (Beck et al. 2004).

[1] For details on pre- and post-dam return period flood magnitudes see Beck *et al*. (2004).

Typical summer and winter conditions were simulated. For the summer conditions the approximately one month long simulation period ran from 1999/02/01 to 1999/03/08 (see Figure 2.9). The period was chosen as a typical tidal period without flood effects, and the spring and neap tide are within the typical range. For the winter conditions an approximately one month long simulation period from 1996/06/01 to 1996/06/23 was chosen. This period included two smaller floods of less than 100 m^3/s magnitude and one large flood of 600 m^3/s magnitude (see Figure 2.10). A water level time series with hourly time steps, representing the tidal variation in the sea, was specified at the downstream boundary (see Figure 2.11). The tidal variations were simulated, based on the tidal constituents at Saldanha.

For the flood simulations, the actual flood hydrographs were simulated together with the observed initial water levels from gauge G1H023 for each of the floods. The simulations were run for five days, to allow enough time for the floods to travel through the estuary.

The sediment transport simulated with the one-dimensional river model for the different flood peaks was specified as a boundary condition as well.

A uniform sediment size of 0.22 mm was specified throughout the whole model, which was based on bed sediment samples taken in the field (see Figure). This also corresponds to the effective particle diameter of the sediment used in the one-dimensional model. The hydraulic resistance was varied such that the resistance on the floodplain was higher than that in the channel. Model parameters for both models are given in Table 2.2 and Table 2.3.

Table 2.2 Hydrodynamic model parameters – tidal action

Parameter	**Value**
Hydrodynamic time step	15 s
Flooding depth	0.2 m
Drying depth	0.1 m
Manning n	45 $m^{0.33}$/s
Eddy viscosity	0.1 m^2/s

Table 2.3 Hydrodynamic and morphological model parameters – floods

Parameter	**Value**
Hydrodynamic time step	5 or 6 s
Morphological time step	21 or 24 s
Flooding depth	0.2 m
Drying depth	0.1 m
Manning n	45 $m^{0.33}$/s
Median grain diameter	0.22 mm
Sediment transport formula	Engelund and Fredsøe
Eddy viscosity	0.1 m^2/s
Mass density of sediment	2650 kg/m^3
Porosity	0.35

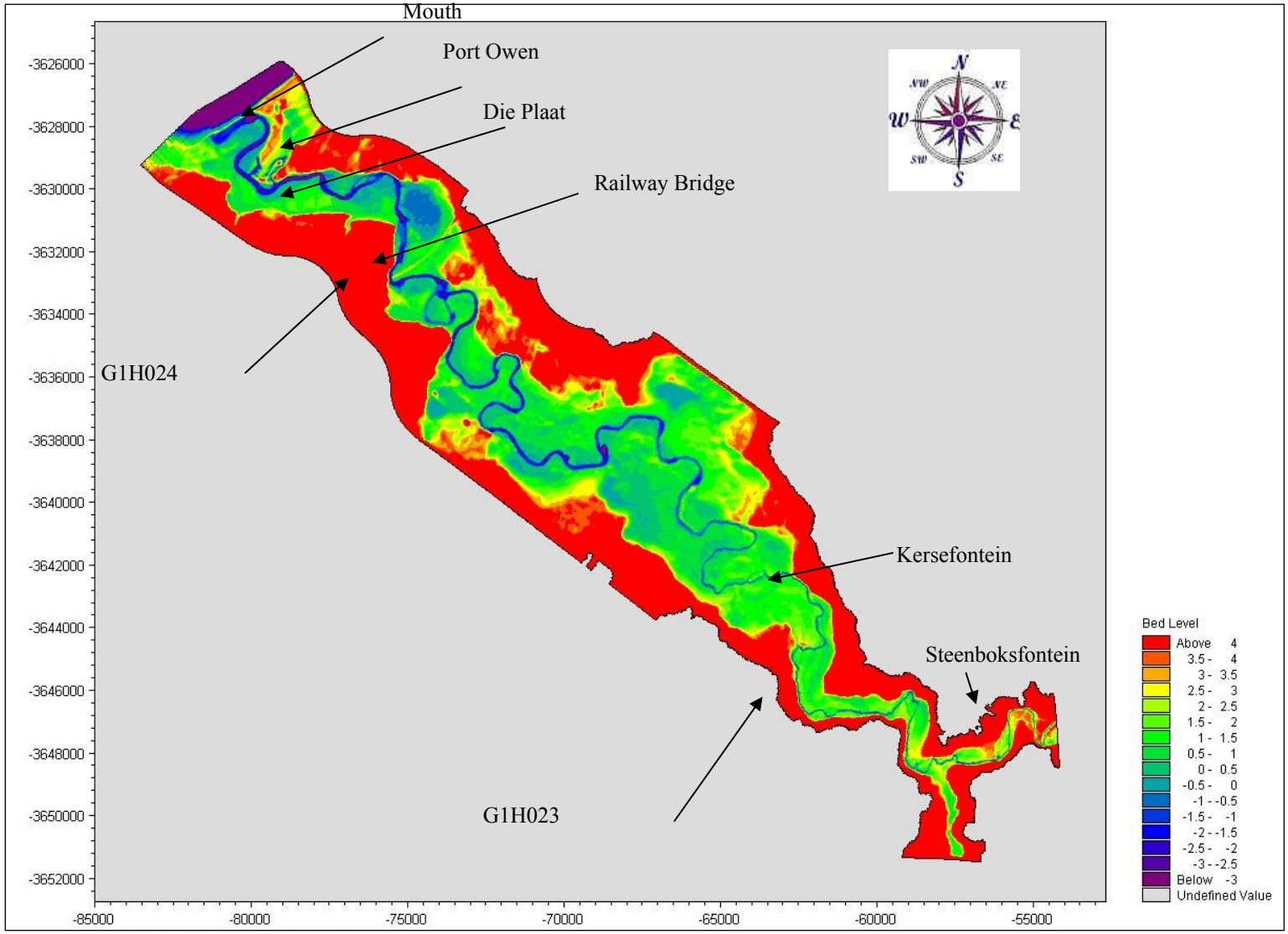


Figure 2.7 Berg River estuary bathymetry (relative to mean sea level) for tidal simulations

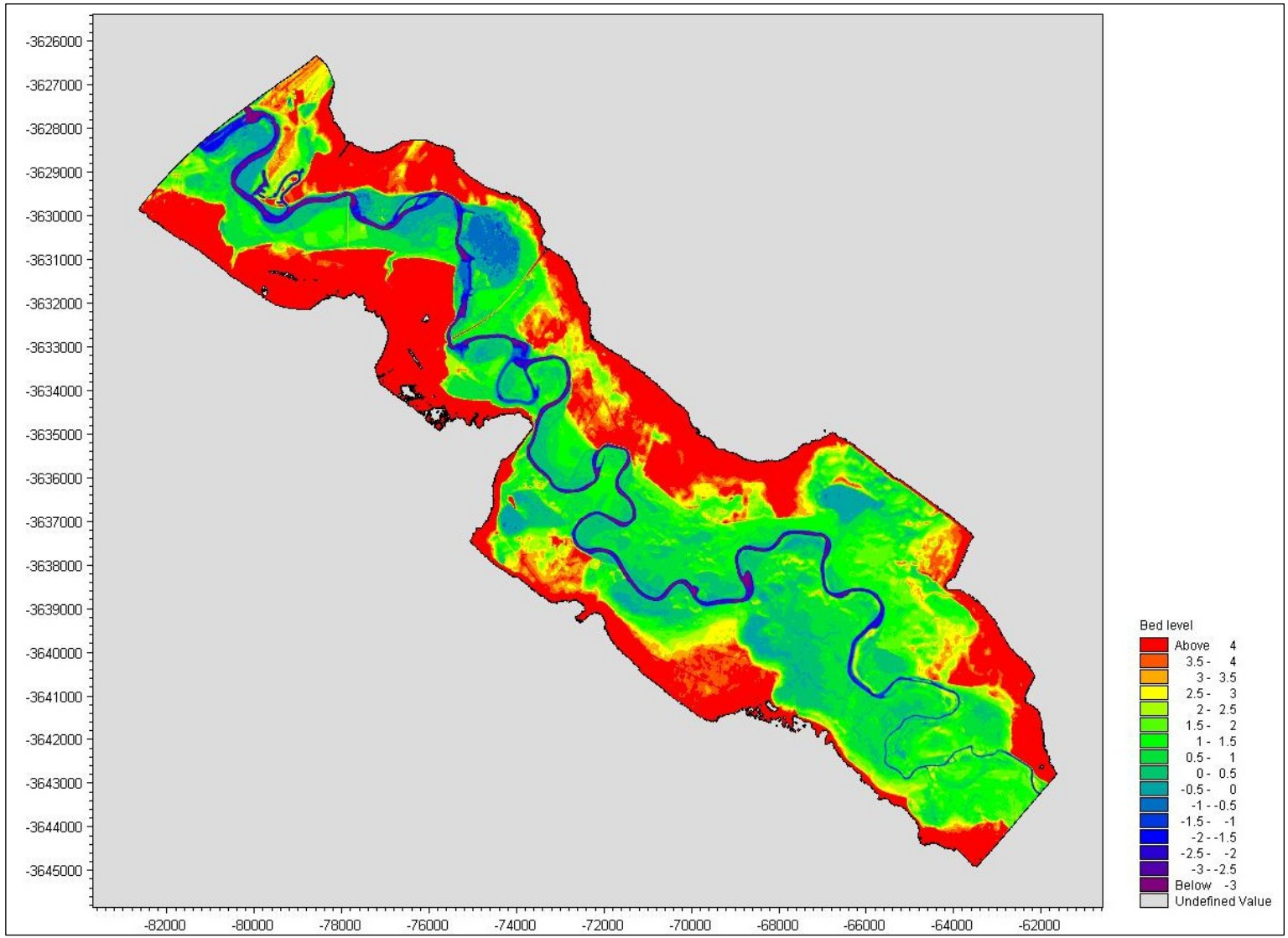


Figure 2.8 Berg River estuary bathymetry (relative to mean sea level) for flood simulations

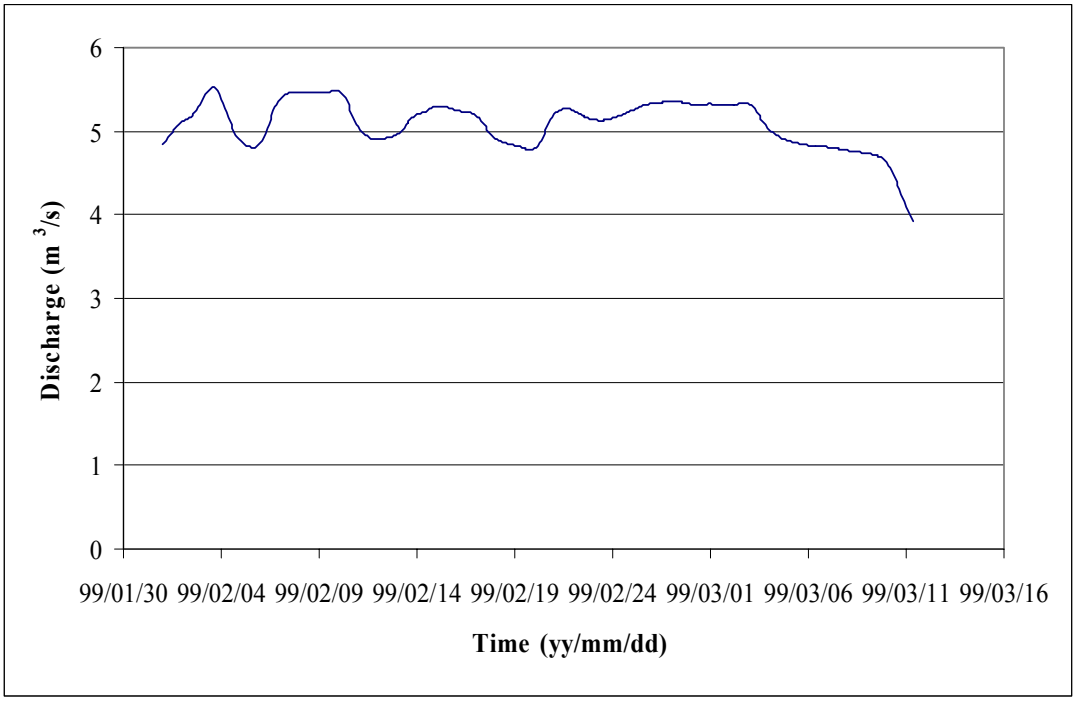


Figure 2.9 Summer river inflow to estuary for the tidal simulation

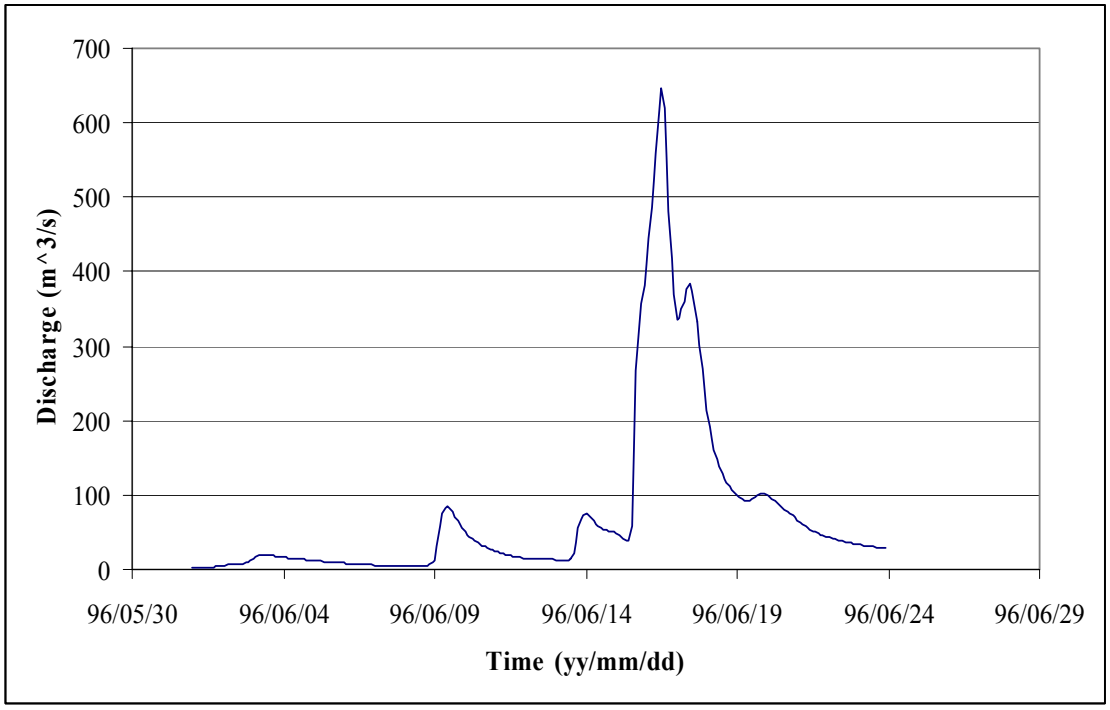


Figure 2.10 Winter river inflow to estuary for the tidal simulation

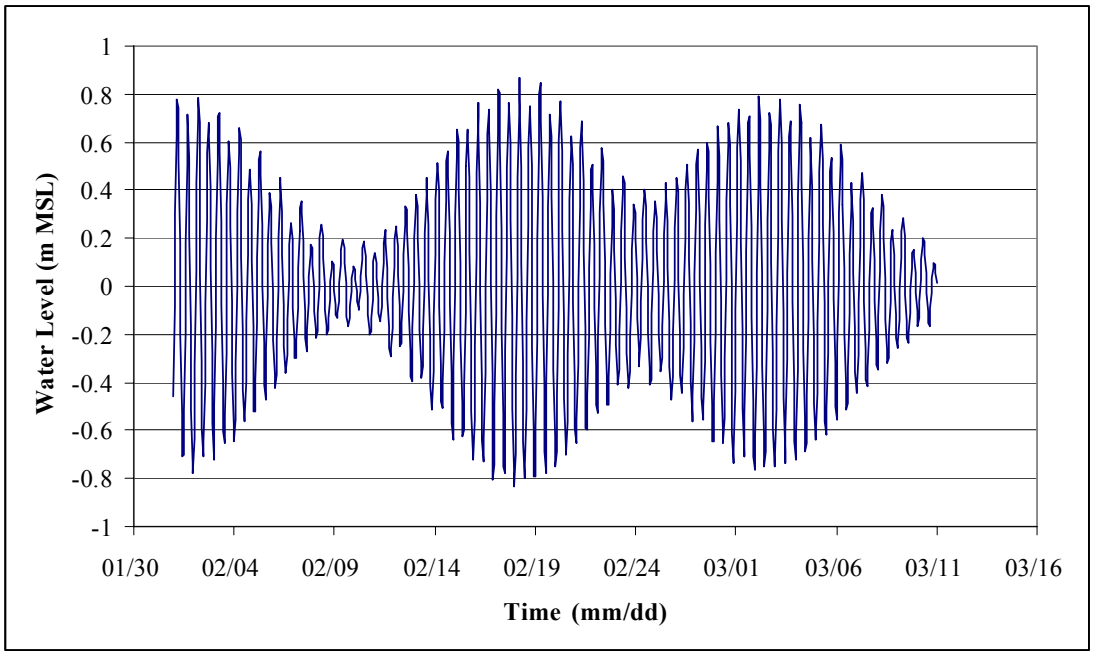


Figure 2.11 Tidal variation at sea boundary during the tidal simulation

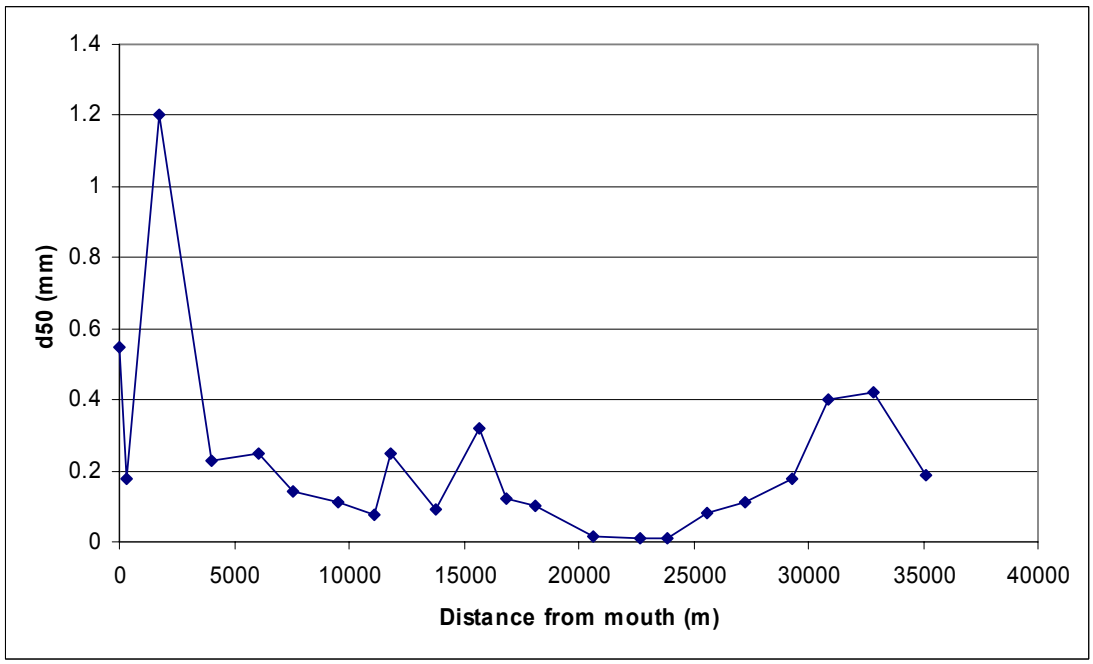


Figure 2.12 Measured sediment d_{50} distribution along the length of the estuary

2.5 CALIBRATION

2.5.1 Tidal action

The model was calibrated using observed water levels at the downstream DWAF water level recorder in the estuary (G1H024). Water levels measured in the field in March 2003, and the water level variations at the upstream water level recorder (G1H023) were used for validation. February 1999 was used as the calibration period for the tidal action simulations.

The calibration was carried out primarily by adjusting the parameters listed in Table 2.2, as well as the bathymetry of St Helena Bay at the mouth of the estuary, which proved to be important. The calibrated water levels fall within 10 to 15 cm of the observed water levels, and the timing was calibrated to be within 30 to 60 minutes (see Figure 2.13). The slight differences in the simulated and observed values could be due to the fact that hourly data were used at the boundary, which means that some detail was lost.

The calibration was verified by examining water level variations at the Carinus Bridge and G1H023. Measured water levels in March 2003 indicated that the tidal variation was approximately 0.8m. The simulations have shown that the water level variations in this model are of the same order. At G1H023 (see Figure 2.7) the observed water level variations are only about 0.2 m, and again the model has produced much the same variations. This can only serve as an indication that the model is accurate as only the water levels at G1H024 were surveyed relative to mean sea level.

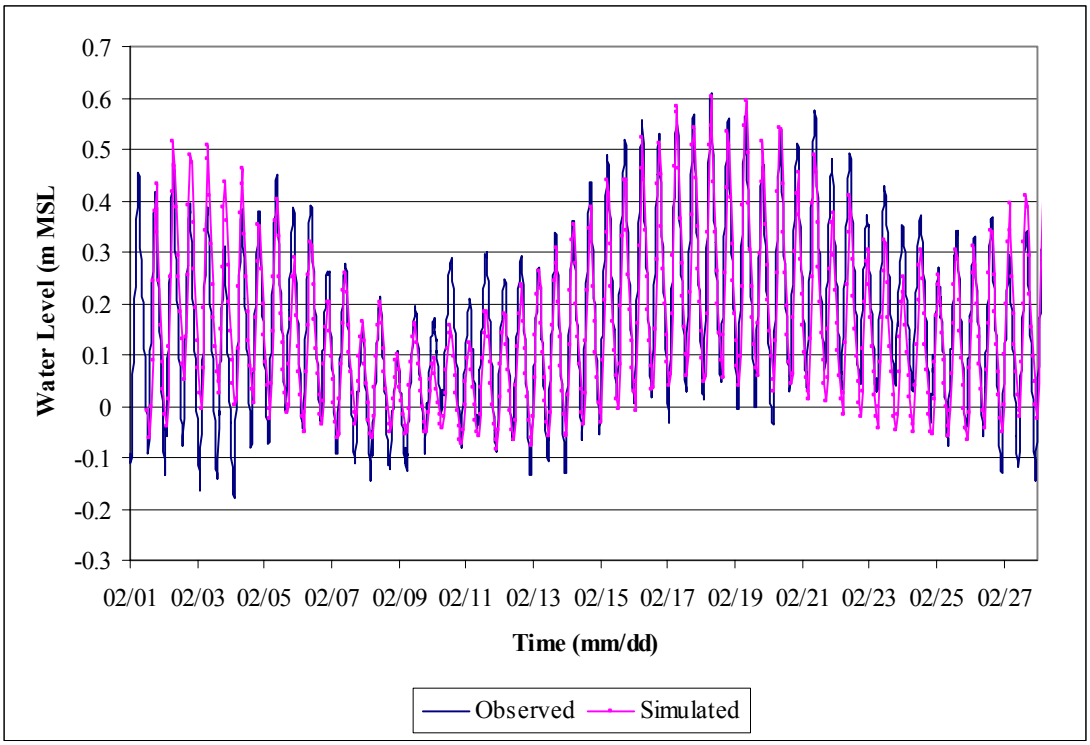


Figure 2.13 Observed and simulated water level at G1H024 (Railway Bridge)

2.5.2 Floods

The flood model was calibrated by adjusting the parameters in Table 2.3, until water levels at G1H023 for the simulated floods were within 0.5 m of the actual measurements taken (see Figure 2.14) for the calibration results of the flood of 2002/07/30). The simulated water levels were always higher than the observed levels. Most of the differences between the observed and simulated data are due to the fact that a shortened model was used for the flood simulations. The specified time series that was used was actually simulated for a point 20 km upstream (around Steenboksfontein) by the river model, but it was applied with limited modification (routing) at Kersefontein in the estuary model. The only modification was that the time series was shifted by about 6 hours to allow some travel time along the intervening 20 km stretch. Some flood attenuation and lagging would have occurred if the floods had been allowed to travel along those 20 km, which would explain the slightly higher water levels and lag. However, for the constant flood discharges this does not create a problem.

At G1H024 the simulated water levels were usually between 0.1 and 0.3 m lower than the observed water levels which is within reasonable error limits.

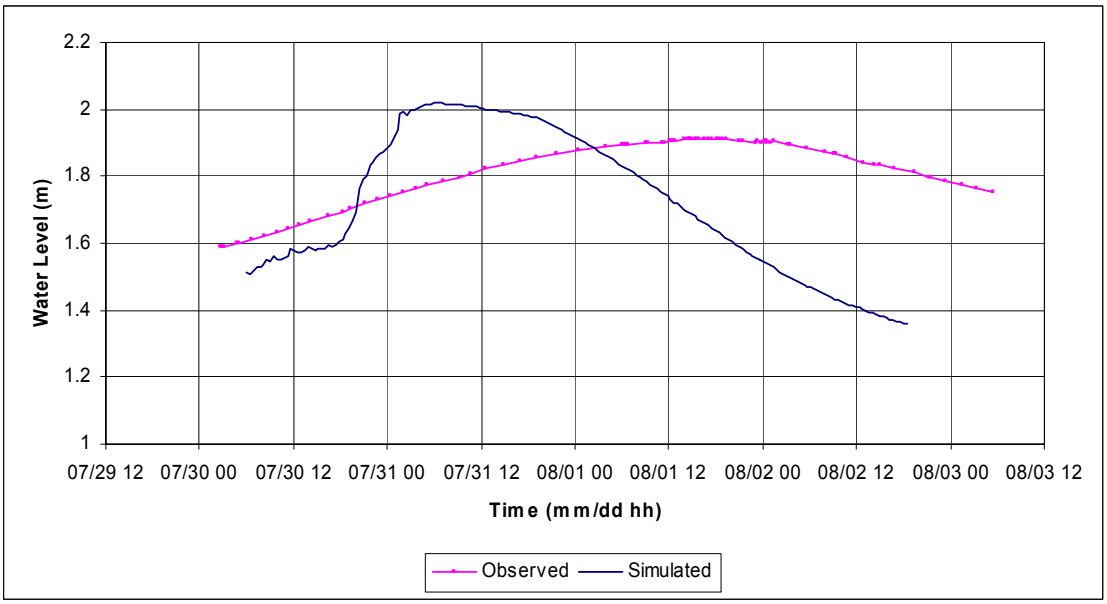


Figure 2.14 Observed and simulated water levels at G1H023 (Jantjiesfontein) for the flood of 2002/07/30

2.6 HYDRODYNAMIC AND MORPHOLOGICAL MODEL SIMULATION RESULTS

2.6.1 Tidal action - Summer

During normal tidal action water flows over part of the floodplain in the lower estuary up to about the Railway Bridge during high tide. For the rest of the estuary the flow is confined to the main channel, except for one or two areas further upstream as indicated in Figure 2.15. The flow depths over the floodplain areas during spring high tide are generally less than 1 m, except on Die Plaat, where some areas are deeper and the flow depths can rise to 1.5 m (see Figure 2.16). Velocities are very low over the floodplain, generally less than 0.3 m/s, while higher velocities occur in the main channel downstream of the Railway Bridge (see Figure 2.17), sometimes exceeding 1m/s. This agrees with the observations during a field excursion in March 2003, where the maximum velocity measured at a cross-section upstream of the Carinus Bridge was 0.8 m/s. The maximum velocities do not occur at high tide, but rather during the rising stages. Velocities at the turn of the low tide seem higher than during the turn of the high tide (see Figure 2.18 and Figure 2.19), probably because the flow is confined to the main channel at low tide.

During neap tide the floodplain area inundated is much smaller (see Figure 2.20) and as such the flow depths and velocities are usually less than half of those during spring tide (see Figure 2.21 to Figure 2.24).

Generally it seems that tidal action attenuates rapidly upstream and inundation of the floodplain is confined mainly to the area downstream of the Railway Bridge.

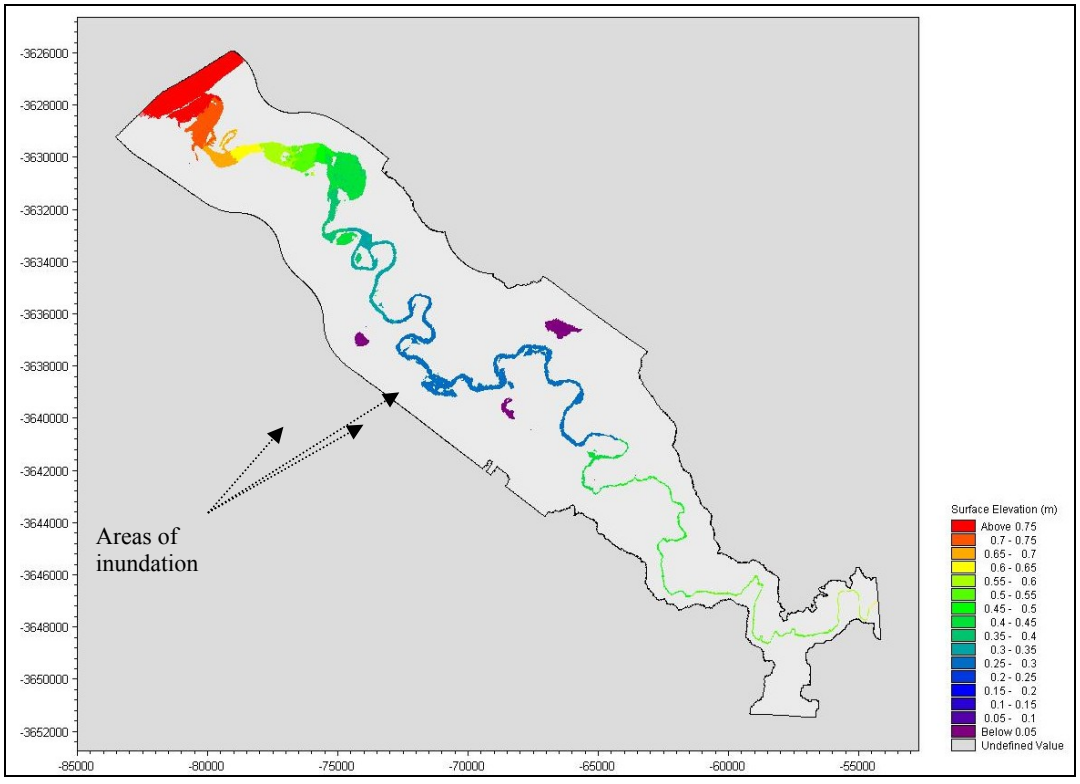


Figure 2.15 Area inundated during spring high tide

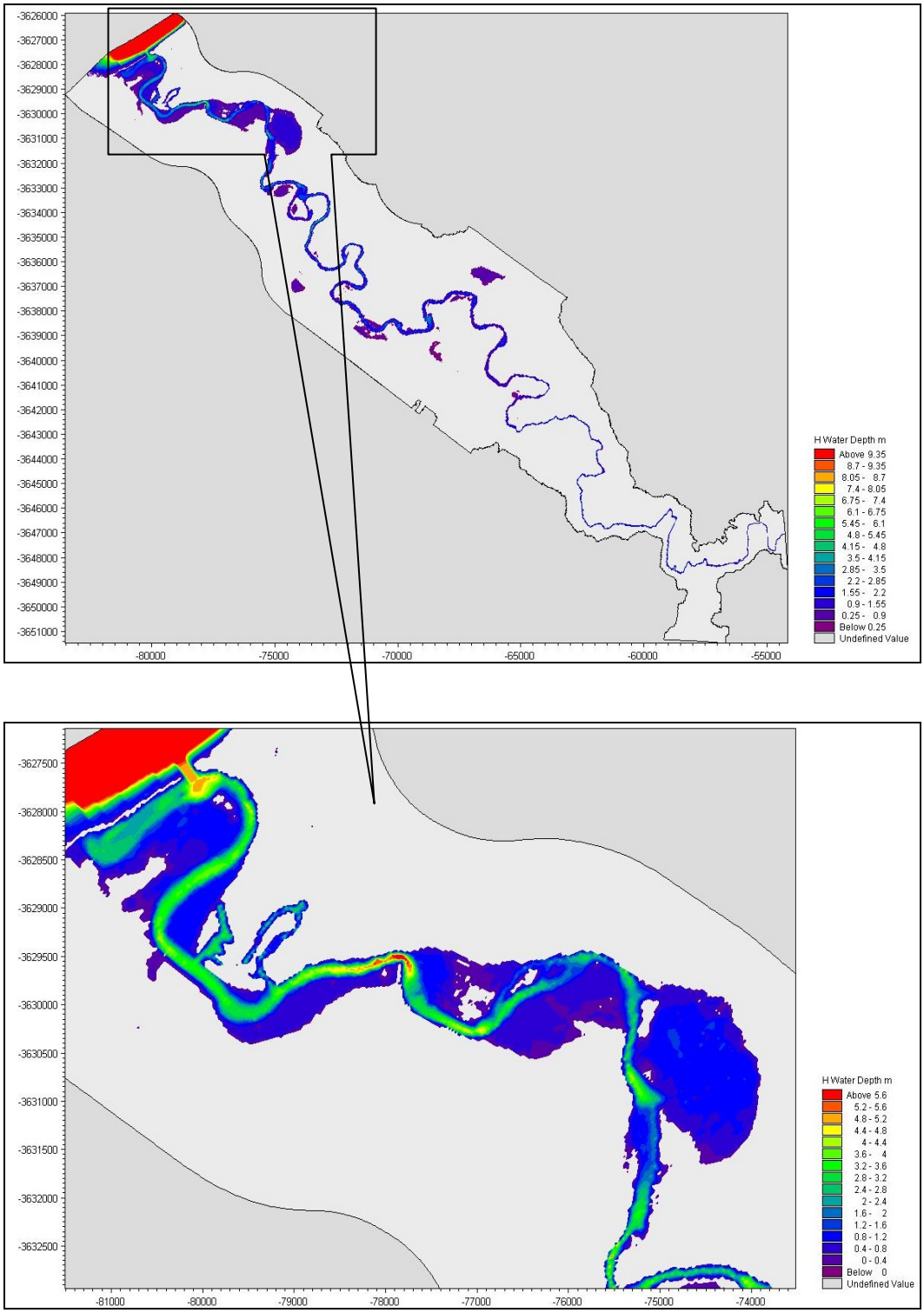


Figure 2.16 Flow depths during spring high tide

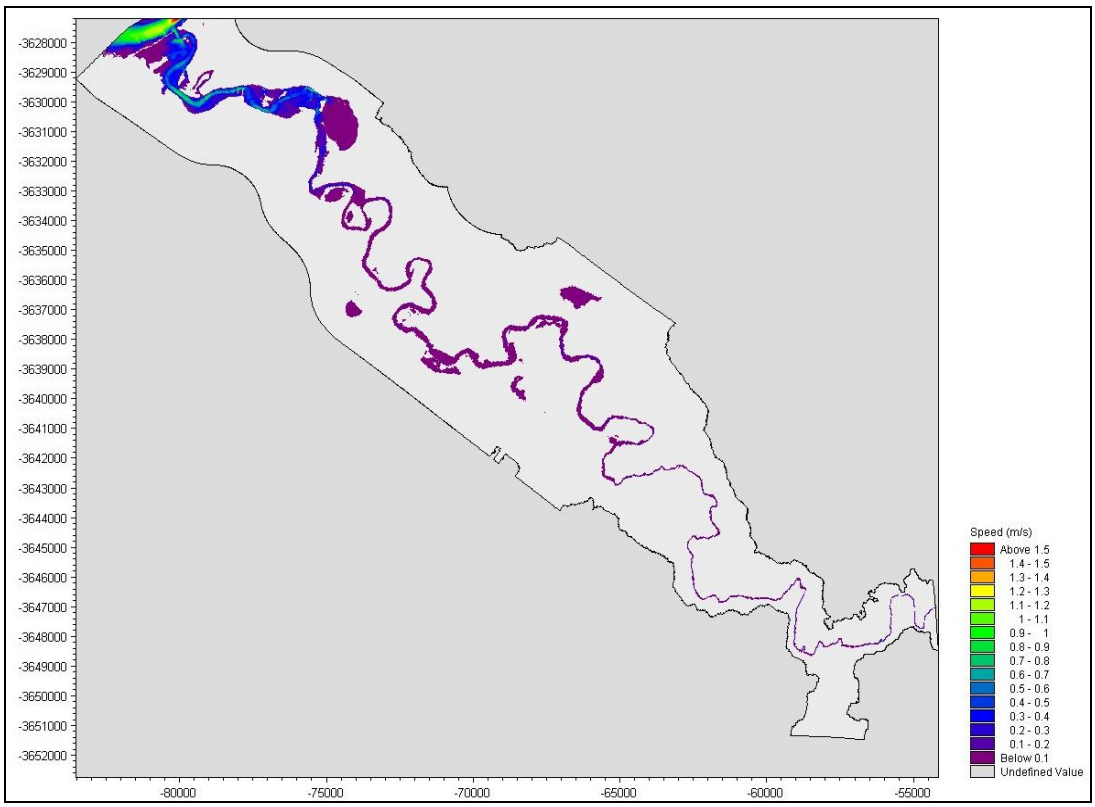


Figure 2.17 Maximum velocities during spring tide

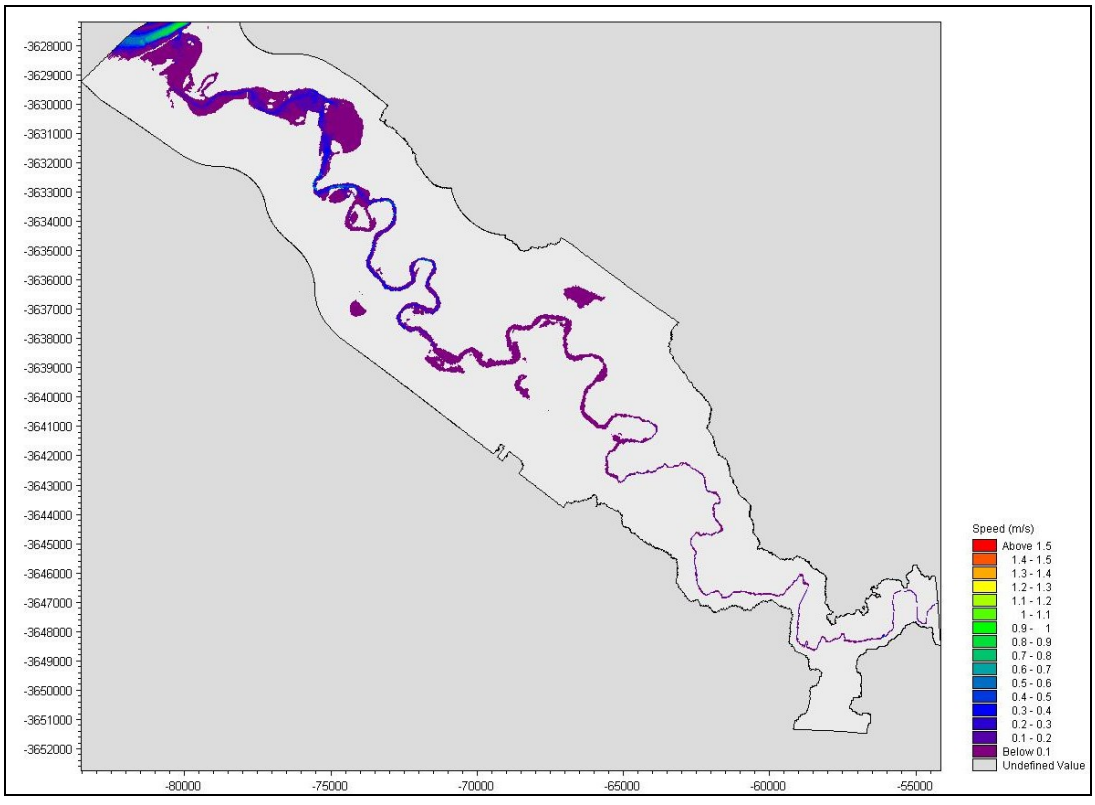


Figure 2.18 Velocities at the turn of the spring high tide

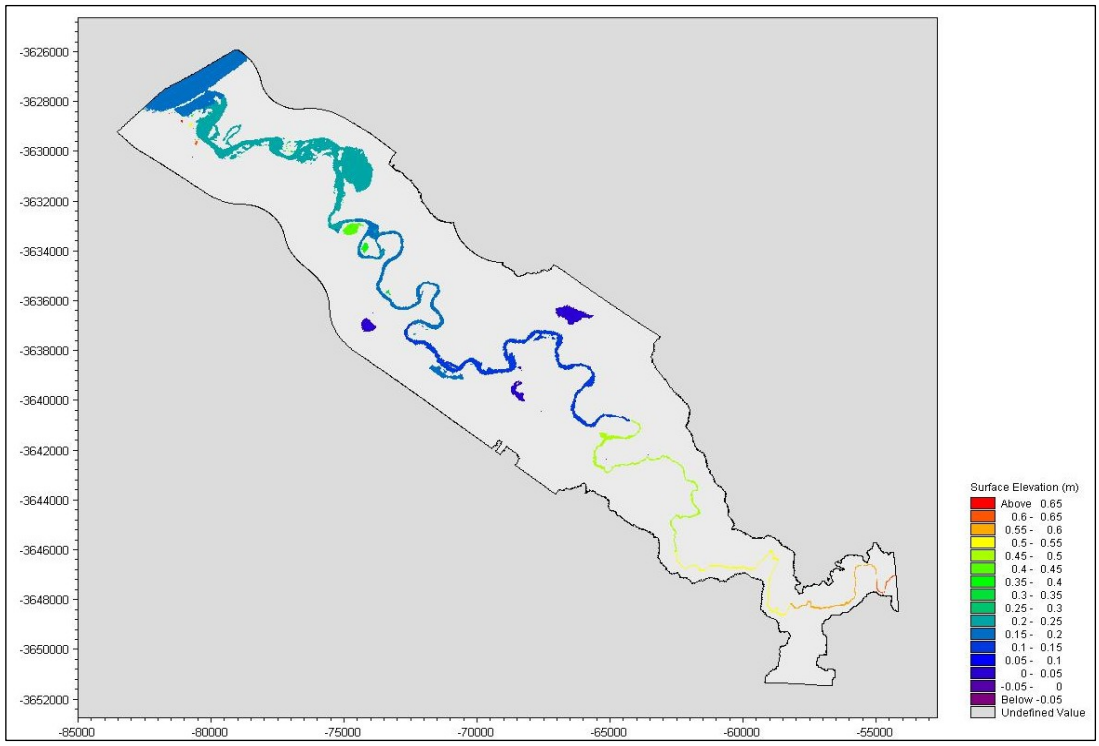


Figure 2.19 Velocities at the turn of the spring low tide

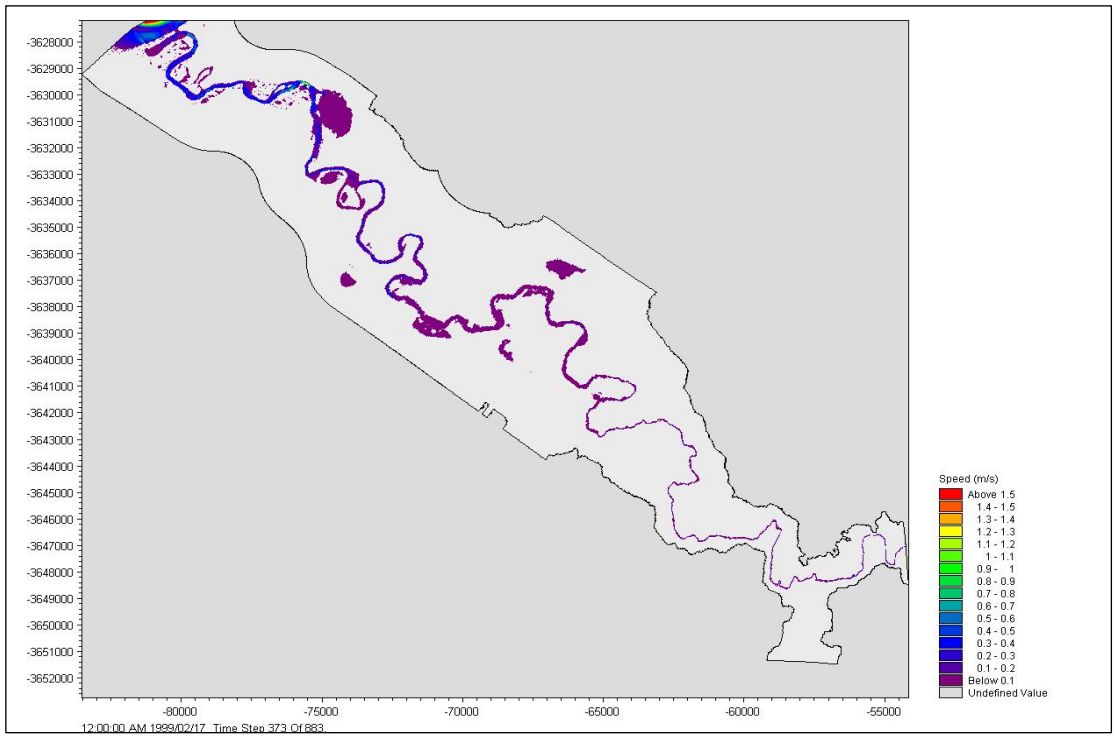


Figure 2.20 Area inundated during neap high tide

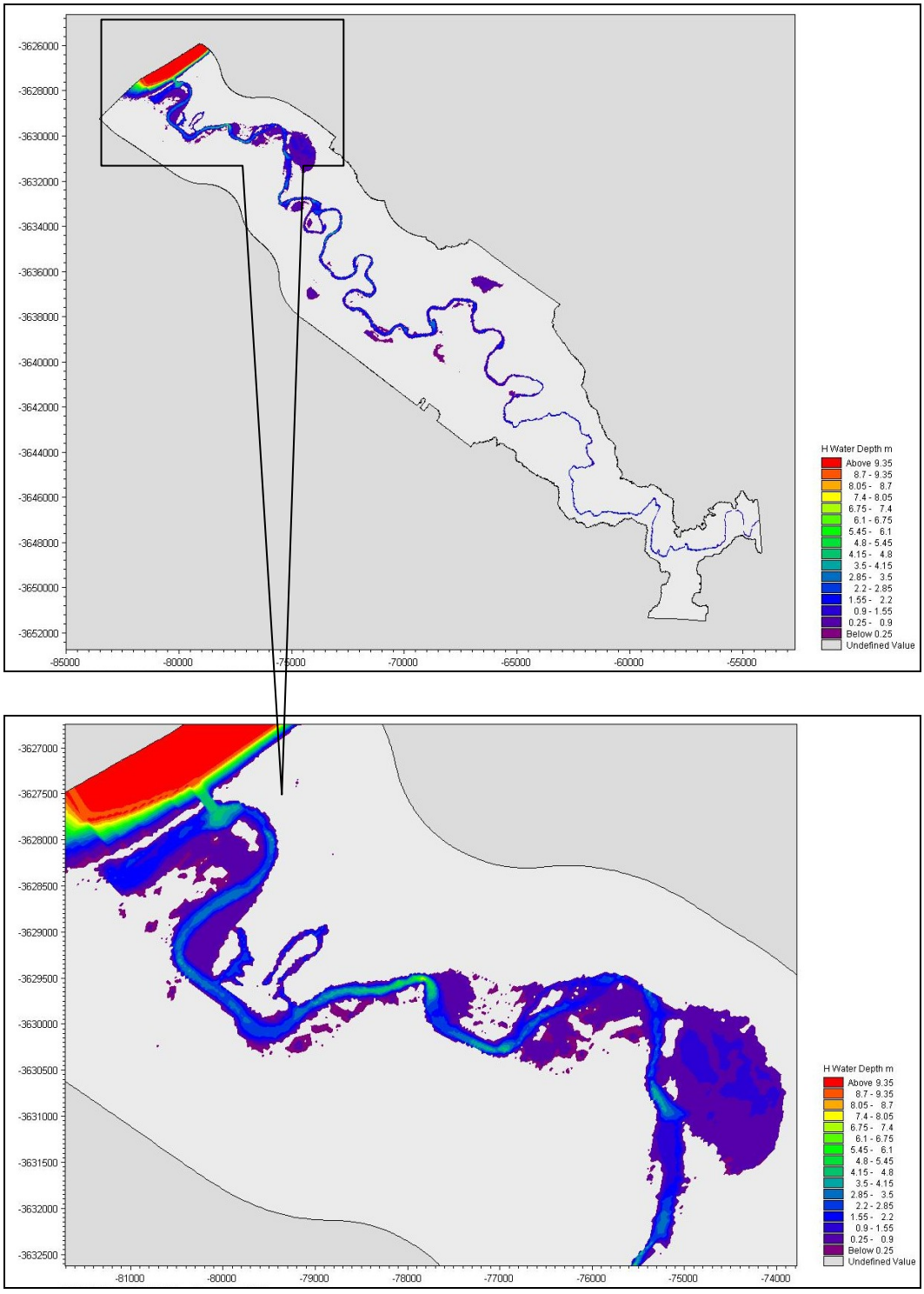


Figure 2.21 Flow depths during neap high tide

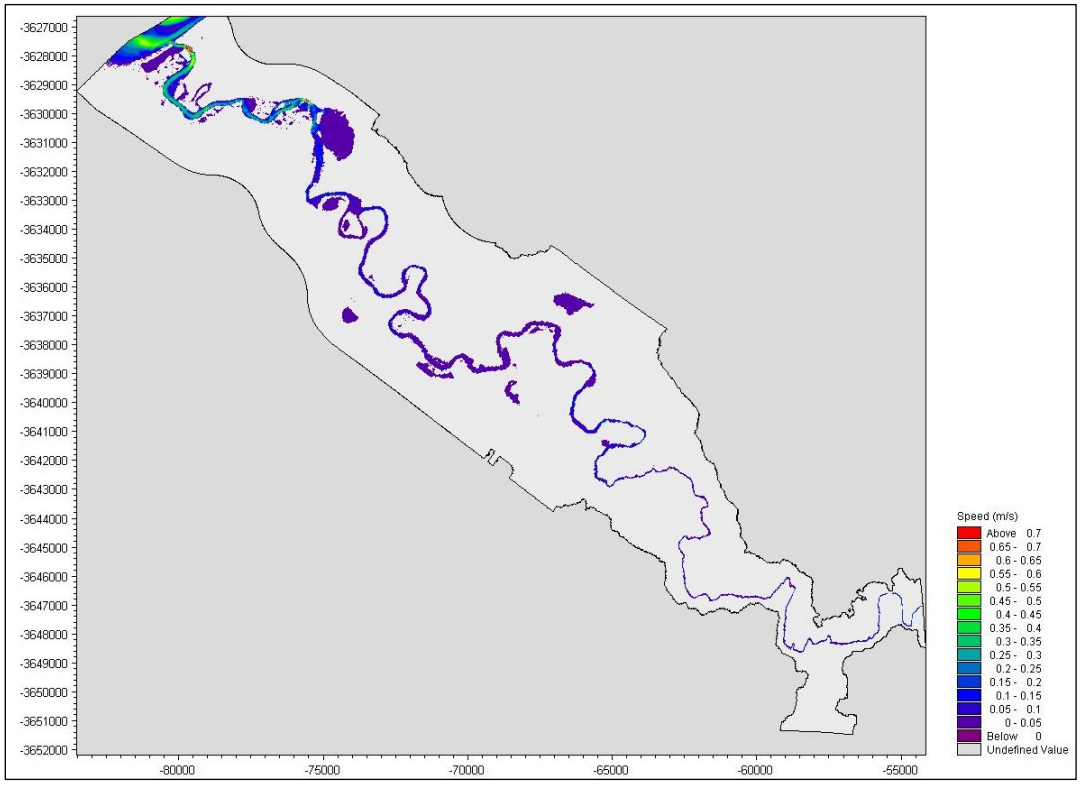


Figure 2.22 Maximum velocities during neap tide

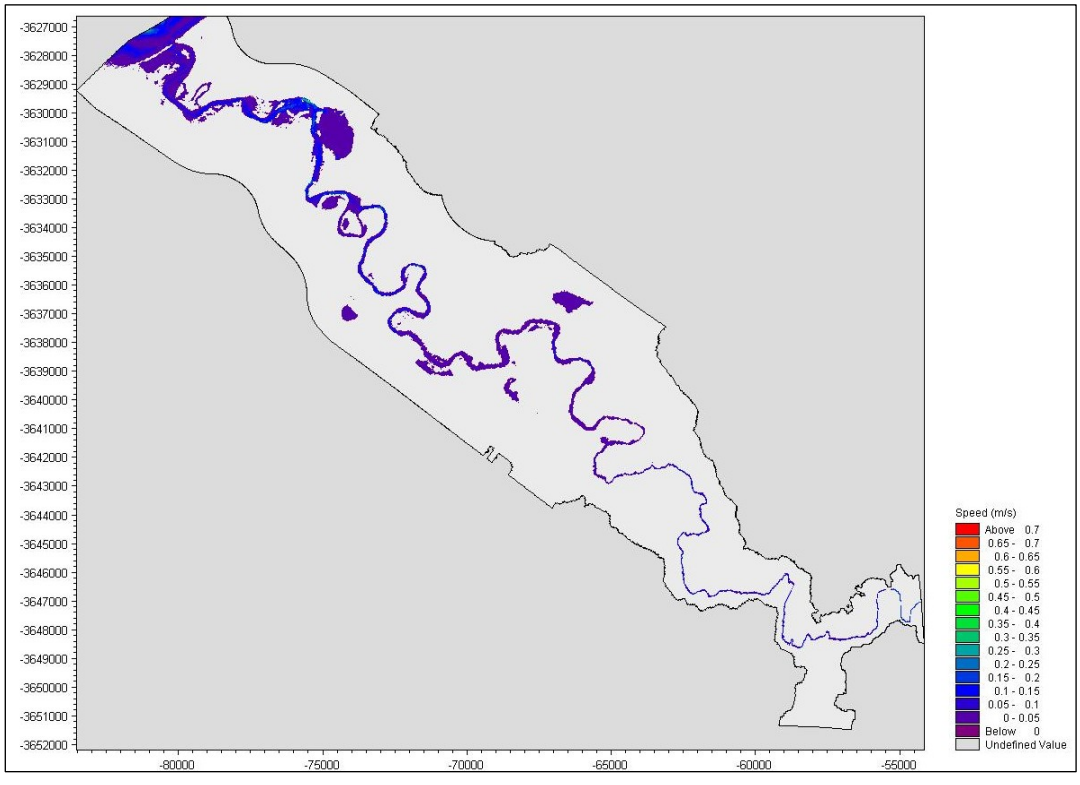


Figure 2.23 Velocities at the turn of neap high tide

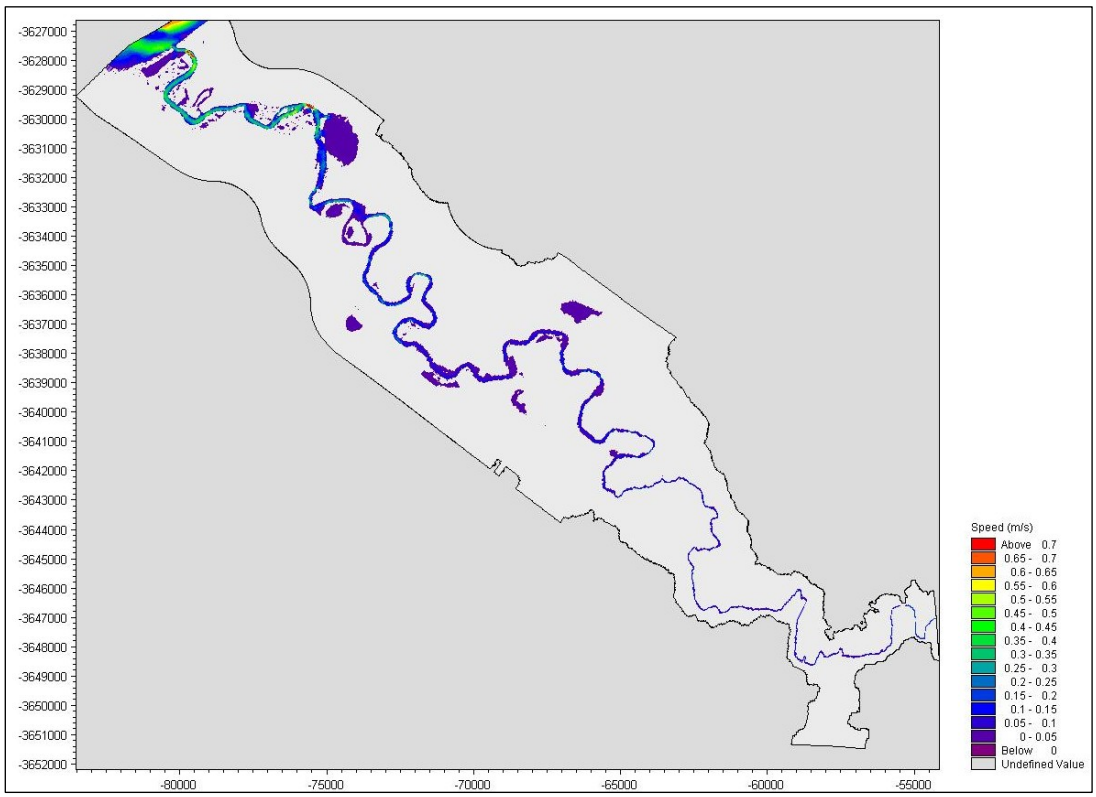


Figure 2.24 Velocities at the turn of neap low tide

2.6.2 Tidal action – Winter

During the winter period the water levels in the estuary are much higher than during the summer months. As soon as the first floods start the water level rises and stays almost constant at about 1 m above MSL in between larger flood events. During flood events the water levels can rise by 2 to 3 m (see Figure 2.25).

Figure 2.26 shows the water levels during a small flood of 90 m3/s coinciding with a spring tide. The initial water levels are therefore relatively high in the upper reaches and the flood waters inundate a relatively large area for such a small flood.

Figure 2.27 shows the inundation during a larger flood with a peak magnitude of about 650 m3/s after about 2 weeks of winter flows and two days after a spring tide. Extensive floodplain inundation occurred during this flood and even seven days after the peak of the flood the flood waters were still receding from the floodplain (see Figure 2.28), probably because the estuary is still fuelled by the winter flows.

Velocities in the main channel are well above 1 m/s in some areas, and floodplain velocities rose to about 0.3-0.4 m/s in widespread areas as can be seen from Figure 2.29.

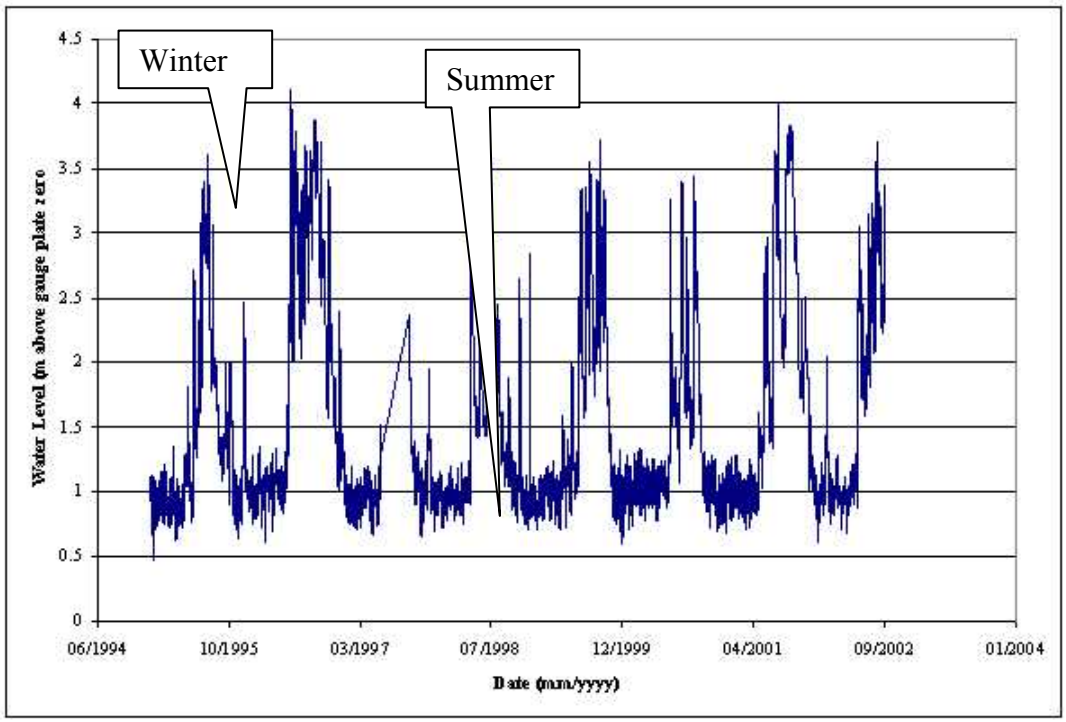


Figure 2.25 Observed water levels at gauging station G1H023

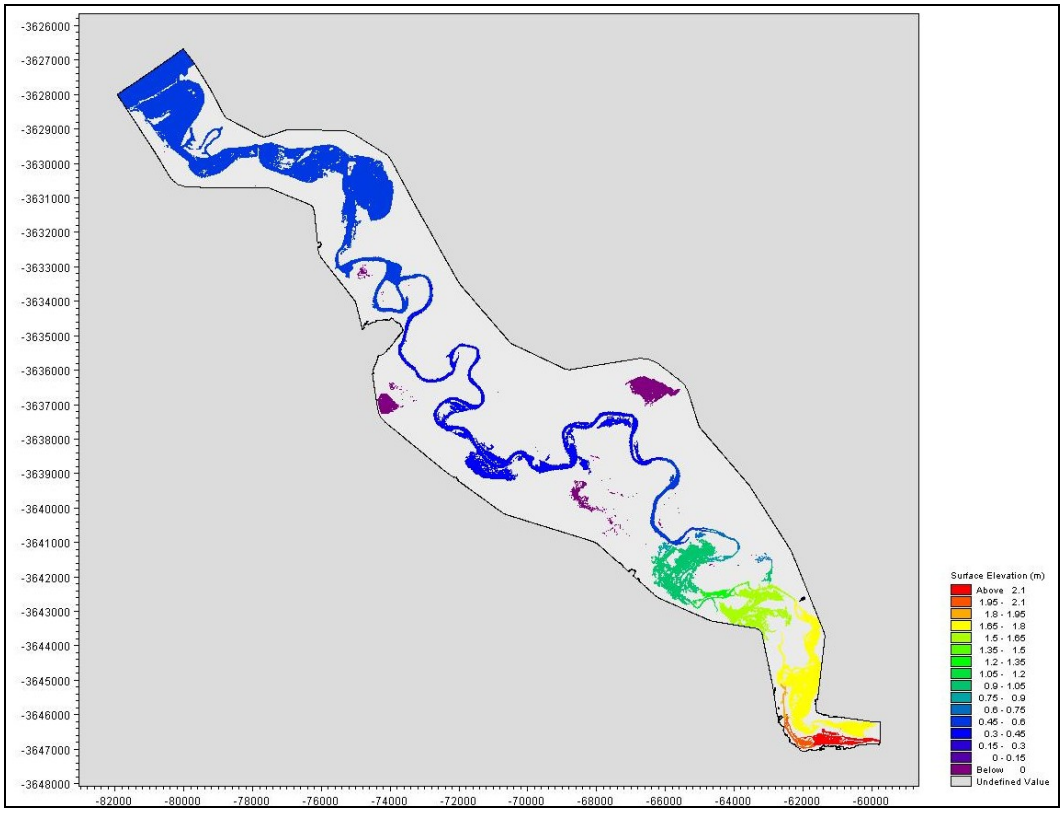


Figure 2.26 Inundation at spring tide coinciding with small flood (90m^3/s)

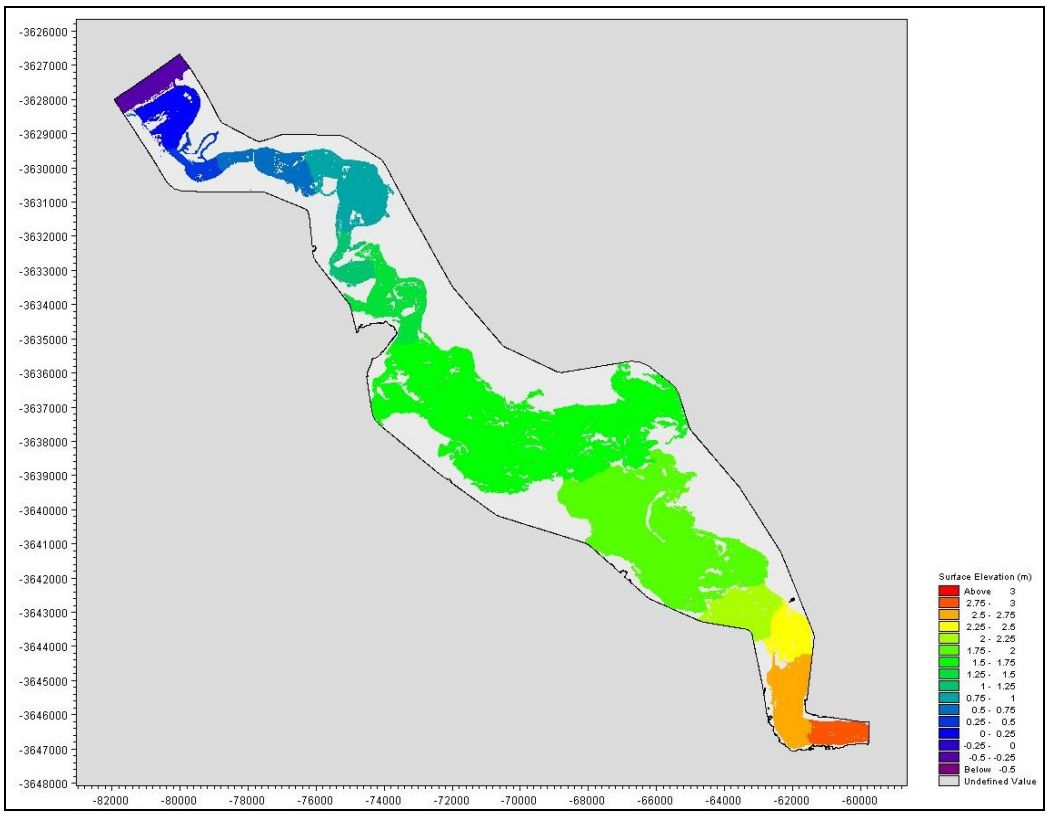


Figure 2.27 Inundation 2 days after spring tide coinciding with large flood (650m^3/s)

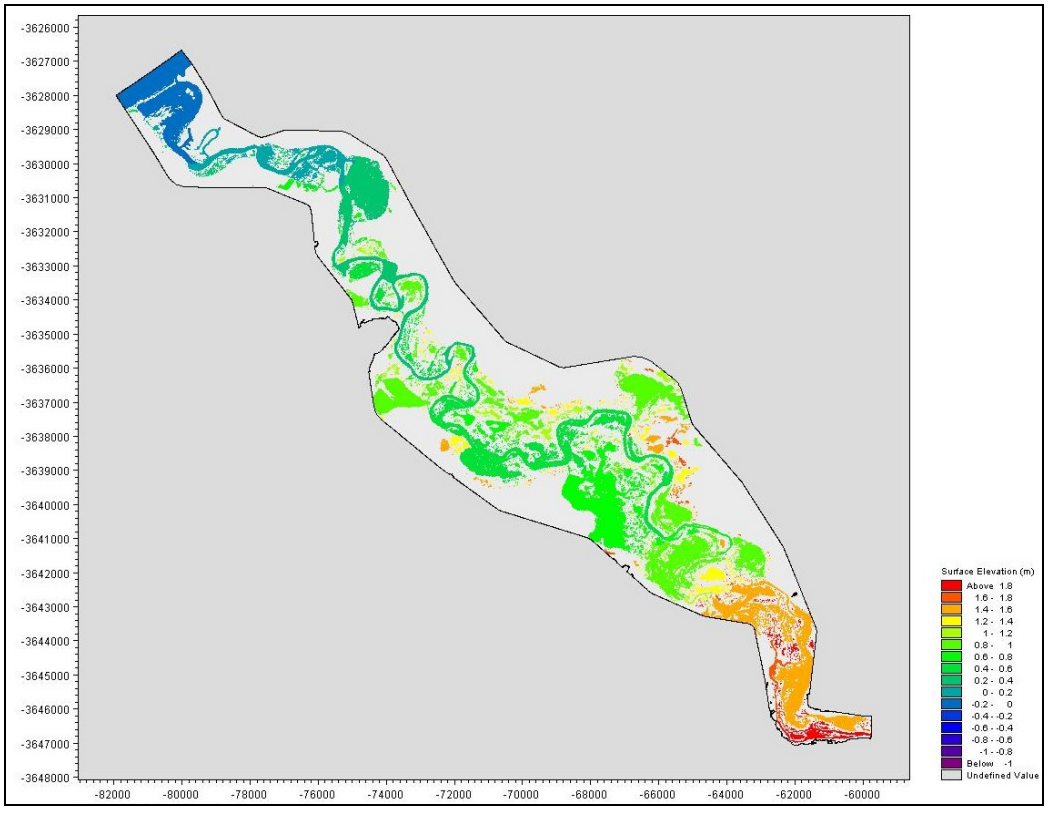


Figure 2.28 Inundation 7 days after large flood

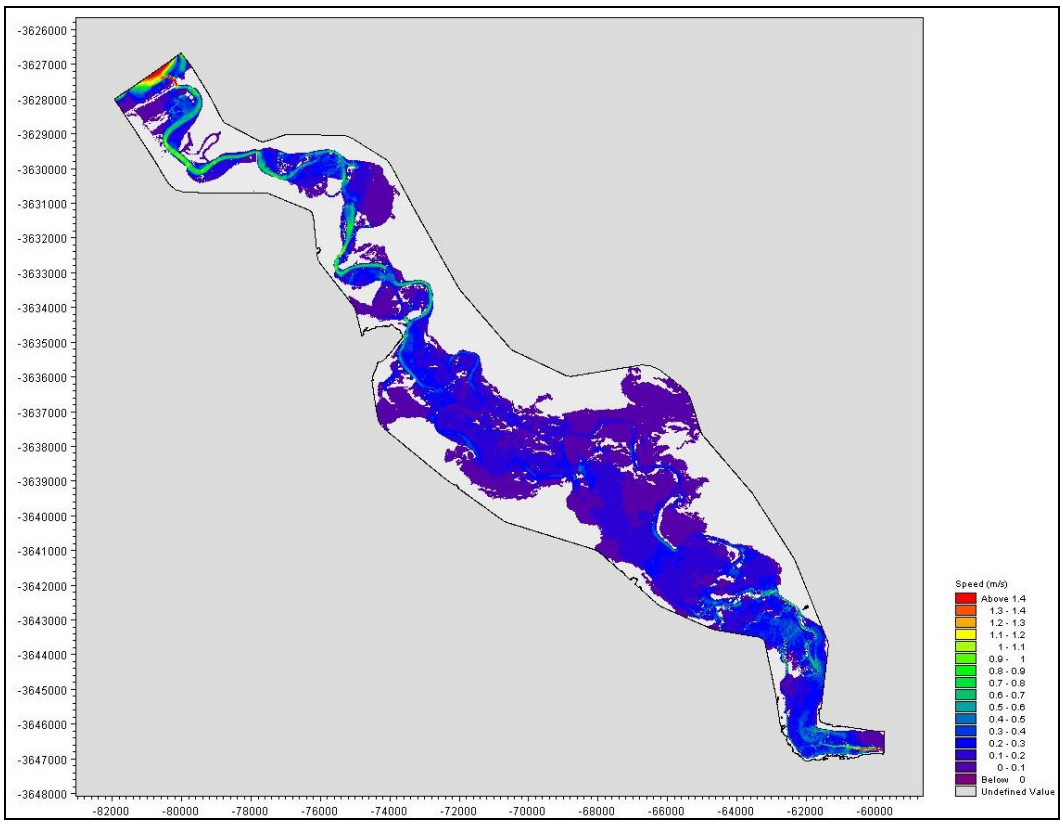


Figure 2.29 Flow velocities during large flood

2.6.3 Floods

Flood 1: hydrograph with 90 m^3/s peak

Five floods were simulated for present and post-dam scenarios respectively. The smallest flood simulated was 90 m^3/s, representing a flood of the size of the second (max 100 m^3/s) of three annual artificial flood releases from the Berg River Dam. The initial water level for this flood was very low (Figure 2.30), and the flood was confined to the main channel (see Figure 2.31). This is probably due to the fact that the tidal flows, at least in the lower estuary, can be in the order of 200 to 300 m^3/s and this flood is therefore relatively small compared to the normal tidal flows. The flood magnitude in this case is expected to be the same for the pre- and post-dam scenarios as simulated by the river model. In the simulations the normal tidal action during those periods was used. Erosion and deposition is also confined to the main channel in the upper reaches of the estuary and the sediment transport is very small. The maximum scour during the flood amounted to about 0.2 m. In the model of the estuary sedimentation loads simulated by the river hydrodynamic model were used as upstream boundary. The sediments in the model were considered to be non-cohesive.

The results from this scenario can also be compared to the results discussed in the preceding section about winter flows. A 90 m^3/s flood was included in the longer-term winter simulations, but with a higher initial water level due to a few weeks of higher winter flows. The differences are quite significant if one compares Figure 2.26 with Figure 2.31. With a low initial water level the flood stays confined to the main channel whereas with a higher initial water level the flood inundates part of the floodplain in the upper reaches of the estuary. Also the flood during the longer-term simulations coincided with a spring tide, which could also be responsible for the more widespread flooding, while the single flood simulated here coincided with a neap tide.

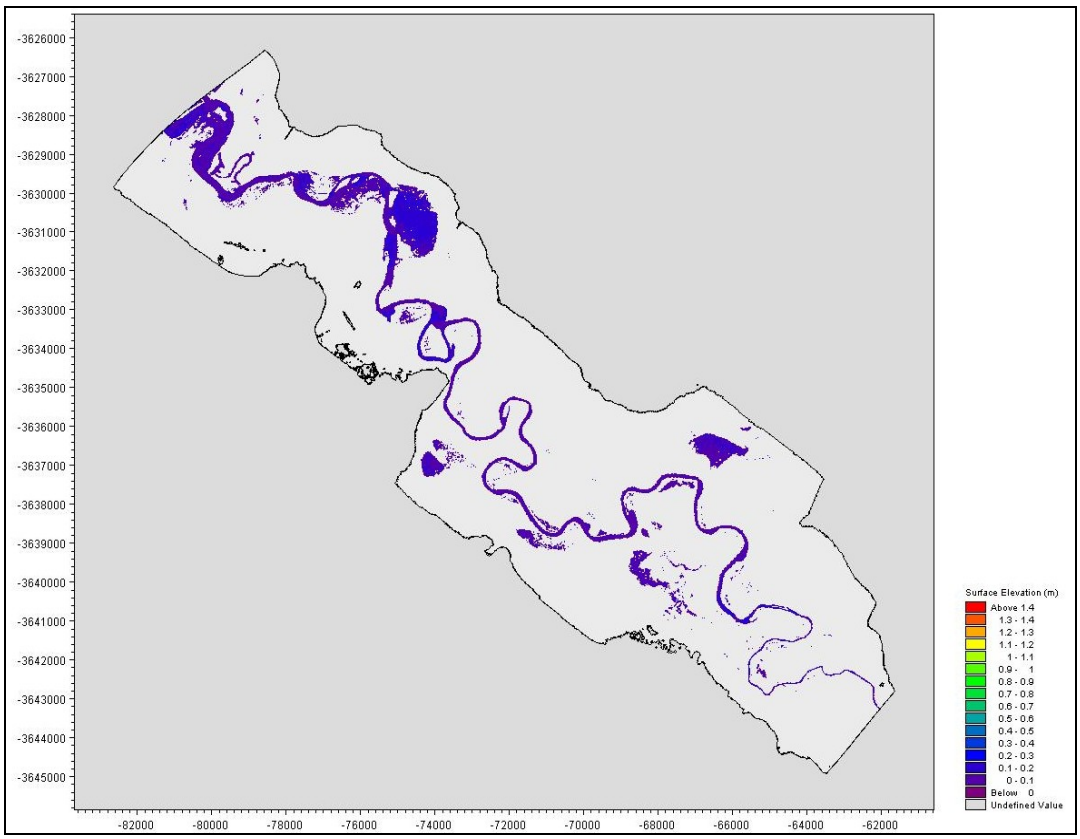


Figure 2.30 Initial water levels (as observed from record at G1H023) for flood 1: 90 m^3/s

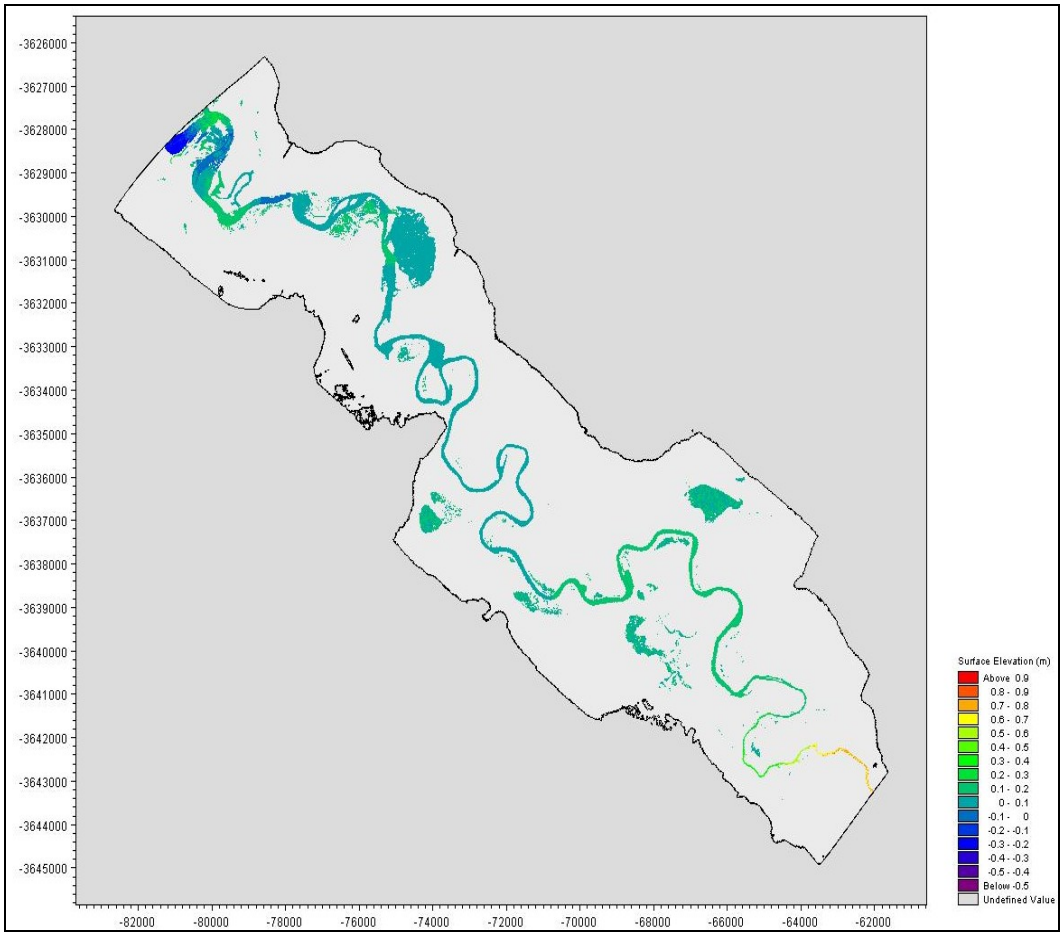


Figure 2.31 Present scenario - area inundated during 90 m^3/s flood peak

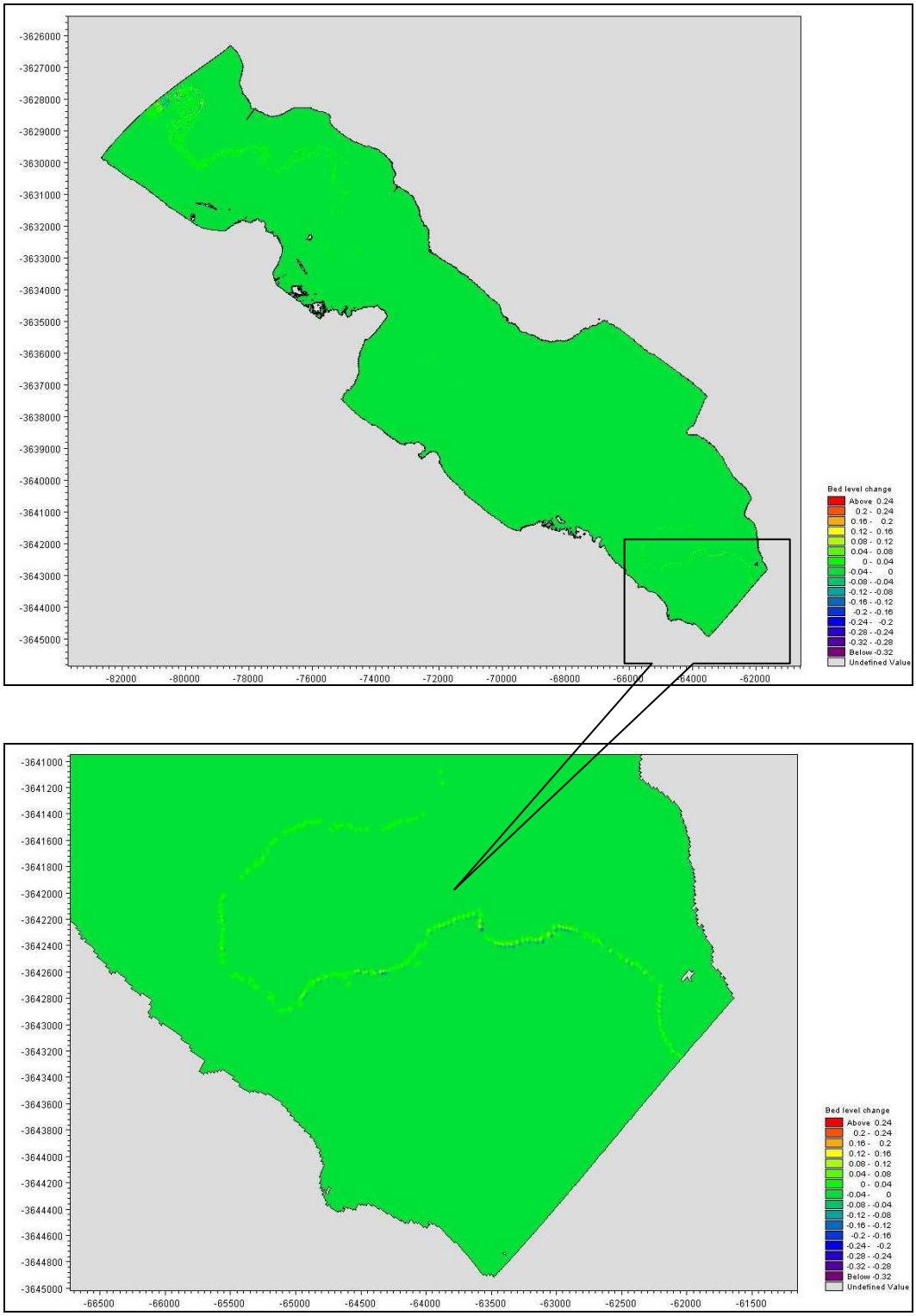


Figure 2.32 Erosion and deposition pattern during 90 m^3/s flood

Flood 2: hydrograph with 284 m^3/s peak (current condition)

The second flood simulated represents the third (max 220 m^3/s) of three annual artificial flood releases from the Berg River Dam, with a magnitude of 284 m^3/s for the present and 274 m^3/s for the post-dam scenario simulated by the river model upstream of the estuary. The initial water level in the estuary was relatively high at 1 m MSL, probably due to previous winter rainfall and flooding (Figure 2.33).

This means that extensive floodplain areas in the estuary were already inundated before the flood reached the estuary.

The flood itself then did not cause much more inundation of the floodplain areas, except in the upper reaches (confined to an area around Kersefontein). The flood was also absorbed quite rapidly by the system and no flood effects could be observed in the lower reaches of the estuary. No differences were evident between the pre- and post-dam scenarios, as the two floods are very similar (see Figure 2.34 and Figure 2.35).

The erosion and deposition patterns are almost identical for the pre- and post-dam conditions, although much more extensive than during the 90 m^3/s flood (see Figure 2.36). In the main channel, scouring and deposition of up to 0.3 m occurs. The interesting thing to note is that the erosion in the main channel is more or less confined to the outer banks, while deposition takes place towards the middle of the channel. It seems that during the flood the main channel tends to become slightly wider and shallower. This is in line with Regime theory, which argues that the size of the river channel, especially the width, is mainly a function of the discharge (see for example Beck and Basson, 2003). Therefore, during floods, the river channel tends to widen to accommodate these floods, and afterwards the channel becomes narrower again.

On the upstream end of the floodplain, simulated maximum erosion and deposition in the order of 0.1 m was observed, however, deposition of sediment on the floodplain was very limited.

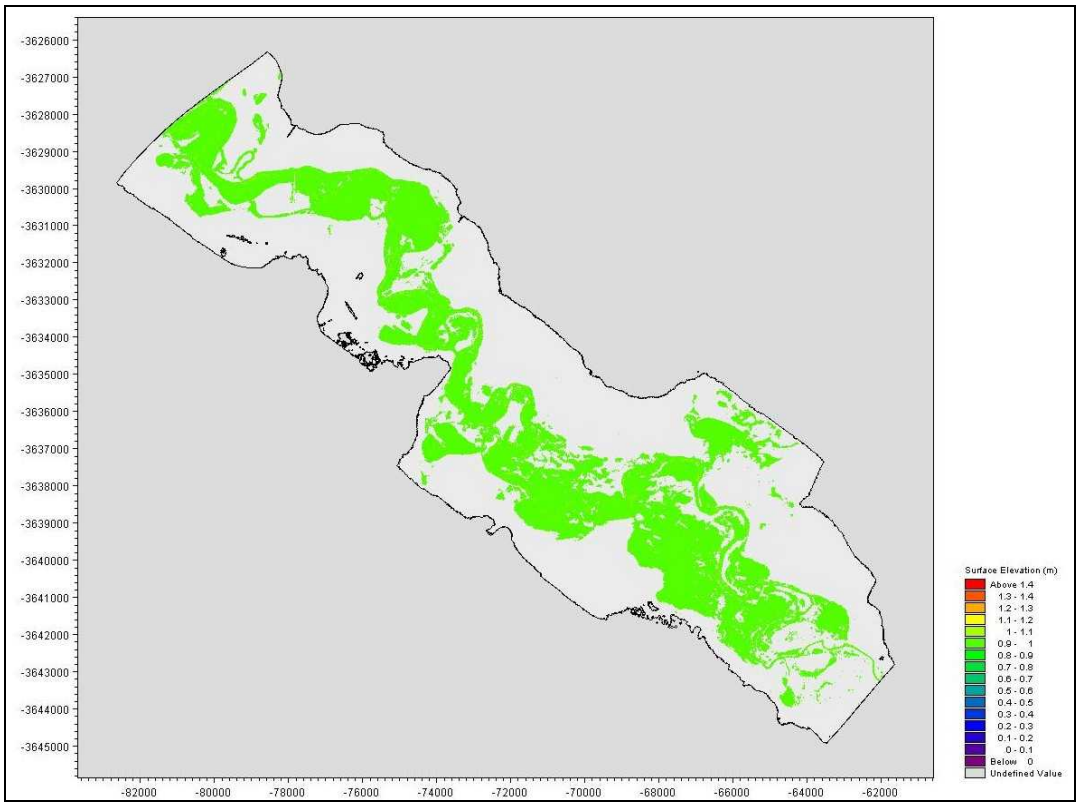


Figure 2.33 Initial water levels (as observed from record at G1H023) for flood 2

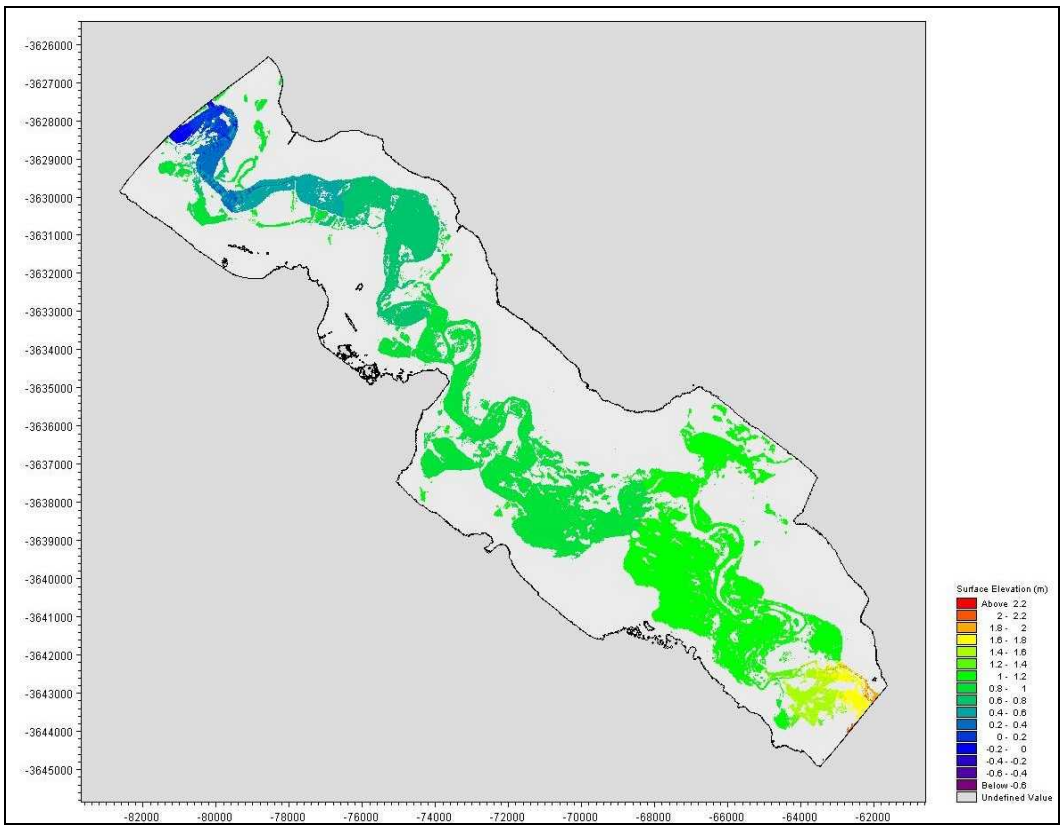


Figure 2.34 Present scenario – area inundated during 284 m^3/s flood

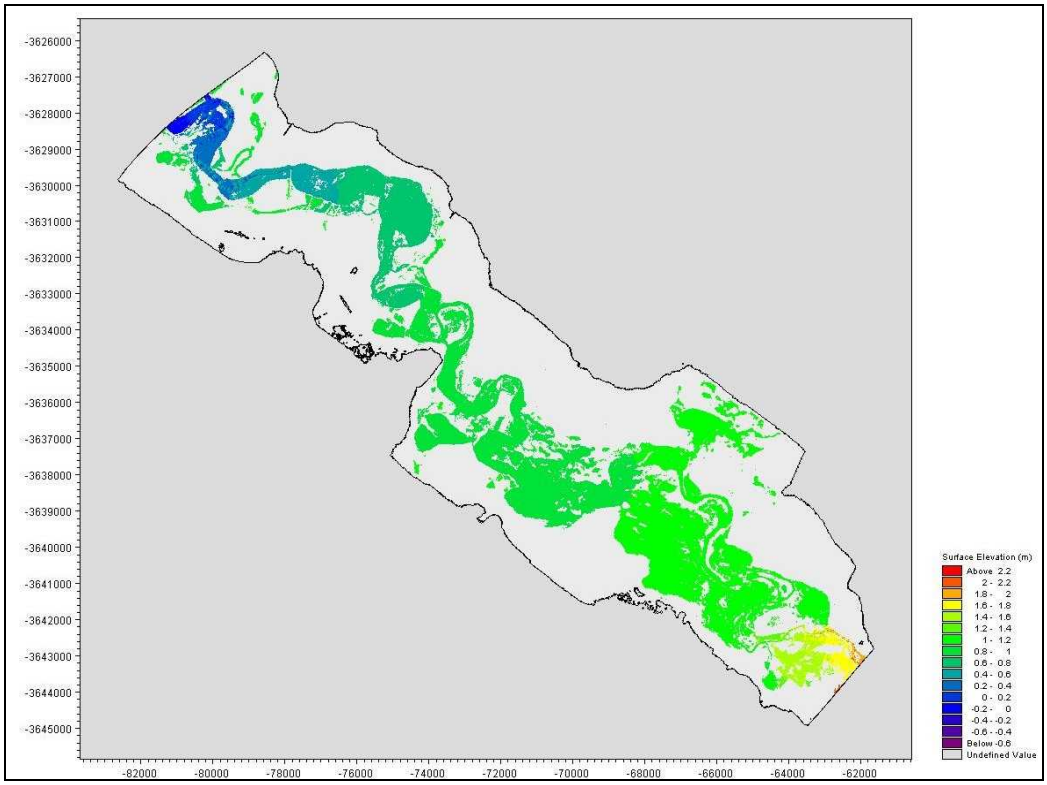


Figure 2.35 Future scenario – area inundated during 274 m^3/s flood

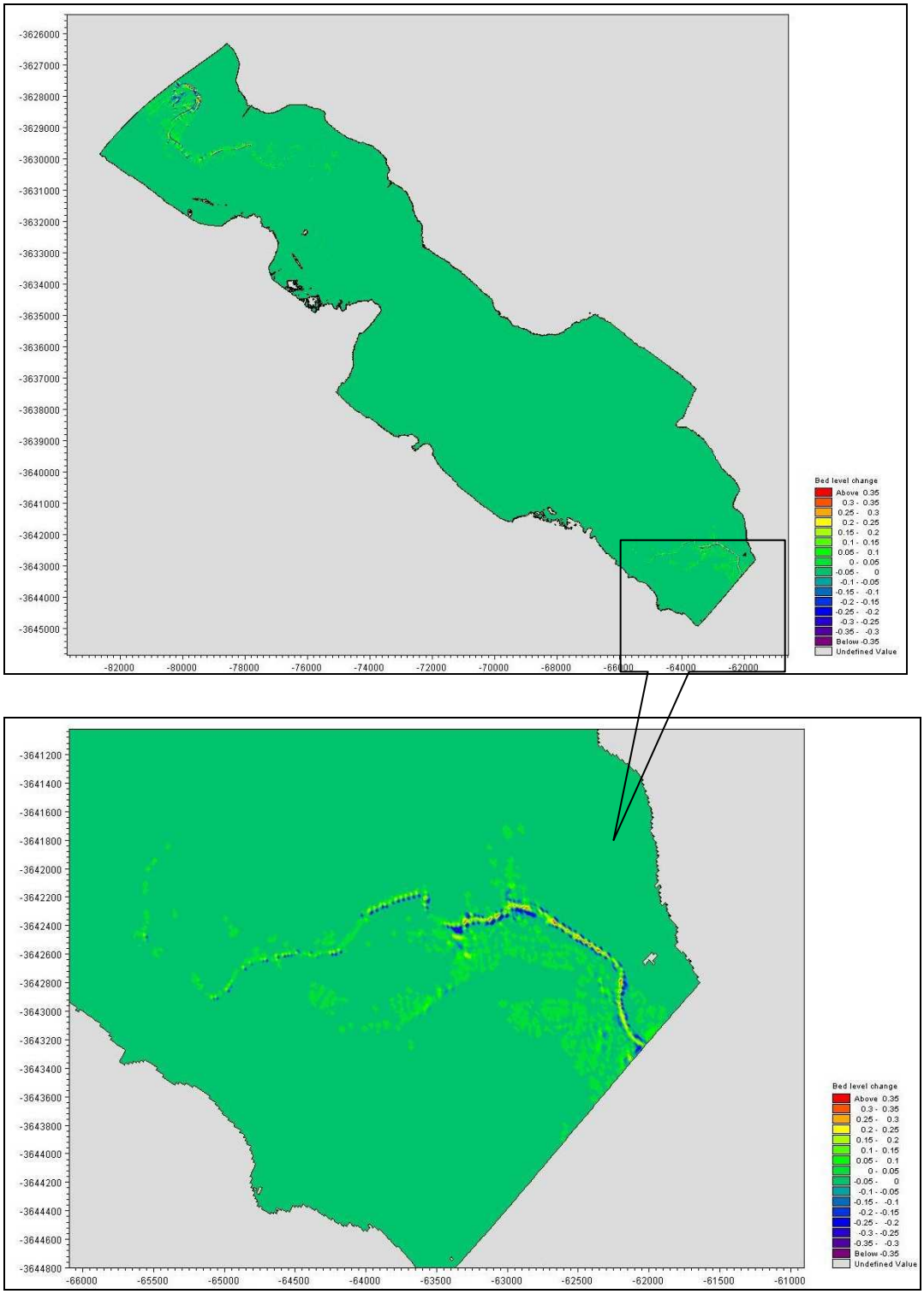


Figure 2.36 Erosion and deposition pattern during 284 and 274 m^3/s flood

Flood 3: hydrograph with flood peak 457 m^3/s peak (current condition)

The third flood simulated (magnitude of 457 m^3/s for the present scenario and 403 m^3/s for the post-dam scenario), was approximately equal to a 1:5-year flood (present scenario). The initial water level in the estuary was relatively high at 1 m MSL, probably due to previous winter rainfall and flooding (Figure 2.37).

This means that extensive floodplain areas in the estuary were already inundated before the flood reached the estuary.

Further inundation of the floodplain was still confined to the upper estuary (see Figure 2.38 and Figure 2.39), but the area was somewhat more extensive than for the previously discussed floods. However, both the pre and post-dam floods were absorbed quickly and their effects were almost unnoticeable closer to Die Plaat. The difference between the pre- and post-dam flood peaks was also more noticeable, with the pre-dam flood inundating a slightly larger area than the post-dam flood.

The pre-dam flood has a higher sediment transport capacity, and even though the post-dam incoming flood had a lower simulated sediment load, and therefore more capacity to pick up sediment, the erosion and deposition pattern was more pronounced for the pre-dam flood (see Figure 2.40 and Figure 2.41). This is probably due to the effect of a lower incoming sediment load being counteracted by a lower flood magnitude for the post-dam flood, and hence a reduced sediment transport capacity. In the main channel, scouring of over 0.4 m and deposition of up to 0.5 m occurs for the present scenario, while the erosion and deposition is only up to 0.3 m for the post-dam scenario. The same pattern that was observed for the previous floods, is evident here, namely that the erosion in the main channel is more or less confined to the outer banks, while deposition takes place towards the middle of the channel.

For the present scenario, on the floodplain scour in the order of 0.2 m can be observed in places, while for the post-dam scenario this is only in the order of about 0.1 m. Sediment deposition is very limited on the floodplain.

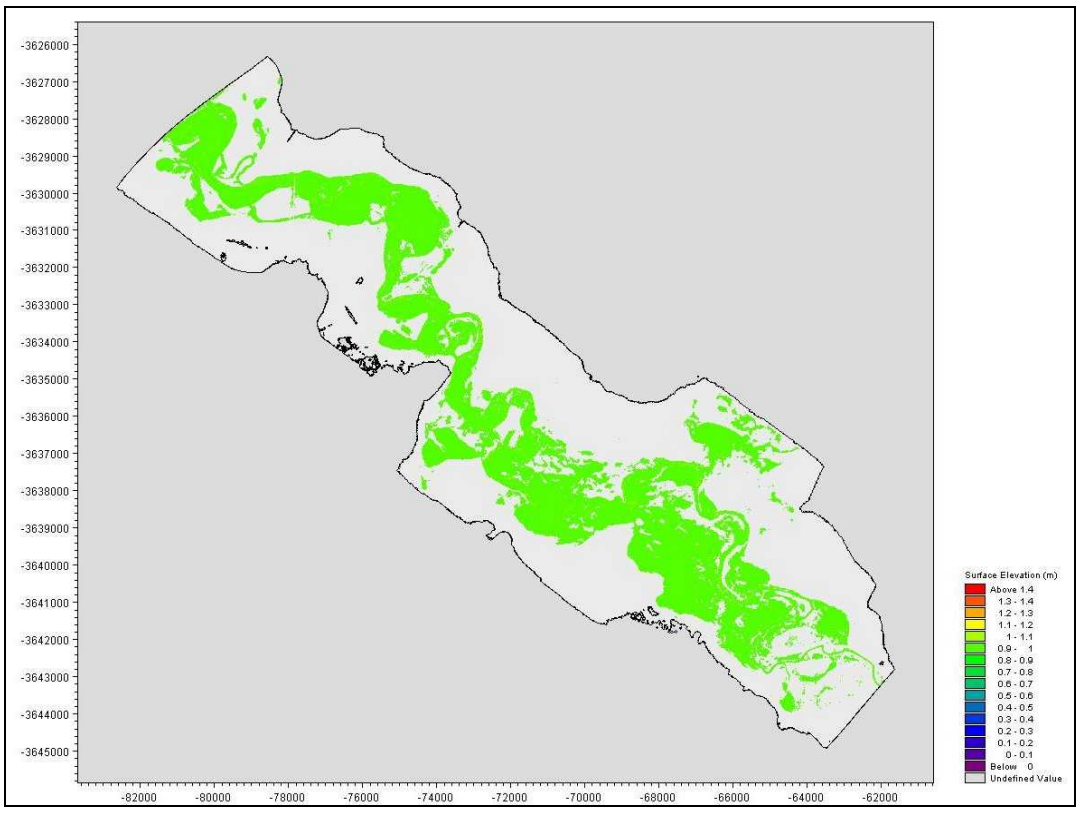


Figure 2.37 Initial water levels (as observed from record at G1H023) for flood 3

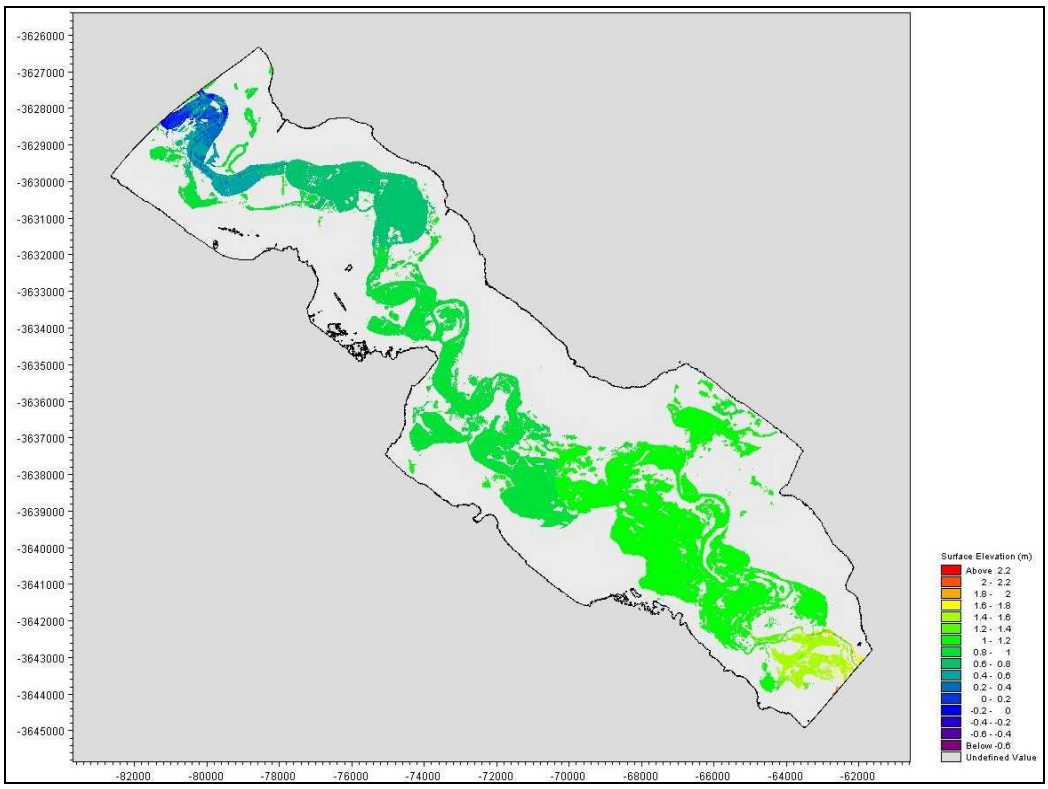


Figure 2.38 Present scenario – area inundated during 457 m^3/s flood

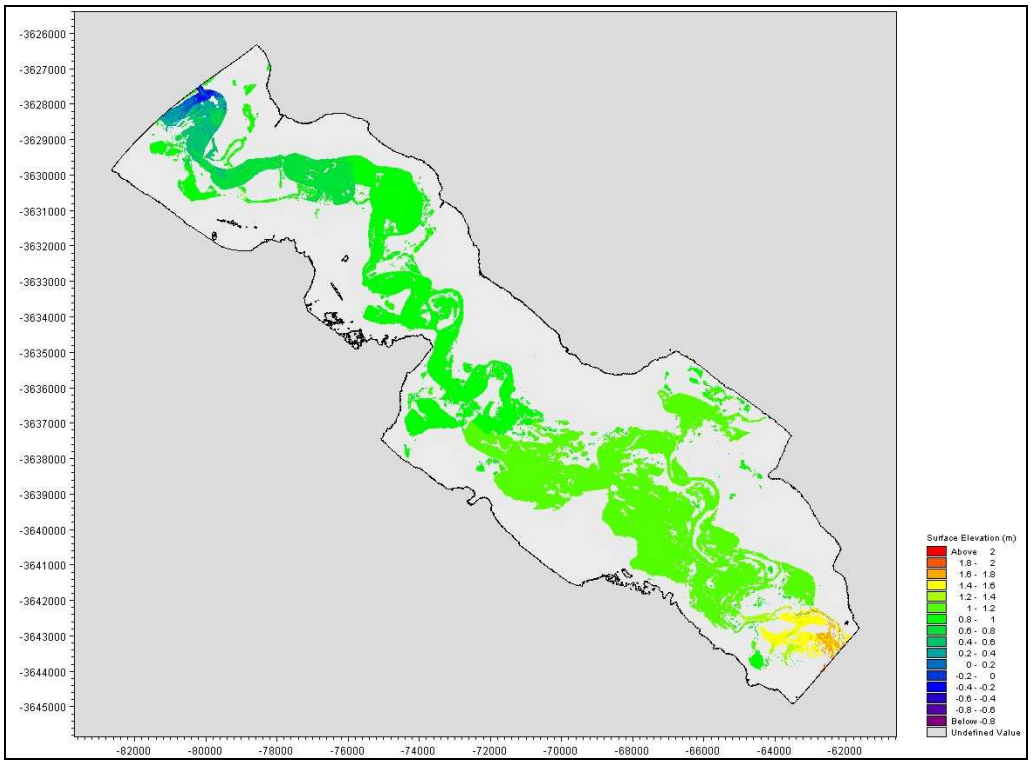


Figure 2.39 Future scenario – area inundated during 403 m^3/s flood

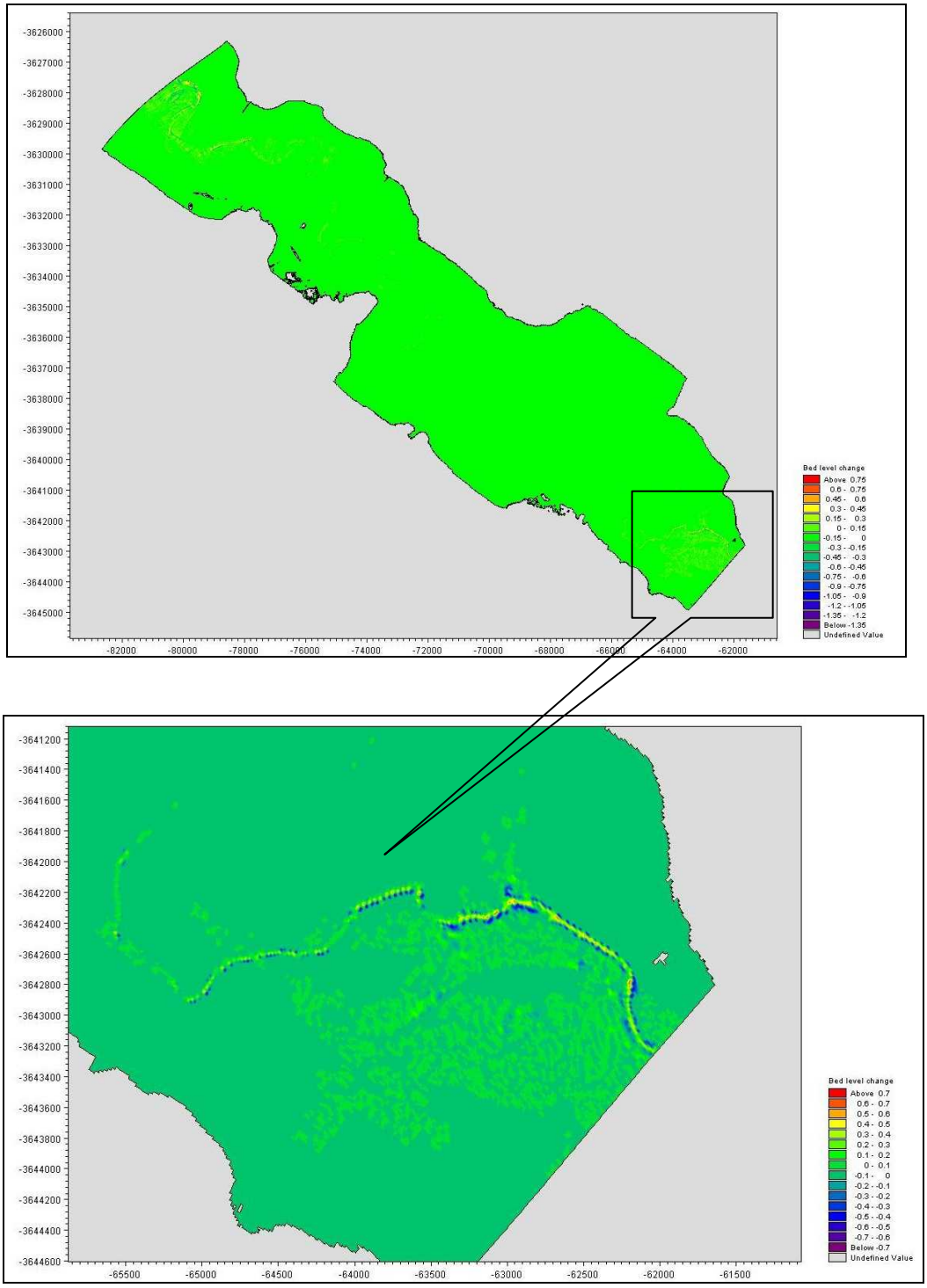


Figure 2.40 Present scenario – erosion and deposition pattern for 457 m^3/ flood

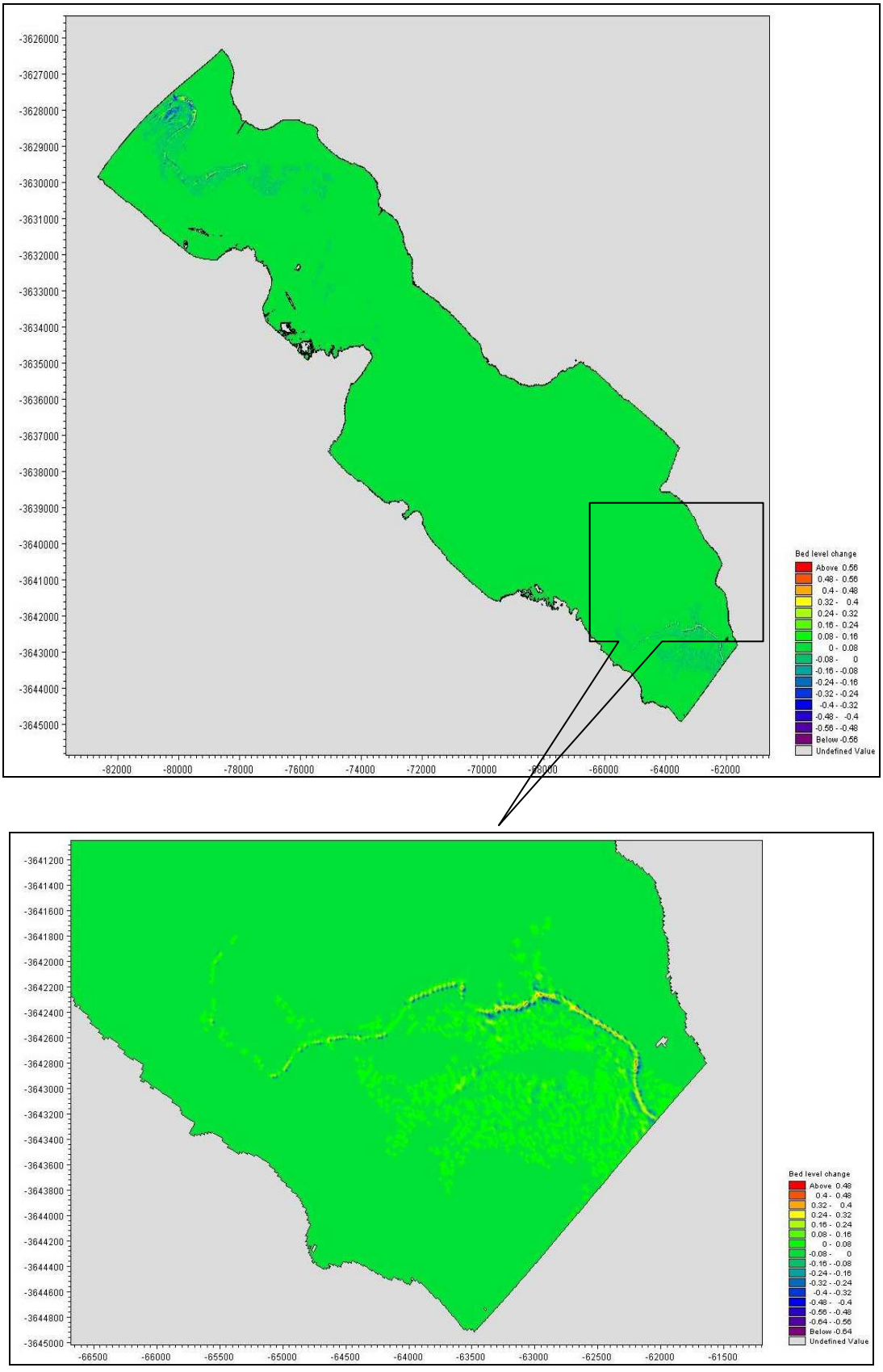


Figure 2.41 Future scenario – erosion and deposition pattern during 403 m^3/s flood

Flood 4: hydrograph with flood peak 622 m^3/s peak (current condition 1:10 year flood)

The fourth flood simulated had a magnitude of 622 m^3/s for the present scenario, and 525 m^3/s for the post-dam scenario, and was approximately equal to a 1:10-year flood (present scenario). The initial water level in the estuary was relatively high at 1 m MSL, probably due to previous winter rainfall and flooding (Figure 2.42).

This means that extensive floodplain areas in the estuary were already inundated before the flood reached the estuary.

Further inundation of the floodplain was again confined to the upper estuary (see Figure 2.43 and Figure 2.44), but was more extensive than for the previously discussed floods. Still, it seems that even floods of such magnitude are also absorbed fairly quickly. The effect of these two simulated floods at the Railway Bridge is only discernible by a rise in water level of about 0.5 m, which is in the same order of magnitude as the normal tidal action. The difference in the two flood peaks pre- and post-dam is not really discernible as both floods inundate about the same area.

The pre-dam flood has a higher sediment transport capacity, and therefore the erosion and deposition patterns are somewhat more pronounced than for the post-dam flood (Figure 2.45 and Figure 2.46). The erosion and deposition pattern in the main channel is very similar to the previous flood, with scouring of over 0.5 m and deposition of up to 0.6 m simulated for the present scenario, while the erosion and deposition was only up to 0.4 m for the post-dam scenario. The primary difference between this type of flood and the previous ones (flood 1 to 3) is that more erosion and deposition takes place on the floodplain for these two floods. For the present scenario, erosion and deposition on the floodplain are up to 0.4 m in places, while for the post-dam scenario this is only in the order of about 0.3 m.

The same pattern that was observed for the previous floods, is evident here, namely that the erosion in the main channel is more or less confined to the outer banks, while deposition takes place towards the middle of the channel.

This flood can also be compared to the large flood (peak discharge of 650 m^3/s) during the long-term winter simulations (see Section 2.6.2). In both cases the flood occurs close to spring tide and inundates large areas of the floodplain. The only difference is the initial water levels, which are higher during the long-term winter simulations. It therefore seems that the floods in themselves do not have the necessary volume to inundate large parts of the floodplain, and they need an initial higher water level in the estuary in order to extend significantly into the floodplain. This shows how important the higher baseflows in winter are, since they seem to be fuelling the elevated water levels in the estuary during winter.

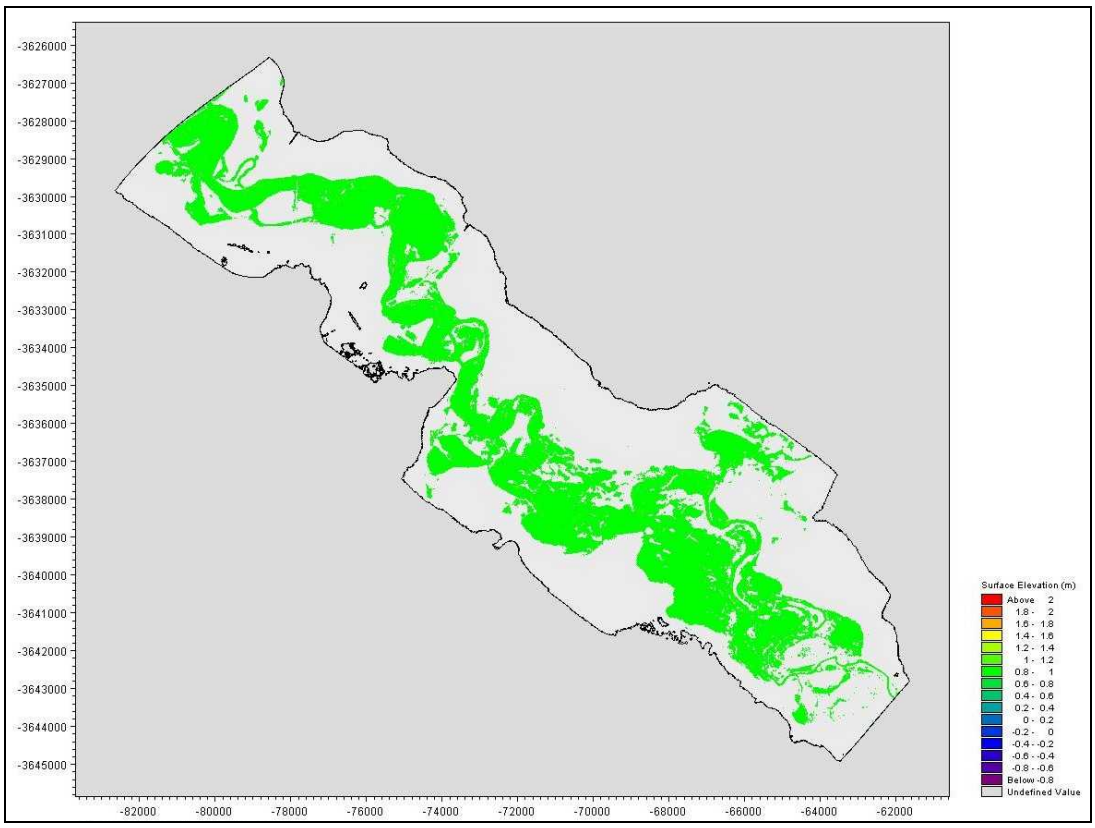


Figure 2.42 Initial water levels (as observed from record at G1H023) for flood 4

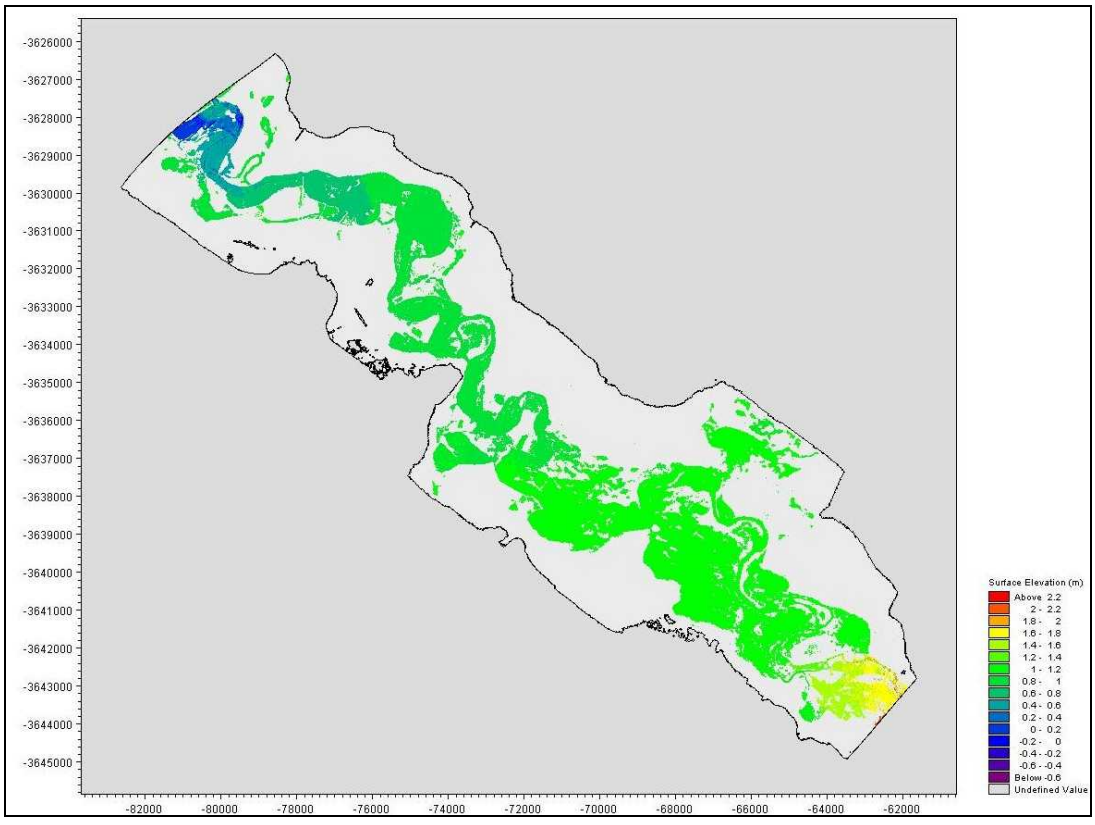


Figure 2.43 Present scenario – area inundated during 622 m^3/s flood

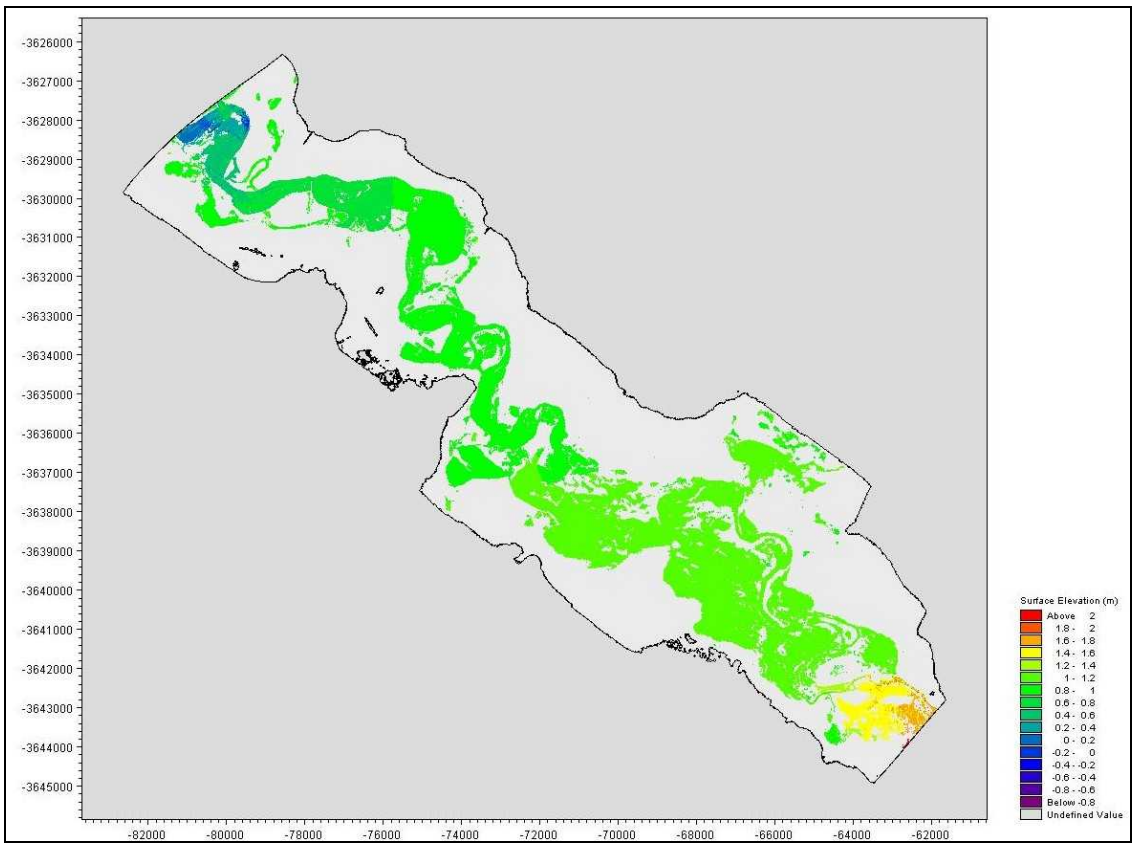


Figure 2.44 Future scenario – area inundated during 525 m^3/s flood

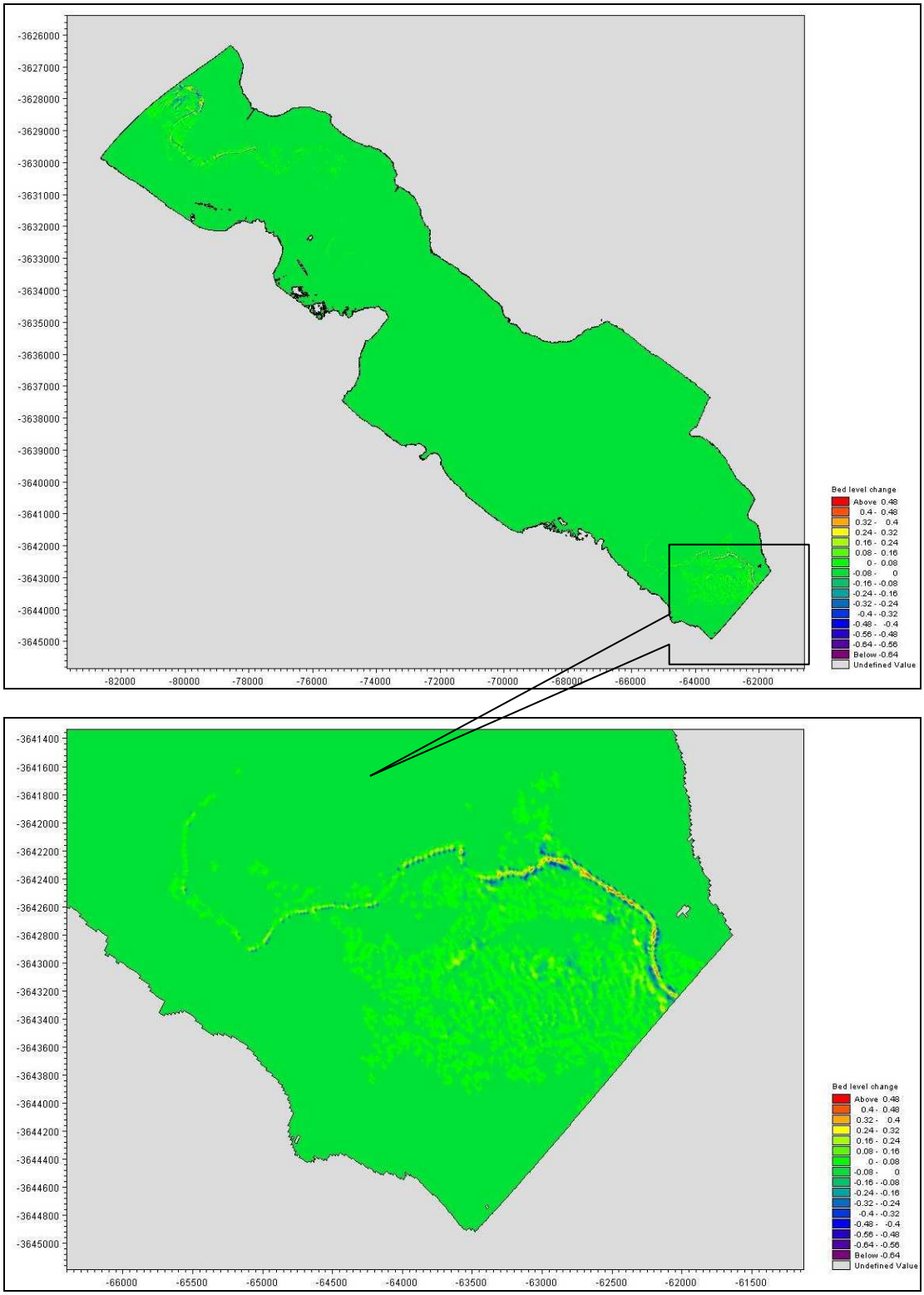


Figure 2.45 Present scenario – erosion and deposition pattern during 622 m^3/s flood

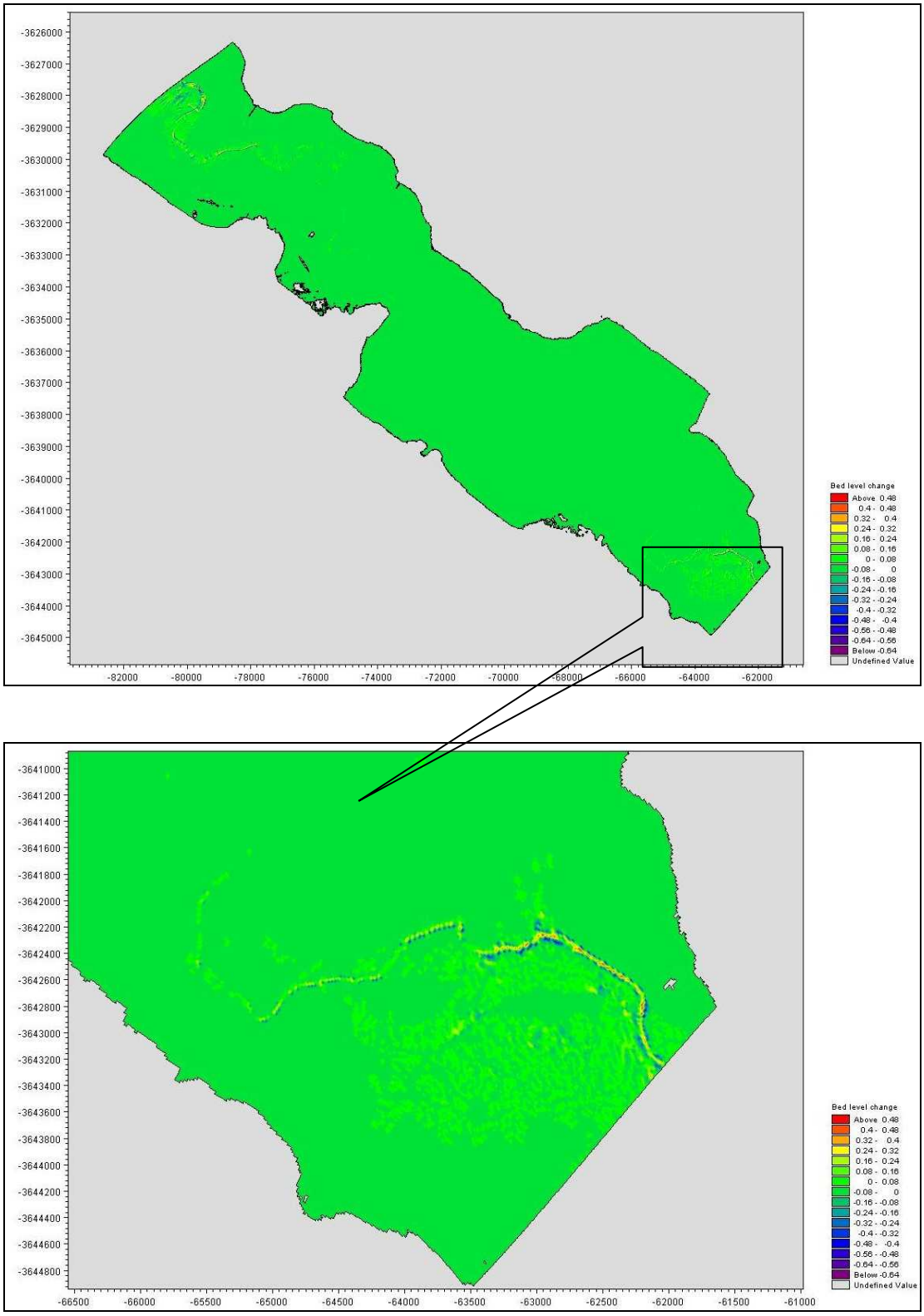


Figure 2.46 Future scenario – erosion and deposition pattern during 525 m^3/s flood

Flood 5: hydrograph with 890 m^3/s peak (current condition 1:100 year flood)

The fifth flood simulated had a magnitude of 890 m^3/s for the present scenario, and 833 m^3/s for the post-dam scenario, and was approximately equal to a 1:100-year flood (present scenario).

The initial water level in the estuary was relatively high at 1 m MSL, probably due to previous winter rainfall and flooding (Figure 2.47). This means that extensive floodplain areas in the estuary were already inundated before the flood reached the estuary. Inundation of the floodplain was significantly more extensive for these floods than for the smaller floods and covered at least a third of the estuary (see Figure 2.48 and Figure 2.49). Still, this flood is also attenuated and there seems to be a dry area that falls between the area inundated during the 1:100-year floods (upper estuary) and the area inundated during normal tidal action (lower estuary, see the shaded area in Figure 2.48). It appears as though it would require either a very high spring tide or an even larger flood to inundate the floodplain in the middle reaches of the estuary. Another possible explanation for the very infrequent flooding of that area could be that the Railway Bridge could have cut off the path of the river flow across the floodplain on the right hand side. However, the effect of these two simulated floods is only discernible by a rise of the water level of about 0.5 m at the Railway Bridge, which is in the same order of magnitude as the normal tidal action. The difference in the two flood peaks pre- and post-dam is definitely noticeable as the pre-dam flood inundates a larger area.

The velocities during the present scenario flood are quite high, with an average of between 1 and 2 m/s in the main channel and up to 1 m/s on the floodplain (see Figure 2.50).

The sediment transport capacity of the pre- and post-dam floods are similar in this case, and therefore the erosion and deposition pattern are very similar (see Figure 2.51 and Figure 2.52). The erosion and deposition patterns are a lot more extensive than for the previous floods, especially on the floodplain. In the main channel, scouring and deposition of around 0.6 m occurs for both scenarios. More extensive erosion and deposition takes place on the floodplain for these two floods, than for the previous floods. For both scenarios, erosion and deposition on the floodplain are up to 0.4 m in places, while on average erosion and deposition of about 0.1 m occurs over most of the inundated floodplain area. Sediment deposition is again limited on the floodplain during the pre-dam flood, while it is more widespread for the future scenario.

The same pattern that was observed for the previous floods, is evident here, namely that the erosion in the main channel is more or less confined to the outer banks, while deposition takes place towards the middle of the channel. This effect is visible over a large part of the main channel.

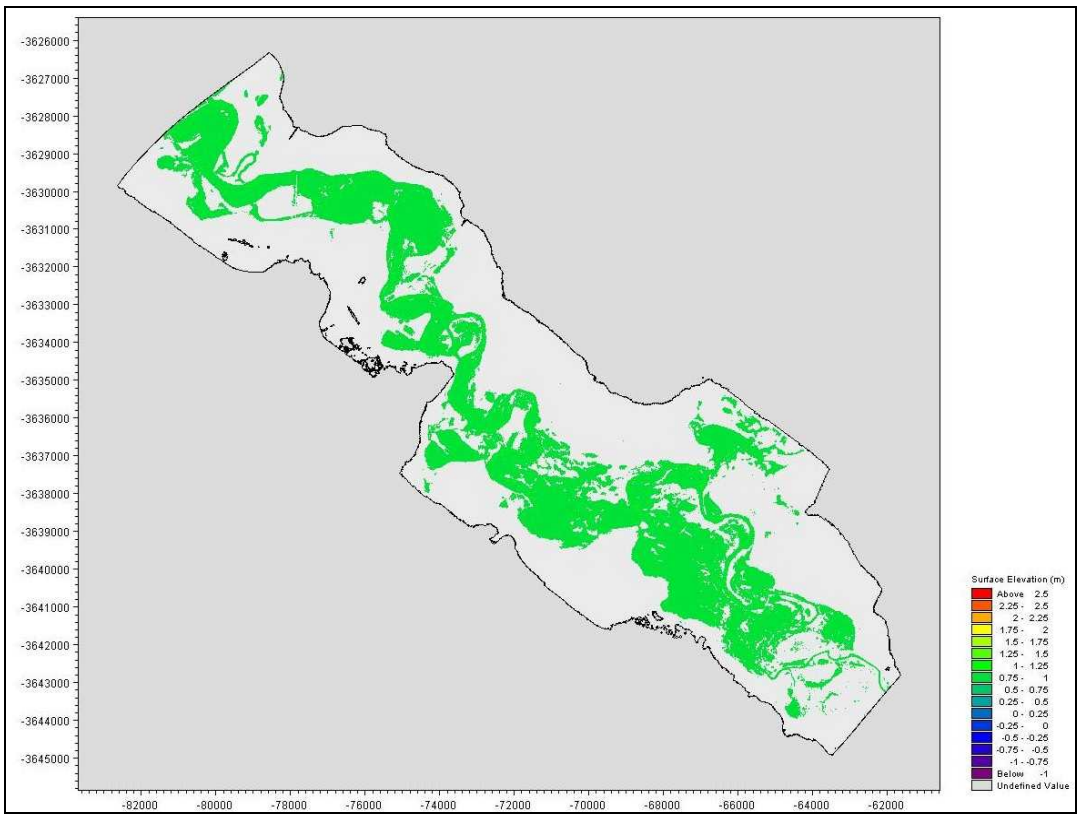


Figure 2.47 Initial water levels (as observed from record at G1H023) for flood 5

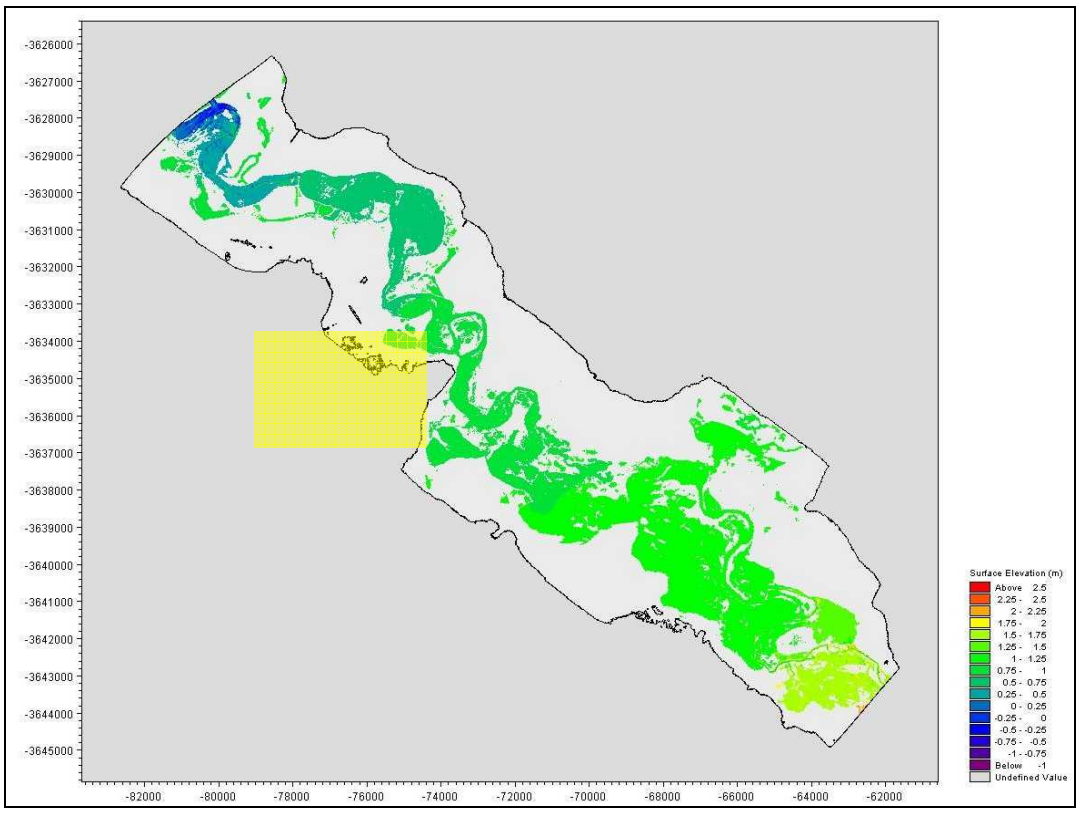


Figure 2.48 Present scenario – area inundated during 890 m^3/s flood

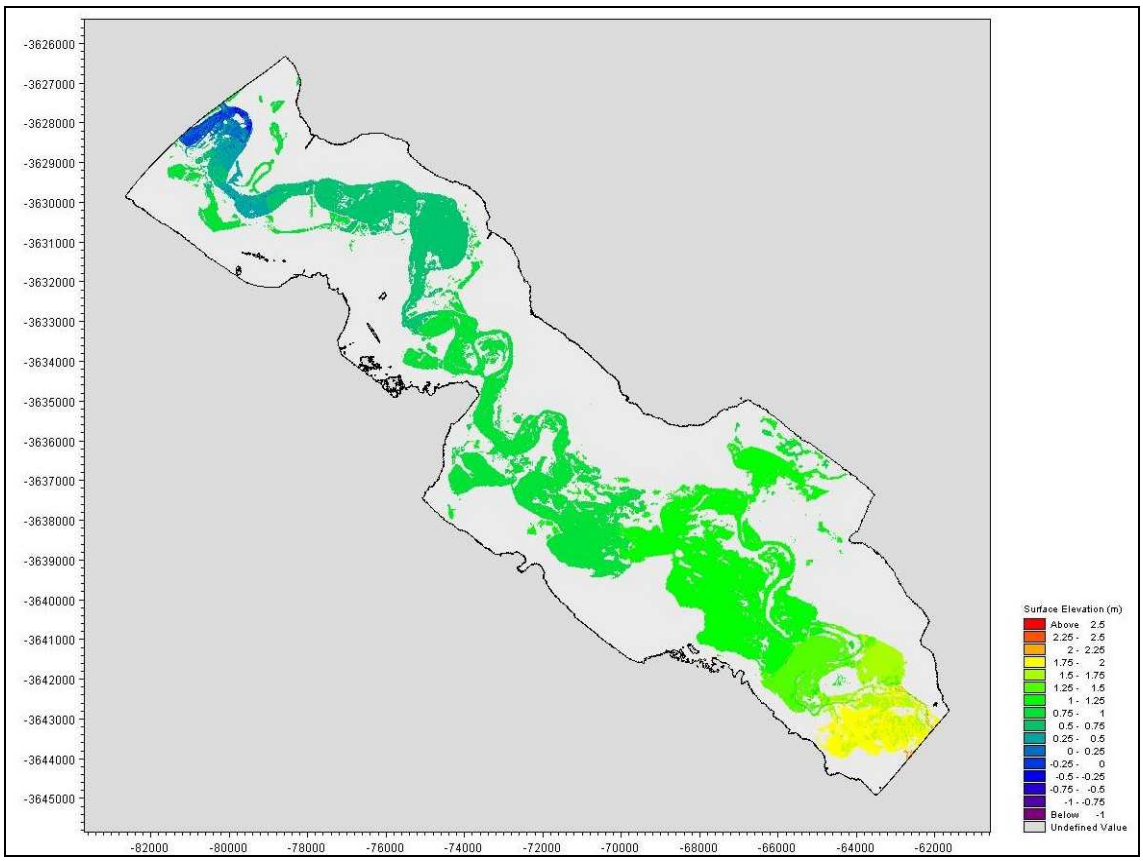


Figure 2.49 Future scenario – area inundated during 833 m^3/s flood

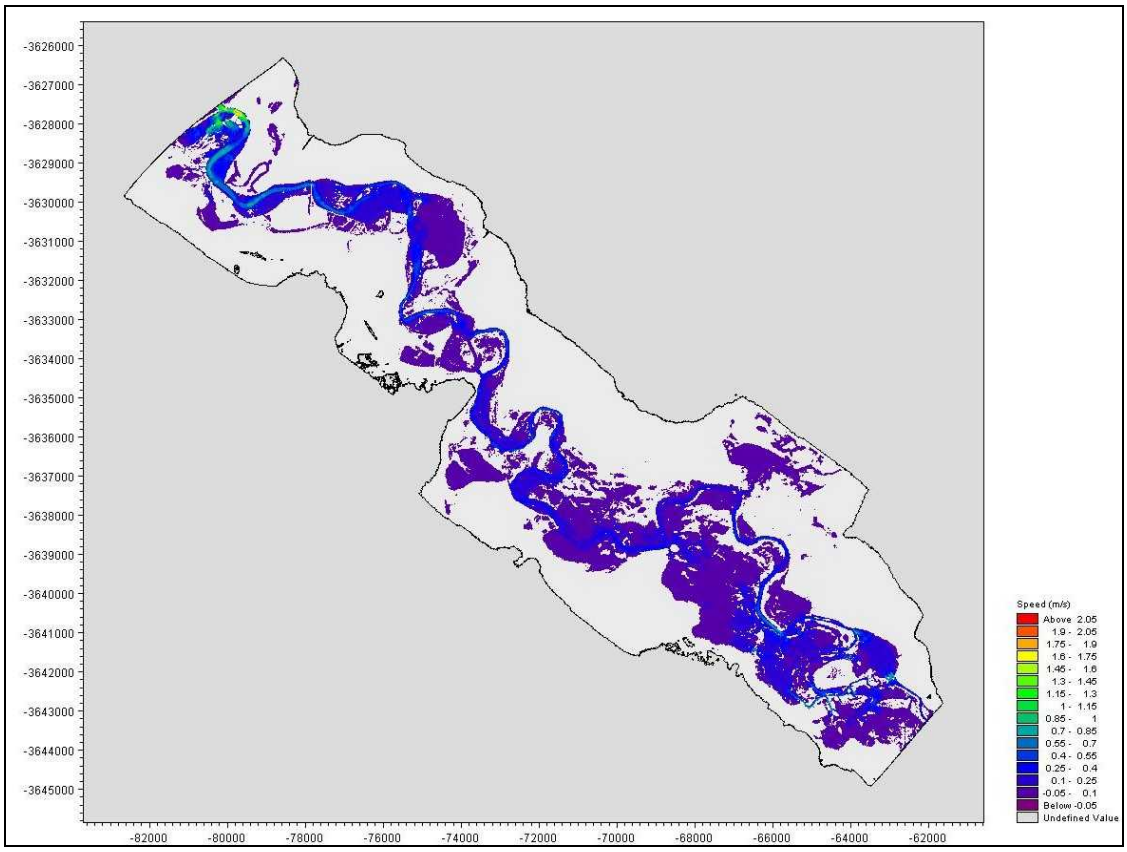


Figure 2.50 Velocities during 890 m^3/s

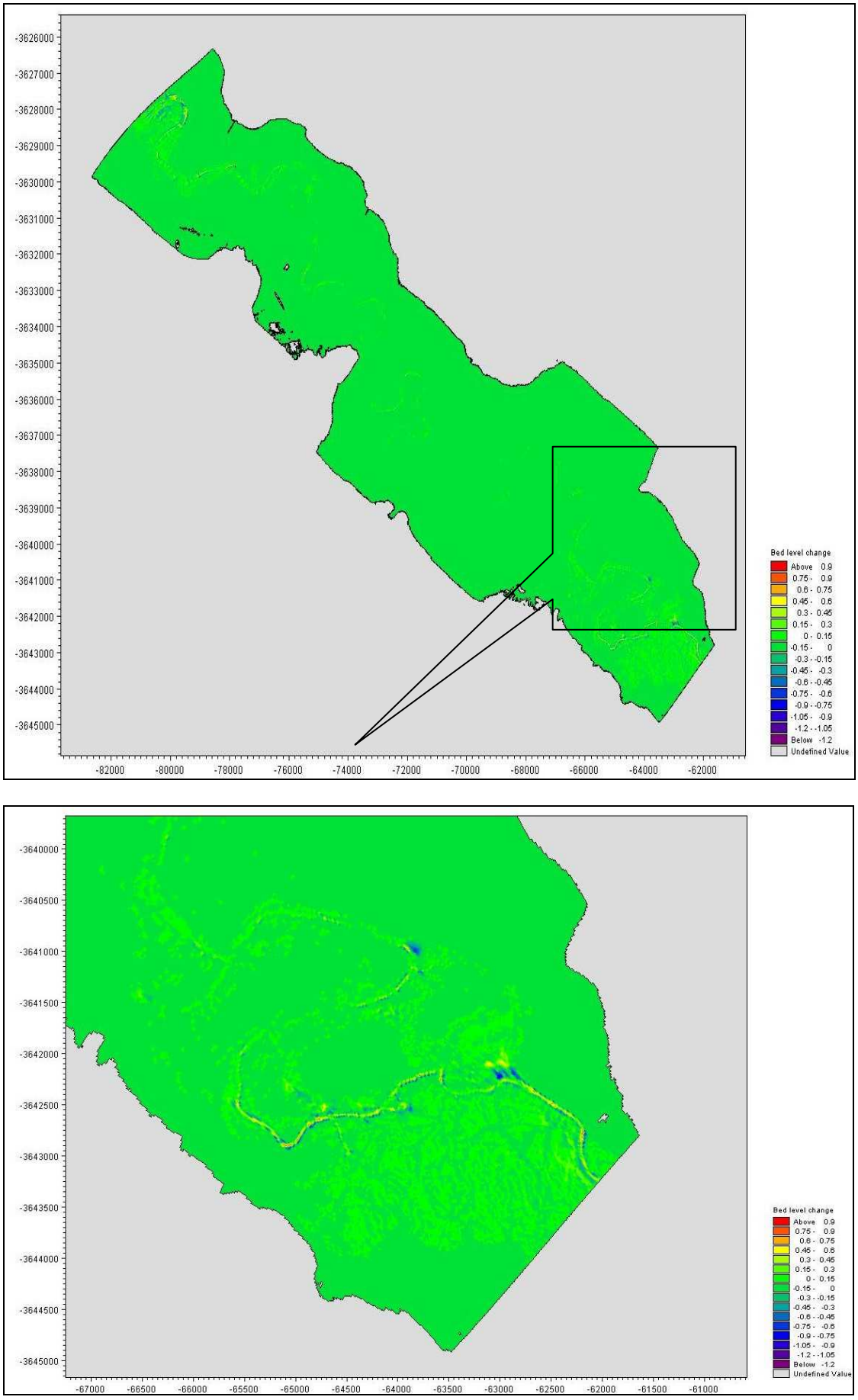


Figure 2.51 Present scenario – erosion and deposition pattern during 890 m^3/s flood

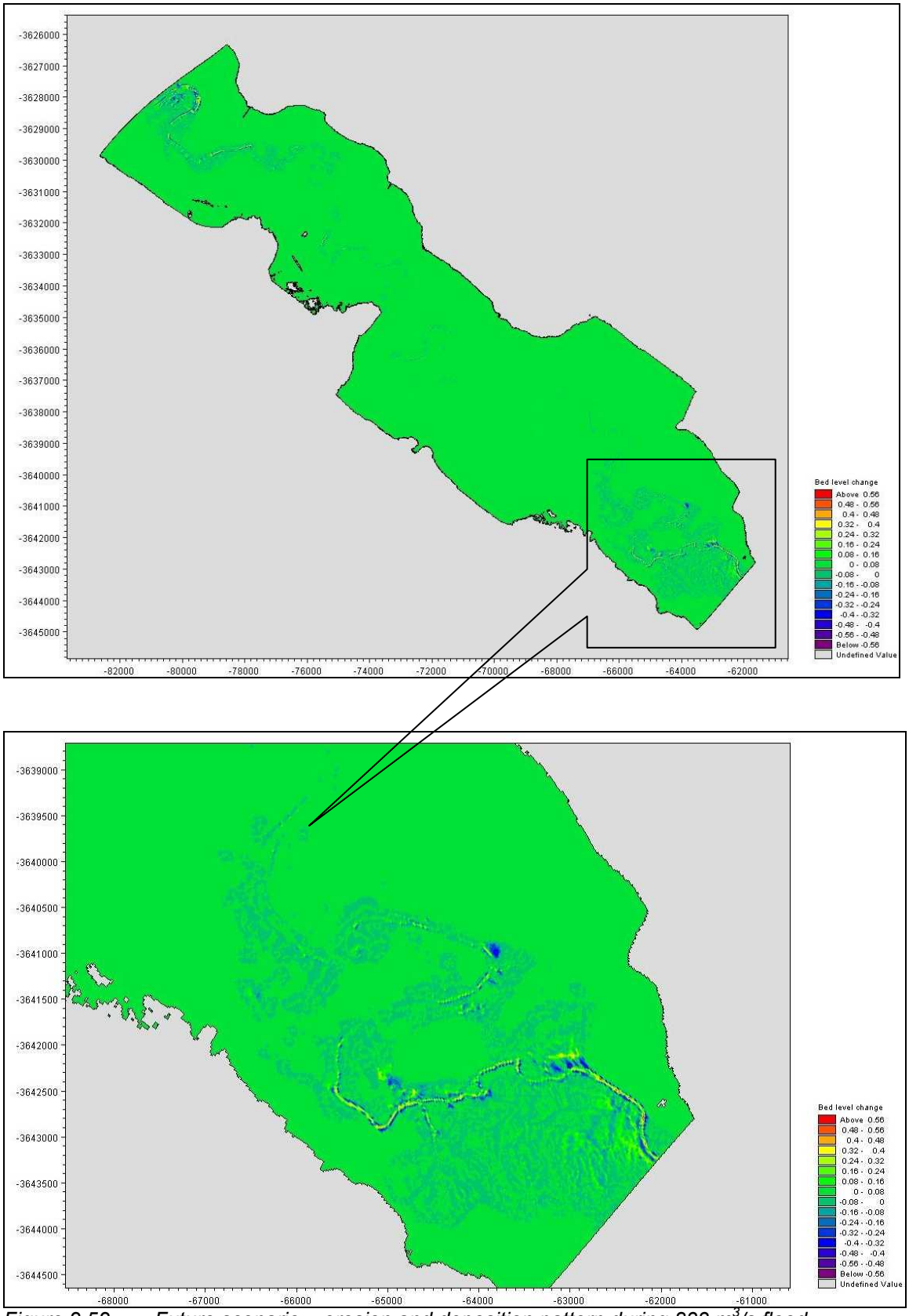


Figure 2.52 Future scenario – erosion and deposition pattern during 833 m^3/s flood

Wet and dry year comparison

For statistical references both a wet and a dry winter were simulated.

The typical wet year that was chosen is the year 1999. Figure 2.53 below shows the hydrological record of that winter. The typical dry year chosen is 2003 and is shown in Figure 2.54.

Velocity and depth data were extracted from the simulation result files and are available on the attached Appendices B to D and CD-ROM, together with the video animation of the floods. The data were used to develop the conceptual model on biotic-abiotic links in the estuary. It was not feasible to carry out longer term simulations than the winter periods due to hardware constraints.

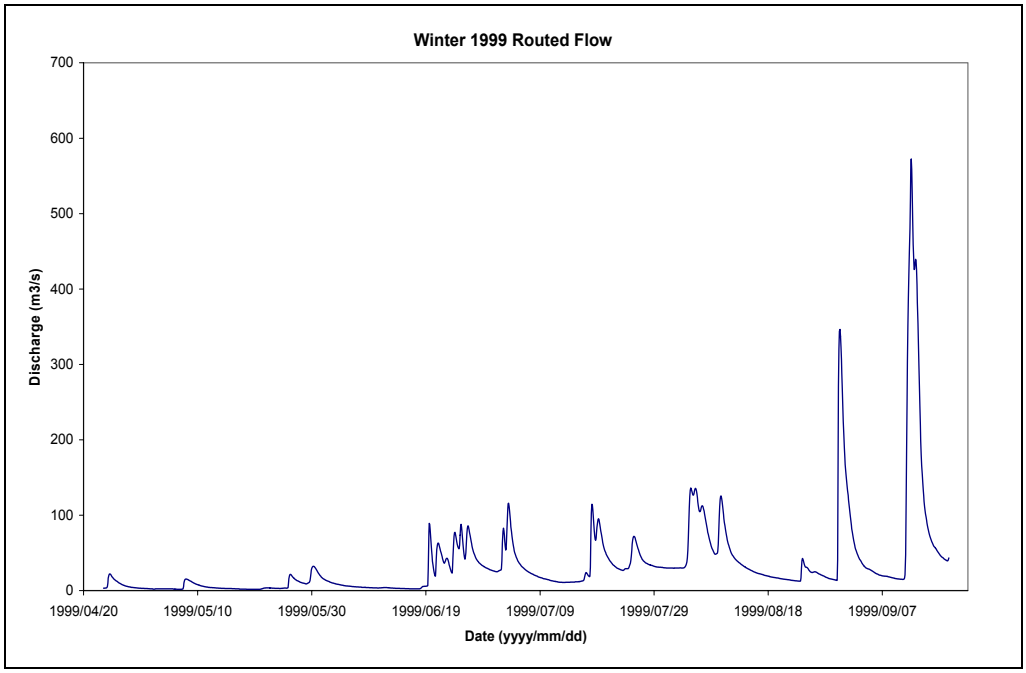


Figure 2.53 Hydrological record of typical wet year

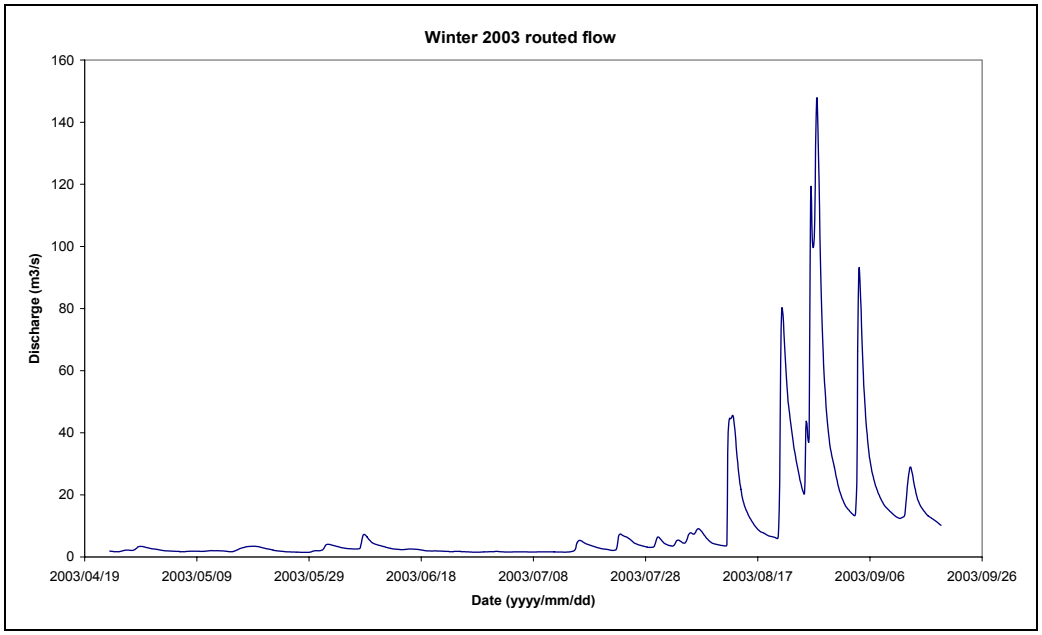


Figure 2.54 Hydrological record for typical dry year

Statistical analysis of typical wet/dry year simulation data

A statistical analysis was carried out on the 1999 and 2003 (winters) simulated flow depth and flow velocity data at 100 locations in the estuary. Refer to Table 2.1 for a list of coordinates. The selected points were obtained from the riparian and ecology experts on the study. The estuary was divided into 4 reaches: upper to downstream of the large right bank pan (reach 1), the reach down to Kliphoek (reach 2), the third reach to upstream of die Plaat (reach 3), and the lower reach to the ocean (reach 4). These four reaches are shown in Figures 2.41 to 2.44. The selection of the reaches were based on the pan/floodplain morphology mainly, with the upper two reaches experiencing most of the flooding onto floodplains. Figures 2.45 to 2.52 show typical duration curves for depth and duration for the two winter periods, at locations in reaches 1 to 4 indicated in Figures 2.42 to 2.44. In reach 1 the selected point is at the water level gauge G1H023 in the river channel, in reach 2 a large left bank floodplain was selected, while in reach 3 a pan close to the river and in reach 4 die Plaat was selected. The statistical analysis indicated that in reach 1 the 1999 and 2003 shallow depths were similar, but during floods the wetter 2003 year resulted in an almost doubling of the exceedance time at high depths. In reach 2, 2003 gives slightly deeper depths than in 1999. Reaches 3 and 4 are tide dominated and there are also small differences between wet and dry winters in terms of flow depth.

The velocities are in general quite low in the pans. The frequency graphs follow the same trends as with the flow depths.

Table 2.4 List of 100 points in the estuary with simulated flow depth and velocity data for 1999 and 2003

Sample Point no.	BERG_ID	X_coord	Y_coord (Decimal degrees, WGS_84 projection)
1	Open pan	-69545.76	-3638742.87
2	Open pan	-69588.63	-3638346.35
3	Open pan	-69674.36	-3637600.4
4	Halophytic floodplain	-69631.49	-3638014.12
5	Reed marsh	-69757.92	-3637846.07
6	Open pan	-71577.29	-3637505.48
7	Sedge marsh	-72271.41	-3637113.15
8	Open pan	-72267.10	-3637117.46
9	Reed marsh - short	-71491.06	-3636005.15
10	Sedge marsh	-71577.29	-3636013.77
11	Halophytic floodplain	-72219.67	-3637419.25
12	Reed marsh	-72573.20	-3637195.07
13	Open pan	-70602.93	-3637669.31
14	Halophytic floodplain	-70917.66	-3638169.42
15	Sedge marsh	-71271.18	-3637850.38
16	Halophytic floodplain	-71154.78	-3637354.58
17	Open pan	-68576.62	-3637466.68
18	Sedge marsh	-68938.77	-3638734.20
19	Reed marsh	-71560.04	-3637971.10
20	Open pan	-68477.46	-3639337.78
21	Inundated mud-flats	-68382.61	-3638716.96
22	Open pan	-68050.64	-3638557.44
23	Open pan	-68033.39	-3638971.32
24	Open pan	-67649.69	-3640463.04
25	Reed marsh	-68813.74	-3638074.57
26	Sedge marsh	-68835.30	-3637841.76
27	Sedge marsh	-67559.15	-3637596.02
28	Sedge marsh	-67028.86	-3637690.87
29	Open pan	-67184.07	-3637488.24
30	Reed marsh	-67835.07	-3637440.81
31	Open pan	-65916.54	-3639079.11
32	Reed marsh	-65981.21	-3638751.45
33	Open pan	-68602.49	-3637940.92
34	Halophytic floodplain	-67222.87	-3638600.55
35	Halophytic floodplain	-67964.41	-3638320.32
36	Reed marsh	-66556.58	-3639599.68
37	Open pan	-67399.63	-3638346.18
38	Reed marsh	-66502.88	3640997.64
39	Open pan	-68361.05	-3639902.57
40	Open pan	-64459.32	-3642071.15
41	Open pan	-63015.04	-3641428.77
42	Open pan	-63381.50	-3641609.84
43	Sedge marsh	-64377.41	-3642510.90
44	Sedge marsh	-64692.13	-3641790.92
45	Reed marsh	-64976.68	-3641743.49
46	Reed marsh	-65278.47	-3642510.90
47	Halophytic floodplain	-64683.51	-3642364.32
48	Sedge pan	-63230.60	-3641903.01
49	Reed marsh	-64044.43	-3641501.06
50	Sedge pan	-63441.86	-3641295.12
51	Halophytic floodplain	-64265.31	-3641790.92
52	Inundated mud-flats	-65175.00	-3642368.63
53	Inundated mud-flats	-64567.11	-3641687.45
54	Open pan	-65528.53	-3640256.09
55	Reed marsh	-66942.63	-3640139.69
56	Halophytic floodplain	-65334.52	-3639687.00
57	Sedge marsh	-65912.23	-3640588.06
58	Sedge pan	-67774.72	-3639523.17
59	Sedge pan	-67593.64	-3640898.48
60	Sedge pan	-67283.23	-3640036.22
61	Open pan	-74077.84	-3637052.79
62	Open pan	-73478.57	-3636841.54
63	Xeric floodplain	-73150.91	-3636673.40
64	Xeric floodplain	-73500.13	-3636199.16
65	Halophytic floodplain	-73793.30	-3635789.58
66	Halophytic floodplain	-72620.62	-3636884.65
67	River	-74379.63	-3631275.65
68	River	-74577.95	-3630810.02
69	River	-74595.20	-3630361.65
70	Halophytic saltmarsh	-80268.88	-3629245.02
71	Halophytic saltmarsh	-79911.04	-3628805.27
72	Inundated mud-flats	-77332.88	-3629758.07

Table2.4 - Continued

73	Sedge marsh	-77056.95	-3629633.04
74	Sedge marsh	-77013.84	-3630085.73
75	Halophytic saltmarsh	-79329.01	-3630271.11
76	Halophytic saltmarsh	-78811.66	-3629917.58
77	Sedge marsh	-75888.59	-3629848.60
78	Open pan	-75599.73	-3630180.57
79	Sedge marsh	-76526.66	-3630167.64
80	Xeric floodplain	-75573.87	-3630525.48
81	Xeric floodplain	-75496.26	-3630382.48
82	Reed marsh	-75328.12	-3631724.02
83	Reed marsh	-74836.63	-3631374.81
84	Sedge marsh	-75052.20	-3632258.62
85	Halophytic saltmarsh	-79760.14	-3628201.69
86	Halophytic saltmarsh	-79824.81	-3628395.69
87	Halophytic saltmarsh	-80510.31	-3628175.82
88	Inundated mud-flats	-78531.42	-3629581.30
89	Halophytic saltmarsh	-78367.59	-3629551.12
90	Halophytic saltmarsh	-80074.87	-3629779.62
91	Sedge pan	-68792.18	-3639704.25
92	Sedge pan	-67503.10	-3638876.48
93	Sedge pan	-63295.27	-3641493.44
94	Sedge marsh	-65076.92	-3642275.43
95	Xeric floodplain	-68869.79	-3639018.75
96	Xeric floodplain	-65550.08	-3640217.29
97	Sedge marsh	-64256.69	-3641286.49
98	Sedge pan	-69792.41	-3637501.17
99	Xeric floodplain	-80070.56	-3628481.92
100	Sedge pan	-71715.25	-3635548.15

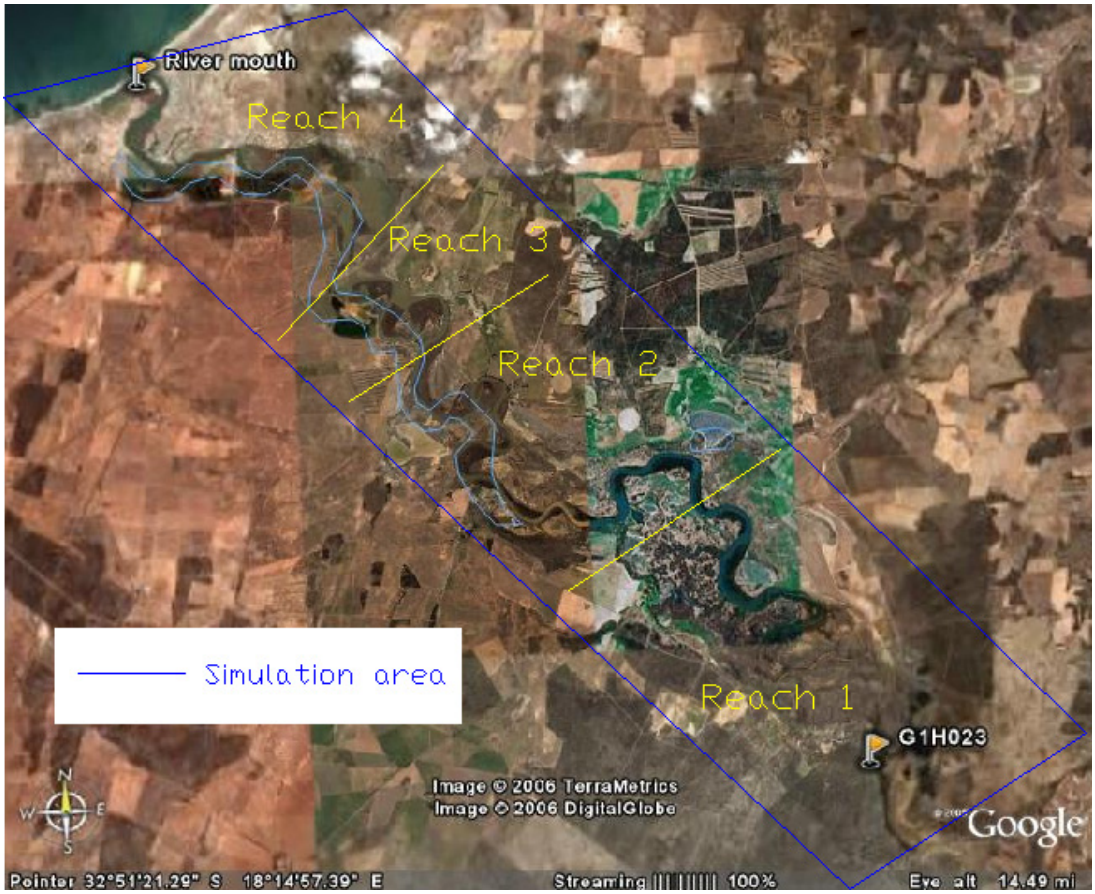


Figure 2.55 Satellite image of the Berg River simulation area

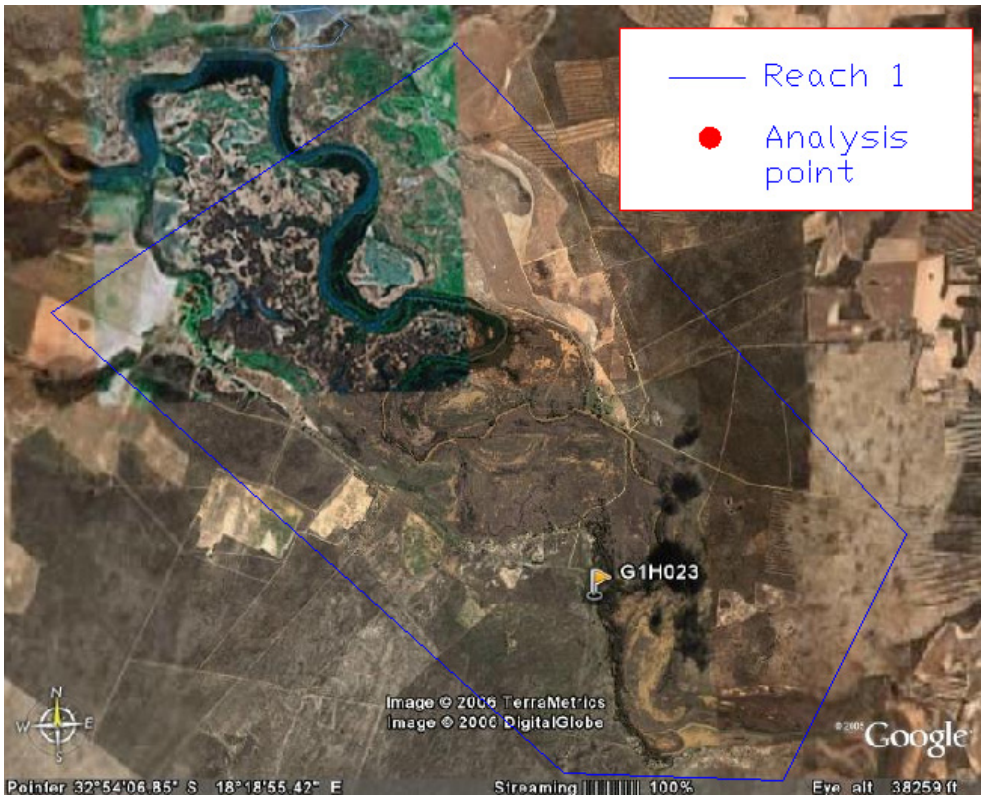


Figure 2.56 Reach 1

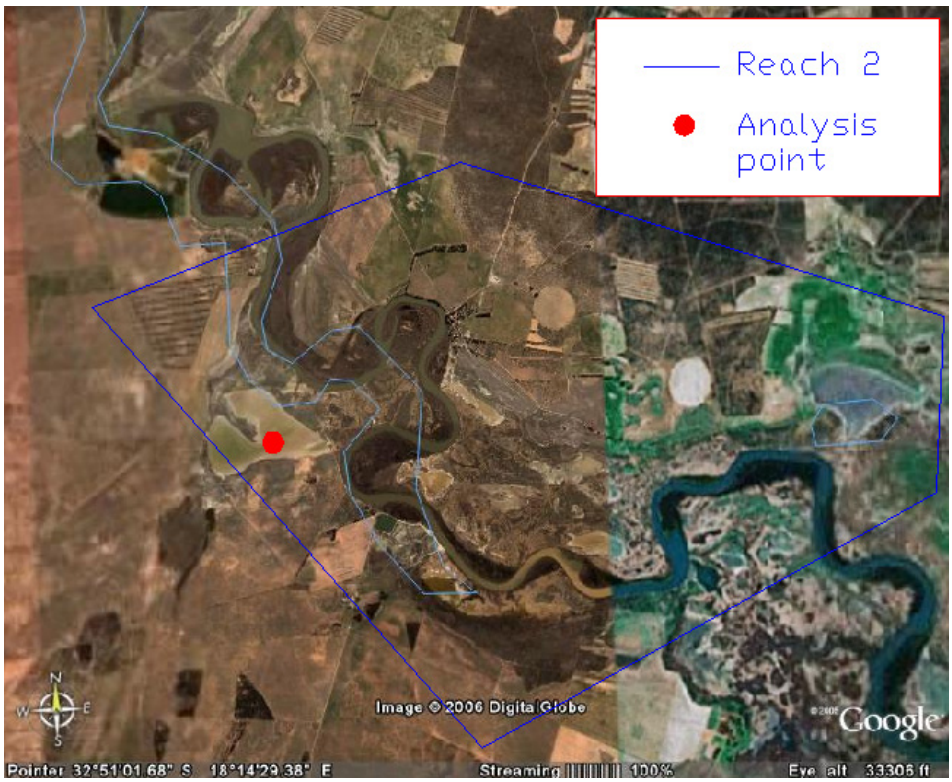


Figure 2.57 Reach 2

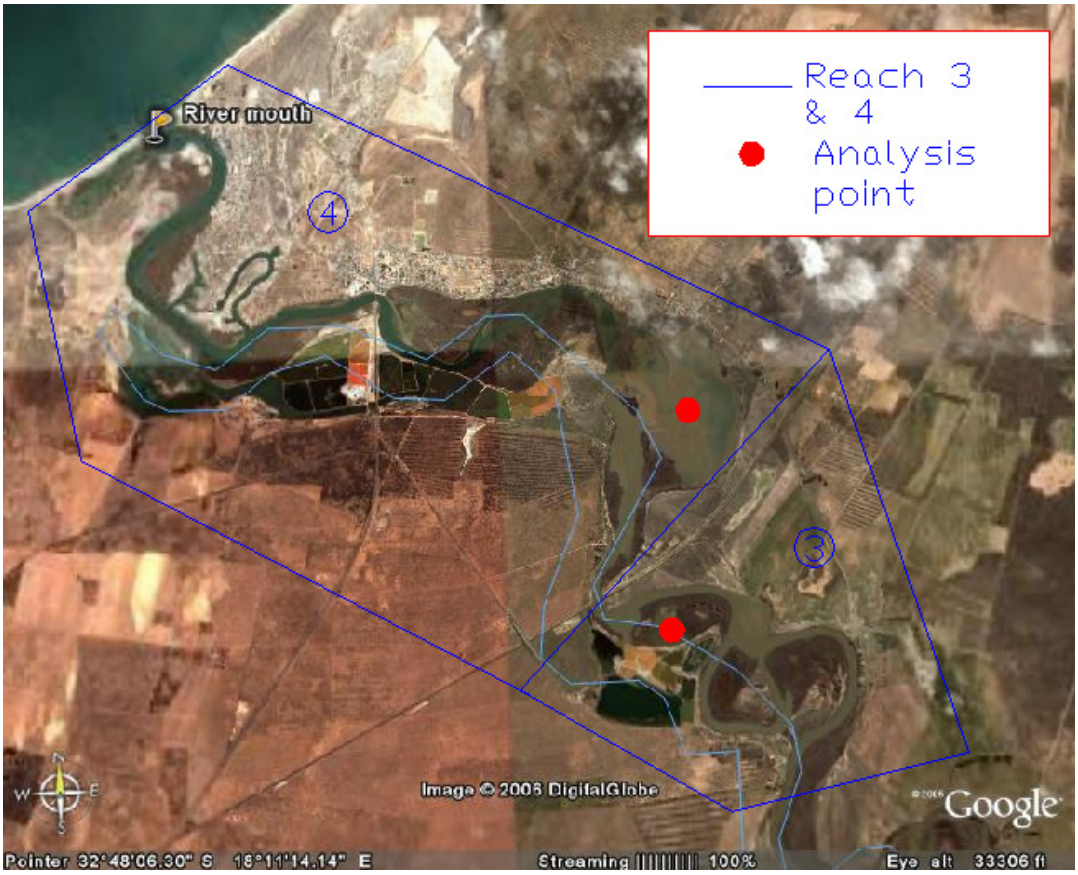


Figure 2.58 Reach 3 & 4

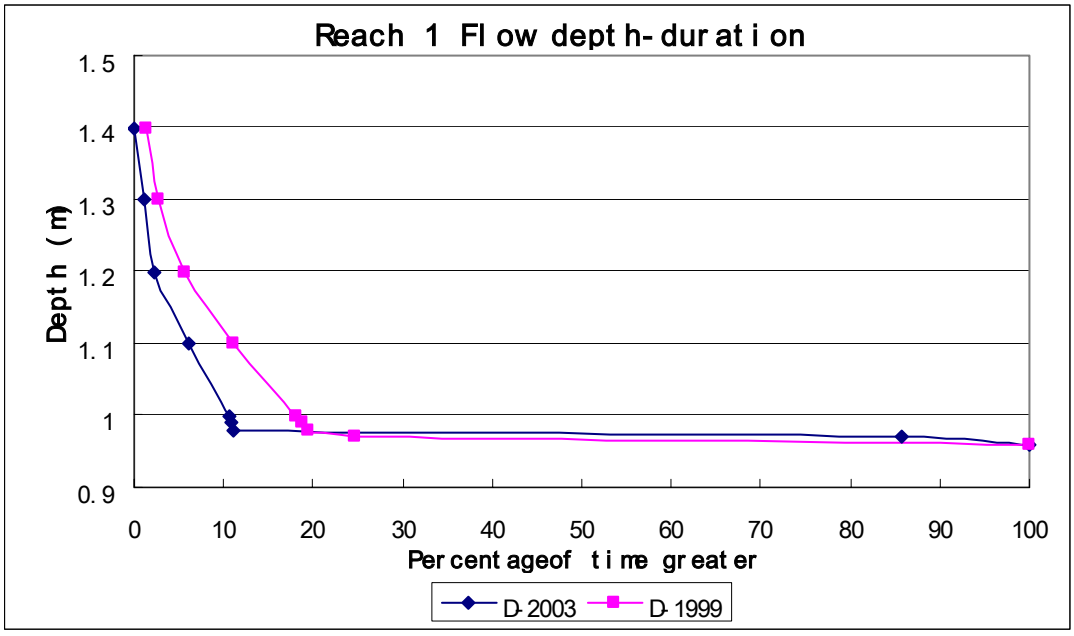


Figure 2.59 Flow depth duration at reach 1 (X -744077.84, Y -3637052.79)

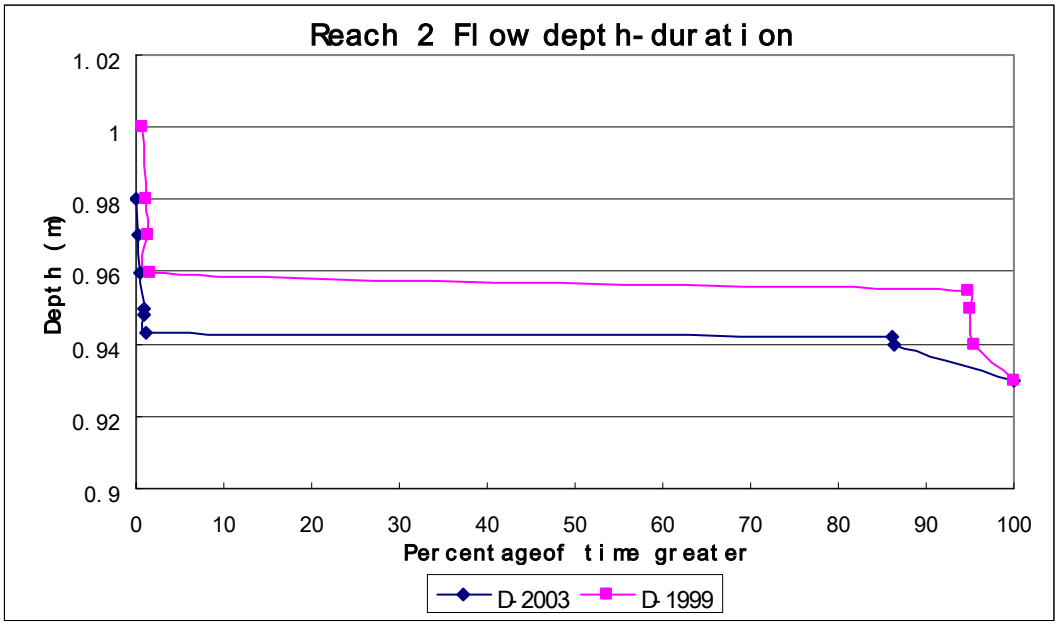


Figure 2.60 Flow depth duration at reach 2 (X -76526.66, Y -3630167.64)

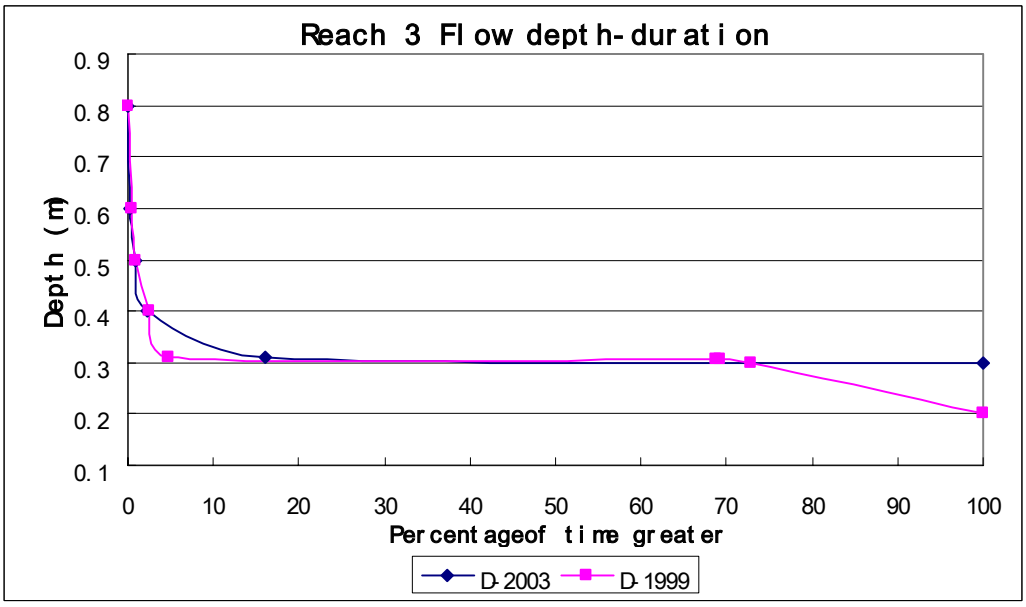


Figure 2.61 Flow depth duration at reach 3 (X -75052.20, Y -3632258.62)

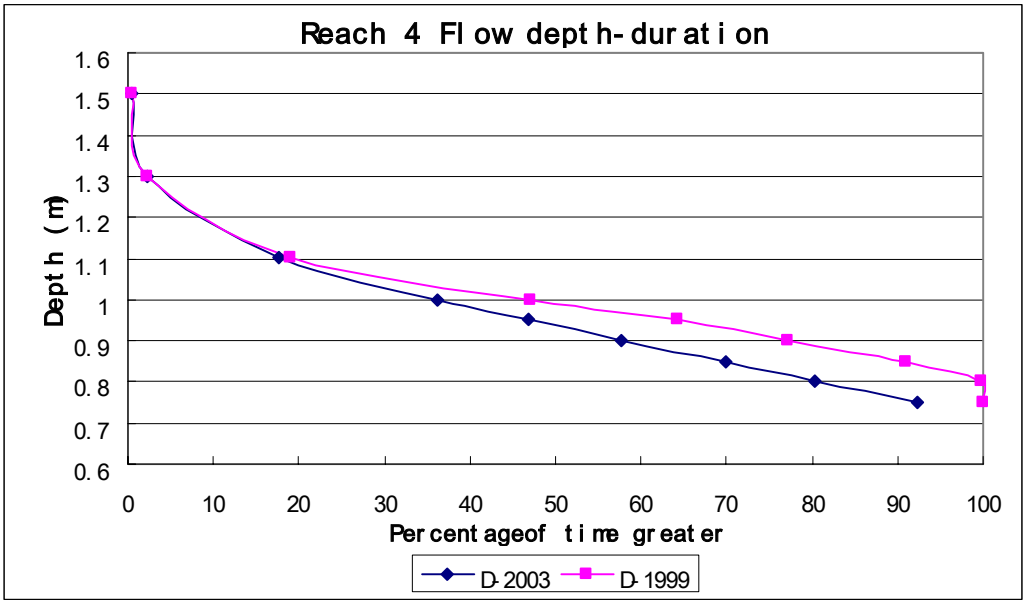


Figure 2.62 Flow depth duration at reach 4 (X -64256.69, Y -3641289.49)

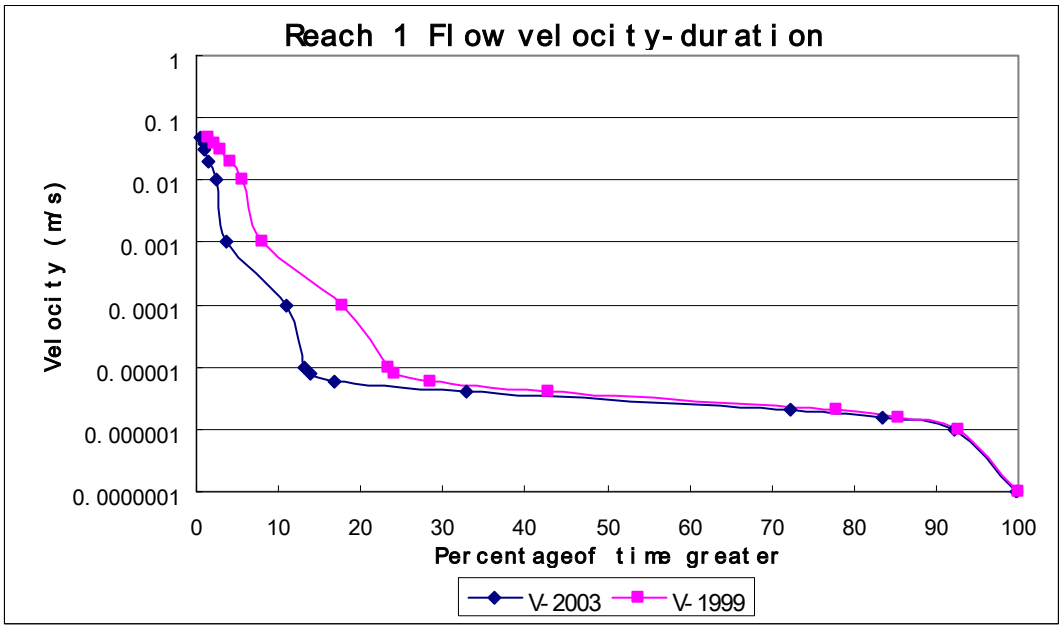


Figure 2.63 Flow velocity duration at reach 1 (X -744077.84, Y -3637052.79)

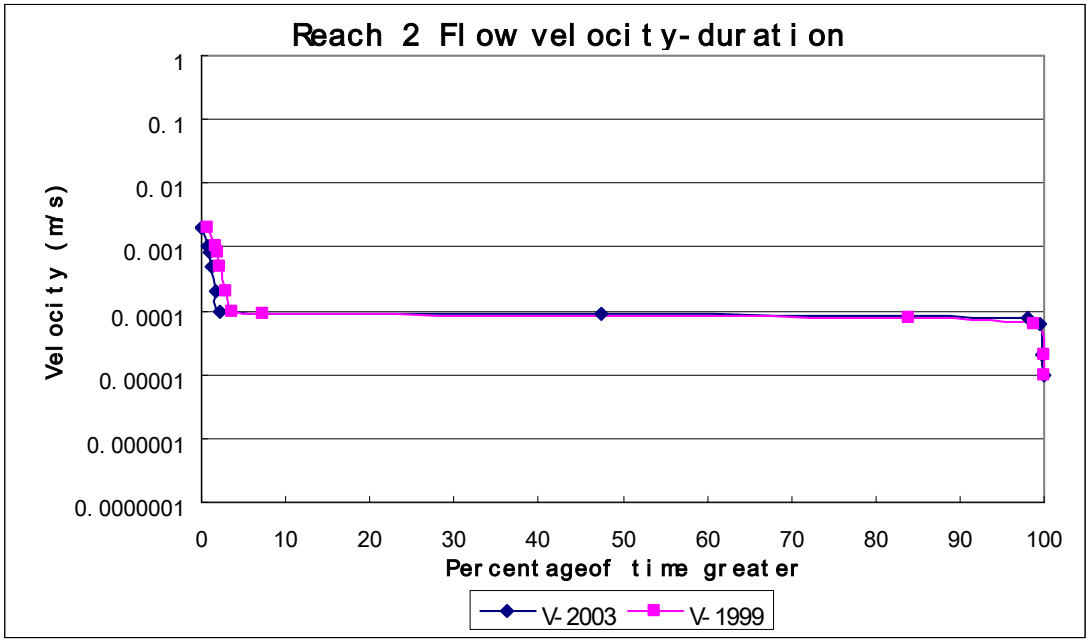


Figure 2.64 Flow velocity duration at reach 2 (X -76526.66, Y -3630167.64)

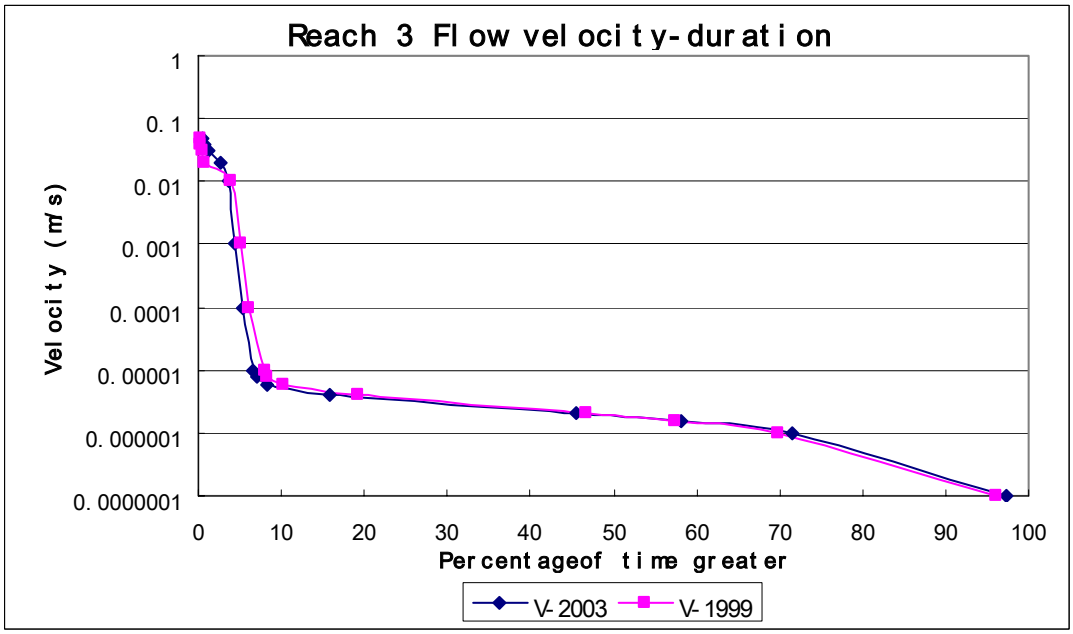


Figure 2.65 Flow velocity duration at reach 3 (X -75052.20, Y -3632258.62)

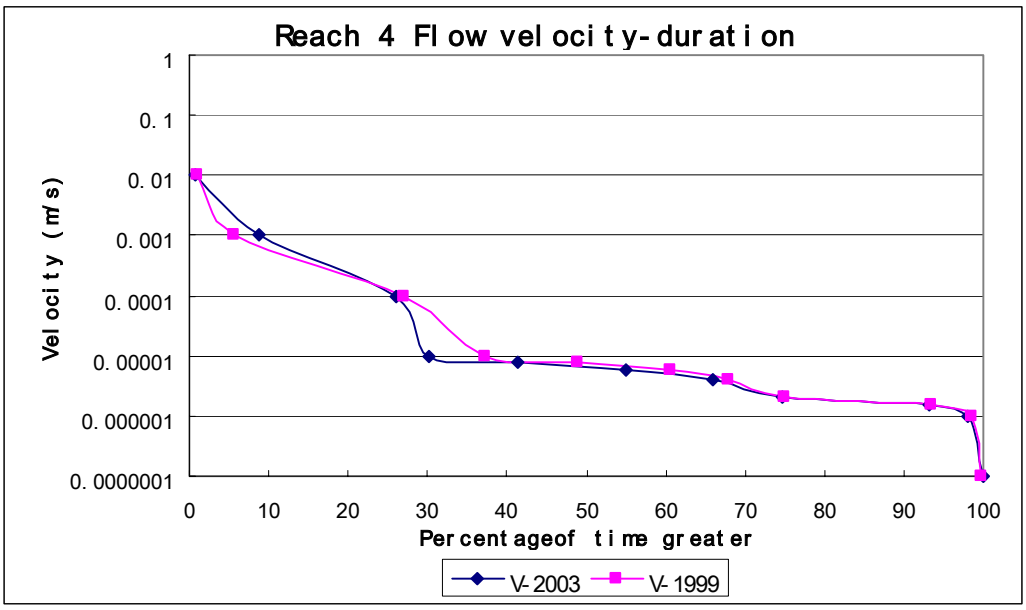


Figure 2.66 Flow velocity duration at reach 4 (X -64256.69, Y -3641289.49)

Graphs showing flow depths for all 100 points for the months May to September for 1999 and 2003 are included in Appendix 1.2, while data for flow depths and velocities at these points are included in Appendix 1.3 and 1.4, and on CD.

2.6.4 Establishing a link between floods and flooding of the floodplains of the estuary

During this study the high flow seasons, typically from May to September of each year could be simulated by hydrodynamic model for the years 1998 to 2003, a 6 year period (Figure 2.53). The 2D hydrodynamic model made it difficult to simulate a longer period due to hardware limitations (computational speed and file size).

The three largest floods of each year of the simulation period were used to establish a possible relationship between the most important variables: flood peak discharge, flood volume, initial upper estuary water level in the main channel, initial sea water level, and the area of inundation of the floodplains for each flood.

From the simulation results it is clear that the initial water level in the upper estuary is very important to create large flooding of the floodplain areas. The maximum area of inundation was 26.4 km^2 in reach 1, by a 290 m^3/s flood peak at an initial water level of 1.8 amsl, while a large flood of 893 m^3/s peak discharge, at starting water level of 1.45 m gives a similar 23 km^2 inundation. The floods selected for this exercise are shown in Table 2.2.

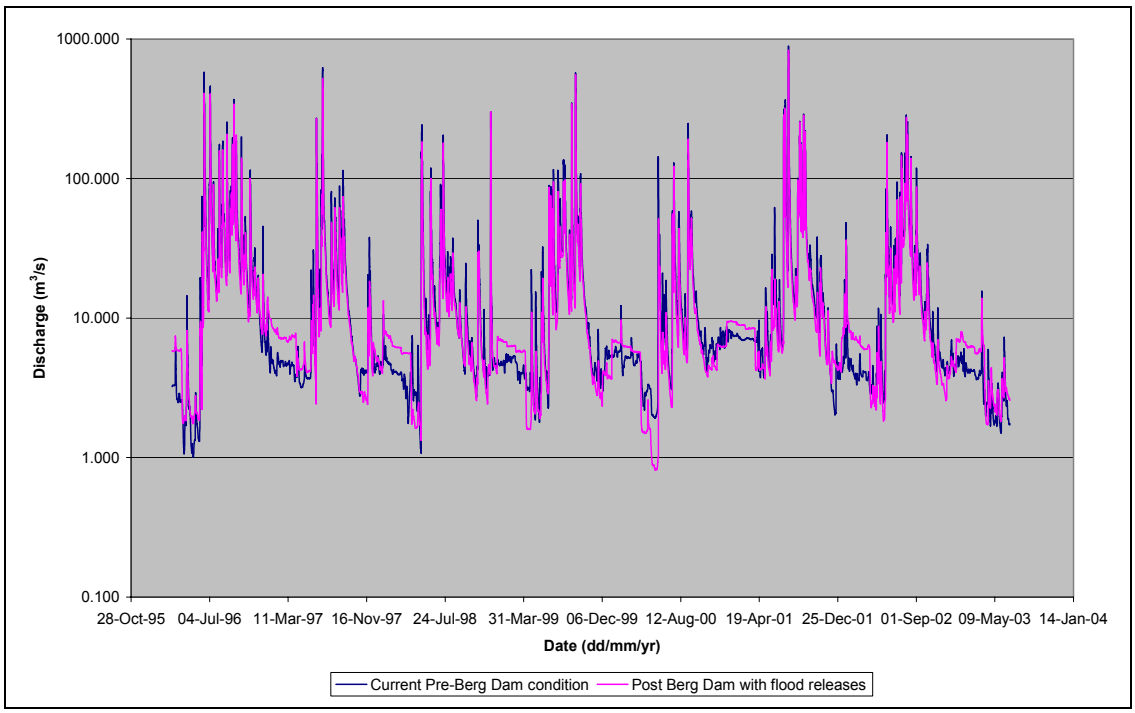


Figure 2.67 Routed historical estuary inflows 1996 to 2003

Table 2.5 Flood data and inundated areas

Flood date	River inflow peak discharge (m^3/s)	River inflow flood volume million (m^3)	Initial upper estuary water level (amsl)	Initial water level at mouth (amsl)	Total area inundated (km^2)			
					Reach 1	Reach 2	Reach 3	Reach 4
10/05/1998	244	79.9	0.16	0.04	20.2	13.4	3.0	10.0
18/07/1998	205	37.8	1.3	0.2	17.6	10.7	2.8	10.0
15/12/1998	301	26.9	0.2	-0.16	16.9	9.9	2.8	9.4
04/08/1999	136	43.1	1.58	0.3	20.9	13.0	3.0	8.8
30/08/1999	347	59.8	0.92	0	21.1	15.7	3.3	9.3
12/09/1999	573	117.5	0.96	-0.16	24.6	21.0	4.4	10.5
10/07/2001	366	108.3	2.44	-0.3	22.9	15.9	3.9	10.2
20/07/2001	893	253.7	1.45	-0.34	23.0	18.9	3.6	10.0
07/09/2001	290	57.8	1.8	-0.38	26.4	22.4	5.0	11.8
30/05/2002	206	32.9	1.68	0.56	17.4	10.7	2.8	8.5
15/07/2002	153	40.0	1.6	-0.28	19.7	12.4	3.4	10.7
30/07/2002	285	49.2	2.16	0.36	22.2	15.1	3.5	10.8
21/08/2003	80	16.6	0.28	0.16	14.3	9.0	2.7	9.0
27/08/2003	148	38.4	1.36	0.36	19.5	12.7	3.2	10.7
04/09/2003	93	21.1	0.84	0.2	15.6	10.0	2.8	9.7

Based on the simulated inundation data in Table 2.2, it was possible to investigate possible relationships between inundated area and the listed variables.

These relationships are viewed graphically in Figures 2.55 to 2.57. Figure 2.54 shows a good correlation between area and peak discharge. The initial water level prior to the flood plays an important role in the area of inundation.

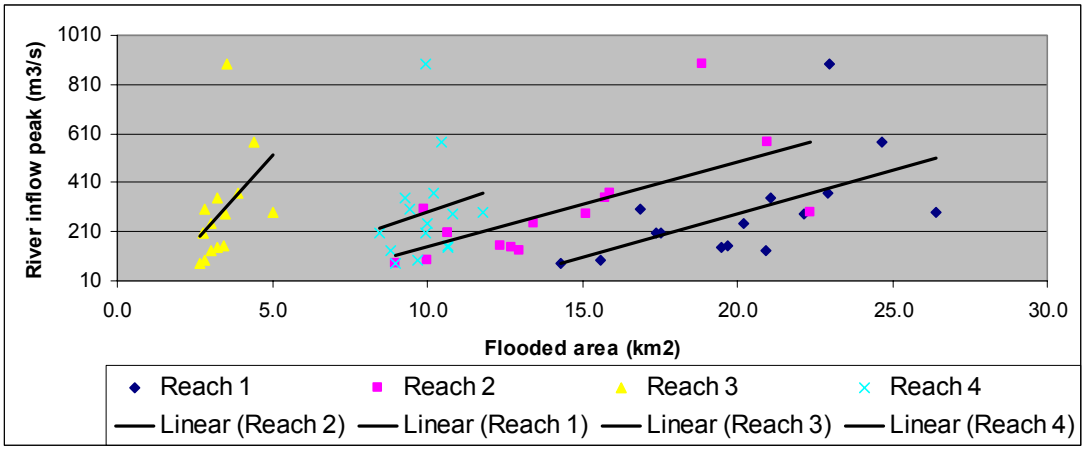


Figure 2.68 Relationship between river inflow peak and flooded area

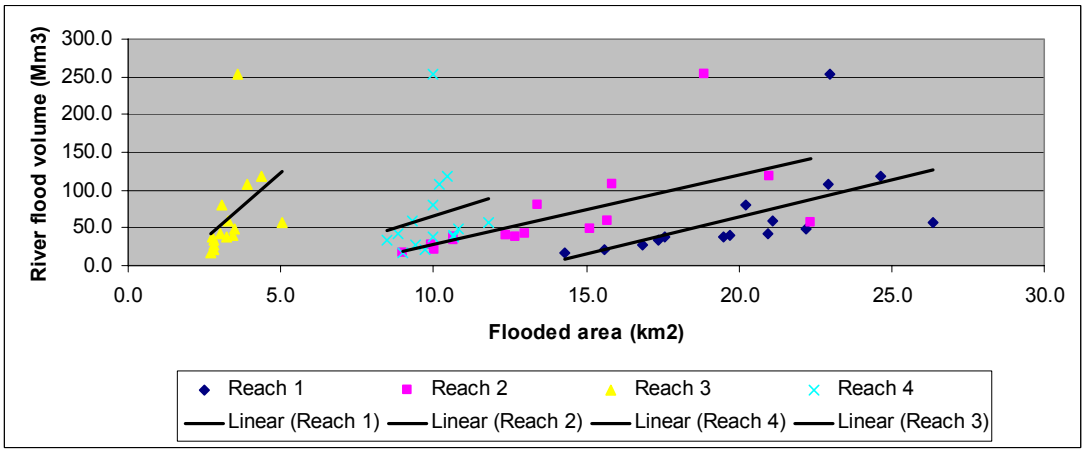


Figure 2.69 Relationship between flood volume and flooded area

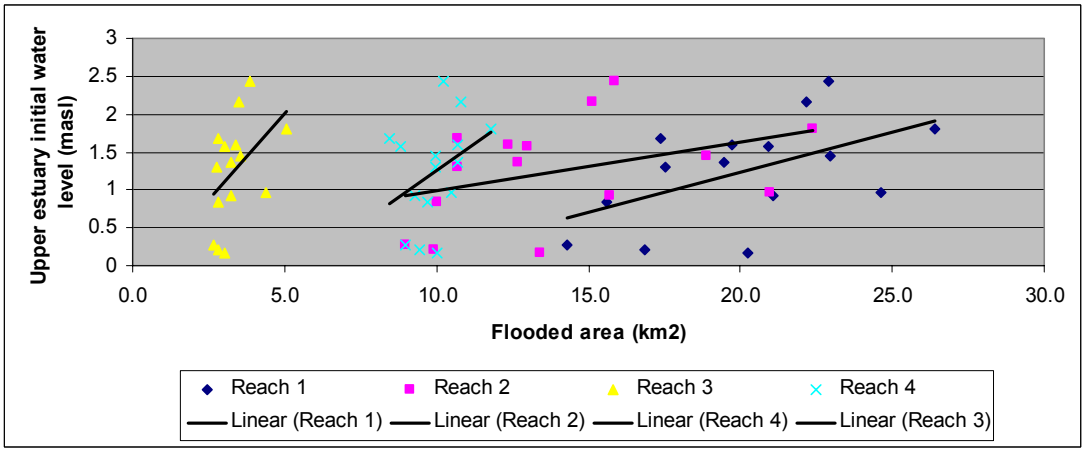


Figure 2.70 Relationship between upper estuary initial water level and flooded area

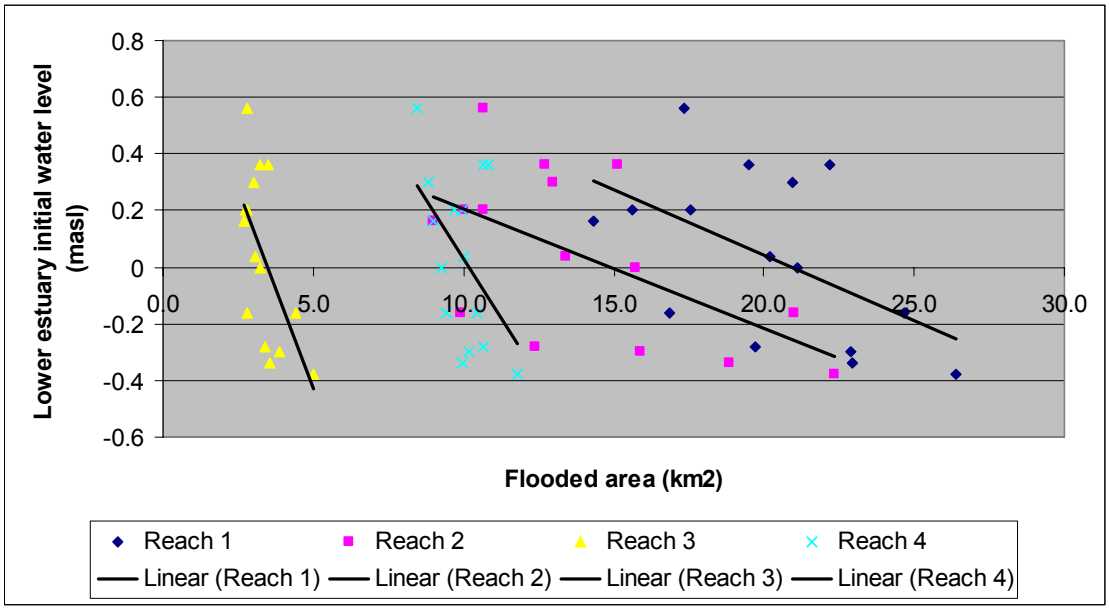


Figure 2.71 Relationship between lower estuary initial water level and flooded area

If linear regression is carried out on the data, the relationships of equations 6-1 to 6-4 are obtained:

$A_{reach\ 1} = 15.59 + 0.009Q - 0.013Vol + 2.39(WL)_1 - 3.85(WL)_4$ ($r^2=0.62$) (eq.6-1)

$A_{reach\ 2} = 8.98 + 0.015Q - 0.022Vol + 1.99(WL)_1 - 4.7(WL)_4$ ($r^2=0.63$) (eq.6-2)

$A_{reach\ 3} = 2.70 + 0.002Q - 0.006Vol + 0.445(WL)_1 - 1.309(WL)_4$ ($r^2=0.62$) (eq.6-3)

$A_{reach\ 4} = 9.59 + 0.0002Q - 0.004Vol + 0.492(WL)_1 - 1.74(WL)_4$ ($r^2=0.39$) (eq.6-4)

Where A = plan flooded area in km^2, Q = inflow flood peak (m^3/s), Vol = inflow flood volume (Million m^3), $(WL)_1$ = water level in reach 1 at gauging station and $(WL)_4$ = water level at mouth (amsl).

With the above equations it is possible to investigate the impact of a modified hydrology. This is illustrated in Table 2.4 with decreased values of variables of 5 %, 10 % and 15 %.

The equations show that only in reaches 1 and 2 are the flooded areas well correlated with the flood peak. In all reaches the flood volume is found to be inversely correlated with the flooded areas which is unexpected, but in all reaches this is a poor correlation. The upstream initial water level (reach 1) is very important to determine the flooded areas in reaches 1 and 2.

The correlation coefficients are not high due to limited data and the complexity of the estuary system. Especially reach 4 has a poor correlation but it forms less than 20 % of the total inundated area during a major flooding event.

As base condition with low river inflows, no spillage from the main channel to floodplains occur, but water is trapped in pans on the floodplain, while other areas are intertidal such as Die Plaat. Figure 2.58 shows the simulated water depths for the tidal condition as on 24 May 2001. Simulated starting water depths and peak depths attained during each of the three largest annual floods for the period 1998-2003 are depicted in Appendix 1.5.

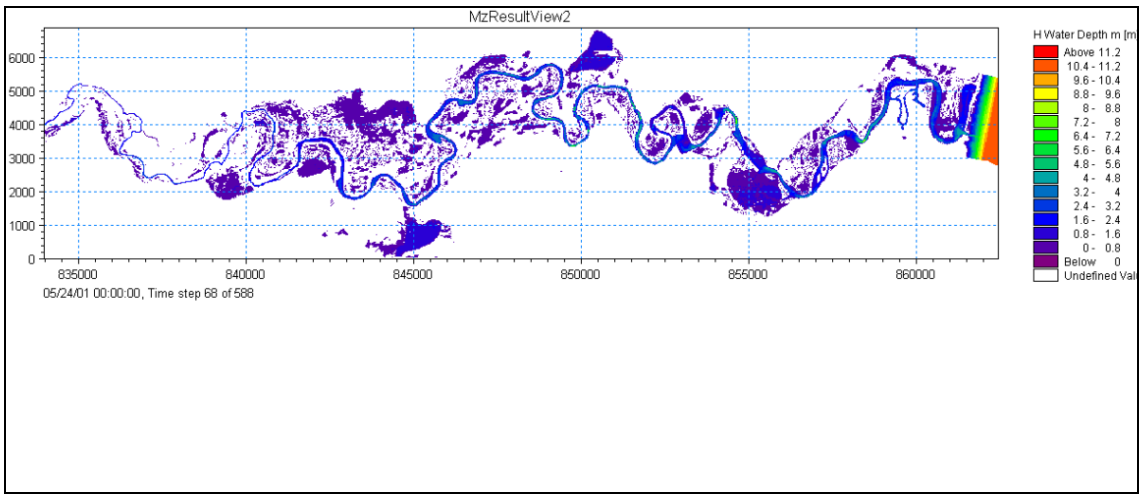


Figure 2.72 Berg River estuary initial flow depths prior to winter

The inundated areas (main channel, pans and intertidal) have been calculated and are shown in Table 2.3.

Table 2.6 Low river flow inundated areas

River flow (m^3/s)	Inundated area (km^2)				
	Reach 1	**Reach 2**	**Reach 3**	**Reach 4**	**Total**
6.2	10.4	8.9	2.7	8.4	30.4
Minimum areas ($80m^3/s$): (Table 6-2)	14.3	9.0	2.7	8.5	34.5
Maximum areas ($290m^3/s$): (Table 6-2)	26.4	22.4	5.0	11.8	65.6
Maximum % area Increase	254 %	252 %	185 %	140 %	218 %

Table 2.6 shows that the flooded areas in reaches 1 and 2 can increase by a factor 2.5 and by 1.9 in reach 3. The flood that gave the largest flooded area was only 290 m^3/s, but the initial water level of this flood was high at 1.8 m which resulted in the large area of flooding. Reach 4 is tidal dominated and floods have a relatively small impact on area of inundation. When considering the total flooded area it could increase from a base low flow condition at 30.4 km^2 by a factor of 2.2 to 65.6 km^2, during a relatively small flood of 290 m^3/s, if initial water levels in reach 1 are high. The initial high water level at reach 1 is determined by regular floods during winter.

Table 2.7 illustrates the possible effect of decreased flood peaks and volumes, and of the upstream initial water level, on the flooded areas in the estuary. In this sensitivity study the initial water level was taken as 1.5 mas*l* at reach 1 at gauging station G1H023, which is slightly above the average of 1.25 mas*l* of the floods investigated in Table 2.2.

The flood volume has been calculated based on a correlation between inflow and observed flood volumes. The sea water level at the estuary mouth was taken constant at 0 amsl. The last 4 columns of Table 2.4 show the percentage decrease in flooded area for each reach due to 5 %, 10 % or 15 % decrease in discharge, flood volume and initial reach 1 water level. The largest changes in flooded area will be in reach 2, then reach 1 and then reach 3. The effect in reach 4 is minimal, since it is tide dominated. The changes are however relatively small and less than the percentage change in inflow parameters.

The expected change in inflow parameters is expected to be a decrease of 10 % on discharge. This is illustrated in Figure 2.59 which shows simulated routed river flows based on a mathematical model of the river.

2.7 CONCLUSIONS

Historical photographs indicate several major modifications to the estuary:

- Modified mouth in concrete lined channel, narrower, but deeper than the original mouth.
- Bridges affecting the main channel and floodplain flows.
- Salt works in the lower estuary on the floodplains/intertidal area.
- Port Owen Marina in lower estuary.
- Dredging in lower estuary for navigation.

Three surveys carried out during the study period indicate that the main channel of the estuary is stable. This was confirmed by sediment transport simulations of the estuary.

During normal tidal action only parts of the floodplain in the lower region of the estuary up to about the Railway Bridge are inundated during high tide. For the rest of the estuary the flow is confined to the main channel, except for one or two areas further upstream.

The flow depths over the floodplain areas during spring high tide are generally less than 1 m, except on Die Plaat, where some areas are deeper and the flow depths can rise to 1.5 m. Velocities are very low over the floodplain, generally less than 0.3 m/s. Higher velocities only occur in the main channel downstream of the Railway Bridge and can be higher than 1 m/s. Maximum velocities seem to occur during the rising tide.

Table 2.7 Flooding sensitivity analysis

Discharge before change (m^3/s)	Flood Volume (Mm^3)	Initial WL_1 (mas*l*)	% Discharge decrease	Flood % Volume decrease	% initial upper estuary depth decrease	Calculated area inundated reach 1 (km^2)	Calculated area inundated reach 2 (km^2)	Calculated area inundated reach 3 (km^2)	Calculated area inundated reach 4 (km^2)	% decrease flooded area reach 1	% decrease flooded area reach 2	% decrease flooded area reach 3	% decrease flooded area reach 4
100	15	1.5	5	5	5	19.7	12.9	3.4	10.3	1.1	1.6	1.1	0.3
		1.5	10	10	10	19.5	12.7	3.4	10.2	2.2	3.1	2.2	0.7
		1.5	15	15	15	19.2	12.5	3.4	10.2	3.2	4.7	3.3	1.0
200	42	1.5	5	5	5	20.2	13.7	3.4	10.2	1.2	1.8	1.1	0.3
		1.5	10	10	10	19.9	13.5	3.4	10.2	2.4	3.6	2.3	0.6
		1.5	15	15	15	19.7	13.2	3.4	10.1	3.5	5.3	3.4	0.9
400	96	1.5	5	5	5	21.2	15.4	3.5	10.0	1.4	2.1	1.2	0.2
		1.5	10	10	10	20.9	15.0	3.4	10.0	2.7	4.3	2.4	0.5
		1.5	15	15	15	20.6	14.7	3.4	10.0	4.1	6.4	3.5	0.7
600	149	1.5	5	5	5	22.2	17.0	3.5	9.9	1.5	2.4	1.2	0.2
		1.5	10	10	10	21.9	16.6	3.5	9.9	3.1	4.8	2.4	0.3
		1.5	15	15	15	21.5	16.2	3.4	9.8	4.6	7.3	3.7	0.5
800	203	1.5	5	5	5	23.3	18.7	3.6	9.7	1.7	2.7	1.3	0.1
		1.5	10	10	10	22.8	18.1	3.5	9.7	3.4	5.3	2.5	0.2
		1.5	15	15	15	22.4	17.6	3.5	9.7	5.1	8.0	3.8	0.2
1000	257	1.5	5	5	5	24.3	20.3	3.6	9.6	1.8	2.9	1.3	0.0
		1.5	10	10	10	23.8	19.7	3.6	9.6	3.7	5.7	2.6	0.0
		1.5	15	15	15	23.4	19.1	3.5	9.6	5.5	8.6	3.9	0.0

Notes: WL_4 = 0 amsl

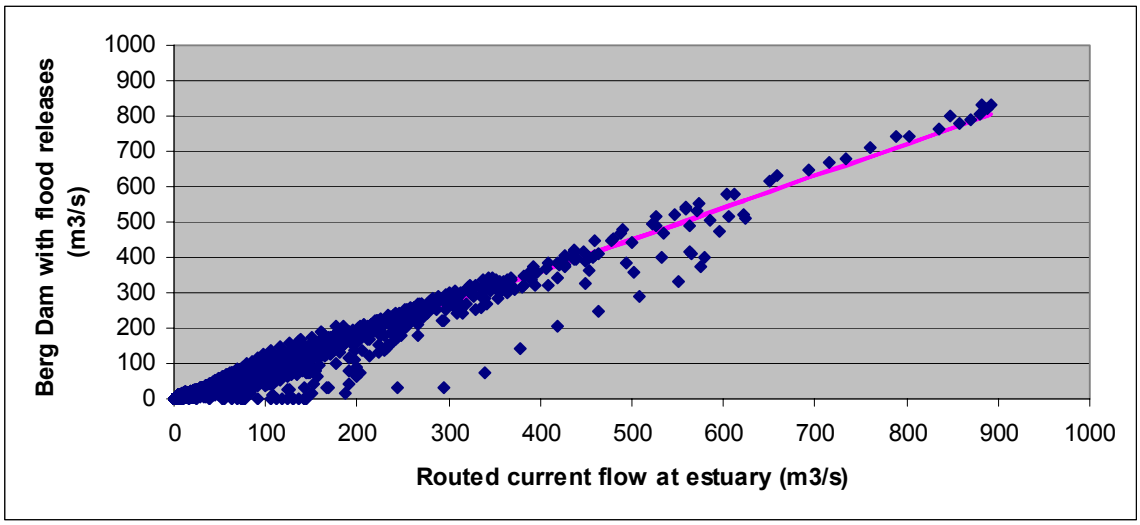


Figure 2.73 Relationship between current and post-Berg River Dam inflows at the estuary

All the simulations have shown that the different combinations of initial water levels (due to higher winter low flows or previous flooding), tides and floods can have very different results in terms of floodplain inundation. Generally during the winter months the water levels in the estuary are elevated by about 1 m above the summer levels. This means that any floodwaters entering the estuary can more readily spread out over the floodplain, without having to fill the river channel first. Also, if these floods coincide with spring tides the inundated area increases. During the summer months on the other hand, water levels are low in the estuary and the first floods coming from the catchment will probably fail to inundate large areas, until large areas of estuary's considerably widespread channel system have been filled. This shows how important the higher baseflows in winter are, since they seem to be fuelling the elevated water levels in the estuary during winter, thus enabling more extensive floodplain inundation.

By using data from winter simulations of 1998 to 2003, individual flood data and inundated estuary areas could be extracted. A relationship was found between the inflow flood peak, flood volume, upstream initial water level and initial water level at the mouth, and inundated areas. By using these correlations the flooding of 4 reaches in the estuary could be calculated for different conditions.

Under normal tidal conditions the inundated area is 30.4 km^2, while during a 290 m^3/s flood, starting at a relatively high upper estuary water level of 1.8 amsl, the flood area could increase to 65.6 km^2. If a much larger flood of 893 m^3/s, starting at 1.45 amsl in the upper estuary is simulated the total flooded area is 55.5 km^2, which is less than with the flood that is 3 times smaller. Initial water levels and therefore high baseflow conditions and regular floods during winter are therefore very important to ensure effective flooding of the floodplain area.

The effect of the Berg River Dam on the estuary inflow would be about a 10 % decrease in flood peaks from small to large floods. The resultant decrease in flooded areas would be as high as 4 %, 6 %, 3 % and 1 %, in reaches 1 (upper estuary) to 4 (near mouth) respectively, for a 10 % decrease in inflow flood peak and volume, and initial upstream water level.

2.8 RECOMENDATIONS: FUTURE MONITORING REQUIREMENTS

It is recommended that the following is monitored in future:

- Install 3 permanent water level gauges on the floodplain at major pans.
- Ensure that these and other monitoring instruments are checked and serviced regularly, that the data is being logged at appropriate intervals, and that data are archived in a suitable and secure format and location.

- Take weekly suspended sediment samples at gauge G1H023 (Jantjiesfontein).
- Survey bed of main channel every three years at same cross-sections used in this study.
- Take sediment samples of the bed of the main channel at same locations as in this study, every 3 years.
- Take aerial photographs of the estuary every 5 years.
- The effect of the Berg River Dam flood release on the estuary from 2007, to evaluate the role of the initial water level at the estuary, and on the flushing of sediments through the system.
- Establish a new gauging station upstream of the estuary out of the tidal effect, to measure inflow (including floods) accurately.

2.9 REFERENCES

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CHAPTER 3 - WATER CHEMISTRY
SALINITY, TEMPERATURE, OXYGEN AND TURBIDITY

E. Schumann

3.1 INTRODUCTION

This chapter presents an integrated description of Berg Estuary physico-chemical structures and dynamics using historical data and reports, as well as results obtained in the three-year measurement programme from 2003 to 2005, as part of the larger Berg River Baseline Monitoring Programme (BRBMP). The objectives were specifically to investigate the estuarine structures in terms of water level, temperature, salinity, dissolved oxygen (DO) and pH measurements, with an additional component investigating turbidity.

Historical data were obtained from a number of sources, and were analysed as part of this study. Some of these data covered short periods, while data available from the DWAF, Weather Bureau and SAN Hydrographer are ongoing, and include the measurement period of this programme.

By combining all these results a comprehensive description of estuarine structures is obtained. This allows key processes influencing water quality to be identified (in terms of DO and pH), and hence possible impacts of the Skuifraam Dam. Finally, suggestions are made for relevant future measurements which will enable changes in the estuary to be monitored.

3.1.1 The Berg River estuary

Figure 3.1 shows the Berg River flowing into St Helena Bay and the Atlantic Ocean.

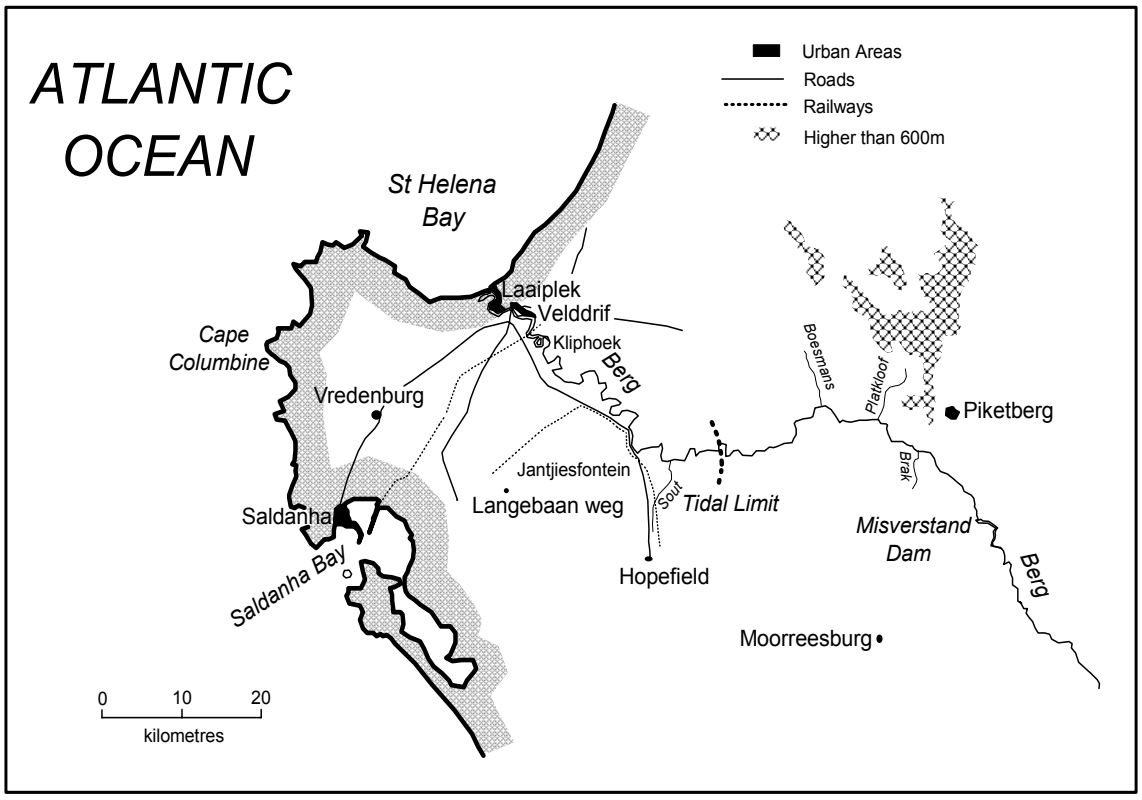


Figure 3.1 The Berg River and Estuary showing the approximate tidal limit and the sites mentioned in the text.

The coastal ocean off the mouth of the Berg River falls into the Benguela upwelling system (Shillington, 1998). As the name implies, it is dominated by wind-driven upwelling, specifically in summer when southeasterly winds move surface waters offshore, allowing colder, nutrient-rich bottom waters to reach the surface at the coast.

Nelson and Hutchings (1983) identified Cape Columbine as an upwelling centre, though waters in St Helena Bay remain warmer. Northwesterly winds in winter correspondingly cause downwelling.

Tides along the South African coast fall into the semi-diurnal microtidal category, with spring tide amplitudes seldom reaching above 2 m, and with neap tide amplitudes as small as 0.5 m. Shillington (1984) has described the existence of edge waves with periods of 20 to 60 minutes, which reached an amplitude of 1.5 m near the Orange River some 500 km to the north. Subtidal coastal trapped waves with typical amplitudes around 30 cm have been described by de Cuevas *et al.* (1986), while Brundrit (1984) investigated variability on monthly and seasonal scales. Furthermore, Hughes *et al.* (1991) demonstrated that there has been a sea level rise of about 1.2 mm/yr, consistent with other tectonically stable world trends.

The Berg Estuary enters the sea through a permanently open mouth, canalised in the late 1966's through the coastal dunes; the construction left a previous channel of the estuary as an appendix extending westwards of the mouth. The estuary meanders upstream through extensive dry pans, tidal flats and marsh areas, rising only 1 m in the first 50 km. The tidal oscillations propagate upstream about 69 km, although sea water has not been known to penetrate this far; Day (1981) has reported that a salinity of 9 was recorded at Kersefontein in February, 1979, some 45 km from the mouth.

The estuary is very seasonal because of the spates of fresh water resulting from winter rainfall in the mountainous catchment to the southeast. These spates flush out sea water which penetrates into the lower reaches of the estuary during the summer, when little rain falls.

Slinger and Taljaard (1994) undertook a preliminary investigation of this seasonal character of the Berg Estuary. Their results showed that during the rainy season (September) the penetration of seawater extended about 10 km upstream at flood tide, whereas in the following summer (February/March) this had reached farther than 40 km upstream. In all the sections measured, little vertical stratification of the water column was found. Water temperatures in the estuary were consistently warmer than in the sea, with the coldest temperatures in the sea in February (13.7 ^{O}C). There was no attempt to assess how typical the measurement period (1989/1990) was.

Slinger *et al.* (1998) have used the *Mike 11* one-dimensional model to simulate conditions in the Berg Estuary. Reasonable salinity structures were obtained, but it was difficult to assess the success of the temperature simulations because of the vertically-averaged nature of the model and the lack of real data as a comparison. Dissolved oxygen (DO) simulations were also performed, but with poor results compared to measurements, especially in the mouth regions; the modelling did not appear to consider tidal differences.

3.1.2 Relevant estuarine processes

The physical characteristics of an estuary are influenced by a range of different processes and driving forces. In particular, the following are important for the Berg estuary:

- Sea level, comprising the ocean tide and other processes affecting sea level such as coastal trapped waves and weather effects. Over the long term sea level rise will also be important.
- The characteristics of oceanic water entering the estuary such as temperature, salinity, dissolved oxygen, nutrients, etc.
- The channel morphology. This will affect the manner in which water flows through the estuary, and the extent of the tidal prism. Important aspects here are the sill often found in the estuary mouth, tidal flats and land elevation. It is assumed that the estuary is permanently open.
- The sediment structure of the channels and flood plains, and the sediment movement in and out and along the estuary. The vegetation on the estuary banks can also influence flow patterns.
- The inflow of fresh water flowing into the estuary at its head, as well as the inflow of groundwater. The quality of this water.

- The circulation of water in the estuary, and the mixing processes that occur between different water masses and the resulting structures and stratification.
- Weather, in particular rainfall, air temperature and evaporation. It is also important to recognise that the climate of an area or region is not necessarily a constant, and that long-term changes can occur.

The form of an estuary develops as a consequence of the interaction between riverine and marine processes (Dyer, 1997). In addition, there are recent developmental impacts such as the building of canals, breakwaters and harbours, while agriculture, particularly in the upper reaches, can have severe impacts on the functioning of an estuary.

There are a range of spatial and temporal scales in the processes operating in an estuary (Schumann *et al.*, 1999). The shortest scales start with turbulence, surface gravity waves, internal waves and details of mixing, though in the context of this investigation these details are not required. On time scales of hours and longer the tides are important as the dominant forcing mechanism, superseded sporadically by spates of freshwater inflows which can dramatically change structures in an estuary. Spatial scales are much shorter vertically where intense stratification can occur, while horizontally changes take place over much longer distances. The relevant processes are those which determine the manner in which waters mix and are transported through an estuary.

3.1.3 Weather and climate

The seasonality of the Berg River derives from the strongly seasonal climate of the western Cape. It is a Mediterranean climate, with more than 80% of the rain falling in winter (Tyson, 1986), and the average rainfall for the estuary is around 300 mm/pa. Of interest is the rapid increase of rainfall with height in the mountainous areas: Jonkershoek near Stellenbosch has an average rainfall of over 3200 mm/pa (Schulze, 1984). It is in these mountainous areas that the Berg River catchment derives most of its runoff.

There are extensive data on surface temperatures over South Africa (Schulze, 1984), although not specifically for the Berg Estuary area. Such temperatures affect the water temperatures in the estuary, but are also a determinant in the extent to which evaporation occurs. Pans in the region show typical evaporation rates of around 200 cm/pa, with about 40% occurring in the summer (December to February). Local winds will increase the evaporation, and can also generate surface waves (depending on the fetch), which will cause vertical mixing.

3.1.4 Available data

There are a number of data sets outside of the measurements made in the programme which can be used to analyse the processes in the Berg Estuary. As indicated already, these consist of ongoing time series data and two sets of data from the CSIR covering short periods. These are described in the sections below.

SAN Tide Gauge Data

The SA Naval Hydrographer=s office provided tide gauge data from the station at Saldanha Bay. This is the closest sea level measuring station, and will be taken to represent sea level off the mouth of the Berg Estuary. The water level is measured relative to chart datum, and subtractions are made to correct these values to mean sea level (Table 3.1).

Table 3.1 According to the SAN, Mean Sea Level (Land Levelling Datum) can be obtained by subtracting the given correction for the period considered.

Period	Correction (m)
1979.01.01 to 1997.12.31	0.900
1998.01.01 to 2002.12.31	0.975
2003.01.01 onwards	0.865

A number of sets of sea level data were provided. Year by year hourly values of raw and calibrated data covered the period 1980 to 2001, though 1998 and 1999 are missing. Only the calibrated files were used. The years 2000 and 2002 also had large sections of data missing in the initial months.

At the stage of writing, the calibrated hourly data files for 2003 and 2004 were available, and these are the main data used here. Within these data files there are a few random days of data missing, and these are interpolated for use.

The available data are listed in Table 3.2.

Table 3.2 Hourly tide gauge data from Saldanha Bay. The data files are in the SAN ASCII format, with the year and Julian Day number given at the start of each row of 24 hourly values.

Start End	No of Data	Units	Comment
1980 to 1997 2000 & 2001	760 8784 (Ly)	cm	Yearly calibrated data files 1998 and 1999 missing
2002.04.20.00:00 2002.12.31.23:00	6144	cm	Calibrated data. (No data before day 110)
2003.01.01.00:00 2004.12.31.23:00	17544	cm	Hourly calibrated data files for each year

Weather Data

Weather, in particular rainfall, varies considerably over the extended area of the Berg River catchment. The mountainous area of the upper river experiences substantially higher annual rainfall than the estuary itself, and provides the main source of freshwater inflow to the estuary. In order to assess the interannual variability in the catchment, rainfall data were obtained from the South African Weather Service (SAWS) for the Franschhoek (Robertsvlei) station in the Hottentots-Holland mountains. Note that the data available for this site starts in 1951 and covers a much longer period than that for stations closer to the estuary; because of costs only the data from 1980 to 2005 are used..

It was also deemed useful to acquire weather data from weather stations in the vicinity of the Berg Estuary itself. Three stations were identified, namely Langebaanweg, Hourerrstat and Geelbek, and rainfall, air temperature, humidity and wind speed and direction data were provided by the SAWS. Langebaanweg was considered to have the most relevant data for the estuary, and in fact this site also had the longest single series of data since there were large gaps in the other series. At this stage only the rainfall and air temperature data are used, with details given in Table 3.3.

Table 3.3 Weather data obtained from the SAWS for the stations at Langebaanweg and Franschhoek.

Site	Variable	No of Days	Start End	Comment
Langebaanweg	Rainfall (mm)	4352	1994.01.01.00:00 2005.11.30.23:00	Hourly values
Langebaanweg	Temp (^{O}C)	4352	1994.01.01.00:00 2005.11.30.23:00	Hourly values
Franschhoek	Rainfall (mm)	7611	1980.01.01 2005.11.30	Daily values

DWAF Stream Flow Data

There were no data for the stream inflow at the head of the Berg Estuary. The only stream flow data were from the gauge at the Misverstand dam, more than 100 km from the estuary mouth (see Figure 3.1), operated by the Department of Water Affairs and Forestry (DWAF).

There are a number of small streams, of which the Boesmans, Platkloof and Brak appear to be the most important, which flow into the Berg River downstream from the measuring gauge. The Sout River is a tributary flowing into the Berg River within the tidal reaches.

Water level data are also available at the Misverstand site, but are not used here.

The details of the extracted data files are given in Table 3.4. The DWAF site reference for the Misverstand dam is G1H031, but the reference used here is B3.

Table 3.4 Time series data of daily water level (m) and stream flow (m^3/s) from the Misverstand dam.

Site	Variable (units)	No of Data Pts	Start End
Misverstand	Stream Flow (m^3/s)	9569	1979.10.10 2005.12.20

DWAF Tide Gauge Data

The DWAF have been operating tide gauge stations at two sites on the Berg Estuary since 1980. In October, 2003, a new site became operational at Laaiplek: details of these three sites are (see Figure 3.1):

DWAF Site G1H024: Berg River Kliphoek Site reference B1
DWAF Site G1H023: Berg River Jantjiesfontein Site reference B2
DWAF Site G1H074: Berg River Laaiplek Site reference B0

Two sets of data for the first two sites were provided by the DWAF. The first set comprised historical data from October in 1980, and ending in September, 2002. These data are very erratic in terms of the times at which measurements are made, with apparent random gaps varying from minutes to hours; it is not clear what timing criteria were used. Processing of the data was done on the basis of using all the data.

The second set of data consists of hourly values of water level from January, 2000, to December, 2005. Note that the accuracy of these second sets is given to two decimal points, i.e. to the nearest cm, whereas the first sets are to the nearest mm. Hourly data from the new site at Laaiplek became available from 21 October, 2003.

Details of extracted data are given in Table 3.5.

Table 3.5 Time series data of water level measured at Kliphoek, Jantjiesfontein and Laaiplek.

Site	Interval	No of Data Pts	Start End
Kliphoek	Variable	112702	1980.10.01.11:01 2002.09.03.12:00
	1 hr	52044	2000.01.01.00:00 2005.12.07.11:00
Jantjiesfontein	Variable	98651	1980.10.01.14:31 2002.09.03.12:00
	1 hr	52045	2000.01.01.00:00 2005.12.07.12:00
Laaiplek	1 hr	18669	2003.10.21.14:00 2005.12.07.10:00

CSIR Hydrological Information System (HIS) Data

These data obtained from the CSIR on a CD (*Water Quality on Disc from the Hydrological Information System*) incorporating river and estuary stations from all over South Africa with a variety of water quality data. For the Berg River, data are available from the Kliphoek and Jantjiesfontein stations up to September, 1999. No indication is given as to where in the water column the water samples were taken, and it is assumed that these were surface samples.

Selected data, namely the station reference, date, pH, EC (electrical conductivity), Cl and time, were extracted onto a text file using the provided software; no dissolved oxygen was available. The details of the data files are given in Table 3.6.

The conductivity of the water is dependent on the salinity, and in fact salinity is now generally determined by measuring the conductivity. However, the conversion uses a non-linear relationship that is also dependent on temperature.

The chlorinity of the water is also related to the salinity through the empirical relationship (Open University, 1989)

$$S = 1.80655\ Cl \qquad (1)$$

Unfortunately there are very few measurements of chlorinity at the Kliphoek site, which makes it impossible to use this variable in the analysis.

pH is a measure of the concentration of hydrogen ions in solution: if the pH is less than 7 the solution is acidic, whereas if the pH is greater than 7 it is alkaline. The pH of seawater usually ranges between 7.9 and 8.2.

Table 3.6 HIS data extracted from the CSIR CD into ASCII format files. The data intervals are not regular, with a limited number of measurements in each year.

Site	Variables (units)	No of Data Pts	Start End
Kliphoek	pH EC (mS/m) Cl (mg/l)	156	1972.03.15.16:15 1999.09.01.15:55
Jantjiesfontein	pH EC (mS/m) Cl (mg/l)	261	1971.07.29.13:15 1999.09.01.09:00

CSIR Boat Section Data

These data were purchased from the CSIR from a measurement programme carried out on the Berg estuary from 1989 to 1995. There were 22 sections measured on 18 different days, with a boat stopping at specified stations and measuring depth profiles of particular variables. Temperature and salinity profiles were measured, while DO and pH were measured only at the surface and bottom, and in many instances only at the surface. The other available variables (Ammonia, chlorophyll-a, nitrate, nitrite, F coliform, F strep and phosphate) fall outside the brief of this analysis.

However, there were numerous problems associated with these data. Thus the latitude and longitude of the stations was not specified, and it was assumed that the station numbers refer to the same sites as those used in the present programme. It is also known that structures in the estuary can vary markedly with the tides, but little cognisance was taken of the state of the tide, or the sequence in which the stations were completed. In some cases repetitive stations were measured for a number of hours.

It is apparent that quality control of the data was not adequate, and that archiving was done very badly.

The following problems were identified during processing of the data:

- Times of stations and measurements are confused, e.g. different stations have the same time; times at different depths on the same profile differ by up to 15 minutes; times of different variables vary at the same depth.
- Values are duplicated, both in terms of whole stations and individual values on a profile. There are apparent spurious values, e.g. at depths of 44 m and 30 m. There are various surface values markedly different from those deeper down, and it is not clear whether these variations are real.
- There are several series where there is a single measurement at a distant station, with salinity values of 0.00. Salinity values of 0 are also given at other stations - it is unlikely that this is correct.
- On some stations the salinity and temperature measurements do not have the same depths. Some station numbers are wrong.
- The second file for 1996 contains time series data measured at Kliphoek, and taken every 30 minutes. However, later in the file a second series, displaced by 9 minutes, appears mixed into the original series - the values of this second series differ significantly from the first. This file is not used.

In spite of these problems, it is clear that these results do not differ in any appreciable or significant manner from the estuary section data discussed in 2.4.4 and presented in detail in the Appendix 2.1 and 2.2. Because of the lack of consistency and the problems outlined above these plots are not discussed in detail in this report, but results are reproduced in Appendix 2.3.

3.2 MEASUREMENTS

A measurement programme was set up in accordance with the specifications of the contract. This involved vertical profile measurements from a boat at selected station positions along the length of the estuary, as well as time series measurements made by self-recording instruments deployed at specific sites.

Figure 10.2 shows details of all the measurement sites that were used in this part of the programme. The details of the measurements, equipment used, problems experienced, and the processing of the data is discussed further in this section.

3.2.1 Boat measurements

Station Positions

In total there were 25 station positions selected on the estuary, extending almost 60 km upstream, while two additional stations were added in the blind appendix of the old estuary mouth (A1 and A2).

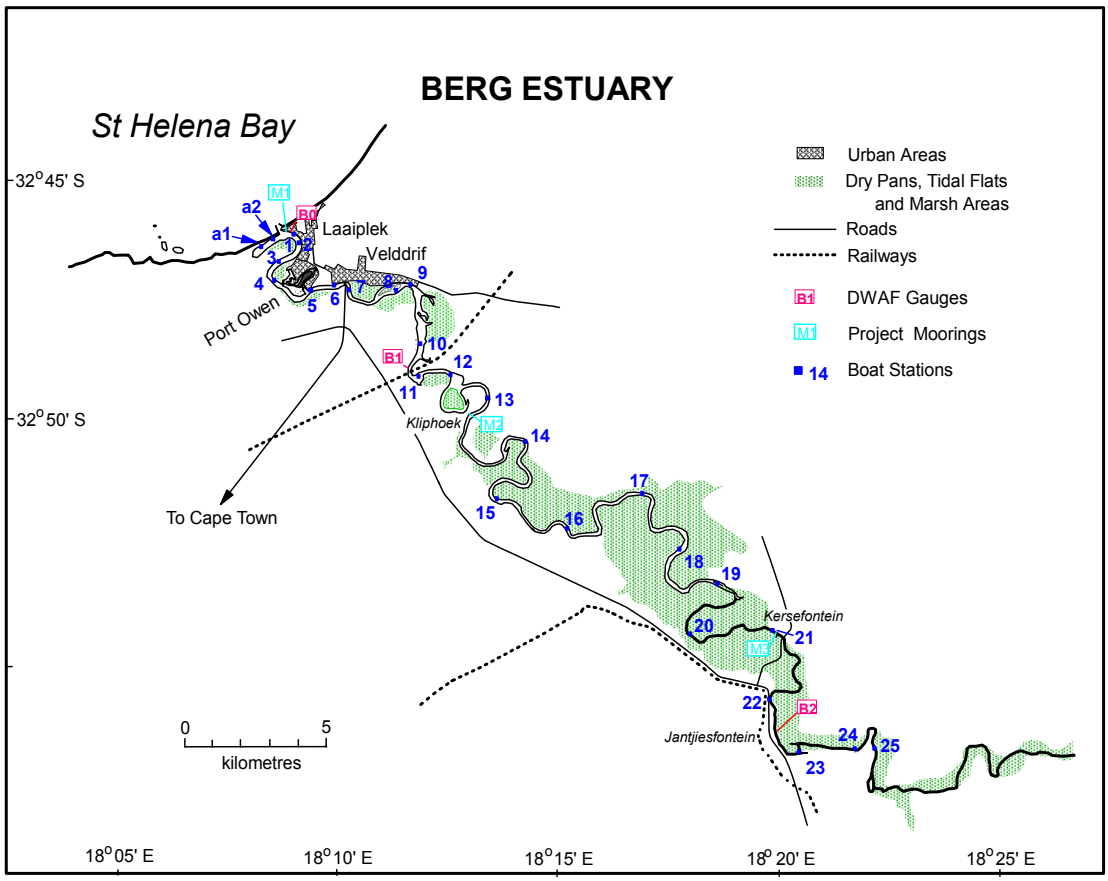


Figure 3.2 Map of the Berg Estuary, showing the locations of all the measurement sites.

The station positions were recorded using a *Garmin 12* GPS. These were then plotted on a 1:50 000 survey map obtained from the Chief Directorate: Surveys and Mapping, and the chainage, or distance upstream from the mouth for each of the stations was found by stepping up the estuary channel on the map. During the November, 2005, measurements the *Garmin 12* GPS was used to measure the distance travelled by the boat to each station; and these distances agreed approximately with the map estimates. Details of the station selections and positions are given in Appendix 2.1, and depicted in blue in Figure 3.2.

In 2003 *Triton Survey* carried out cross-sectional surveys of the Berg Estuary at 42 positions on the estuary, including an additional position at the outer end of the breakwaters, and depicted here as being 350 m offshore of the mouth. The maximum estuary depth extracted from each of the 42 cross-sectional surveys was provided in a file by *Triton Survey*, and this was used as the estuary bottom profile in the estuarine sections. At a later stage the detailed cross-sectional files were obtained, and different maximum depths were extracted. No clarity could be obtained as to which is correct - details of these anomalies are given in Appendix 2.1.

Triton Survey also obtained the chainage distances of the cross-sections from the CSIR, however, at the position of the bridge at the farm *Kersefontein* this distance differed by approximately 4 km from that obtained by stepping and the GPS. This is a substantial difference, and since the distances given in the paper by Slinger and Taljaard (1994) and in other CSIR reports also corresponds with the stepping and GPS distances found here, these are consequently used in all the figures. The reason for these differences has not been resolved; details are given in Appendix 2.1.

Equipment Used

The main instrument used in this programme was a Sea-Bird Electronics *SeaCat* SBE 19-03 conductivity, temperature and pressure recorder, with an SBE 22B (Beckman) combination dissolved oxygen (DO)/pH sensor.

Salinity can be calculated from the conductivity measurements, including temperature, and using the so-called practical salinity scale equations. Similarly, pressure is dependant on the density of water, its compressibility and even gravity, and these factors are incorporated in determining the water depth.

The accuracy of the sensors is listed below.

Depth:	0.05 m
Temperature:	0.01 ^{O}C
Salinity:	0.01 psu
Dissolved Oxygen (DO):	0.1 mg/l
pH	0.1

The *SeaCat* has a built-in pump to circulate water over the sensors, but should be immersed in water for a period of at least ninety seconds to allow the pump to turn on and the sensors to stabilize. The recording interval was set at 0.5 s.

In October, 2002, before the start of the first measurements, the *SeaCat* was sent to *Thales Geosolutions* for a service. The report stated that >*The sensors have all been checked and corrected. They are all in good working order*.=

The *SeaCat* was therefore used on this basis, however, it soon became apparent that the sensors were not in good working order. The pH sensor gave erroneous values around 1 from the start, while the DO sensor was calibrated after the second set of measurements in February, and the values also appeared suspect: the trends are probably correct, but the absolute values wrong. The Beckman DO/pH sensor was therefore sent to SBE in the USA for servicing, and it was found that both the pH electrode and DO module were >*found to have reached the end of their life expectancies*=. Both were replaced and the sensors recalibrated.

DO and pH calibrations were carried out on 24 March, 9 May (at SBE) and 29 October, 2003, and 24 March, 2004, and 27 January, 2005. In each case new calibrations files were produced for use in the SBE data processing software.

Additional instruments were also used in the first two experiments. Thus a *WTW* pH and temperature sensor was used in November, 2002, while a *YSI* depth, temperature, salinity, DO and pH meter was used in the first two estuarine sections measured in February, 2002.

Unfortunately the DO sensor on the *YS*I instrument did not work, and because of a limited memory and the fact that the data had to be transcribed, this meter proved less user-friendly than the *SeaCat.*

From November, 2003, a Secchi disk was used to obtain estimates of water turbidity.

Measurement Procedures

The boat measurements were made every three months, starting in November, 2002, and then being repeated in February, May, August and November of 2003, 2004 and 2005; this gives a total of thirteen such experiments. On each occasion measurements were made at high and low tides during spring and neap tide, with four sections completed. It is known that the tidal signal propagates upstream from the mouth (Schumann *et al.*, 1998), and the measurements therefore started at the mouth, following the signal upstream and thereby contriving to measure at approximately slack water over the whole distance. The results of Slinger and Taljaard (1994) showed a tidal lag of up to 7 hours in the upper reaches, more than 50 km from the mouth.

The average duration of the measurements was about four hours, which means that, starting at slack tide at the mouth, the tidal state retreated slightly farther upstream.

The procedure at each station was as follows: the depth of the station was checked using a portable echo-sounder (*Hondex Echotest*), and the boat was positioned as nearly as possible in the deepest part of the cross-section (often this was difficult for the duration of the station because of currents and wind).

The *SeaCat* was then switched on and hung over the side of the boat at a depth of about 1 m for a period of 90 seconds - this is required for the pump to start working and the sensors to polarize. The *SeaCat* was then raised until the upper frame was out of water but the plastic tubing was still immersed, and then lowered slowly - at least 2 seconds per metre. The instrument was allowed to touch bottom and then raised again slowly. Because of the size of the *SeaCat* (about 1 m tall), it was difficult to obtain reliable measurements shallower than 0.5 m, even using the procedure of turning the instrument on its side before lifting it out of the water.

The station log sheets were filled in on board the boat, making a note of station time and water depth. From November, 2003, a Secchi disk reading was taken to get an estimate of water clarity, and this was also entered on the station log.

Data Processing

Standard data processing software supplied by SBE was used to convert the hexadecimal raw data into engineering units, and to determine depth, salinity and DO values. The data were then averaged into 0.25 m bins for both the downcast and the upcast, and written into ASCII files. Thereafter a *Pascal* program combined all the stations on one estuarine section into a single standard output text file for use with later programs; at that stage the date, tide and times of the individual stations were also entered.

Sections were plotted of temperature, salinity and dissolved oxygen (mg/l), and are shown in Appendix 2.2. The depicted water depth is the given maximum depth profile adjusted for a varying tidal height. Thus at spring high tide an additional 0.6 m was added to the msl water depth at the mouth, and then decreased linearly to the farthest station; similarly spring low tide started 0.6 below msl, and neap high and low 0.3 m above and below, respectively. Some of the earlier sections have slightly different values. During periods of strong freshwater inflow the water depths in the upper reaches of the estuary can be increased considerably because of this additional flow (cf. the Jantjiesfontein water level records), however, this is not accommodated in the sections.

To comply with the requested data format, for each experiment the four estuarine sections as well as the mouth appendix stations were transferred into a single *Quattro-Pro* data file.

Details of the dates of section measurements, equipment used and relevant comments are given in Table 3.7.

Table 3.7 Details of the thirteen experimental periods during which estuarine sections were completed. The dates, state of the tide (NL: Neap Low; NH: Neap High; SL: Spring Low; SH: Spring High), number of stations completed (+ number in mouth appendix), instruments used, variables measured, and any relevant comments are given.

No	Date	Tide	No of Stns	Equipment	Variables Measured	Comment
1	20.11.02	SH	22	*SeaCat*, *WTW*	D,S,T,DO,pH	pH at 0.5m; DO suspect.
	21.11.02	SL	22	*SeaCat*, *WTW*	D,S,T,DO,pH	pH at 0.5m; DO suspect
	27.11.02	NL	22	*SeaCat*, *WTW*	D,S,T,DO,pH	pH at 0.5m; DO suspect
	28.11.02	NH	22	*SeaCat*, *WTW*	D,S,T,DO,pH	pH at 0.5m; DO suspect
2	11.02.03	NH	22	YSI	D,S,T,pH	DO sensor faulty
	12.02.03	NL	22	YSI	D,S,T,pH	DO sensor faulty
	18.02.03	SH	25+2	YSI, *SeaCat*	D,S,T,DO,pH	Appendix stns; DO suspect
	19.02.03	SL	25+2	YSI, *SeaCat*	D,S,T,DO,pH	Appendix stns; DO suspect
3	22.05.03	NL	22+1	*SeaCat*	D,S,T,DO,pH	Too dark to complete stns.
	23.05.03	NH	25+2	*SeaCat*	D,S,T,DO,pH	Appendix stns now standard
	29.05.03	SH	25+2	*SeaCat*	D,S,T,DO,pH	
	30.05.03	SL	25+2	*SeaCat*	D,S,T,DO,pH	
4	20.08.03	NL	25+2	*SeaCat*	D,S,T,DO,pH	
	22.08.03	NH	25+2	*SeaCat*	D,S,T,DO,pH	
	27.08.03	SH	25+2	*SeaCat*	D,S,T,DO,pH	
	28.08.03	SL	25+2	*SeaCat*	D,S,T,DO,pH	
5	17.11.03	NL	25+2	*SeaCat*, Secchi	D,S,T,DO,pH	
	18.11.03	NH	25+2	*SeaCat*, Secchi	D,S,T,DO,pH	
	24.11.03	SH	25+2	*SeaCat*, Secchi	D,S,T,DO,pH	
	25.11.03	SL	22+2	*SeaCat*, Secchi	D,S,T,DO,pH	3 stations not recorded
6	12.02.04	NL	25+2	*SeaCat*, Secchi	D,S,T,DO,pH	
	13.02.04	NH	25+2	*SeaCat*, Secchi	D,S,T,DO,pH	
	20.02.04	SL	25+2	*SeaCat*, Secchi	D,S,T,DO,pH	
	21.02.04	SH	25+2	*SeaCat*, Secchi	D,S,T,DO,pH	

No	Date	Tide	No of Stns	Equipment	Variables Measured	Comment
7	18.05.04	SH	25+2	*SeaCat*, Secchi	D,S,T,DO,pH	
	19.05.04	SL	24+2	*SeaCat*, Secchi	D,S,T,DO,pH	Stn 19 missing
	26.05.04	NL	25+2	*SeaCat*, Secchi	D,S,T,DO,pH	
	27.05.04	NH	22+2	*SeaCat*, Secchi	D,S,T,DO,pH	
8	23.08.04	NL	22+2	*SeaCat*, Secchi	D,S,T,DO,pH	Stns 19, 24 & 25 missing
	24.08.04	NH	25+2	*SeaCat*, Secchi	D,S,T,DO,pH	
	30.08.04	SH	25+2	*SeaCat*, Secchi	D,S,T,DO,pH	
	31.08.04	SL	25+2	*SeaCat*, Secchi	D,S,T,DO,pH	
9	11.11.04	SH	25+2	*SeaCat*, Secchi	D,S,T,DO,pH	
	12.11.04	SL	24+2	*SeaCat*, Secchi	D,S,T,DO,pH	Stn 25 missng
	18.11.04	NL	24+2	*SeaCat*, Secchi	D,S,T,DO,pH	Stn 24 missing
	19.11.04	NH	24+2	*SeaCat*, Secchi	D,S,T,DO,pH	Stn 4 missing
10	08.02.05	SH	25+2	*SeaCat*, Secchi	D,S,T,DO,pH	
	09.02.05	SL	25+2	*SeaCat*, Secchi	D,S,T,DO,pH	
	14.02.05	NL	25+2	*SeaCat*, Secchi	D,S,T,DO,pH	
	15.02.05	NH	22+2	*SeaCat*, Secchi	D,S,T,DO,pH	
11	16.05.05	NL	25+2	*SeaCat*, Secchi	D,S,T,DO,pH	
	17.05.05	NH	25+2	*SeaCat*, Secchi	D,S,T,DO,pH	
	21.05.05	SH	23+2	*SeaCat*, Secchi	D,S,T,DO,pH	Stns 24 and 25 missing
	22.05.05	SL	22+2	*SeaCat*, Secchi	D,S,T,DO,pH	
12	17.08.05	SH	22+2	*SeaCat*, Secchi	D,S,T,DO,pH	Stns 23, 24 & 25 missing
	18.08.05	SL	23+2	*SeaCat*, Secchi	D,S,T,DO,pH	Stns 24 & 25 missing
	25.08.05	NL	21+2	*SeaCat*, Secchi	D,S,T,DO,pH	Stns 22 to 25 missing

No	Date	Tide	No of Stns	Equipment	Variables Measured	Comment
	26.08.05	NH	22+2	*SeaCat*, Secchi	D,S,T,DO,pH	Stns 20 to 25 missing
13	14.11.05	SH	25+2	*SeaCat*, Secchi	D,S,T,DO,pH	
	15.11.05	SL	25+2	*SeaCat*, Secchi	D,S,T,DO,pH	
	21.11.05	NL	25+2	*SeaCat*, Secchi	D,S,T,DO,pH	
	25.11.05	NH	25+2	*SeaCat*, Secchi	D,S,T,DO,pH	

3.2.2 Moored measurements

Three sites were identified for additional time series measurements, namely the Berg estuary mouth, the farm Kliphoek about 17 kilometres upstream, and the farm Kersefontein, at a distance of about 47 kilometres from the mouth. These sites are identified as positions M1, M2 and M3 on Figure 3.2.

Equipment

The temperature recorders are made by the *Onset Computer Corporation*. Two types of recorders were used, namely the *Hobo-Temp* miniature logger, and the *Optic Stowaway* logger.

The *Hobo logger* is not waterproof and is deployed inside a specially designed plastic holder; the plastic is a few mm thick, with a temperature response of around 1 hour. The accuracy of the sensor is given as $\forall$ 0.2 ^{O}C. For the Berg Estuary deployments the recording interval was set at 1.2 hours, which with 1800 data points, gives a recording period of 90 days. From May, 2004, the data interval was increased to 1.5 hours, as short data gaps had occurred with the shorter interval.

The *Stowaway* is a sealed temperature recorder that can be deployed to a depth of 30 m. The accuracy is rated typically at around $\forall$ 0.12 ^{O}C, but with a worst case of $\forall$ 0.25 ^{O}C. For the Berg Estuary deployments the recording interval was set at 1.0 hours, which with 8000 data points, gives a recording period of 330 days.

The *Hydrolab Quanta* instrument has sensors to measure depth, salinity and temperature; note that corrections have to be made to the depth reading for changes in air pressure. The given accuracies of the sensors are: temperature $\forall$ 0.2 ^{O}C, salinity $\forall$ 1% of reading and depth $\forall$ 0.1 m. A cable takes the measured values to a *Campbell Scientific PC208W* data logger, which was set to record at 30 minute intervals. The logger was situated inside a large lockable stainless-steel case, with a suitable battery.

Unfortunately the program provided by the supplier to set the recording characteristics of the *Campbell* data logger accessed the wrong parameter, and for the first three deployments depth was not recorded. Moreover, biological fouling affected the salinity sensor (Figure 3.3), which meant that limited periods of valid salinity data were obtained. Because of these problems, from November, 2003, the *Quanta* recorder was replaced with a *Stowaway* temperature recorder.

Mooring Site M1 - Berg Estuary Mouth

On 27 November, 2002, the Laaiplek harbour master was consulted about the possibility of attaching a recorder to the jetty, however, he did not think it was a good idea because of the possibility of theft.

The harbour wall was then inspected for a possible mooring site, but no suitable attachment point was found. At the end of the experiment the harbour at Port Owen was also inspected, but no suitable site was found.



Figure 3.3 *Biological fouling of the Quanta sensor head meant that limited good data was available.*

On 18 February, permission was granted by the harbour master=s office in Laaiplek (Jacoba Visser) to attach a temperature recorder on a jetty pole. An Onset *Optic Stowaway* temperature recorder was then tied at the bottom of the second outer pole of the jetty next to the boat launch slipway, in a depth of about 1m. This was done near slack low tide at about 10:30, while there was still a strong ebb current.

The *Stowaway* was set to record temperature every hour, and the memory would therefore last for 330 days. Unfortunately, when it was due to be replaced in November, 2003, the recorder could not be found. It was therefore not replaced. A subsequent search in November, 2004, recovered the *Stowaway*, but it was found to have leaked and therefore provided no data.

Mooring Site M2 - Kliphoek

After obtaining permission from the owner of the farm Kliphoek, Mr J Kotze, an old boathouse on the main stretch of estuary was selected for the main mooring. This moored unit comprises an anchor near the middle of the estuary with the *Quanta* sensor measuring depth, salinity and temperature. The cable to the shore takes the values to the *Campbell* data logger, set to record at 30 minute intervals, and situated inside the stainless-steel case with a suitable battery.

The *Quanta* DST recorder was deployed from the boathouse on 28 November, 2002. This involved attaching the *Quanta* sensor to a 52 kg cement block, and then carrying it out about 20 m into the estuary in a depth of about 5 m, using SCUBA. The visibility was absolute zero. A 12 mm ski-rope was also tied to the cement block and to a boathouse pole, with the cable from the sensor tied to the rope and weighed down at several points. The cable was then connected to the *Campbell* data-logger in the metal case. As described already, the *Quanta* was replaced with a *Stowaway* in November, 2003.

A second *Hobo* temperature recorder was deployed in the reeds in shallow water and attached to the jetty with a rope.

Mooring Site M3 - Kersefontein

Permission was obtained from the owner of Kersefontein, Mr J Melck, to deploy a *Hobo* temperature recorder to his jetty. An inspection showed that the floating jetty was only attached to the fixed jetty by means of a thin ski-rope, and it was therefore decided to hang the *Hobo* temperature recorder on a rope tied to the fixed jetty. The average depth of the recorder is about 0.5 m.

Data Available

Table 3.8 gives the details of the data records available for the different moorings.

Table 3.8 Details of time series data available from the Berg Estuary mooring sites. The mooring reference is given (M1, M2 and M3), with the associated deployment number; at M2 the >a= denotes the upper recorder (Hobo) and >b= the bottom recorder (Quanta and later the Stowaway).

Mooring Ref	Instrument	Variables	Interval	Data Start End	No of Data
M1/01	*Stowaway*	Temperature	1.0 hr	2003.02.16.21:00	Instrument damaged
M2a/01	*Hobo*	Temperature	1.2 hrs	2002.11.29.13:11 2003.02.18.11:59	1620
M2b/01	*Quanta*	Temperature Salinity	30 mins	2002.11.29.10:30 2003.02.18.12:30	3839
M3/01	*Hobo*	Temperature	1.2 hrs	2002.11.27.19:01 2003.02.19.11:49	1675
M2a/02	*Hobo*	Temperature	1.2 hrs	2003.02.19.15:36 2003.05.17.20:24	1745
M2b/02	*Quanta*	Temperature Salinity	30 mins	2003.05.06.06:00 2003.08.22.08:30	5190
M3/02	*Hobo*	Temperature	1.2 hrs	2003.02.19.13:12 2003.05.17.20:24	1747
M2a/03	*Hobo*	Temperature	1.2 hrs	2003.05.22.15:37 2003.08.17.12:01	1738
M3/03	*Hobo*	Temperature	1.2 hrs	2003.05.23.13:14 2003.08.17.12:02	1720
M2a/04	*Hobo*	Temperature	1.2 hrs	2003.08.20.18:00 2003.11.11.07:12	1652
M3/04	*Hobo*	Temperature	1.2 hrs	2003.08.20.18:00 2003.11.11.07:12	1652
M2a/05	*Hobo*	Temperature	1.2 hrs	2003.11.24.15:36 2004.02.21.16:48	1782
M2b/05	*Stowaway*	Temperature	1.0 hrs	2003.11.25.09.00 2004.10.20.06:00	7918
M3/05	*Hobo*	Temperature	1.2 hrs	2003.11.25.14:24 2004.02.21.18:00	1764
M2a/06	*Hobo*	Temperature	1.2 hrs	2004.02.21.20:24 2004.05.09.07:12	1550
M3/06	*Hobo*	Temperature	1.2 hrs	2004.02.21.21:36 2004.05.09.07:12	1549
M2a/07	*Hobo*	Temperature	1.5 hrs	2004.05.19.13:32 2004.08.24.10:32	1551
M3/07	*Hobo*	Temperature	1.5 hrs	2004.05.19.13:29 2004.08.24.11:59	1552
M2a/08	*Hobo*	Temperature	1.5 hrs	2004.08.24.12:01 2004.11.06.09:01	1183
M3/08	*Hobo*	Temperature	1.5 hrs	2004.08.24.13:31 2004.11.11.15:01	1266

Mooring Ref	Instrument	Variables	Interval	Data Start End	No of Data
M2a/09	*Hobo*	Temperature	1.5 hrs	2004.11.06.10:30 2005.02.09.09:00	1520
M2b/09	*Stowaway*	Temperature	1.0 hrs	2004.11.06.11:01 2005.09.24.09:01	7847
M3/09	*Hobo*	Temperature	1.5 hrs	2004.11.11.19:31 2005.02.09.12:01	1436
M2a/10	*Hobo*	Temperature	1.5 hrs	2005.02.04.12:01 2005.05.21.15:01	1619
M3/10	*Hobo*	Temperature	1.5 hrs	2005.02.04.13:32 2005.05.21.16:32	1619
M2a/11	*Hobo*	Temperature	1.5 hrs	2005.05.21.21:01 2005.08.18.10:31	1418
M3/11	*Hobo*	Temperature	1.5 hrs	2005.05.21.18:02 2005.08.18.12:02	1421
M2a/12	*Hobo*	Temperature	1.5 hrs	2005.08.18.12:00 2005.11.25.13:30	1586
M3/12	*Hobo*	Temperature	1.5 hrs	2005.08.18.13:29 2005.11.25.13:29	1585

3.3 RESULTS

3.3.1 Weather and flow variability

Weather - in particular rainfall - is probably the most important influence on the Berg Estuary. This section investigates the longer-term fluctuations of weather, as well as mean yearly variability.

Rainfall and Flow: Interannual Variability

The longest periods of reliable available data are those for the stream flow at Misverstand and the rainfall at Franschhoek, both dating from 1980. The three-year measurement period from 2002 to 2005 should therefore be put into the context of these data to determine how typical - or atypical - conditions were. This will then also enable a better assessment to be made of a reference state, assuming that the 25 years from 1980 can represent some sort of average condition.

Figure 3.3 shows a plot of all the daily values of streamflow over the 26-year record. The seasonal nature of the flow is very clear, and in addition there is also marked interannual variability. A visual inspection shows that the streamflow over the last three years (2003 to 2005) was some of the lowest on record; in particular 2003 had a very low flow.

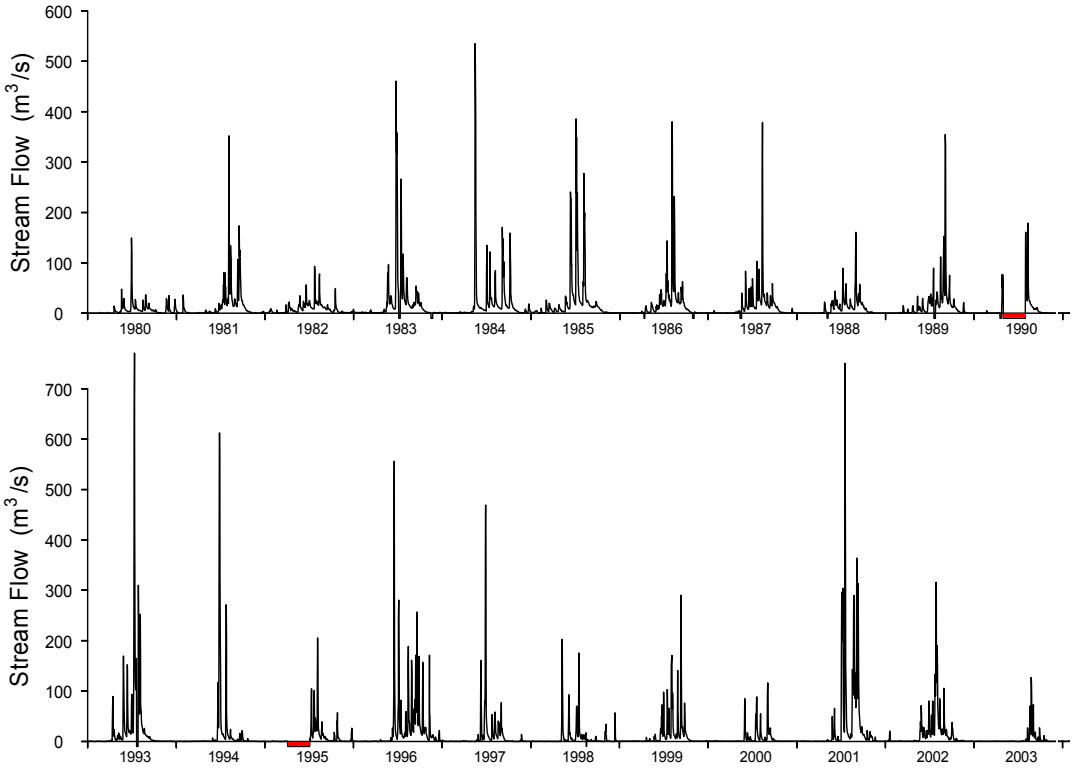


Figure 3.4 Streamflow measured at the weir at Misverstand over the years 1980 to 2005. Where no readings were taken a negative flow of -10 m^3/s is shown; in particular the three periods missing data in 1990, 1992 and 1995 are indicated in red.

This is taken further in Table 3.9, where the total volume flows for each year have been calculated. From the table it is apparent that 2003 had the lowest flow volume on record, namely 108.27 H 10^6 m^3, where the mean has been calculated as 443.46 H 10^6 m^3 for the 23 years available. 2004 was only marginally better, while 2005 was still well below the mean at 377.86 H 10^6 m^3.

The correlation between rainfall at Franschhoek and streamflow at Misverstand is shown in Figure 3.5.

The correlation is good, and indicates that the pattern of water flow at Misverstand can in large measure be accounted for by rain falling in the Franschhoek and Drakenstein mountains. On the other hand, the mean annual rainfall in the Berg River Basin above the Misverstand dam is poor, and shows the spatial variability in the catchment. This means that the rain is essentially brought in by large-scale weather patterns, with similar trends over the upper catchment. The poorer correlation at Langebaanweg is because of the lower overall rainfall in that area, and the smaller impact on the inflow.

This does mean that longer-term interannual variability can be ascertained in large measure from the rainfall variability at Franschhoek . However, as indicated in 10.2.2, the rainfall dating back to 1950 data were not bought, and consequently this longer-term variability was not addressed.

Table 3.9 Total annual volume flows of water at the Misverstand Dam, maximum flows measured, and annual rainfall totals measured at the Franschhoek weather station. The question marks in the flow column relate to years when there were missing data, and these years were omitted in average calculations.

Year	Misverstand		FranschhoekRainfall (mm)
	Annual Flow (m^3)	Max (m^3/s)	
1980	207.67 H 10^6	149.5	1888.2
1981	417.42 H 10^6	352.2	1787.4
1982	278.20 H 10^6	93.2	1596.5
1982	603.11 H 10^6	460.8	1934.6
1984	571.70 H 10^6	535.1	1916.0
1985	673.61 H 10^6	385.6	1903.2
1986	487.03 H 10^6	380.1	2099.4
1987	416.55 H 10^6	379.0	2210.1
1988	309.01 H 10^6	160.5	1659.4
1989	442.49 H 10^6	354.5	2064.4
1990	104.06 H 10^6 (?)	179.1	2026.1
1991	757.81 H 10^6	418.6	2472.1
1992	179.06 H 10^6 (?)	354.9	2477.5
1993	729.61 H 10^6	770.9	2161.0
1994	420.57 H 10^6	612.5	1958.0
1995	133.32 H 10^6 (?)	205.6	1960.9
1996	780.29 H 10^6	556.0	2523.3
1997	317.89 H 10^6	469.1	1385.2
1998	220.04 H 10^6	202.4	1836.8
1999	387.64 H 10^6	290.3	1748.1
2000	168.38 H 10^6	116.5	1551.6
2001	931.57 H 10^6	750.6	2090.5
2002	454.28 H 10^6	316.0	1767.2
2003	108.27 H 10^6	126.9	1106.5
2004	135.69 H 10^6	165.6	1513.3
2005	377.86 H 10^6	232.9	2047.4
Average	**443.46 H 10^6**	**346.9**	**1910.9**

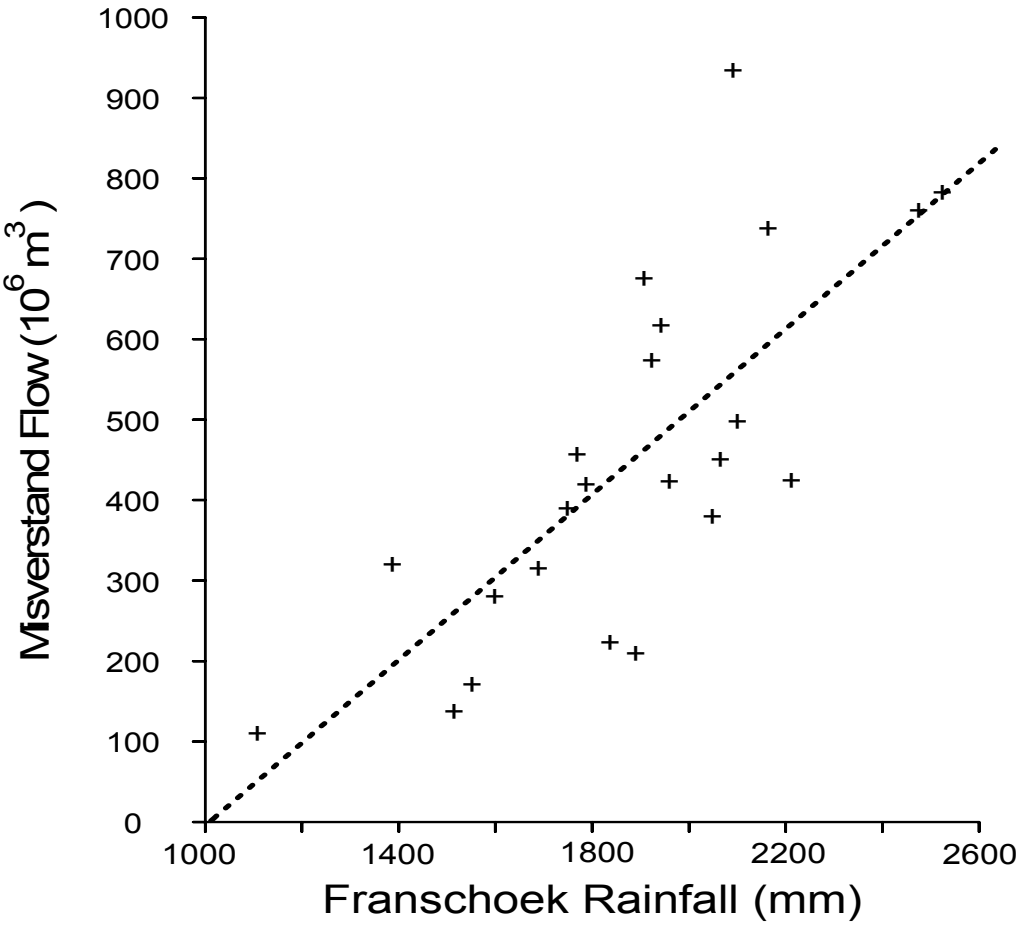


Figure 3.5 Correlation between annual Franschhoek rainfall and total annual flow measured at Misverstand. The years 1990, 1992 and 1995 are excluded. The dotted line represents the least squares regression, with a correlation coefficient of 0.76.

Rainfall and Flow: Monthly Variability

Depicts the marked seasonal variability of the rainfall and consequent fresh water inflow into the Berg Estuary. In order to investigate this further, the monthly means have been calculated for the 26-year data records for comparison with the monthly totals for the three measurement years, 2003, 2004 and 2005. These values are given in Table 3.9 and depicted in Figure 3.6.

It is important to note that there are no months with a totally zero flow, although quite obviously there were days when the flow stopped altogether. Thus a monthly flow of 1.0 $\times 10^6$ m^3 corresponds to a mean flow of about 0.38 $\times 10^6$ m^3 s^{-1} over the whole period; the minimum value in Table 3.10 (0.13 $\times 10^6$ m^3) for March, 2005 corresponds to 0.05 $\times 10^6$ m^3 s^{-1} over the whole month.

Table 3.10 Monthly values of Misverstand volume flow and Franschhoek rainfall. The means for the 26-year data record are given as well as the individual values for 2003, 2004 and 2005.

Month	Misverstand Volume Flow (10^6 m^3)				Franschhoek Rainfall (mm)			
	Mean	2003	2004	2005	Mean	2003	2004	2005
Jan	2.12	1.04	0.90	0.63	52.11	22.80	9.80	162.70
Feb	1.35	0.81	0.63	0.49	33.03	11.20	0.00	2.10
Mar	2.43	1.05	0.63	0.13	53.09	78.20	38.00	9.30
Apr	4.78	0.99	1.00	0.77	137.30	61.70	153.10	120.50
May	22.49	0.98	0.70	3.93	253.12	63.30	25.80	332.10
Jun	65.96	1.07	12.60	105.36	369.24	62.00	259.40	424.30
Jul	102.44	0.93	13.66	81.13	359.12	103.90	299.10	374.60
Aug	86.41	60.54	93.49	157.56	257.33	327.90	453.90	377.20
Sep	66.64	31.56	3.33	23.35	189.92	183.10	70.10	134.50
Oct	20.76	7.51	7.10	3.24	89.18	105.00	175.70	67.00
Nov	5.58	0.77	0.74	0.75	57.99	0.00	15.20	43.10
Dec	3.30	1.04	0.93	0.85	59.60	87.40	13.20	0.00

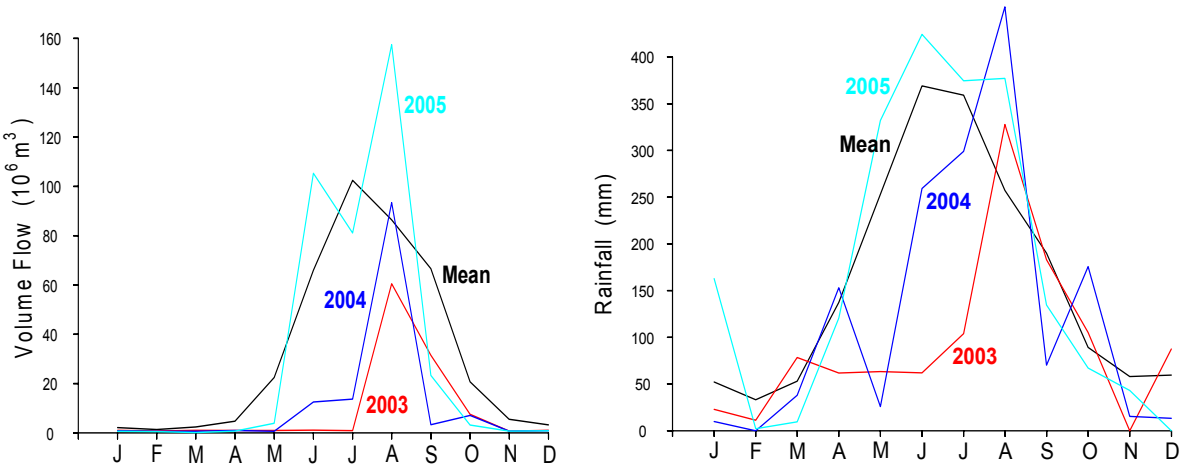


Figure 3.6 Graphical depiction of the values given in Table 3.10

The years 2003 and 2004 show considerable changes from the mean values in both volume flow and rainfall. Apart from the numbers being down considerably on the mean, the maxima in both cases occurred in August, and not in July. Maximum flow in 2005 also occurred in August, though the rainfall shows a broader maximum covering May to August.

Of interest is the fact that substantial seasonal rainfall starts in about April at Franschhoek, but that the response at the Misverstand weir only occurs around May or June; this is also shown in the minimal response in the flow to the heavier rainfalls in April, 2004, and January, 2005. Such responses may be due to first rainfalls soaking into dry ground, or being trapped in dams dry from the previous summer, with consequent minimal runoff.

Yearly Air Temperature Variability

Air temperature has an important effect on water temperatures in the estuary, particularly in the upper reaches where flow is slow. Consequent diurnal variations in water temperature, particularly in the upper layers, can be several degrees Celsius.

Moreover, combined with the wind, air temperature is an important determinant of the rate of evaporation.

Figure 3.7 shows the maximum and minimum daily air temperatures for the data record available at Langebaanweg. The seasonal variation in temperature is the most significant feature, with some interannual variability, and for such a short series it is not possible to discern any trends.

Maximum daily air temperatures in summer are frequently over 35 ^{O}C, with minimum temperatures consistently above about 15 ^{O}C. In winter the daily maxima are generally below 20 ^{O}C, while minima are frequently near to freezing.

Water Level Variability

Water exchanges through the estuary mouth constitute a major perennial input of energy into the Berg estuarine system. These exchanges are driven by sea level variability in the adjacent ocean, in particular at tidal and longer periods. The dynamics of these fluctuations is investigated in this section.

There are four sites where water level was measured, namely Saldanha Bay, Laaiplek, Kliphoek and Jantjiesfontein; details are given in 3.1.4. In order to investigate the water level variability, 100-day records from the beginning of 2004 were selected.

In particular, at this time there was little influx of fresh water at the head of the estuary, and therefore the resulting water level variations in the estuary were due only to water exchanges with the sea.

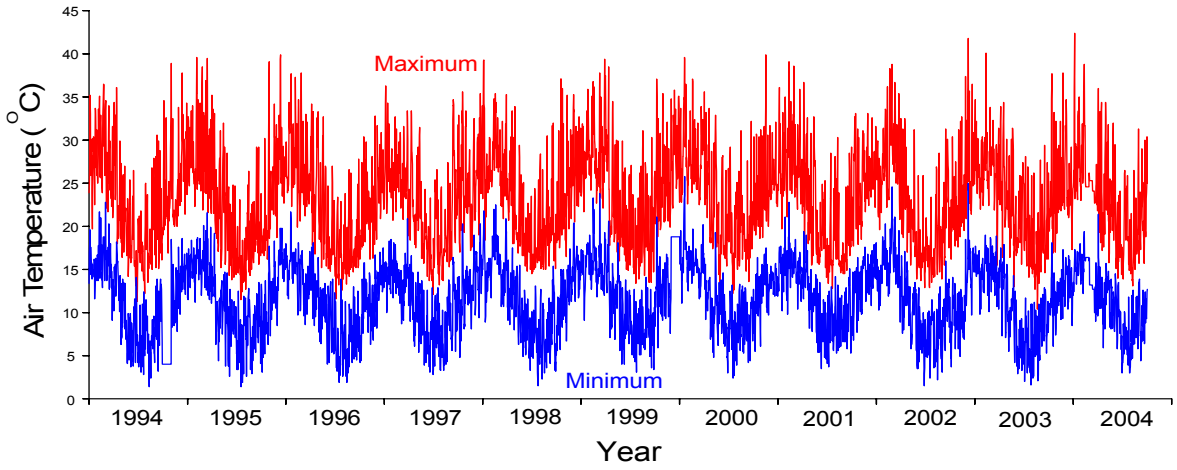


Figure 3.7 Minimum (blue line) and maximum (red line) daily temperatures measured at Langebaanweg.

In order to separate out the semidiurnal (M_2) and diurnal (K_1) tidal fluctuations from longer-period variations, a symmetrical Cosine-Lanczos filter with 97 weights and a quarter-power point at 0.031 cycles per hour was used. Before using the data, the values were corrected to msl by subtracting 0.865 m from the chart datum values (see 3.1.4). Table 3.11 gives some statistics for the various series discussed below.

Table 3.11 Statistics for the 100-day hourly time series of water level data from Saldanha Bay, Laaiplek, Kliphoek and Jantjiesfontein. The series correspond to Figure 3.8, Figure 3.9 and Figure 3.10.

Site	Original Data Series			Tidal			Long Period		
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
Saldanha Bay	-0.72	1.20	0.21	-0.83	0.91	-0.00	-0.06	-0.38	0.21
Laaiplek	-0.86	0.84	-0.15	-0.79	0.81	-0.00	-0.45	0.09	-0.15
Kliphoek	-0.62	0.38	-0.11	-0.30	0.31	0.00	-0.50	0.11	-0.12
Jantjiesfontein	-0.31	0.31	-0.01	-0.12	0.12	-0.00	-0.30	0.22	-0.02

It is clear from Table 3.11 that the msl correction recommended by the SAN in Table 3.1 essentially means that the tidal fluctuations oscillated about the zero line, and it is the long-period fluctuations that caused differences to occur.

Figure 3.8 shows the actual measured time series of water level at the four sites, together with the superimposed longer-period variability (in blue). The semidiurnal M_2 tidal variability is the dominant component at Saldanha Bay and Laaplek, while it is apparent that the diurnal K_1 tide contributes to a diurnal inequality. In addition the two-week spring-neap cycle is clearly evident.

The longer-period fluctuations serve to alter the extent of the tidal oscillations by changing the background water level, though it is important to realise that the periodicity is not affected. Nonetheless, it is not altogether uncommon in estuaries that, for instance, a high tide on one day can be lower than a low tide on the next day. This effect is evident on day 30 in the Laaiplek series, where the midnight high tide on day 29 was only marginally higher than the afternoon low tide the next day, while the following low tide was actually higher (shown by the red circle on the figure). Higher up in the estuary at Jantjiesfontein this is a regular occurrence.

The tidal components are reduced considerably at Kliphoek, and even more so at Jantjiesfontein. At the same time it is apparent that the longer-period fluctuations are amplified and at Jantjiesfontein it is these effects that have the largest influence on water level.

A search was made for minima and maxima in the available water level data at the four sites from November, 2002, to November, 2005, and these results are given in Table 3.12. These values include tidal and longer-period variations, while the large variation at Jantjiesfontein is due to the influx of fresh water from the Berg River.

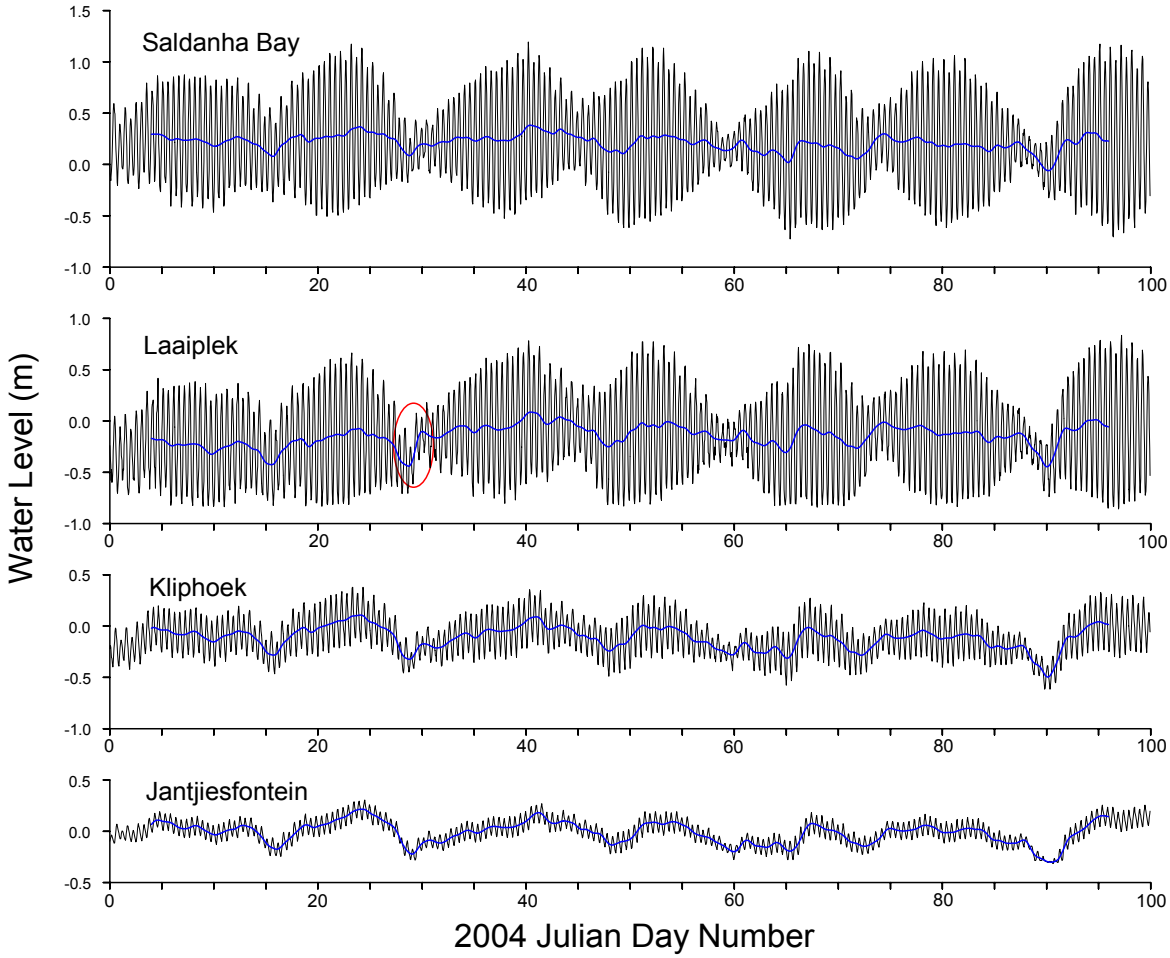


Figure 3.8 *Measured water level relative to msl at Saldanha Bay, Laaiplek, Kliphoek and Jantjiesfontein. The blue lines show the longer-period fluctuations, while the situation at the red ellipse is discussed in the text.*

Tidal Variability

Figure 3.8 depicts the tidal variability at the four sites. With the long-period fluctuations removed, the regularity of the tides is evident within the envelope of the spring-neap variability. The diurnal inequality is appreciable at times, though it is not consistent. Table 3.10 gives a maximum tidal variation at Saldanha Bay of 1.74m, reducing to 1.60m at Laaiplek, 0.61m at Kliphoek and finally 0.24m at Jantjiesfontein.

Table 3.12 *Minimum and maximum water levels, and overall variation measured at the various sites from November, 2002, to November, 2005.*

Site	Min (m)	Max (m)	Var (m)	Site	Min (m)	Max (m)	Var (m)
Saldanha Bay	-0.86	1.38	2.24	Kliphoek	-0.64	0.66	1.30
Laaiplek	-0.86	1.07	1.93	Jantjiesfontein	-0.32	2.69	3.01

Figure 3.9 investigates the propagation of the tidal signal from the mouth of the estuary to the recording site at Jantjiesfontein; 3 days are shown from 2 to 4 March, where there was limited diurnal inequality. The lags for high water and low water at two of the tidal peaks and troughs are shown, and can be used to estimate propagation speeds.

Note that the data interval is 1 hour, with the result that the estimates cannot be expected to be much more accurate than this.

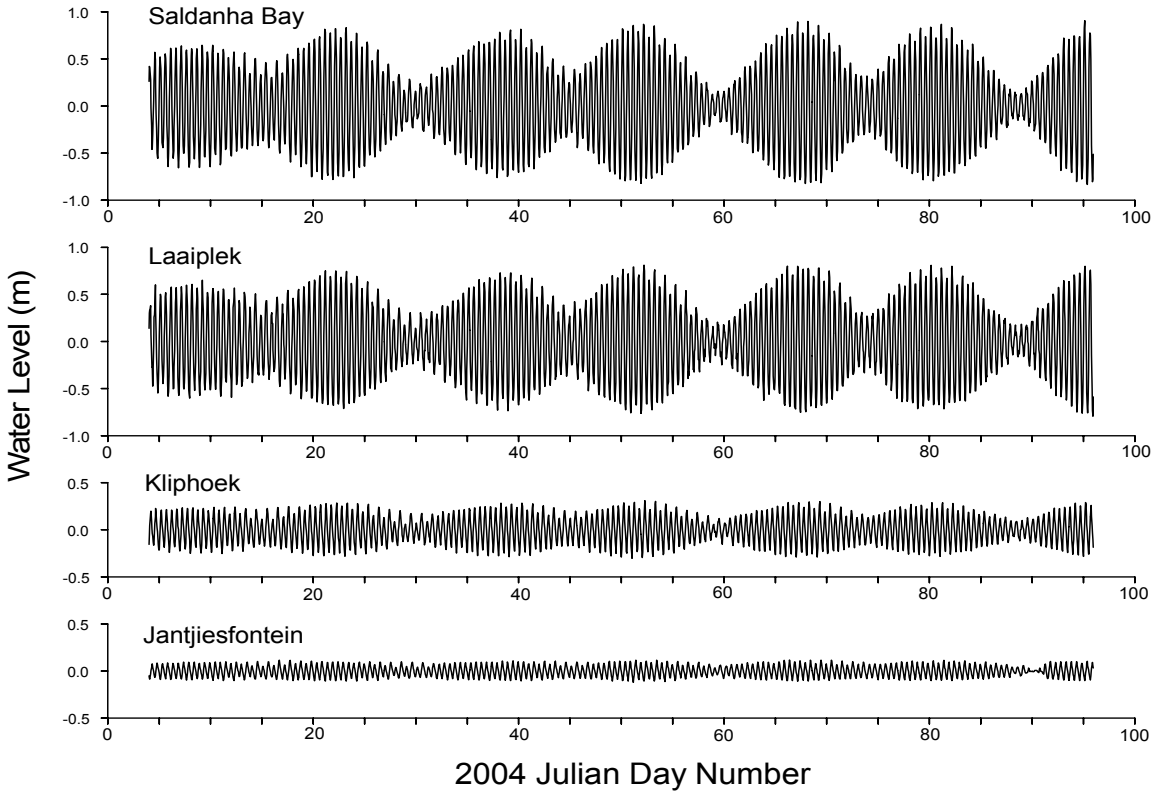


Figure 3.9 Tidal variability at the four measurement sites.

Table 3.12 lists the estimated lags and corresponding speed of the tidal signal to the different sites.

In an unstratified estuary the tidal wave can be expected to travel at the shallow water wave speed c, where

$$c = (gh)^{1/2} \qquad (2)$$

and g is the gravitational constant and h the water depth (Dyer, 1997).

The calculated propagation speed can be used to determine an effective water depth as perceived by the wave, and these values are also given in Table 3.13.

The water depth varies considerably along the length of the estuary (see Appendix 2.1), and there are quite wide tidal flats with very shallow areas. It is also important to note that the depth varies with the tide, thus also affecting the speed of the tidal wave. Nonetheless, the estimated wave depths are small, probably also a consequence of frictional effects, which are not incorporated into the shallow-wave equation. Slinger and Taljaard (1994) found that high tide lagged the mouth by 4 hours at Kliphoek and by 2.3 hours at low tide. At a position 56 km from the mouth the lags were 7 hours and 6.7 hours at low and high tides, in approximate agreement with values found here; note that they did not consider the effects of the longer-period variations.

Table 3.13 Propagation speeds of the tidal signal at the measurement sites determined from Figure 3.10. The calculated water depth from the shallow water wave speed is also given. Note that constrictions in the mouth area mean that additional factors affect the lag at Laaiplek, and this is taken as the starting point for the tidal signal.

Site	Distance (km)	Tidal Peak Lag	Tidal Trough Lag	Speed (m/s)	Depth (m)
Saldanha Bay	0.0	00:00	00:00		-
Laaiplek	0.4	35 m	35 m		-
Kliphoek	16.8	3 h 7 m	3 h 24 m	1.77	0.32
Jantjiesfontein	53.5	6 h 22 m	6 h 40 m	2.50	0.64

Longer-period Variability

Figure 3.11 shows the water level variability at periods longer than the diurnal tidal period. Of particular interest here is the amplification of the signal immediately within the estuary at Laaiplek, and then the further undiminished propagation up to the farthest measuring point at Jantjiesfontein (Table 3.11). As is evident in the foregoing figures, it means that these longer-period oceanic water level variations are more important in the upper reaches of the Berg Estuary than tidal variations.

Vertical lines have been drawn at significant peaks and troughs on Figure 3.10 in order to estimate propagation speeds of these longer-period oceanic signals. It is apparent that Laaiplek leads Sadanha Bay, and this is consistent with the existence of coastal trapped waves (Schumann and Brink, 1990) which travel southwards along the west coast, and therefore reach St Helena Bay before Saldanha Bay. These longer-period waves will also travel as shallow-water waves up the estuary, and rough estimates for a lag between Laaiplek and Jantjiesfontein give values around 10 hours.

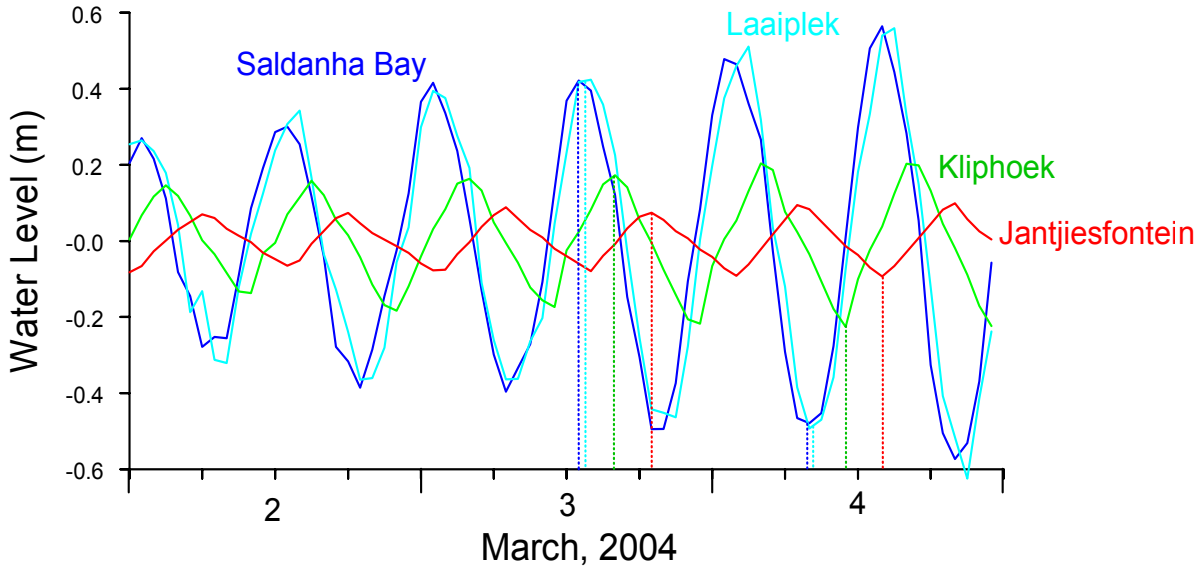


Figure 3.10 Tidal variability at the four sites during three days in March, 2004. The dotted lines show positions where tidal lags are investigated.

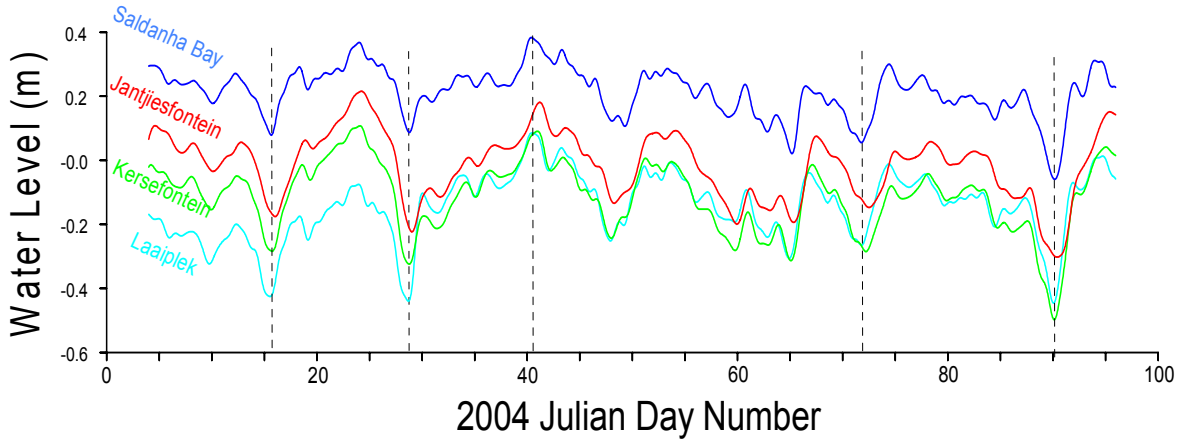


Figure 3.11 Longer-period water level variability at the four sites.

3.3.2 Air and water temperatures

As described in 3.2.2, data loggers were deployed at sites M1, M2 and M3 along the length of the Berg estuary – see Figure 3.2. Unfortunately the temperature recorder at position M1 was damaged, and the results presented here will therefore only consider sites M2 and M3.

The yearly air temperature variability at Langebaanweg has already been presented (3.3.2), and this influence is investigated further here. Figure 3.12 shows the time series of temperature measurements from M2, M3 and Langebaanweg during winter, 2004, and summer, 2004/2005.

The diurnal variation in water temperatures is due to the heating by the sun during the day, and the cooling at night. This is most apparent during the summer when the sun=s radiation is most intense, though the influence is also evident in winter. The correlation between air and water temperatures is very close, with a short lag between the peak air temperature and the peak water temperature. Water temperatures are seen to vary by more than 1^{O}C on some days.

The variation in water temperatures also follows air temperature over periods of days, where a trend of warmer days will mean a general increase in water temperatures, and colder days will lead to a corresponding decrease. Air temperatures in summer reached over 40 ^{O}C on some days.

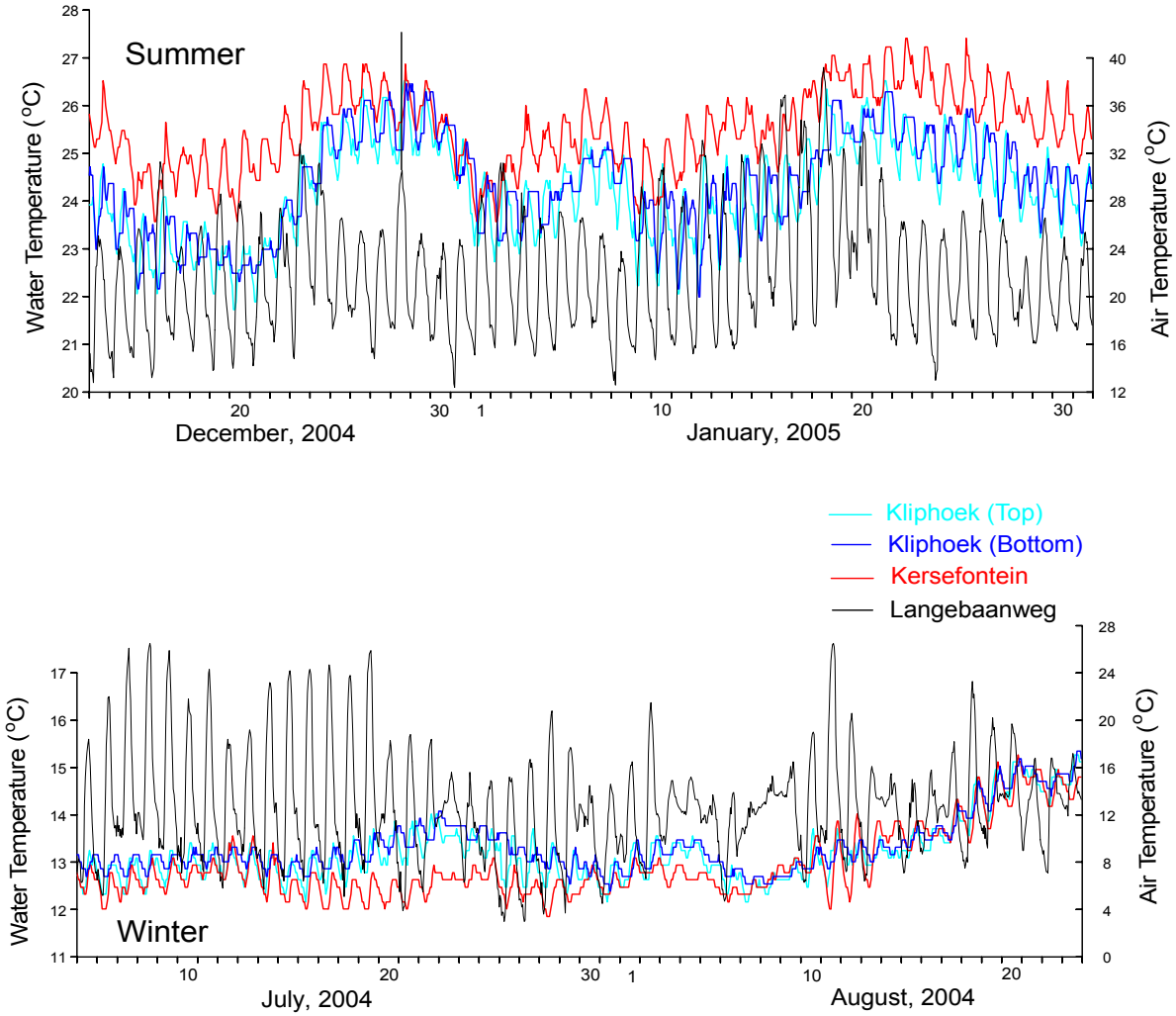


Figure 3.12 *Water temperatures measured at Kliphoek (M2) and Kersefontein (M3), as well as air temperatures measured at Langebaanweg.*

Water temperatures at Kliphoek varied substantially more at the surface than deeper down. Thus during the day it can be expected that the insolation will heat up the surface layers, while at the same time there will be greater radiation loss from the surface at night. It can be seen that the surface temperatures were generally slightly less than bottom temperatures at night, particularly in summer, and this instability will also lead to some vertical mixing.The winter record also includes the period of the largest fresh water spates of 2004 (see Figure 3.17). On 26 July a flow of over 35 m^3/s was measured at the Misverstand weir, while on 10 August the maximum yearly flow of 165.6 m^3/s was recorded. It is apparent that, during these periods the temperatures through the whole estuary varied little, as the spates flushed through the whole system.

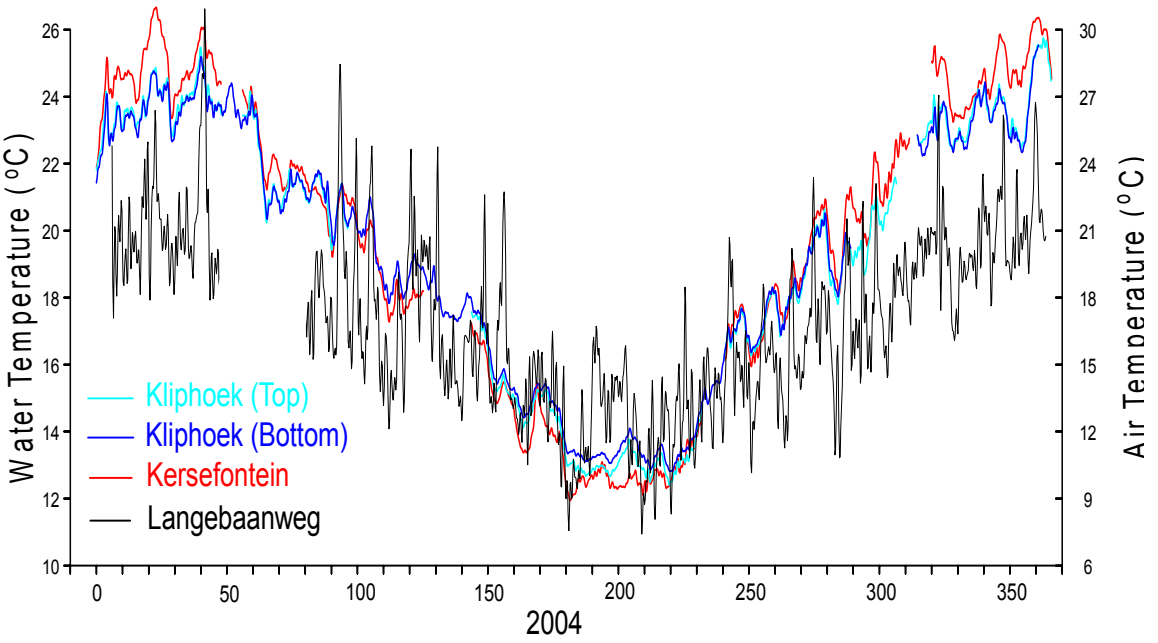


Figure 3.13 Filtered water temperatures from Kliphoek and Kersefontein, as well as air temperatures measured at Langebaanweg during 2004.

Figure 3.13 shows the filtered temperature records for 2004, where the Cosine-Lanczos filter has been used to remove the diurnal fluctuations. There are some gaps in the data records, particularly at Langebaanweg during February.

The shorter gaps in the mooring records occurred during the *Hobo* recorder exchanges; as indicated in 3.2.2 a longer recording interval introduced in May, 2004, reduced the extent of these gaps.

The largest and most obvious temperature variation occurs on an annual basis, due to differing insolation and air temperatures through the year. In summer - December to February - both the surface and bottom water temperatures at Kliphoek reached 26 ^{O}C, while at Kersefontein they reached 27 ^{O}C. On the other hand, in winter the Kersefontein water temperatures decreased to around 12 ^{O}C, a degree or so colder than the temperatures at Kliphoek. It is probable that the seasonal effect is most marked in the upper reaches of the estuary because there is less of an exchange of water with the much greater reservoir of the sea. Moreover, the inflow of fresh water derives from the Berg River itself, where it is also directly affected by changes in solar radiation and air temperature.

The *Quanta* recorder at the Kliphoek site measured temperature and salinity for a short period at the beginning of the programme, and Figure 3.14 shows ten days of these data. The diurnal temperature fluctuations are again evident, particularly in the latter half of the record. However, there is a strong semidiurnal variation in the salinity fluctuations associated with the M_2 semidiurnal tide; these are strongly accentuated at spring tide. The earlier boat sections (Appendix 2.2) in November revealed an intense longitudinal salinity gradient around Kliphoek (station 13), and consequently the flood and ebb tidal flows resulted in salinity changes of more than 6 or 7 every six hours.

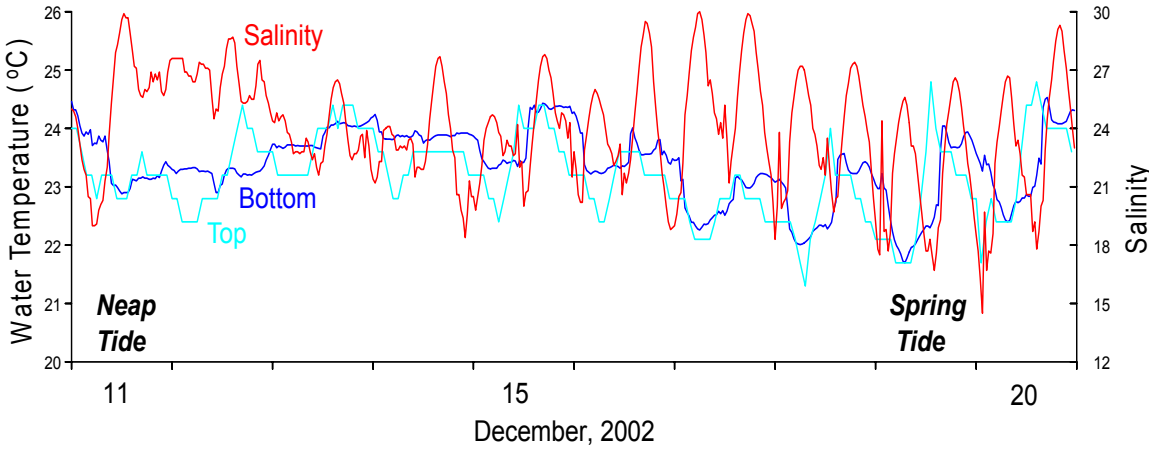


Figure 3.14 Surface and bottom water temperatures, as well as salinity, measured at the Kliphoek mooring in December, 2002.

3.3.3 CSIR Hydrological Information System (HIS) Results

Figure 3.15 shows the time variation of EC over the years 1983 to 1999 as measured at Kliphoek and Jantjiesfontein. The seasonal nature of the variation is evident at Kliphoek, where during the summer months the saline waters move up the estuary. During winter the freshwater spates then push this saline intrusion down the estuary again. There is no apparent pattern at Jantjiesfontein, with the highest value of EC (737 mS/m) measured on 1 March, 1995.

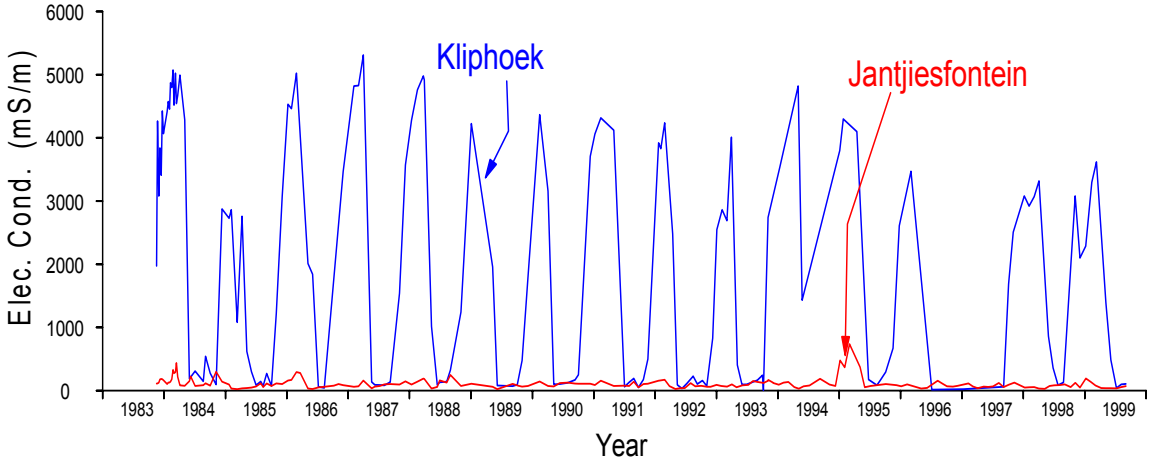


Figure 3.15 Time variation of electrical conductivity (EC) measured at Kliphoek (blue line) and Jantjiesfontein (red line).

A regular and consistent time series of EC at Kliphoek would be very valuable in determining salinity variations in the estuary, in particular in assessing the movement of the saline wedge with the seasonal influxes of fresh water. However, the HIS data available leaves much to be desired. Over the 17 years plotted (1983 to 1999), there were only 150 measurements, i.e. an average of 8.8 measurements per year. Moreover, these measurement times appear random, with some years having as little as 2 measurements, and in 1996/97 there were no measurements to show the influx of higher salinity water to Kliphoek. Unfortunately these data cannot be used for quantitative assessments of the state of the estuary.

Figure 3.16 shows the corresponding values of pH measured at the two sites. In the first few years of the series, up to 1989, there is a tendency at Kliphoek for a similar variation as for EC.

Thus during the summer the pH increased as fresh water inflow decreased and seawater penetrated up the estuary, but then decreased during winter when fresh water from the spates flushed out the seawater. It is not clear what happened after 1989, as the pH values remained relatively high, irrespective of season, though in the range for essentially fresh river water. The Jantjiesfontein pH values were also lower initially, with some seasonal variation, but after 1989 these also remained relatively high.

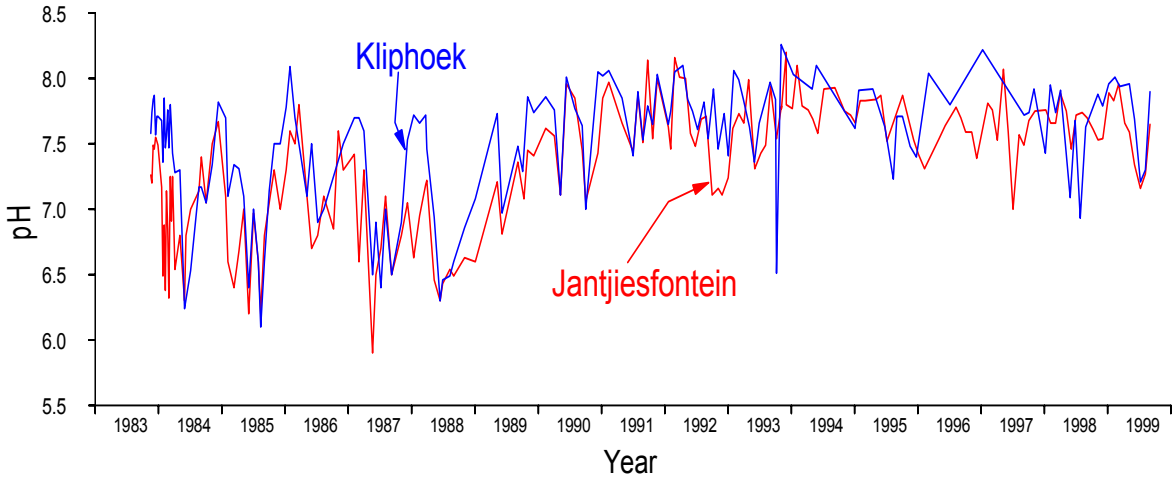


Figure 3.16 Time variation of pH measured at Kliphoek (blue line) and Jantjiesfontein (red line).

3.3.4 Estuarine boat sections

There were thirteen experimental periods on the Berg Estuary from November, 2002, to November, 2005.

As described in Section 3.3.1, in each case a longitudinal section was measured along the length of the estuary at spring high and low tides, and neap high and low tides. The variables measured were salinity, temperature, dissolved oxygen (DO), pH and Secchi depth, and for each profile the processing programs extracted values in 0.25 m bins. Appendix 2.2 depicts the results of these measurements. Figure 3.17 shows the measurement periods in the context of the freshwater flow measured at the Misverstand dam.

As indicated already in 3.3.1, there was considerable variability in the rainfall and freshwater inflow over the four years. In terms of volume flow, 2002 was close to being an >average= year, with 454 H 10^6 m^3, compared to the mean of 443 H 10^6 m^3. On the other hand, 2003 had the lowest recorded flow, with a total of only 108 H 10^6 m^3. As shown in Figure 3.4, the rainfall and flow increased to 135 H 10^6 m^3 in 2004 and 377 H 10^6 m^3 in 2005.

A brief description of each of the thirteen experimental periods is given below, and should be seen in conjunction with the detailed longitudinal estuarine sections given in the Appendix 2.2.

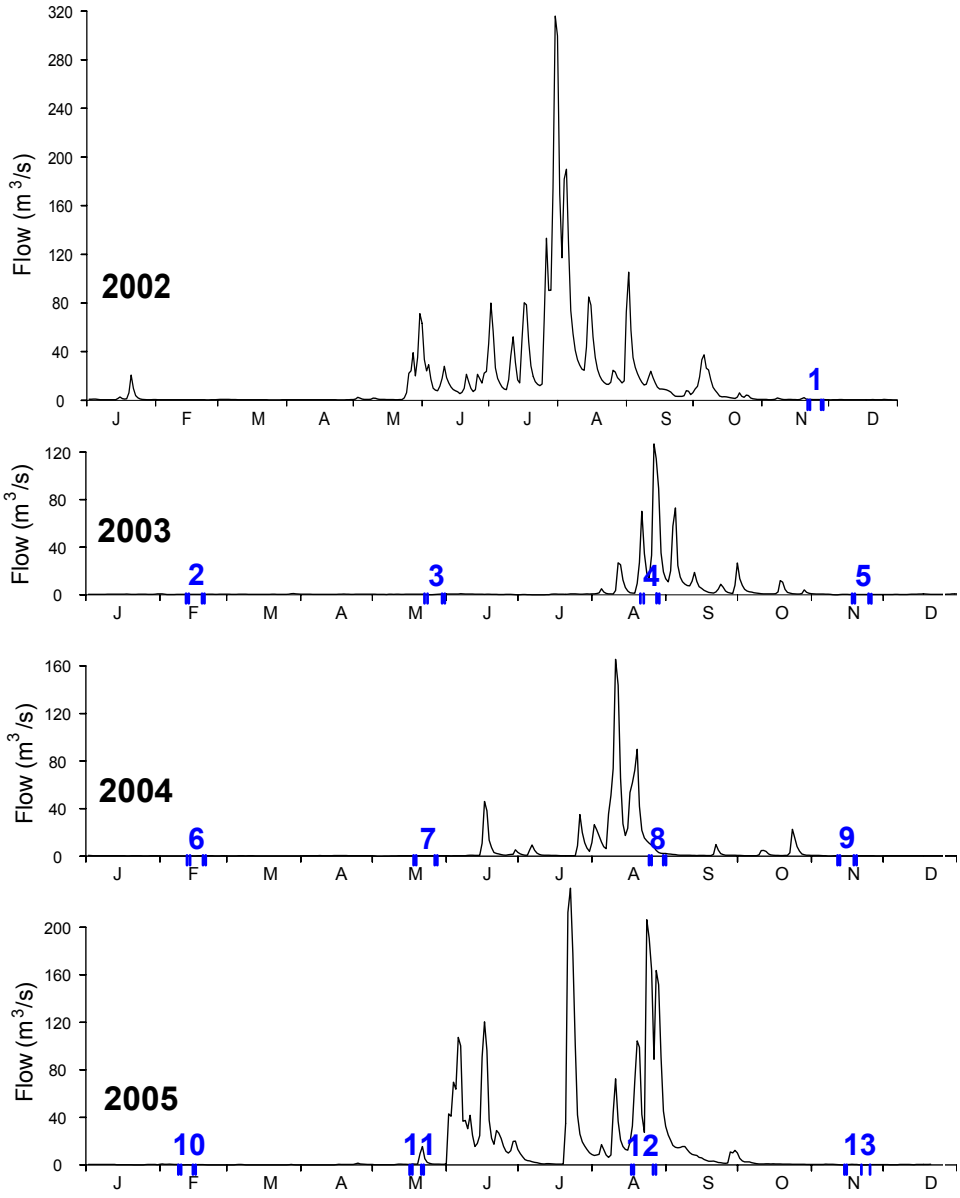


Figure 3.17 Freshwater flow measured at the Misverstand Dam. The thirteen experimental periods are shown in blue along the time axis.

#1: November, 2002

These sections were measured more than a month after the last winter/spring freshwater spates (Figure 3.17).

The results of later experiments indicate that the earlier winter spates in July and August would have flushed out the saline marine waters that had ingressed the estuary during the previous summer. These sections therefore represent the ongoing stages of the intrusion of marine waters back into the estuary.

The effects of the spring high tides is evident in the salinity sections. Thus on 20 November marine waters with salinities over 34 had progressed beyond station 4, and farther upstream the 1 isohaline had almost reached station 15. At the following spring low tide these waters had again been moved a few kilometres towards the mouth, while salinities at the mouth itself were only 32.

The effect of the neap tides was much less, particularly in the upper reaches. There was little change in the position of the 1 isohaline from low to high tide, and the main effect was at the mouth.

Water temperatures in the upper reaches of the estuary had already warmed up with the onset of spring and summer, reaching over 24 ^{O}C. There are also indications of some diurnal heating in the surface layers. On the other hand, the marine waters entering from the sea were cold, with temperatures at times below 14 ^{O}C.

The DO sections consistently show that the concentrations were higher in the sea during the measurement period, with values around 8 to 9 mg/l, decreasing upstream. There are some sections where lower values were measured, e.g. around stations 4 to 8, but the trend decreased upstream to values between 5 and 6 mg/l.

pH values were only measured near the surface, but show a consistent decreasing trend from a value just over 8 at the mouth, to around 7.5 in the upper reaches.

In all cases there was no appreciable vertical stratification, even during the neap tide measurements. With the limited freshwater inflow, the implication is that tidal currents are sufficiently strong to cause such mixing throughout the water column.

#2: February, 2003

These salinity sections show the further progression of saline marine waters into the estuary. In particular, the 1 isohaline had advanced approximately 13 to 17 km farther upstream.

The neap tides did not appreciably affect the position of the isohalines in the higher reaches of the estuary, with the in-and-outflow of marine waters affecting mainly the mouth area. Of interest is the occurrence of some vertical stratification in the middle reaches during neap tide when tidal mixing energy would have been less than at spring tides. The spring tidal differences are not that apparent, but this may be due to the fact that the measurements were started at the mouth well in advance of the occurrence of slack water, and therefore do not adequately represent the particular tidal state.

Water temperatures in the upper reaches of the estuary had increased by 1 to 2 ^{O}C from November to over 26 ^{O}C as a result of summer insolation. Diurnal heating of the surface layers is again evident, particularly on 11 February. Ocean temperatures also appear to be warmer than on the previous experiment in November, 2002, being between 16 and 19 ^{O}C.

As indicated in 3.2.1, the DO values measured in February are suspect, though trends are probably valid. In both the spring tide sections (c and d) values near the mouth were relatively low, increased in the middle reaches, and then decreased slightly in the headwaters.

Values of pH of 7.5 and under were measured near the mouth, while typical values for seawater should range between 7.9 and 8.2 (DWAF, 1995).

The values increase with distance upstream, reaching values of over 9. While anaerobic conditions can increase pH values through decomposition of organic matter, the oxygen results show no such conditions; these pH values are therefore anomalous.

#3: May, 2003

The salinity sections measured in May generally show that the 1 isohaline had retreated seawards by some 5 km compared to the situation in February. The reason for this is not clear, since Figure 10.16 shows that there were no substantial inputs of freshwater in the intervening period, with less than 1 m^3/s recorded over the whole month. There was little change in the position of the 1 isohaline over all four sections, though the salinities at the mouth varied markedly with flood and ebb tides.

The water temperatures show that the water in the estuary had cooled considerably at this stage, with the upper reaches at around 16 ^{O}C and the oceanic water at the mouth at around 14 ^{O}C.

The DO values at the estuary mouth at low tide on 22 May were anomalously low, under 2 mg/l. Thereafter they increased to over 8 in the middle reaches before dropping to below 7 mg/l at the estuary head.

At neap high tide on the next day it appears that the marine low DO values had been forced farther into the estuary, in the region of stations 5 and 6. Values in the vicinity of stations 15 and 16 were still as high as 8 mg/l, while at stations 24 and 25 values decreased rapidly to below 4 mg/l; it is not known what could have caused this reduction.

A week later there were again low DO values in the marine waters at the estuary mouth, under 3 mg/l. Thereafter increases occurred in the middle reaches, and at the low tide values below 4 mg/l were again evident at the estuary head. The indication is that these low DO waters derived from the river inflow.

pH values varied from about 7.5 near the mouth of the estuary, with slightly higher values in the middle reaches (up to about 8.2 on 22 May), and then decreasing to about 7.7 at the estuary head.

#4: August, 2003

Figure 3.17 shows that these measurements were taken during the course of the freshwater spates in August, coinciding with the only period in which substantial rain fell during what was a very dry year (Table 3.9). In particular, sections A and B (neap low and high tides) took place during first peak, but before the second peak had reached the estuary. At neap low tide the 1 isohaline was still beyond station 11, indicating that the first peak flow of 26.9 m^3/s had not entirely flushed out the marine waters. The temperature section shows little influence of the spate, in particular because the temperature of the inflowing fresh water was little different to the oceanic waters at the estuary mouth. The DO section shows a relatively constant value of about 9.5 mg/l in the inflowing freshwater, with slightly lower oceanic values, and an indication of decreasing values with depth in the sea.

The second estuarine section, b (22 August), was probably measured in the middle of the second peak flow (a peak of 70.1 m^3/s). At neap high tide, the 1 isohaline had nevertheless been forced about 3 km seaward, with intense vertical salinity stratification resulting between stations 3 and 5. Again the water temperatures showed little indication of the fresh water inflow, while the lower oceanic DO values (~ 7 mg/l) are clearly evident at the estuary mouth in the incoming seawater.

The third estuarine section, c (27 August), was measured in the middle of the third and largest of the freshwater inflows, reaching a peak daily flow of 126.9 m^3/s. Even at spring high tide the intrusion of oceanic water at the mouth of the estuary did not progress farther upstream than station 5, with an intense salinity front occurring seaward of this station. Water temperatures varied by about 1 ^{O}C along the length of the estuary, while the DO in the fresh water section of the estuary remained high, reaching over 10 mg/l in the upper reaches. However, the DO in the oceanic water at the mouth of the estuary was also high.

On the subsequent low tide, section d (28 August) shows that fresh water essentially filled the estuary, with a maximum salinity value of 2 at the mouth. Temperature values again showed little structure, varying from less than 12 ^{O}C at the upper stations, to 13.5 ^{O}C at the mouth. DO values reached a high of over 11 mg/l upstream of station 23, decreasing to less than 9 mg/l at the estuary mouth.

Lower pH values were generally associated with the freshwater which filled much of the estuary. It was only during the spring high tide on 27 May that pH values in excess of 8 were found at the stations 1 to 6.the first real spate of the winter, while the spring tide sections were measured during the largest inflow of the year.

The first estuarine section, a (20 August), was therefore completed about 9 days after the

#5: November, 2003. From Figure 3.17 it is apparent that the fresh water inflow conditions after the winter spates were similar from about the end of August to those in 2002.

However, the salinity sections show that the marine waters had intruded substantially farther into the estuary in 2003 than in 2002; thus the 1 isohaline was located between stations 17 and 18 in the spring high tide section, compared with the previous year when it was between stations 14 and 15. It also appears that there was a marked intrusion farther into the estuary from the neap tide situation the week before. These differences are possibly associated with the much higher rainfall earlier in 2002, and consequent variations in the base flow into the estuary.

At neap tide the sea temperatures were considerably colder (~14 ^{O}C) compared to the situation a week later at spring tide (~20 ^{O}C). Temperatures in the upper reaches were similar (~24 to 25 ^{O}C), and consequently the along-estuary gradients were much stronger at the neap tide. There is an indication of some vertical structure.

Oxygen distributions were fairly similar to those in November, 2002, but with more detailed structures evident (noting that the 2002 values are suspect).

Values in the middle reaches were highest, but some low values (< 4 mg/l) were measured in the parts of the estuary lined with trees.

pH values all started at values between 7.6 and 7.9 near the mouth of the estuary, then increased to above 8 in the middle reaches, before finally decreasing again in the upper part of the estuary.

#6: February, 2004

The salinity intrusion in this February section was marginally farther upstream than in 2002, with possibly a greater effect at the mouth. During the neap tides there was some indication of vertical stratification between stations 14 and 18 at neap tide, but this was effectively eliminated at the subsequent spring tide; there was little difference in the range of the 1 isohaline.

Sea temperatures at neap tide were in the region of 18 ^{O}C, but at spring tide the next week these had dropped to under 16 ^{O}C, possibly due to an upwelling event in the ocean. Temperatures increased upstream to around 27 ^{O}C, and in the middle reaches there is some indication of temperature stratification due to solar heating.

DO values in the oceanic water at the mouth remained around 5 and 6 mg/l for the duration of the experiment. Higher surface values occurred in the middle reaches, with values around 7 or 8 mg/l near the tidal limit.

#7: May, 2004

As in the previous year, there did not seem to be any appreciable inflow into the estuary, but the upstream extent of the 1 isohaline had moved seawards since the February measurements; it is also significant that at spring low tide the salinity at the mouth was less than the oceanic value of over 34. At the spring tide the water was well mixed throughout the estuary, but at the subsequent neap tide there was some indication of the development of vertical stratification between stations 15 and 18.

With the onset of the colder winter months, the water temperatures had decreased in the upper reaches, and were very similar to oceanic values at the mouth of the estuary. There is some indication of diurnal heating of the upper layers.

DO values generally increased upstream, with abnormally low values of less than 3 mg/l measured at the mouth at spring low tide. There were again higher surface values around stations 14 to 19.

#8: August, 2004

Figure 3.17 shows that these measurements were made at the end of the main winter freshwater inflows. From the results of 2003, it is likely that this freshwater inflow was strong enough to have flushed out the saline oceanic water, and the measurements depict the first intrusions of oceanic water back into the estuary.

Thus at neap low tide the freshwater outflow persisted out of the mouth in the upper layers, while deeper down there were vestiges of more saline oceanic water from the previous high tide. Measurements at the subsequent neap high tide show this saline oceanic water pressing farther upstream. By the next spring high tide (section BR8c) the 1 isohaline had progressed almost 10 km farther upstream, and the section shows that tidal energy was sufficient to mix the water column. The following spring neap tide section shows the 1 isohaline slightly farther upstream, although the water at the mouth had a salinity of only 30.

Sea temperatures were one or two degrees lower than estuary temperatures, but with the strong flow of fresh water, there was little variation along the length of the estuary. DO values also increased upstream to the highly-oxygenated inflowing fresh water.

#9: November, 2004

The salinity distributions show the further ingress of seawater into the estuary over the three months since the last measurements.

At spring tides the 1 isohaline had only moved a farther 10 km upstream, but at the neap tides a week later this had increased by another 5 km; possibly the minor freshettes (Fhad served to push out the saline water in the intervening period. At spring tides the water columns were well-mixed, with some vertical structure at the neap tides.

With the advent of spring and early summer, water temperatures in the upper reaches of the estuary reached 27 ^{O}C. On the other hand, sea temperatures at the mouth were as low as 14 ^{O}C, with the main gradients in the downstream section.

Considerable day to day variability was evident in the DO structures, with values generally in the range 5 to 8 mg/l, but with some lower values around stations 20 to 22.

#10: February, 2005

At the spring high tide the 1 isohaline had penetrated almost to station 20, with some fairly sharp horizontal gradients to station 17, where salinities were around 12; there was also some vertical structure. Sea water with a salinity greater than 34 was present at spring tide sections more than 5 km from the estuary mouth.

At the neap low tide measurements the sea water had been pushed farther out, and there appears to have been a greater outflow at mid-depth in the estuary, though reasons for this are not apparent. Some vertical structure is evident around stations 17 and 18 at neap high tide, but in both cases the position of the 1 isohaline changed little.

High water temperatures (over 25 ^{O}C) were evident throughout much of the estuary, with sea temperatures around 19 ^{O}C cooling conditions around the estuary mouth. However, it is apparent that an upwelling event must have occurred in the ocean at the time of the neap tide measurements, because at the neap high tide on 15 February, the sea temperatures dropped suddenly to less than 14 ^{O}C.

DO values were generally between 4 and 6 mg/l throughout, but with lower values at the bottom in places.

#11: May, 2005

The first small freshette of the year occurred on 21 May (Figure 3.17), with a maximum daily flow of 15.46 m^3/s measured at the Misverstand wier. On 21 May at about 07:00 water level at Jantjiesfontein rose about 10 cm and then fell back after a few hours. It started rising again in the afternoon, reaching a maximum height around 60 cm above the background level at 19:00 on 22 May.

The neap tide measurements on 16 and 17 May were completed before the freshwater inflow, and show the 1 isohaline at approximately the same position in the estuary as in February; some stratification had developed between stations 16 and 17. At the spring high tide measurements on 21 May the impact of the freshwater inflow was already apparent, with the 1 isohaline forced seawards by two or three kilometres, and developing an intense longitudinal salinity gradient.

During the spring low tide measurements on the next day mixing had occurred at the freshwater boundary, with the 1 isohaline in about the same position as before, but with the 2 isohaline and the intense salinity gradient pushed some four kilometres downstream.

With the colder air temperatures approaching winter, there was little temperature structure in the estuary. Before the freshette, the water throughout the estuary was around 16 ^{O}C, but it is apparent that the freshwater inflow was about 1 ^{O}C higher.

The DO values at the mouth were around 4 and 5 mg/l, increasing through the rest of the estuary. Of particular interest is the situation between stations 16 and 17 on 16 May, where the salinity stratification had probably isolated water close to the estuary bed leading to lower DO values (decomposition processes use up oxygen, and the pycnocline inhibits mixing with water higher in the water column). Complicated structures are evident once the freshwater arrived on 21 May, but by 22 May the situation had eased.

#12: August, 2005

These measurements were taken in the midst of a strong freshwater inflow from the Misverstand weir (Figure 3.17). At the time of the first measurements (spring high tide on 17 August), 32.76 m^3/s were recorded, increasing to 70.58 m^3/s on the next day (spring low tide measurements), and peaking at 104.50 m^3/s on 19 August. The next peak flow was reached on 23 August, when 206.50 m^3/s was recorded, decreasing to 190.80 and 164.30 m^3/s on the next two days when the neap low and neap high measurements were made; these would then have taken place in the midst of a very strong freshwater outflow.

The spring high tide measurements show the ingress of saline water even with the strong freshwater flow, with near-marine waters at the mouth, and the 1 isohaline some 12 km upstream. However, at the next days spring low tide a salinity of 11 was recorded at the mouth, and the 1 isohaline was less than 5 km from the sea. During both of these section measurements there was very little temperature structure, with values throughout between 13 and 14 ^{O}C. Similarly DO values increased slightly from the mouth to the head of the estuary.

The neap low tide measurements on 25 August showed freshwater throughout the estuary, with the 1 isohaline only at depth at the mouth. At the next days high tide sea water had penetrated at the bottom at the mouth, with water essentially fresh at the surface. There were again very little temperature and DO structures.

#13: November, 2005

These section measurements took place two months after the last freshwater spates, and show the ingress of sea water into the estuary.

At spring high the 1 isohaline had reached over 30 km upstream, while there was sea water more than 5 km from the mouth. At spring low tide there was a general movement sea wards of some 4 km. At neap high and low the next week there had been a further progression upstream of the 1 isohaline by a few kilometres.

Sea temperatures were relatively high over the two weeks, ranging from 16 to 19 ^{O}C. The effect of summer insolation was again evident, with temperatures in the upper reaches over 25 ^{O}C, with evidence of diurnal heating of upper layers.

There was considerable localised variability in measured DO values. Marine waters at the mouth were around 5 or 6 mg/l, while values in the estuary varied between 3 and 7 mg/l.

3.3.5 Temperature, salinity, dissolved oxygen, pH and secchi depth

The results of the previous section show that, for the most part, the conditions within the Berg Estuary were well mixed. This means that stratification seldom occurred, and did not seem to last very long, probably because of strong mixing from tidal exchanges and inputs of fresh water.

In order to analyse the temperature, salinity, dissolved oxygen (DO), pH and Secchi depth measurements, an overall approach will be adopted. This means that the temperature, salinity, DO and pH values have been integrated over the water depth at each station and a mean value obtained; the Secchi Depth is already recorded as a single value per station. With the marked seasonal variability in the Berg Estuary, this is again emphasized with all these variables.

Temperature

Figure 3.18 shows the vertically-integrated temperature values measured at each of the stations during the seasonal experiments.

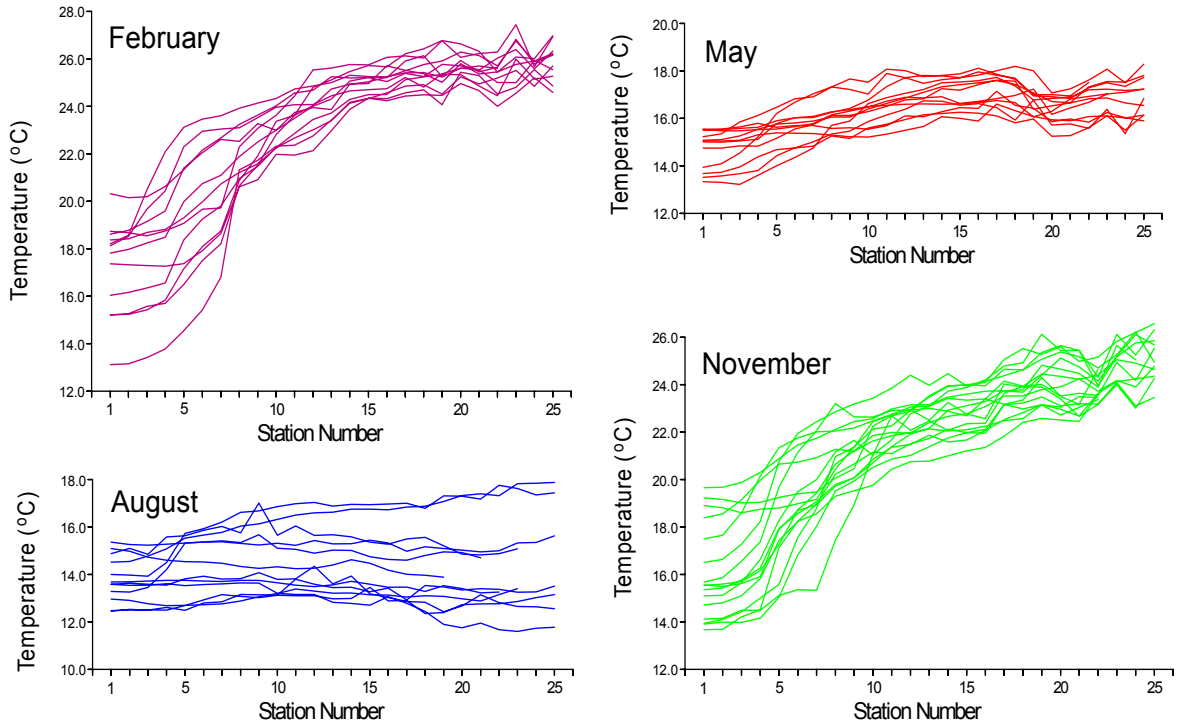


Figure 3.18 Vertically-integrated values of water temperature at each of the stations for all the experimental sections measured on the Berg Estuary during the specified months.

The marked seasonal dependence of temperature is clear. Summer insolation has a marked influence on the upper reaches of the estuary, the effect becoming apparent in the November records, and reaching a maximum in February - see also 3.3.2. In this month the maximum temperatures reached almost 28 ^{O}C, and from about station 15 upstream varied in a narrow range at over 24 ^{O}C. There is a much greater temperature range at the mouth because of the advent of summer upwelling, which brought in sea water with temperatures as low as 13 ^{O}C; on the other hand downwelling conditions brought in warmer water of over 20 ^{O}C.

With the approaching winter the water temperatures of the inflowing fresh water also decreased, and the May records show a maximum temperature of about 18 ^{O}C. Again, the variability over the whole estuary is low, being less than 5 ^{O}C. At the mouth temperatures varied between 13 and 16 ^{O}C.

In August the whole estuary was dominated by the fresh water spates entering from the Berg River. This input flow varied in temperature between about 12 and 18 ^{O}C. At the mouth sea temperature variability was again fairly low, less than 4 ^{O}C.

Salinity

Figure 3.19 shows the vertically-integrated salinity values measured at each of the stations during the seasonal experiments.

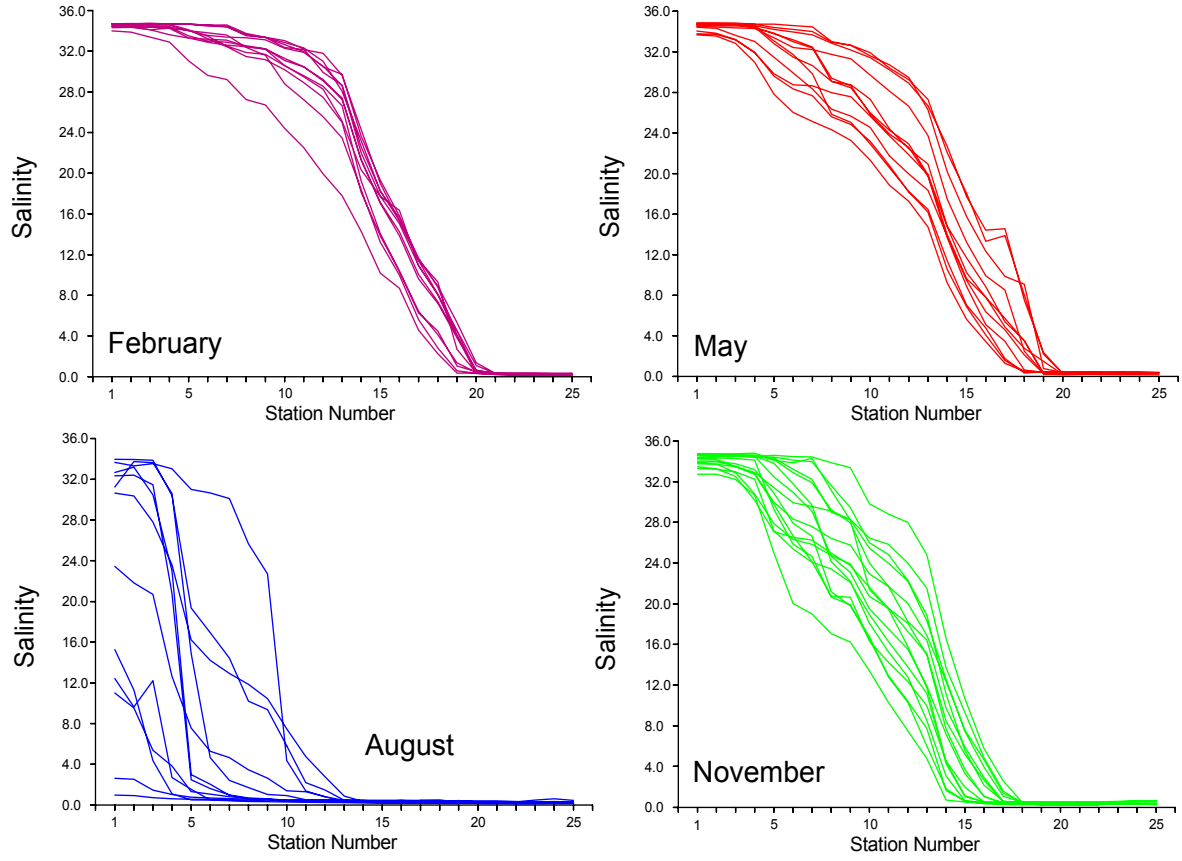


Figure 3.19 Vertically-integrated values of salinity at each of the stations for all the experimental sections measured on the Berg Estuary during the specified months.

The February sections start with oceanic values between about 34.0 and 34.9 at the mouth of the estuary. Thereafter they show remarkably little variability in salinity, apart from the outliers measured in 2003, particularly at the neap tides.

Inspection of Figure 3.16 shows that the previous winter of 2002 was an average rainfall year, while 2003 and 2004 were very poor years.

The relevant sections (Appendix A2.2) also reveal that, particularly at neap low tide, there appears to have been an influx of fresh water at the time; this was probably associated with sources other than the Misverstand dam, and would explain these variations.

It has already been found that, in general, the more saline marine waters had retreated seawards in May, and this is confirmed in Figure 3.19. Thus the upper limit of saline water lies seawards of station 20, whereas in February it reached station 21. Moreover, there is a much greater spread of salinity values, and even at the mouth there is an indication of a dilution of pure sea water.

The impact of the winter fresh water inflow is very apparent in August, and the measured salinity structure is very dependent on whether there had been a recent spate. In particular, at spring high tides the influx of marine waters soon pushed upstream as soon as the fresh water inflow abated.

Finally, the November results are intermediate to the February sections, with the fresh water inflow minimal, and saline marine waters pushing upstream.

Dissolved Oxygen

Figure 3.20 shows the vertically-integrated dissolved oxygen values measured at each of the stations during the seasonal experiments.

Dissolved oxygen is an essential requirement for most heterotrophic marine life (DWAF, 1995).

DO is a non-conservative property, and its natural levels are governed by temperature and salinity, as well as the organic content of the water. Colder and lower salinity waters have a higher saturation limit than warmer, saltier waters.

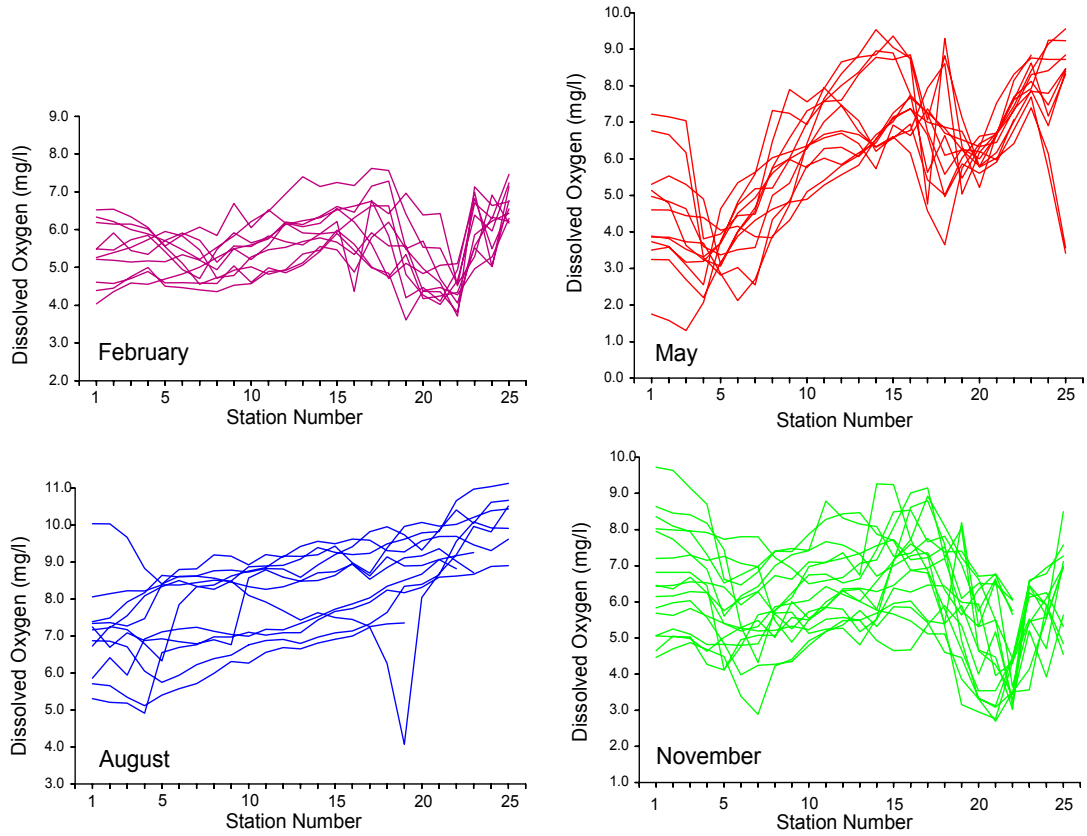


Figure 3.20 Vertically-integrated values of DO at each of the stations for all the experimental sections measured on the Berg Estuary during the specified months.

The marine waters entering the mouth of the Berg Estuary have a wide range of DO values, and in particular Chapman and Shannon (1985) identified St Helena Bay as a zone for the formation of oxygen-deficient waters. Values measured ranged from around 1 to 10 mg/l.

The warmer water temperatures in November and February led to lower DO values in the upper reaches of the estuary. It is also apparent that, around station 20 there were consistently lower DO values, and this can be ascribed to the extensive trees (blue gums) lining the estuary. There is abundant rotting vegetation - branches, leaves etc - in the water which will use up DO, while shade will inhibit photosynthesis.

The situation in the August measurements was completely different, with the highly-oxygenated fresh water spates filling the estuary, and flushing out any lower DO water.

pH

Figure 3.21 shows the vertically-integrated pH values measured at each of the stations during the seasonal experiments.

The pH of water is a measure of the concentration of hydrogen ions in solution, with a value of less than 7 being acidic, and greater than 7 being alkaline. The pH of sea water usually ranges between 7.9 and 8.2 (DWAF, 1995). The decomposition of organic matter under anaerobic conditions can lead to an increase in pH.

Values of pH at the mouth of the estuary varied between 7.45 (all in May), and about 8.3. Higher up the estuary there is a much bigger spread of values, with maxima of around 8.6, (possibly due to rotting vegetation), and minima as low as 7.1 (August).

Day (2004) reported mean values for 2003 at Kliphoek (about station 13) of 7.75 and at Jantjiesfontein (about station 22) of 7.59. These values fit in with the spread on the graphs.

The August situation is very different to the other months because of the large volume of fresh water entering the estuary from the Berg River and its tributaries. The results of Day (2004) show that this river water had relatively low pH values, with the upstream site G1Hoo4 (Driefontein) even reflecting acidic conditions with a mean pH of 5.66. It is apparent that this fresh water lowered the pH in the estuary as well.

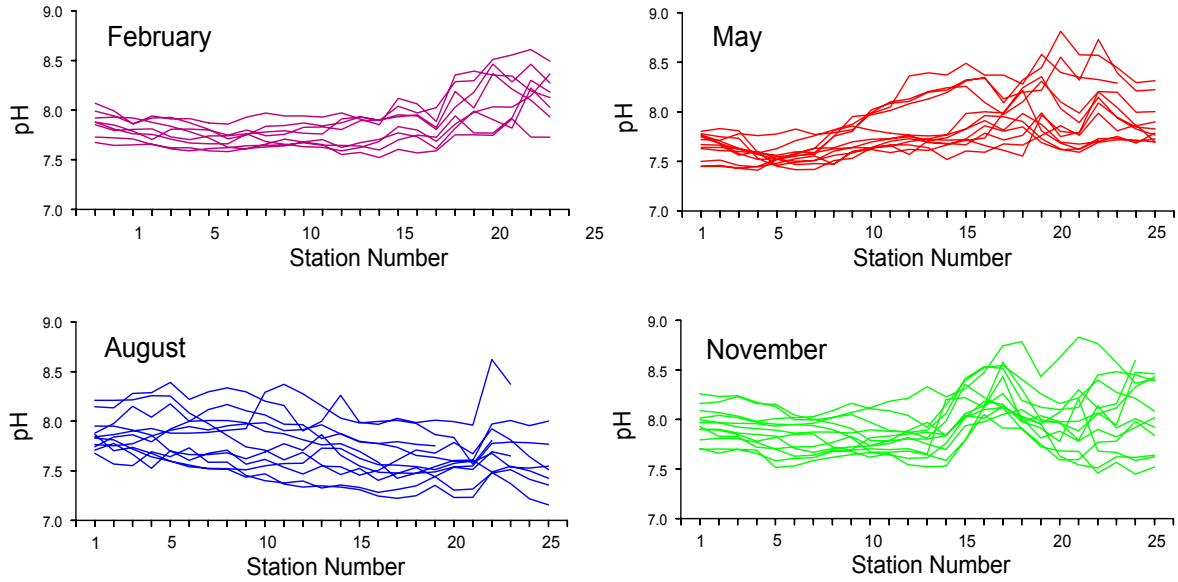


Figure 3.21 Vertically-integrated values of pH at each of the stations for all the experimental sections measured on the Berg Estuary during the specified months.

Secchi Disk

Figure 3.22 shows the Secchi depths measured at each of the stations during the seasonal experiments.

Water turbidity is caused by particulate inorganic and organic matter (which may include microscopic organisms) suspended in the water column. In particular, the >murky= appearance of water is caused by colloidal suspension of clays and silts. On the other hand, colour is introduced by substances which dissolve in water (DWAF,1995).

Light penetrating water is absorbed by the water itself, and is also scattered by the suspended matter. In this way the transmission of light is inhibited, and the Secchi disk is a simple measure of the extent to which this absorption and scattering takes place. The measurements give no information on the matter in the water column, or which part of the light spectrum is most affected.

Observation of the colour of the water in the Berg Estuary would classify it generally as >murky= brown, while occasionally clearer sea water was noticed near the mouth. Wooldridge (2004) found an abrupt increase in the percentage of silt and mud (<0.63µm), from less than 20% to more than 80%, in the sediments in going from station 15 to 16.

This high percentage was maintained at stations 17 and 18, but then decreased again after station 18; there was a corresponding increase in the organic content in the sediments at these stations.

The existence of a turbidity maximum is a distinctive feature of partially and well-mixed estuaries (Dyer, 1997), and it generally occurs near the head of the salt intrusion. From Figure 10.18 for most of the year the salt intrusion reaches to about stations 17 to 20, being only pushed seawards in winter by the fresh water spates.

It is also apparent from the decrease in the Secchi depth values in Figure 3.22 that turbidity in the water increased substantially in the region of stations 16 to 20; this was maintained right up to station 25. Unfortunately Wooldridge=s measurements did not extend past station 21, but upstream from station 23 the estuary banks are muddy, with adjacent farmlands, and this may be an additional source of mud.

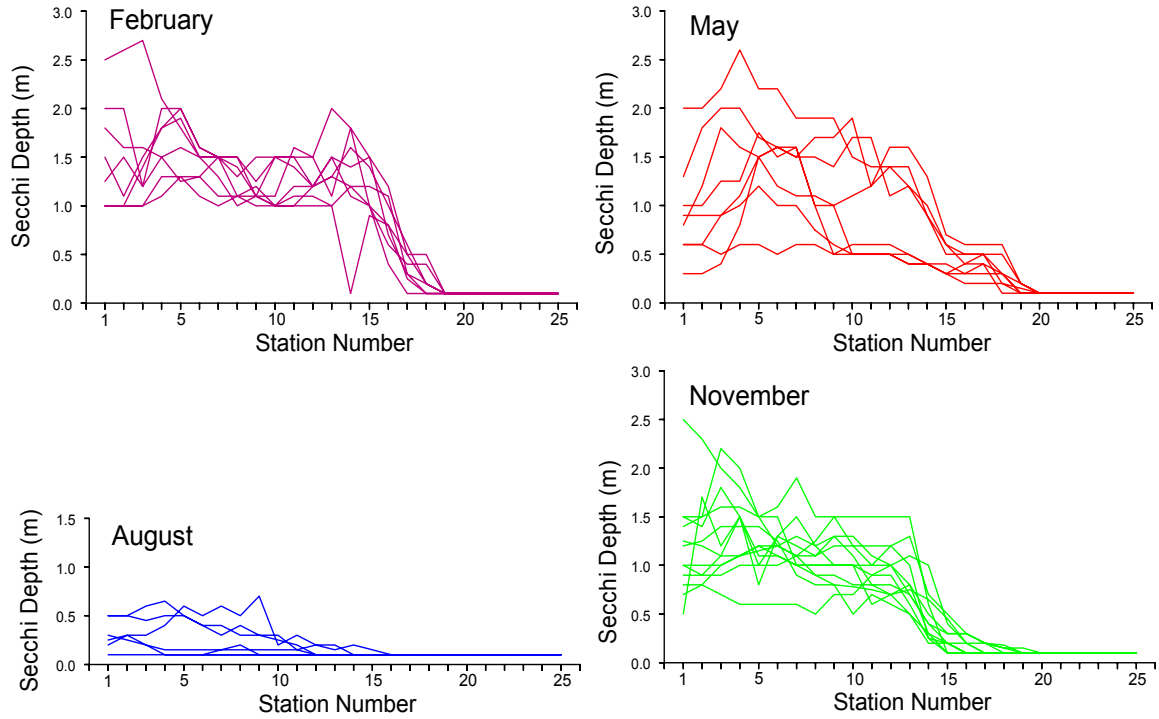


Figure 3.22 Secchi depths measured at each of the stations for all the experimental sections measured on the Berg Estuary during the specified months.

3.4 DISCUSSION

It is apparent from the results presented here that there was considerable variability in the structure and dynamics of the Berg Estuary over the three-year investigation. This variability took place over a wide range of time scales, from tidal periods, through seasonal, and extending to inter-annual fluctuations. It is particularly at these longer periods that it is difficult to ascertain whether there are or have been changes and/or trends.

The longest relevant records available are those of rainfall at Franschhoek and river flow at the Misverstand weir (Figure 3.4 and Table 3.9). These two variables also combine to produce the greatest seasonal influence on the estuary, namely the fresh water flooding in winter, and the relatively dry conditions in summer.

Compared to the preceding twenty-two years, the four years 2002 to 2005 had relatively limited weir outflow and rainfall, and in fact 2003 had the smallest total volume flow (108 H 10^6 m^3 as against an average of 443 H 10^6 m^3) and rainfall (1106 mm as against an average of 1910 mm – see Table 3.8).

The year 1982 had the smallest peak flow (93 m^3/s as against an average of 346 m^3/s), but the total flow of 278 H 10^6 m^3 means that the flow was spread much more widely throughout the year without being concentrated in the August period. Inspection of Figure 3.4 indicates that this longer annual fresh water inflow to the estuary could be significant, and this is investigated further in Figure 3.2.3.

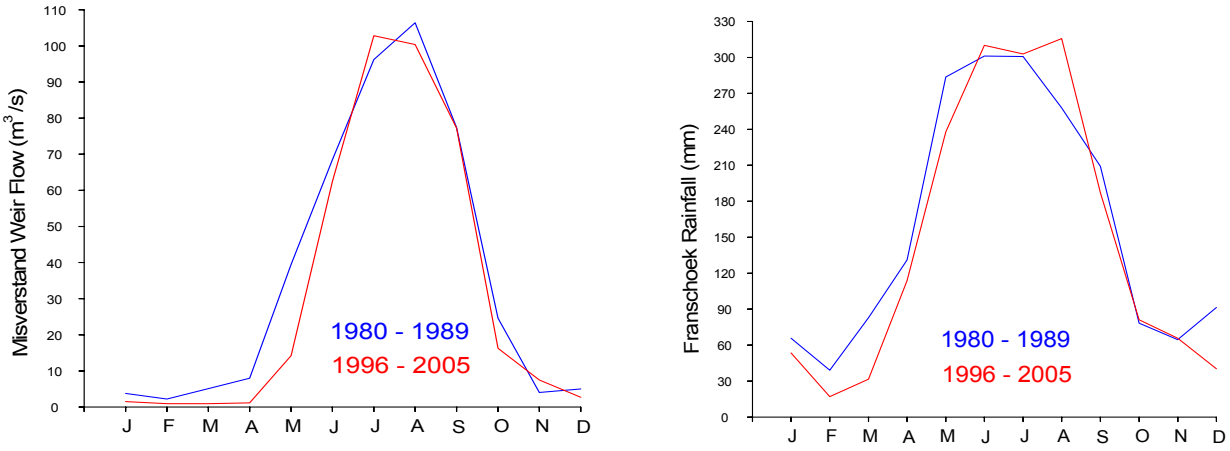


Figure 3.23 *Left: Monthly means of rainfall measured at Franschhoek during 1980 to 1989 (blue) and 1996 to 2005 (red). Right: Monthly means of weir flow measured at Misverstand during 1980 to 1989 (blue) and 1996 to 2005 (red).*

This greater rainfall and correspondingly greater runoff in the first few months of the year is confirmed in the figure; peak rainfall months do not appear vastly different. The differences may not appear very large, but lead to a decrease in the mean annual rainfall from 1905 mm (1980 to 1989) to 1757 mm (1996 to 2005). Correspondingly, there are also changes in the Misverstand flow, and the mean annual flow decreased from 441 H 10^6 m^3 (1980 to 1989) to 388 H 10^6 m^3 (1996 to 2005). The lag of a couple of months in the weir flow response has already been noted in 3.4.1.

As noted in 3.1.4 rainfall data for Franschhoek are available from 1950, and it will probably be worthwhile analysing this additional period to assess longer-term changes.

The response of the estuary to the different fresh water inflows can be gauged by the extent of the seawater intrusion, and this can be assessed by investigating the positions of various isohalines. Since the estuary was for the most part vertically well mixed, the longitudinal position of such isohalines could be judged for each of the sections. For present purposes, the isohalines chosen are 1, 10, 20 and 30; the results are presented in Figure 3.20.

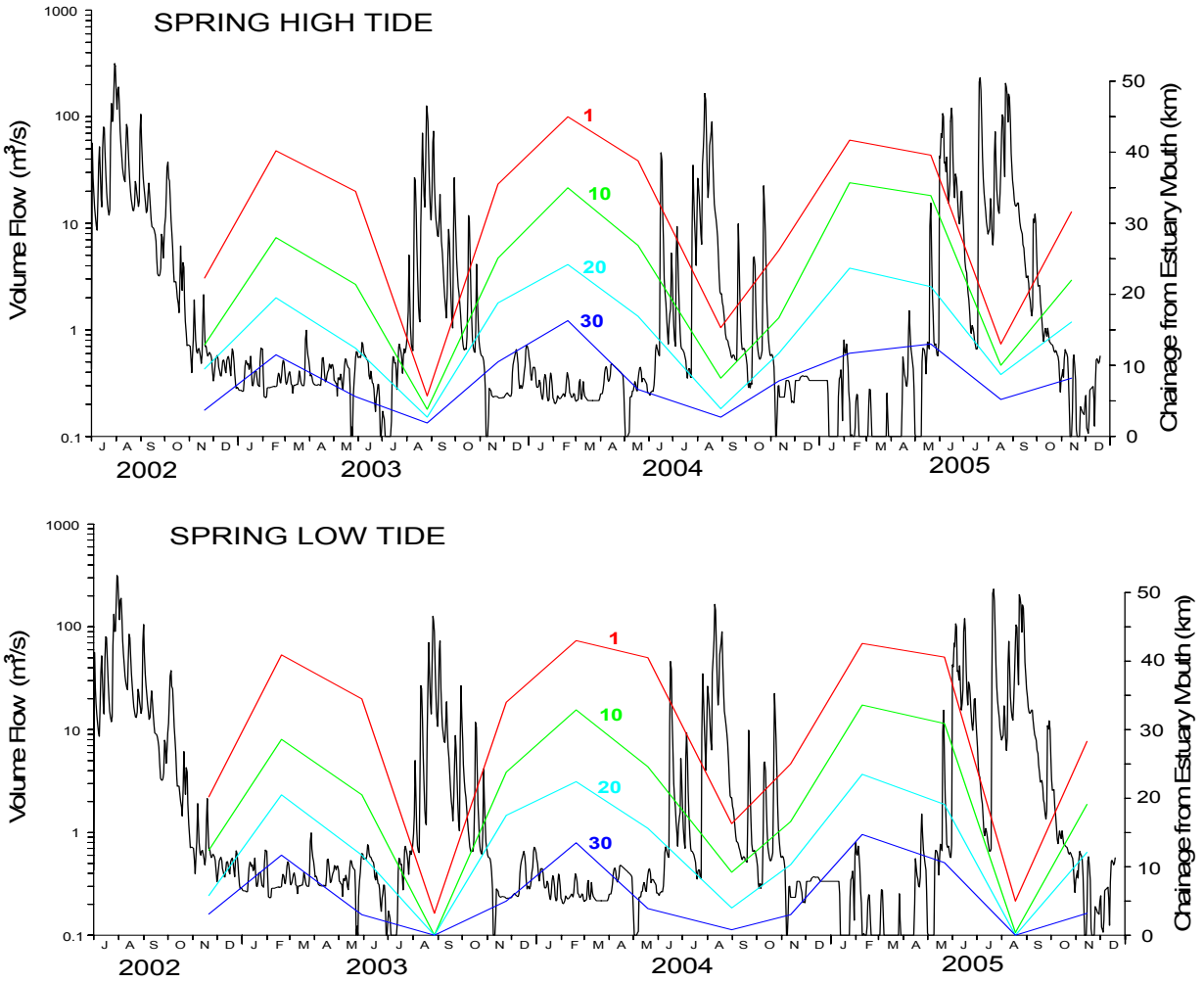


Figure 3.24 The chainage of the 1, 10, 20 and 30 isohalines during the 13 experimental periods from 2002 to 2005 at spring high and low tides. The volume flow at the Misverstand weir is also shown on a log scale.

The marked seasonality of the sea water intrusion into the estuary is evident. It is also apparent that the extent to which the saline water is forced out of the estuary by the winter fresh water spates depends on whether the measurements were made during the spate or not. Thus the measurements in winter in 2003 took place in the midst of the fresh water inflow, and the 1 isohaline was within 10 km of the mouth, even at spring high tide. On the other hand, with a bigger prior volume flow in 2004, the 1 isohaline had already progressed more than 15 km upstream when the measurements were made. This confirms that the initial movement of salt into the estuary after a fresh water spate is rapid.

However, in spite of the varying rainfall and fresh water inflow, the salinity structure of the estuary was remarkably similar in all three years. The position and variability of the four isohalines follow much the same pattern over this period.

The situation during the May measurements has already been discussed, but is emphasized again in Figure 3.24. In all three years there was no additional fresh water flow recorded at the Misverstand weir between the February and May measurements, yet in each case there is a definite movement of the salinity structures towards the mouth of the estuary.

Such a movement would be consistent with a greater presence of fresh water in the upper reaches, and the implication is that this water entered the estuary via a route other than the Misverstand weir.

It has already been found that rainfall recorded at Franschhoek in the first five months of the year was not immediately reflected in flow at the weir, and Figure 3.25 shows the rainfall at Langebaanweg in the years 2003 to 2005.

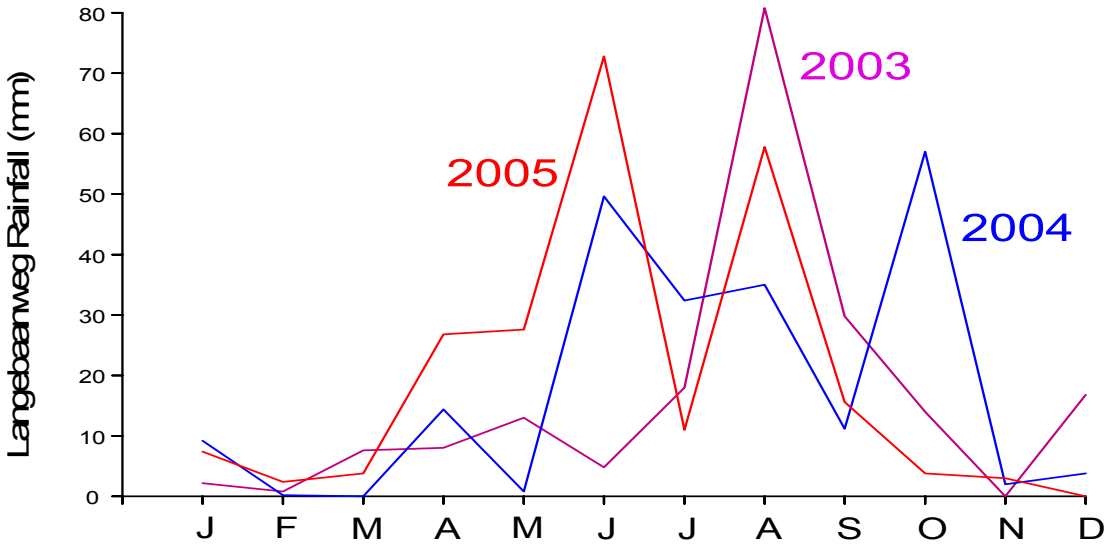


Figure 3.25 Monthly rainfall at Langebaanweg over 2003 to 2005

There was some rainfall before June at Langebaanweg in each of the years, however, at this stage the impact of the resulting flow into the estuary is unknown. A reason for the apparent increasing inflow in the autumn may also lie in the manner in which agriculture uses available water. Thus during the summer months there is considerable abstraction of flow in the Berg River downstream of Misverstand, while in the autumn this stops or is largely reduced. At this latter time more water would thus be allowed to flow into the estuary.

3.5 CONCLUSIONS

The results presented here have demonstrated the marked seasonal variability of the Berg Estuary, with the winter inflow of fresh water being the dominant influence. Measurements were made over a three-year period in which the total river inflow in all the years was well below the 26-year mean (Table 3.8); indeed, 2003 had the smallest total annual flow, with 2004 not far behind.

According to the RDM methodology, the reference condition in an estuary refers to its ecological status 50 to 100 years ago. Without good quality historical data, it is impossible to assess the condition of the estuary relative to such a scenario. Consequently the assessment here will be in terms of the processes that have been observed during the measurement programme.

All the data - the three-year measurement programme, the earlier boat section data of the CSIR (Slinger and Taljaard, 1994), and the HIS data when it was taken - indicate that the winter fresh water input must be sufficient to remove the saline marine waters that enter the estuary in summer. In this respect, the measurements in August, 2003 (#4, Figure 3.17) were very fortunate since they occurred during such spates after a long dry period.

The first peak flow of about 27 m^3/s (measured at the Misverstand dam) was not sufficient to remove all the salt water from the estuary, with the 1 isohaline pushed out to the area of station 11 (~ 13 km upstream). A subsequent flow with a maximum of 70 m^3/s forced the 1 isohaline another 3 km seaward, while a week after the first measurements a flow of 127 m^3/s was sufficient to ensure that there was no water with a salinity greater than 3 within the estuary at spring low tide. This gives an indication of the volume flows necessary to remove the saline water from the estuary, though it is probably true that all the spates prior to the third were also important in achieving this removal.

An approximate estimate can be made of the volume of saline water in the estuary at the end of the dry summer season. Thus while the longitudinal extent of the estuary has not been determined accurately (see Appendix 2.1), the estuarine sections in Appendix 2.2 show that the 1 isohaline penetrates to around 35 km upstream (boat station 16 to 17). The cross-sections available (Appendix A2.1) show that up to station 26 (~ 35 km) an average width of about 60 m can be assumed for the estuary, while the sections show that 3 m can be taken as an average depth.

On this basis, the volume of salt water (salinity > 1) in the estuary is approximately

35 km H 60 m H 3 m = 6.3 H 10^6 m^3.

The estuary sections (Appendix A2.2rticularly during the winter fresh water inflows, show little stratification, indicating that there is enough turbulent energy in the inflow to cause mixing throughout the water column. This means that, as a minimum requirement, there must be enough fresh water flowing into the estuary to replace all the saline water. An inflow of 120 m^3/s flowing for a period of about 15 hours (6.5 H 10^6 m^3) will be sufficient to accomplish this removal.

This very simple calculation cannot be taken to represent details of the processes involved in the winter floods, in particular, it gives no consideration to flooding of adjacent floodplain areas, or tidal flows at the time (Beck and Basson, 2006). Nonetheless, the rough agreement with the observations in 2003 confirm a minimum requirement in removing the summer saline water.

The report by Beck and Basson (2006) indicates that post-dam peak flows under about 300 m^3/s will be reduced by less than 5 %, with those around 100 m^3/s not reduced at all. Provided such flows are allowed to continue for at least one day, this means that the fresh water flows should be enough to remove the summer build-up of saline water in the estuary.

The importance and extent of the small summer inflow of fresh water has not been clarified, and the report by Beck and Basson (2006) does not consider these low-flow conditions (their Figure 4.3 for tidal simulation in summer, 1999, appears to have flows ten times greater than measured). From Table 3.10 and Figure 3.6, it can be seen that the months with lowest Misverstand volume flow are January to April, corresponding as well to the lowest Franschhoek rainfall. The relevant values are reproduced in Table 3.14, together with the corresponding mean instantaneous flows.

Table 3.14 Misverstand total volume flows per month, and the corresponding instantaneous flows for the months January to April. The means over 26 years are given, as well as the values for 2003, 2004 and 2005.

Month	Misverstand Volume Flows							
	Mean		2003		2004		2005	
	10^6 m^3	m^3/s	10^6 m^3	m^3/s	10^6 m^3	m^3/s	10^6 m^3	m^3/s
Jan	2.12	0.79	1.04	0.39	0.90	0.34	0.63	0.24
Feb	1.35	0.56	0.81	0.33	0.63	0.25	0.49	0.20
Mar	2.43	0.91	1.05	0.39	0.63	0.24	0.13	0.05
Apr	4.78	1.84	0.99	0.38	1.00	0.39	0.77	0.30

It is evident that the below average fresh water inflow into the estuary in the years 2003, 2004 and 2005 also extended to the summer period.

The lack of stratification - primarily in salinity - in the estuary evident in the boat sections (Appendix 2.1) also has implications for the quality of the water, and in this situation specifically the DO levels. Thus intense stratification can isolate bottom water, and if organic detritus is present the DO levels can be depleted through decomposition processes.

Inspection of the boat sections reveals that lower DO levels occur on occasion in the bottom waters, but with values seldom lower than 3 mg/l.

Moreover, these effects are very localised, primarily in the central regions, and do not appear to last very long. On occasion lower DO water also enters from the sea, when low DO water originating in the bottom boundary flow in the Benguela region enters St Helena Bay (Shillington, 1998).

Such lower DO water is only found in the Berg Estuary during the summer months. In winter the turbulence associated with the fresh water spates ensures that the whole water column is well-oxygenated.

pH values lie within the range expected for estuarine waters, namely between about 7 and 8.5. The lower values are associated with the fresh water spates entering the head of the estuary in winter (Figure 3.21).

Slower flow in the upper reaches in summer will also affect the eventual temperature of the estuary water, since insolation warms the surface layers (Figure 3.18). In particular, the hot summer sun and high air temperatures (Figure 3.8) in February resulted in water temperatures in excess of 24 ^{O}C farther upstream than station 18. However, all three the measurement years had fresh water flows considerably down on the average (Figure 3.14), so it is not known whether greater flows will result in a reduction in water temperature. Long stretches of the upper estuary are also in the shade of exotic trees, which would limit these effects.

The apparent anomalous May inflow has not been clarified, but obviously plays an important part in limiting the extent to which the marine waters progress up the estuary during the dry summer and autumn months. There were no evident inflows from the Misverstand dam (Figure 3.24) in April and May in the three years, though there was some rain at Langebaanweg in April (Figure 3.25). Whether this was sufficient to cause the necessary inflow needs to be ascertained.

These results indicate that, in terms of the variables measured and discussed here, the estuary is functioning satisfactorily, but it is not possible to assess to what extent it is different to conditions 50 to 100 years ago. Substantial changes have taken place, but a lack of data precludes any definite statements about prior times. There is anecdotal evidence from farmers in the area that salinities at Jantjiesfontein reached values more than 1 when fresh water was being pumped from the estuary, but there don't seem to be records of volumes pumped. Such data would give information on the effect of further limiting the fresh water inflow.

There is substantial interannual variability in the Berg Estuary system, essentially stemming from the variability in rainfall. It may well be that longer-term climatic changes are also taking place which will ultimately impact on the estuary. Nonetheless, at present it seems that, even with small fresh water inflows such as during 2003, the seasonal flushing of the summer-time salinity intrusion was successful. The impacts on other variables such as DO are not clear from these analyses.

It is therefore difficult to determine a reference state for the Berg Estuary. Moreover, it is unfortunate that the RDM methodology does not incorporate the potential effects of climate change, since it is known that such changes are in the offing (Midgley *et al.*, 2005).

3.6 RECOMMENDATIONS FOR FUTURE MONITORING

In any recommendations for future monitoring it is important to take the natural variability of the Berg River and Estuary system into consideration. As a consequence such monitoring should take place on a continuous basis, so that perceived changes can be put into the context of the overall influence of weather and ocean processes.

It is therefore assumed that the systematic time series data at present available will continue into the future. These include the following:

- Weather data from sites such as Langebaanweg and Franschhoek ;
- Ocean tidal data;
- Water level data from the three sites on the estuary, namely Laaiplek, Kliphoek and Jantjiesfontein;

- Stream flow data from the Misverstand dam. It would be preferable to have a gauging station at the head of the estuary.

In order to obtain continuous information on the state of the estuary, i.e. the manner in which sea water moves in and out on the tides, as well as the summer salinity ingress and winter flushing, it is recommended that:

- The monitoring station at Kliphoek be resurrected. Water temperature and electrical conductivity (salinity) should be measured at a depth of 1 m - this can be achieved from a floating platform, which will accommodate tidal and flood changes in water level. Ideally, these variables should be measured at hourly intervals.
- At a lower priority, the monitoring station at Jantjiesfontein should be resurrected. The measurements should be the same as at Kliphoek.

Obtaining boat section data is a substantial exercise, and has the disadvantage of essentially being an *instantaneous snapshot* of the estuary. Nonetheless, it is recommended that:

- Every three years boat sections be measured in winter (August, after the dam flood release) and summer (February). The same variables should be measured as in this programme, but it is only necessary to measure at spring high and low tides.

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CHAPTER 4 – WATER CHEMISTRY: NUTRIENTS

B.M. Clark & S. Taljaard

4.1 INTRODUCTION

Estuaries are generally regarded as being amongst the most productive aquatic cosystems on earth (e.g. Odum 1963, Ryther 1969). Nutrients are important in this respect, as the concentration of these elements in the environment is often the primary factor responsible for determining the rate of primary production in estuaries (Flemer 1970, Malone et al. 1996, Herbert 1999, Flemer & Champ 2006), and ultimately the productivity and harvestable yield of secondary producers in these systems (Fisher et al. 1988). Nutrients in estuaries are derived from a number of sources, the most important being river runoff, the sea, and internal recycling (McCarthy 1975, Stanley & Hobbie 1977, Fisher *et al*. 1982). The relative contribution from these different sources varies considerably from one system to another, and it is important to quantify the contribution by each.

Nutrient dynamics of the Berg estuary have been studied on a number of occasions in the past, but most of these cover only one or two seasons (typically winter and or summer) and only a single phase of the tide (high or low tide), and are now somewhat dated (>10 years old) (Eagle and Bartlett, 1984, Taljaard, *et al.*, 1992a, Slinger and Taljaard, 1996, Slinger *et al*., 1996). More recent studies on the inorganic nutrient dynamics of the Berg Estuary were undertaken as part of the Berg River Baseline Monitoring study to further quantify the relative contribution by river runoff, internal cycling and the sea to inorganic nutrient dynamics in the system at different times of the year and states of the tide, and to provide up to date information on nutrient concentrations in the system to examine any historical changes that may have taken place in the system.

4.2 METHODS

4.2.1 Sampling methods

Water samples for dissolved inorganic nutrient analysis (nitrate, nitrite, ammonia, inorganic phosphate, and reactive silicate) were collected from between 10 and 22 stations along the length of the Berg Estuary (including a seawater sample collected outside the mouth) on eight occasions during 2005 (Figure 4.1). Sampling covered high and low tide periods during the months of February (spring and neap low tide), May (spring and neap low tide), August (spring high, neap high) and November (spring low, neap low). Flows indicative of river inflow into the estuary at the time of sampling is shown in Figure 4.2. Note that the February, May 2005 were during low flow periods, the August sampling was at the peak of the high flow period and the November sampling immediately after the high flow season. Historic data covered both high and low flow periods, where the October 1975, January 1990, and February and March 1996 sampling coincided with low flows, and the August 1976, September 1989 and August 1995 sampling coincided with high flow periods. The same sampling sites were used in each survey and only those required to span the full salinity gradient up the length of the estuary were used on each occasion, with the result that fewer stations were sampled during the high flow season (August) than the other seasons. Samples were collected from the surface (0 m) and the bottom (max depth) using a Niskin bottle and immediately filtered through 0.45 µm Millipore filters. Water samples were kept in opaque one litre plastic bottles, stored in cool boxes at 4ºC and frozen for later analysis.

A variety of other water quality parameters were measured at the same time as the water samples were collected, including temperature, salinity, oxygen concentration and pH, but these data are reported separately (Schumann 2007).

Historic data on inorganic nutrients in the Berg Estuary were obtained from (Eagle and Bartlett (1984 - data for October 1975 and August 1976), Taljaard *et al.* (1992a – data for September 1989 and January 1990), Slinger and Taljaard (1996 – data for August 1995) and Slinger *et al*. 1996 (data for February 1996).

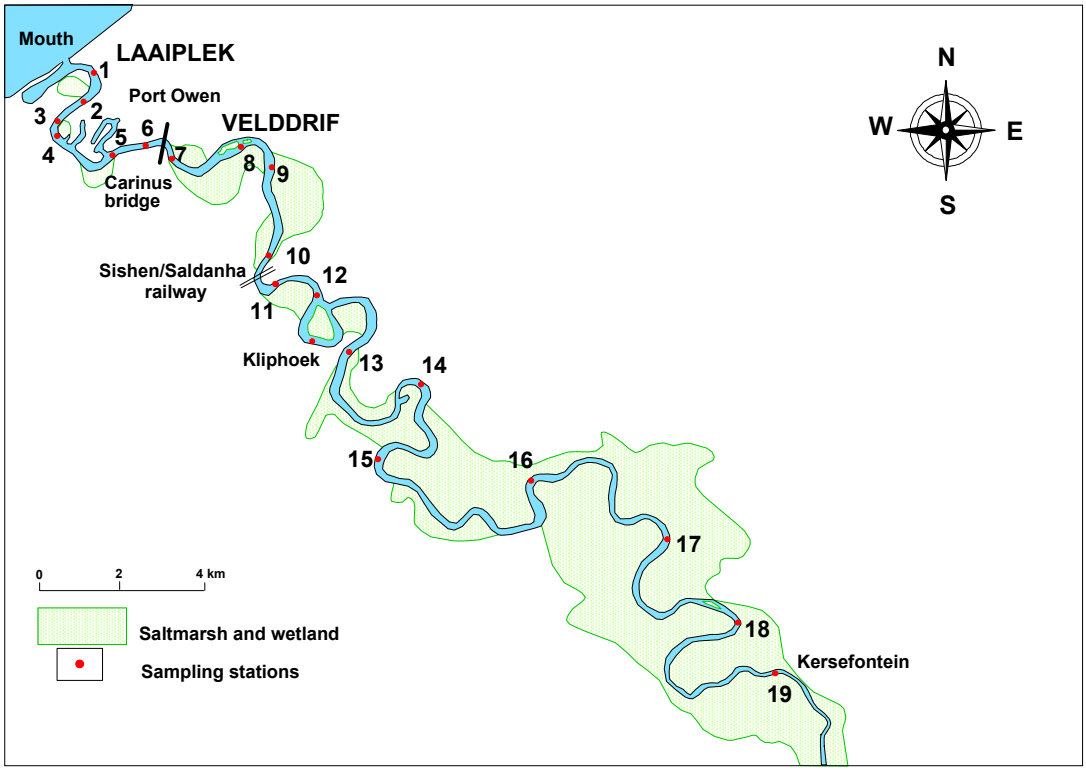


Figure 4.1 Sampling stations on the Berg Estuary

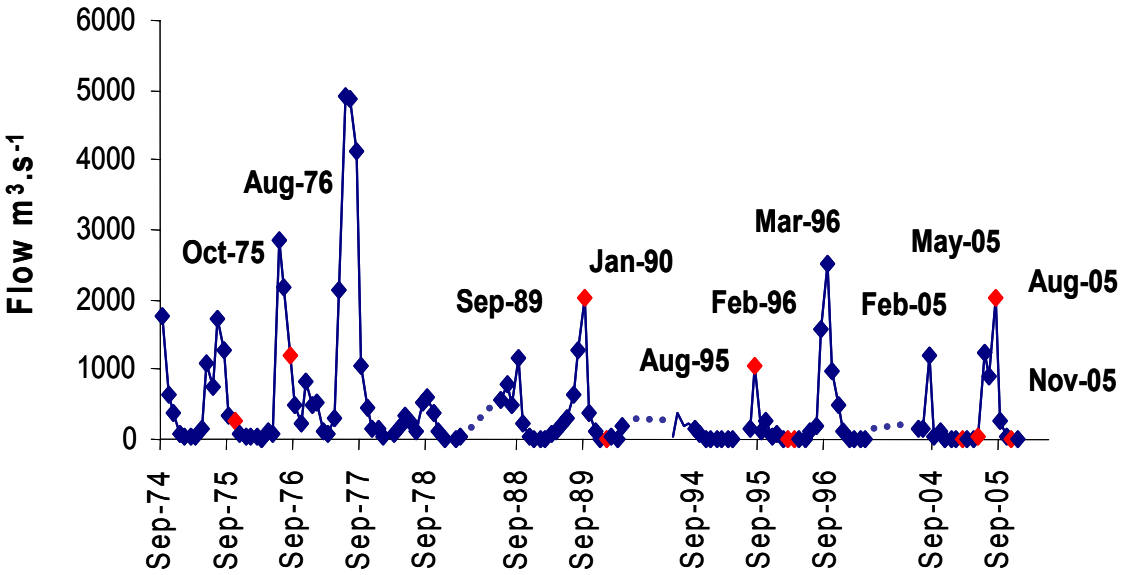


Figure 4.2 Flows in the Berg River at Misverstand indicating the times at which nutrient data were collected from the Berg Estuary during the 2005 Berg River Baseline Monitoring Study and historic sampling activities. Dotted lines indicate time gaps in the sampling regime.

4.2.2 Analytical methods

Inorganic nutrient analyses on the water samples taken from the Berg Estuary were done according to the methods described by Mostert (1983), using an autoanalyser.

An approach that is widely used to assess nutrient cycling in estuaries is mixing diagrams (or property-salinity plots) (Church, 1986; Fisher *et al*., 1988; Ball, 1994; Eyre, 2000; Ferguson *et al*., 2004) where nutrient processes are assessed by comparison to a theoretical line representing conservative mixing of river and seawater.

The mixing diagram approach plots nutrient concentrations against salinity along the estuarine gradient. Mixing diagrams provide a convenient method for displaying the net effect of nutrient processes within estuaries, whereby deviation from the conservative mixing line is used to interpret results. For example, downward (concave) curvature in the mixing diagram implies nutrient uptake, while upward (convex) curvature implies nutrient release (e.g. remineralisation).

4.3 RESULTS

4.3.1 Dissolved Nitrate

Property-salinity plots for dissolved nitrate (NO_3-N) differed markedly between the four sampling events in 2005 (Figure 4.3). February and May samples were both taken after a long period of low flows and show similar distribution patterns. In both cases the concave curvature showed nitrate removal from the water column with near depleted concentrations in the mid-salinity ranges (mostly <25 µg.l^{-1}), representative of conditions in the middle reaches of the estuary. On both occasions renewal of nitrate occurred across estuary-sea boundary, and to a limited extent river-estuary boundary. Significant renewal occurred along the seaward boundary (up to 300 µg.l^{-1}), probably linked to upwelling, a common feature along the west coast. Limited renewal occurred across the river-estuary boundary (25-150 µg.l^{-1}), probably associated with agricultural return flows from the catchment. These types of nutrient distribution patterns are typically associated with significant biological uptake and suggest that nitrogen is probably the limiting nutrient in the Berg Estuary.

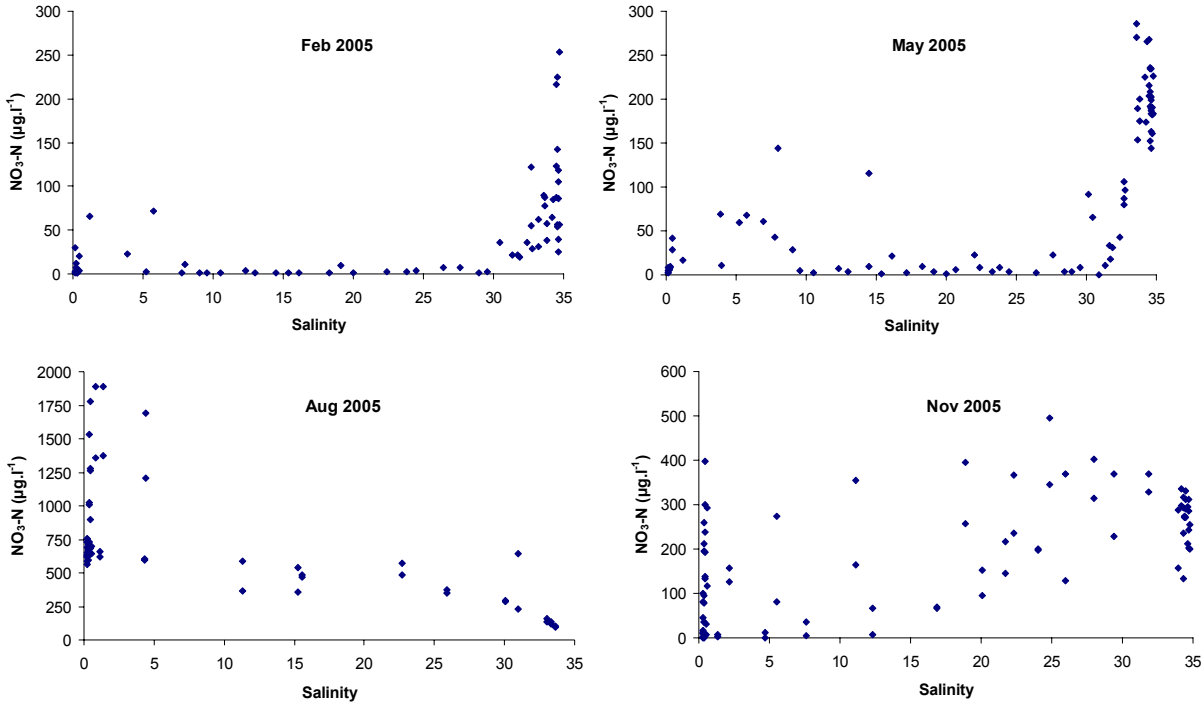


Figure 4.3 Concentration of nitrate (NO_3-N) in the Berg Estuary measured on 4 occasions in 2005.

In August, during the peak of the high flow, nitrate concentrations were replenished throughout the estuary due to strong river inflow and very high concentrations in the river water (601-1 892 µg.l^{-1}). Concentrations decreased towards the mouth as river water mixed with saline waters (seawater) at much lower nitrate concentrations (98-163 µg.l^{-1}).

During the November survey, taken immediately after the high flow season, elevated nitrate concentrations were maintained in the estuary, due to short flushing times (i.e. regular renewal across source boundaries and short retention times limiting the effect of biological uptake).

A comparison with historic data is provided in Figure 4 where salinity-property plots show similar trends for low and high flow periods, respectively, over different years. However, of note is that the nitrate concentrations in river inflow in the high flow season have increased incrementally over the years, from 150.5 µg.l^{-1} in 1975 to 819.8 µg.l^{-1} in 2005 (a 5.4-fold increase) (Table 4.1), presumably linked to increased agricultural activities and human settlements in the catchment. The same cannot be said of the nitrate concentration in seawater at the mouth of the estuary, which presumably simply fluctuates in response to variations in the upwelling cycle (Table 4.2).

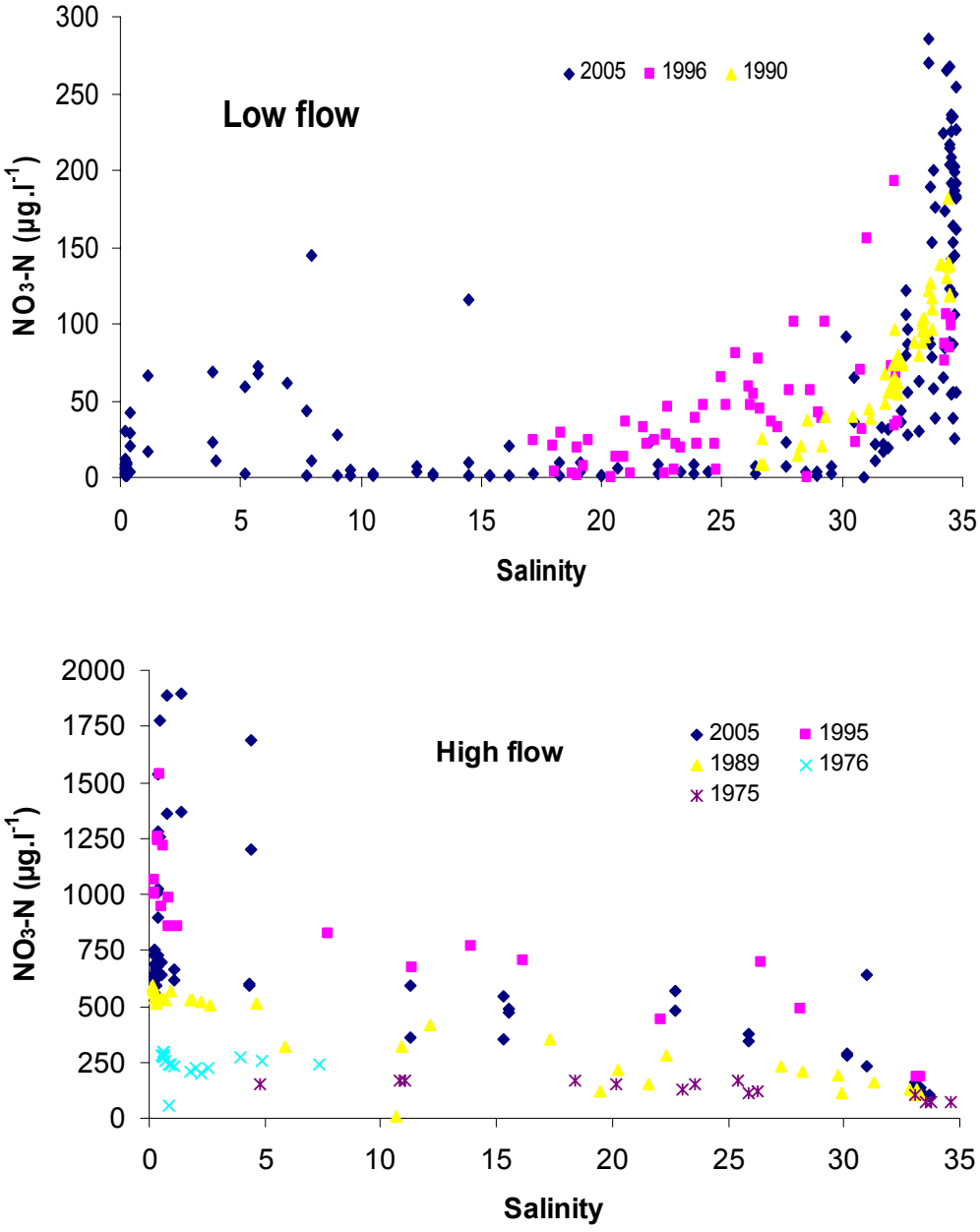


Figure 4.4 Concentration of nitrate (NO_3-N) in the Berg Estuary measured in the low and high flow seasons between 1975 and 2005.

Table 4.1 Mean concentration of dissolved inorganic nutrients (nitrite, nitrate, ammonia, dissolved inorganic nitrogen, inorganic phosphate and reactive silicate) in freshwater flowing into the Berg Estuary during high and low flow seasons between 1975 and 2005

	Year	NO_3-N (µg/l)	NO_2-N (µg/l)	NH_3-N (µg/l)	DIN-N (µg/l)	PO_4-P (µg/l)	SiO_4-Si (µg/l)
High flow	1975	150.5	1.1	-	-	-	337.4
	1976	274.2	3.0	-	-	22.0	656.2
	1989	561.9	5.9	73.6	644.1	27.2	1675.2
	1995	975.5	8.3	56.3	1193.2	44.5	2218.5
	2005	819.8	12.1	48.1	880.0	38.6	3634.3
Low flow	1990	12.0	1.0	57.0	70.0	41.0	-
	1996	3.9	-	32.7	36.6	13.7	2409.1
	2005	12.2	3.7	21.1	37.0	6.4	858.1

Table 4.2 Mean concentration of dissolved inorganic nutrients (nitrite, nitrate, ammonia, dissolved inorganic nitrogen, inorganic phosphate and reactive silicate) in seawater at the mouth of the Berg Estuary during high and low flow seasons between 1975 and 2005

	Year	NO_3-N (µg/l)	NO_2-N (µg/l)	NH_3-N (µg/l)	DIN-N (µg/l)	PO_4-P (µg/l)	SiO_4-Si (µg/l)
High flow	1975	108.9	5.9	-	-	59.3	943.9
	1976	225.7	3.6	-	-	33.4	622.8
	1989	127.7	10.4	149.5	287.6	90.4	835.5
	1995	182.9	17.9	113.4	314.2	34.9	798.7
	2005	132.2	28.1	81.0	241.3	32.4	1556.7
Low flow	1990	366.5	6.2	80.3	439.3	68.6	1720.8
	1996	32.8	7.4	31.5	70.7	106.3	2190.5
	2005	158.9	27.0	358.8	544.6	155.6	2873.4

4.3.2 Dissolved Nitrite

Nitrite (NO_2-N) concentrations in the Berg Estuary were relatively low (usually <30 $ug.l^{-1}$) compared to other inorganic N species (e.g. nitrate) (Figure 4.5) which is generally the case in oxygenated systems.

During February and May (low flows periods), property-salinity plots showed a concave curvature with concentrations dropping to near depletion towards the mid-salinity ranges (representative of the middle reaches of the system) and renewal occurring across the source boundaries, in particular the seaward boundary, as for nitrate. This type of nutrient distribution is typically attributed to biological uptake and supports the suggestion that nitrogen is the limiting nutrient in the Berg Estuary.

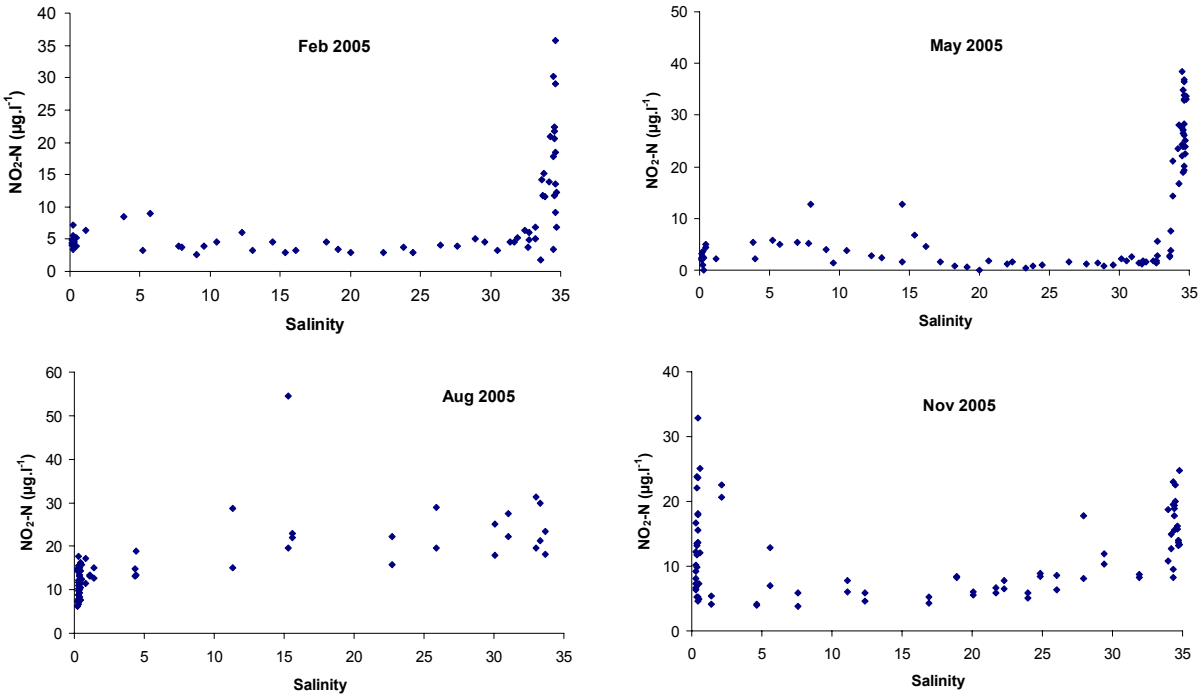


Figure 4.5 Concentration of nitrite (NO_2-N) in the Berg Estuary measured on 4 occasions in 2005.

During August (high flow) elevated nitrite concentrations were maintained in the estuary (although still relatively low), due to short flushing times (i.e. regular renewal across source boundaries and short retention times limited the effects of biological uptake). Concentrations within the estuary were mainly a function of mixing between river and seawater, as suggested by the near linear relationship.

In November, the property-salinity plot reverted to a concave curvature again suggesting removal of the nutrient from the estuary in the mid-salinity ranges (or middle reaches), similar to the low flow scenarios. This relationship differed from the more linear relationship observed for nitrate, suggesting that nitrite is probably removed more rapidly from the water column than nitrate (the former is also a less stable form of inorganic N).

A comparison with historic data is provided in Figure 4.6 where property-salinity plots for nitrite suggest a similar trend for low and high flow periods, respectively, over the years. Although concentrations in river inflow are still considered to be low, there is a clear incremental increase in nitrite concentration in the influent river water between 1975 and 2005 in the high season (increasing from around 1 to 12 µg.l-1 in this period) (Table 4.1). Similarly, nitrite concentrations in seawater at the mouth of the estuary has also increased incrementally over the years (Table 4.2).

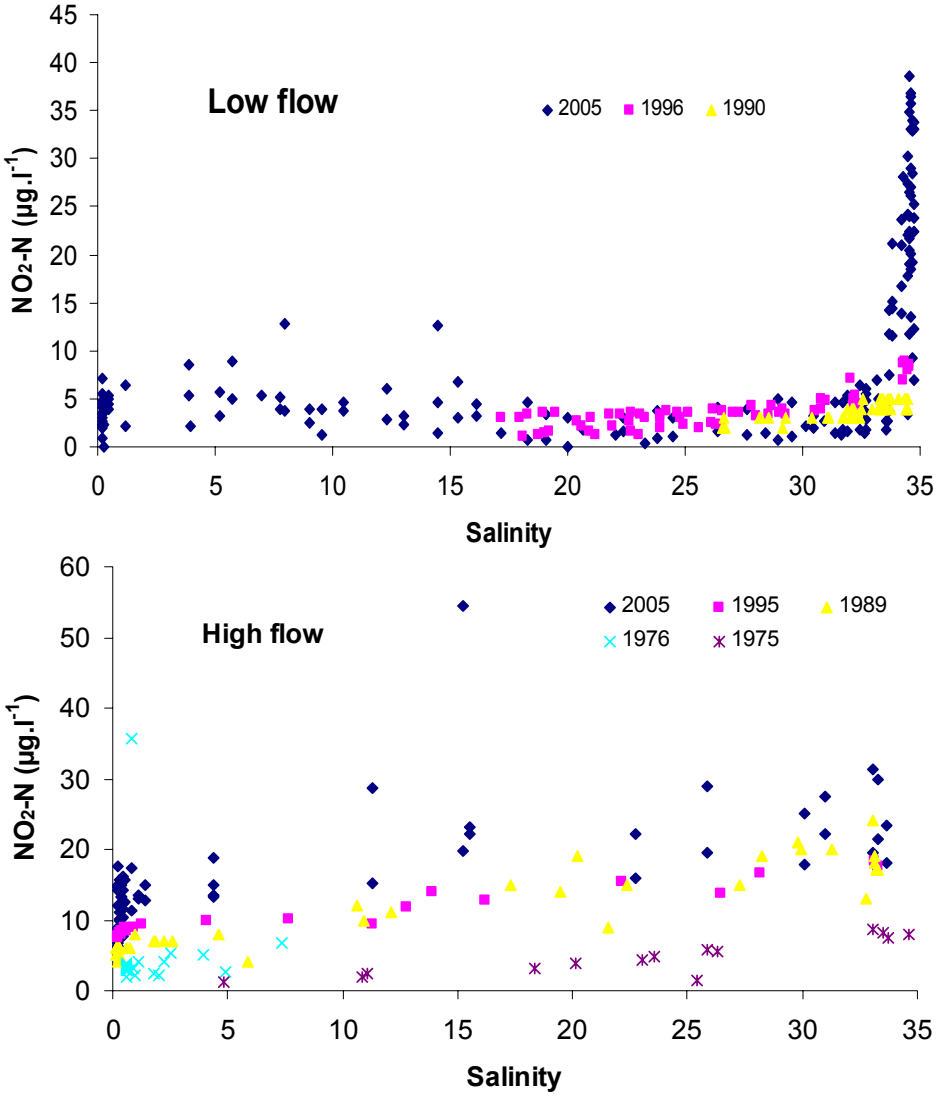


Figure 4.6 Concentration of nitrite (NO_2-N) in the Berg Estuary measured in the low and high flow seasons between 1975 and 2005.

4.3.3 Dissolved Total Ammonia

Property-salinity plots for dissolved total ammonia (NH_4-N) measured in the Berg Estuary during low flows (February and May 2005) also showed a concave curvature, with near depleted concentrations in the mid-salinity ranges (or middle reaches) with renewal occurring across the source boundaries, in particular the seaward boundary. This relabtionship is attributed to biological uptake and (as for nitrate and nitrite) supports the suggestion that nitrogen is the limiting nutrient in the Berg Estuary at these times.

During August (high flow) elevated total ammonia concentrations were maintained throughout the estuary, ascribed to short flushing times (i.e. regular renewal across source boundaries and short retention times limiting the effects of biological uptake). However, unlike the trends observed for nitrate and nitrite (near linear relationships), results showed a convex relationship, suggesting that total ammonia was introduced to the water column in the mid-salinity (or middle reaches). This pattern is usually indicative of internal processes releasing N into the water column (e.g. remineralisation) or anthropogenic inputs (e.g. N-enriched effluents). However, these processes and activities are usually not expected to have such marked effects during high flow periods when river water volumes and flushing rates are relatively high.

High variability in total ammonia concentrations in river inflow could also result in such distribution patterns (e.g. a pulse of higher nutrient river water may have entered the river just prior to the survey).

In November, the slight concave curvature of the mixing diagram suggested some removal of the total ammonia from the mid-salinity ranges (or middle reaches of the estuary), similar to the low flow scenarios. This relationship differs from that observed for nitrate, suggesting that total ammonia (as with nitrite) is removed more rapidly from the water column than nitrate. Total ammonia has also been reported as the preferred source of inorganic N from certain primary producers (Short and McRoy 1984).

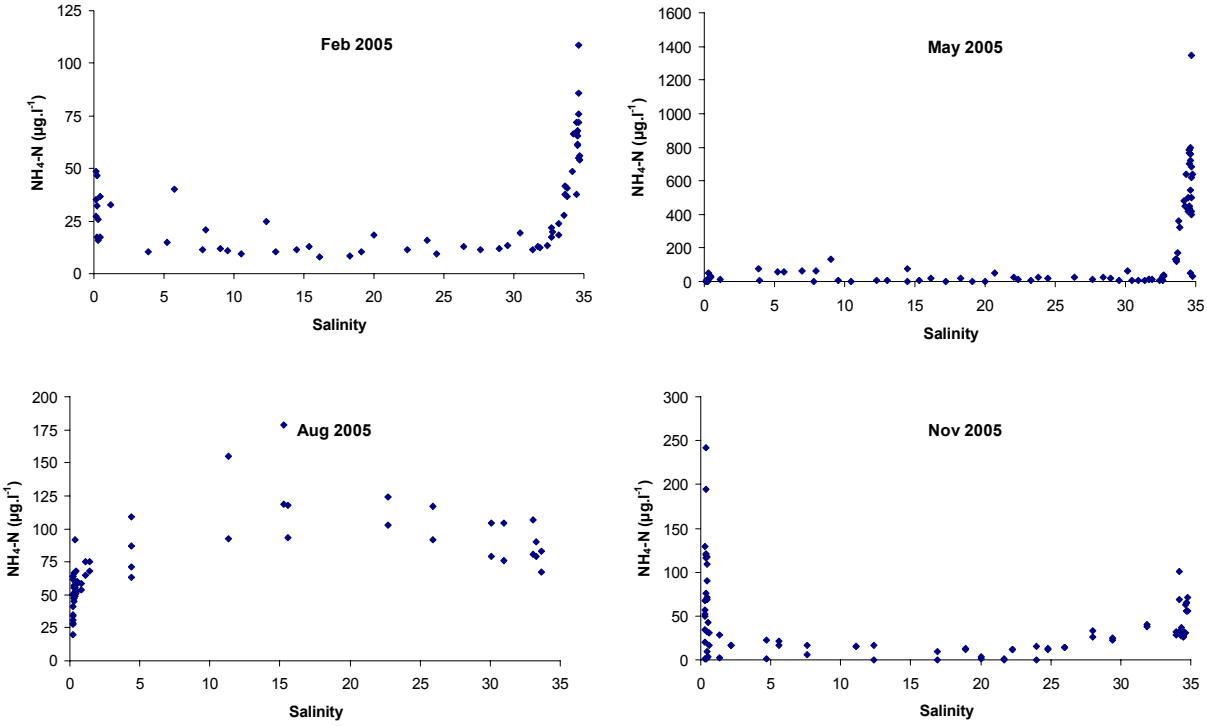


Figure 4.7 Concentration of dissolved total ammonia (NH_4-N) in the Berg Estuary measured on 4 occasions in 2005.

A comparison with historic data is provided in Figure 4.8 where property-salinity plots of total ammonia suggest a similar trend for low and high flow periods, respectively, over the years. However, there appears to be marked change in concentrations measured along the seaward boundary. Concentrations of ammonia low flow periods (usually summer) concentrations increased from around 32-80 in 1990/96 to 359 in 2005 (Table 4.1).

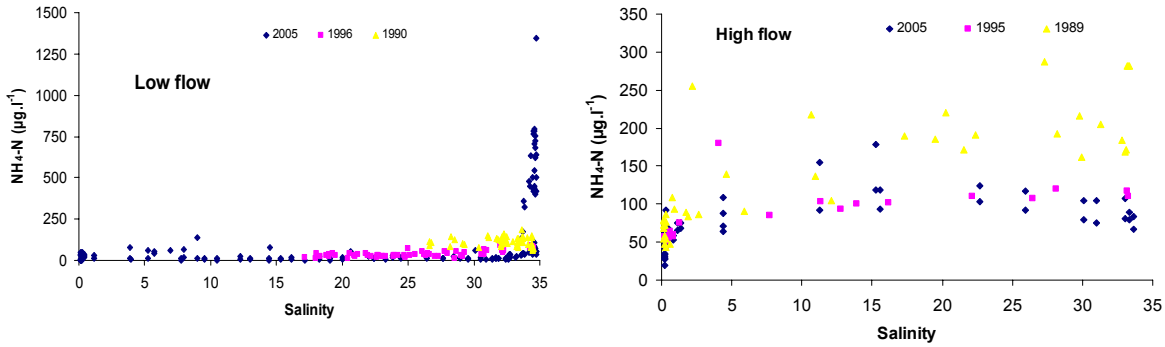


Figure 4.8 Concentration of dissolved total ammonia (NH_4-N) in the Berg Estuary measured in the low and high flow seasons between 1975 and 2005.

4.3.4 Dissolved Inorganic Phosphate

Property-salinity plots for dissolved inorganic phosphate (DIP or PO_4-P) measured in the Berg Estuary on four occasions in 2005 showed distinctly different distribution patterns (Figure 4.9).

During February 2005 (low flow) DIP declined linearly with salinity up to salinity of about 10 from which point concentrations remained low throughout. A similar pattern was evident in May 2005, where DIP concentration declined linearly with salinity to salinity of 25 from which point concentrations remained low right to the top of the estuary. This slight concave curvature, suggested removal of DIP from the water column towards the upper salinity ranges, although not as distinct as for the dissolved inorganic nitrogen species (nitrate, nitrite an total ammonium), again supporting the suggestion that N is the limiting nutrient in the Berg Estuary during low flow periods.

In the high flow season (August), DIP concentrations were low (mostly <75 $\mu g.l^{-1}$) but variable down the full length of the estuary, with no clear pattern emerging. Change in DIP concentration with salinity in November (start of the dry season) was similar to patterns observed in February and May, in that mean concentration declined with a drop in salinity, but that the range of DIP concentrations and any particular salinity was much more variable.

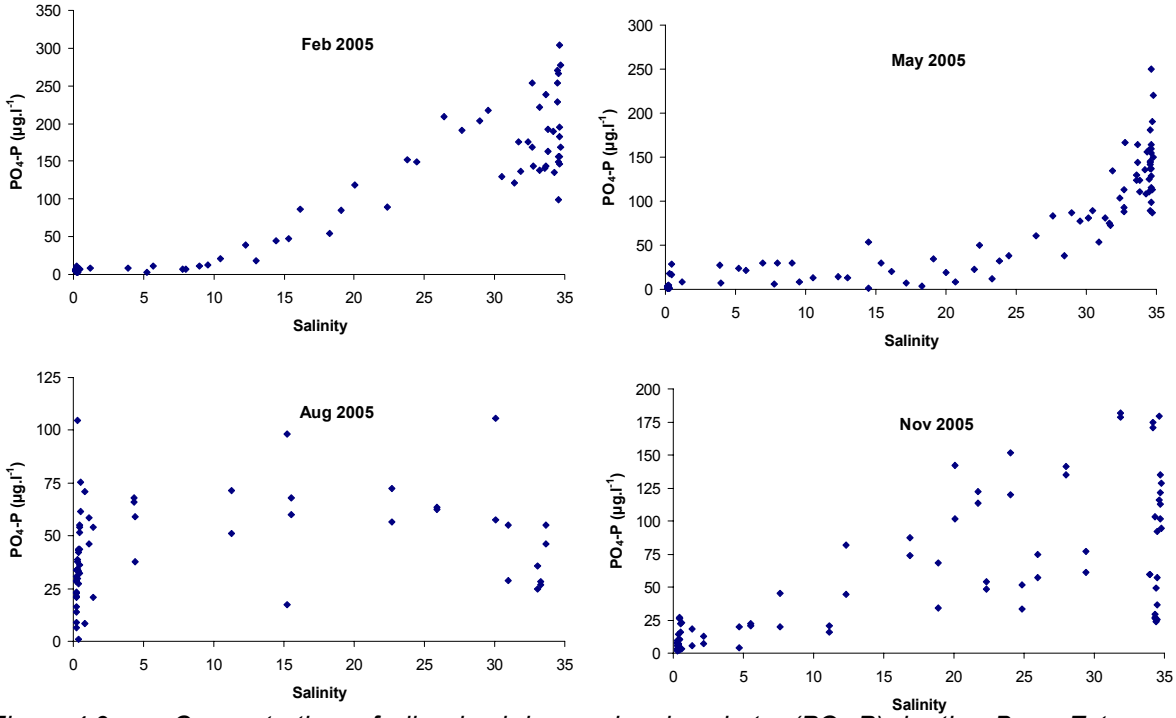


Figure 4.9 Concentration of dissolved inorganic phosphate (PO_4-P) in the Berg Estuary measured on four occasions in 2005.

A comparison with historic data is provided in Figure 4.12, where property-salinity plots for DIP show similar trends for low and high flow periods, respectively, over the years. However, as with total ammonia, there was a marked increase in DIP concentrations along the seaward boundary during low flow periods (summer), where concentrations increased from 69 $\mu g.l^{-1}$ in 1975 to 156 $\mu g.l^{-1}$ in 2005 (Table 4.1).

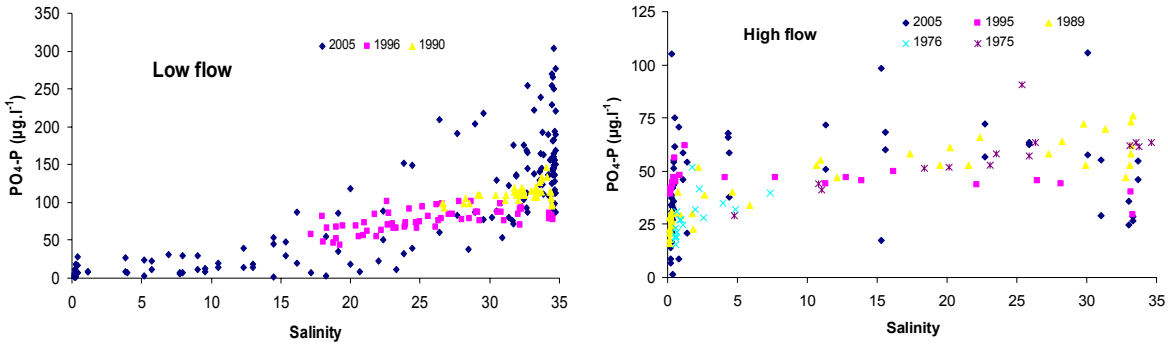


Figure 4.10 Concentration of dissolved inorganic phosphate (PO_4-P) in the Berg estuary measured in the low and high flow seasons between 1975 and 2005.

4.3.5 Dissolved Reactive Silicate

Property-salinity plots for dissolved reactive silicate (DRS or SiO_4-Si) measured in the Berg Estuary during 2005 showed distinctly different distribution patterns (Figure 4.13).

During the low flow periods (February and May 2005), DRS declined from the seaward boundary (salinity 35) to the head (salinity 0). This is surprising, as in most systems (including the Berg – see Figure 4.14) a reverse relationship is expected since DRS is usually higher in the freshwater than in the sea (Eagle and Bartlett, 1984).

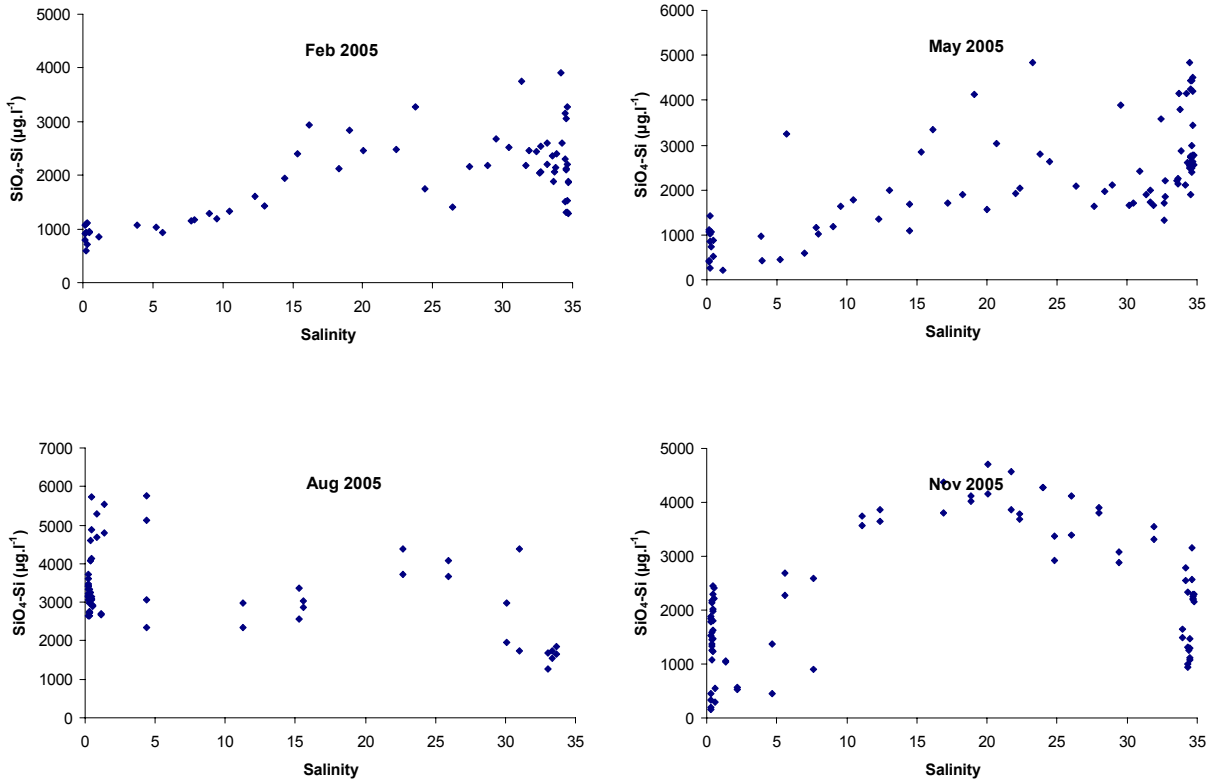


Figure 4.11 Concentration of dissolved reactive silicate (SiO_4-Si) in the Berg estuary measured at four occasions in 2005.

During both August and particularly during November 2005, property-salinity plots showed a convex curvature, suggesting that DRS is introduced to the estuary towards the mid-salinity ranges.

This relationship was again surprising, as DRS is typically reintroduced to the water column through the dissolution of diatom skeletons (Kamatani *et al* 1980), but such processes generally do not have a significant influence during high flow periods or when residence time of water in the systems is short (e.g. immediately after high flow season).

A high variability in DRS concentrations in river inflow could also result in such distributions (e.g. a pulse of higher nutrient river water may have entered the river just prior to the survey).

A comparison with historic data is provided in Figure 4.14. For the low flow periods it is difficult to make clear comparison as historic data sets did not sample the system along the entire salinity gradient. However, results do show that DRS concentrations measured along the seaward boundary were significantly higher in 2005 (1 500-2 000 µg.l^{-1}) than in previous years (600-900 µg.l^{-1}) (Table 4.1). Although during high flow periods, the DRS property-salinity plots show similar trends, i.e. concentrations tend to increase along the salinity gradient, concentrations in river inflow have gradually increased from 1976 (337 µg.l^{-1}) to 2005 (3634 µg.l^{-1}) Table 4.1.

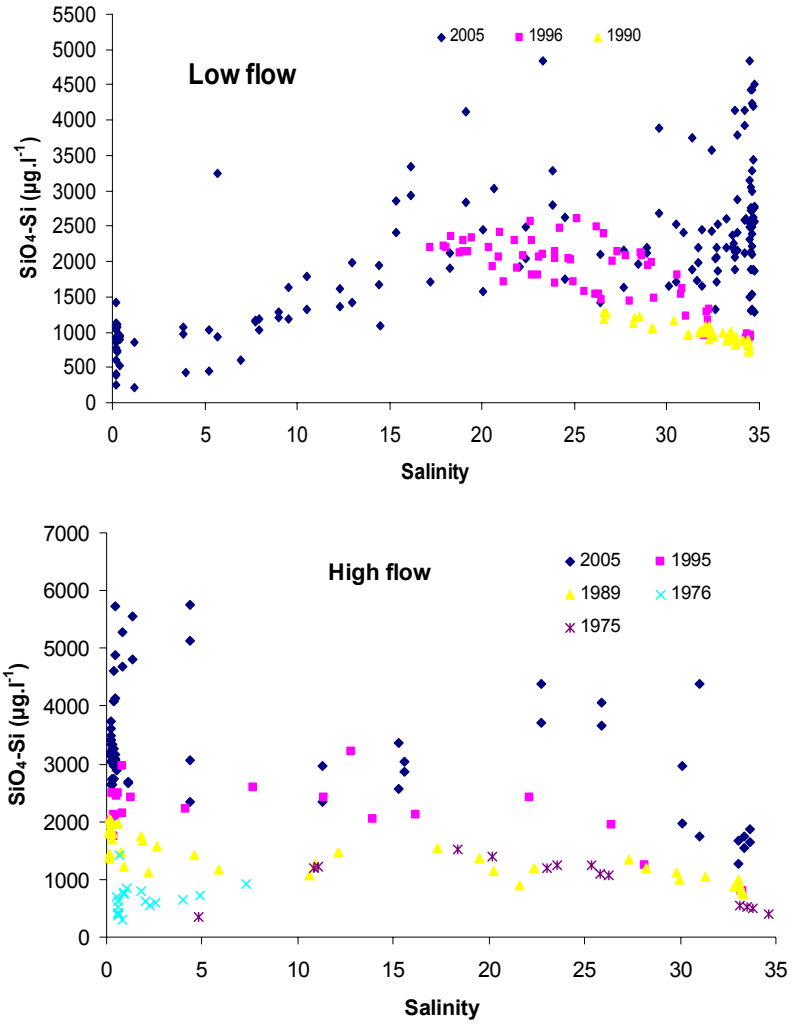


Figure 4.12 Concentration of dissolved reactive silicate (SiO_4-Si) in the Berg estuary measured in the low and high flow seasons between 1975 and 2005.

4.4 DISCUSSION

4.4.1 The role of nutrients in estuaries

Historically, many estuaries were oligotrophic (nutrient poor) systems, with nitrogen (N) and in some cases also phosphorus (P) being the primary limiting nutrients that controlled primary production (Nixon 1995, Herbert 1999, Flemer & Champ 2006), although light, temperature, and rate of flushing may also have played a role in some systems (Breitburg *et al*. 1999, Sin *et al.* 1999, Flemer & Champ 2006, Roy *et al*. 2001).

Nutrient cycling and transformation are one of the key abiotic components that drive biological production in estuaries.

On the other hand, the complex nature of nutrient cycling and transformation in these ecosystems are easily perturbed by external (anthropogenic) forces that may lead to changes in the trophic status and ultimately impacting on the ability of the system to support higher trophic orders (Ferguson *et al*. 2004). Therefore, human activities that change the processes influencing nutrient cycling and transformation in estuaries (e.g. waste loading and reductions in freshwater inflows) can potentially impact on the ecological services provided by these ecosystems.

Mobilisation of N and P through land clearing, application of fertilizer, discharge of human wastes, animal production, and combustion of fossil fuels has fundamentally changed this situation, with the result that eutrophication is now a worldwide problem affecting estuaries (Nixon 1995, Bennett *et al*. 2001). Eutrophication has in fact recently been singled out as one of the major concerns for estuarine health across the globe (Flemer & Champ 2006).

Over-enrichment by N and P are widely known to stimulate undesirable types and amounts of aquatic plant growth, particularly phytoplankton and nuisance macrophyte growth (e.g. reeds). In estuaries, phytoplankton tends to proliferate at the expense of submerged and emergent vegetation as the microscopic phytoplankton species grow faster than the larger macroscopic plant species. As such, phytoplankton reduces the amount of light reaching the larger rooted plant species thereby inhibiting their growth. Other undesirable effects of nutrient over-enrichment include oxygen depletion or hypoxia which arises from the decomposition of phytoplankton and plant biomass, which in turn can kill fish and invertebrates, and can cause a general reduction in biodiversity. In contrast to nitrogen and phosphate, silicate is derived almost entirely from natural weathering and erosion and depends on the geology of the river catchment feeding an estuary. It can also serve to limit primary production in estuaries–such as the production of large diatoms.

For all of these reasons, it was recognised that it was imperative to obtain a more detailed understanding of nutrient dynamics in the Berg Estuary as it is currently, and to understand how this may have changed from the historical condition as this would assist in understanding potential future changes in response to changes in freshwater flow and other developments.

4.4.2 Hydrology and its effect on nutrient dynamics

Nutrients dynamics in the Berg Estuary cannot be understood in isolation, and in particular requires an understanding of the hydrology, hydrodynamics and physicochemical characteristics of the system. Temperature and salinity are particularly important in this respect, as these can serve as a proxy for the typical water circulation patterns in a system. Detailed descriptions of the hydrology, hydrodynamics, and physicochemical characteristics (temperature, salinity, oxygen and turbidity) of the Berg Estuary are provided in Volume 1 of this reports series (Chapter 5, Howard & Ractliffe 2007) and in the preceding chapters of this Volume (Chapters 2-3, Beck & Basson 2006, Schumann 2007) but a brief summary of the characteristics most relevant to nutrient dynamics is presented below.

The Berg Estuary reflects a strongly seasonal hydrological regime, being fluvially-dominated (freshwater dominated) during winter (Jul-Sep) and marine-dominated during summer (Dec-Feb). Conditions in Autumn and Spring are generally intermediate between these two states.

Temperatures throughout the estuary during winter are low and typically range between 13°C to 17°C. During summer, there is usually a strong longitudinal gradient in temperature with no marked vertical stratification. Near the mouth the temperatures are cool (13-20°C) owing to the influx of cool seawater during flood tides, but increase with distance upstream rising to around 24-27°C at the head of the estuary.

The salinity regime of the Berg Estuary also has a strong seasonal signal. During winter, strong fresh water flushing on ebb tides reduced the salinity of virtually the entire estuarine water column to below 1. Only limited saline intrusion occurs near the mouth during flood tides.

After the winter floods have receded salt water begins to intrude progressively further and further upstream on each tidal cycle. By the end of spring (November), saline influences are detectable up to approximately 20 km from the mouth, but increase in extent to 45 km upstream of the mouth by the end of summer (February). Depending on when the rains start, conditions in autumn (Mar-May) may be similar to those in summer or there may be some regression in the upstream extent of the saline water penetration.

4.4.3 Sources of nutrients for the Berg Estuary

The primary sources of nutrients for the Berg estuary is the river flowing in at the head of the estuary and the sea entering the system through the mouth. Internal biogeochemical processes, as well as anthropogenic inputs can also become significant sources of nutrients to estuaries.

Under natural conditions, inorganic N and P inputs to the estuary from the Berg River was probably low considering that much of the catchment, especially that part from which perennial flow is derived, is comprised of Table Mountain Sandstone (TMS) which typically leaches very few ions (Bath 1993, Day 2007 – BRBMP Final Report Volume 2, Chapter 4). The middle and lower parts of the Berg River traverses bedrock composed mostly of Malmesbury shale, which although low in nutrients is often associated with mineralisation of surface waters (which is indeed the case for the Berg River) (Fourie and Görgens 1977, Day and Dallas 1996). Over time, human activities in the catchment have increased runoff of nutrients into the Berg River, hence increasing contributions from this source to the estuary. Principal amongst these have been land clearing (mostly for agriculture), application of artificial fertilizers, discharge of human wastes, and animal production (Bath 1993, Day 2007 - BRBMP Final Report Volume 2, Chapter 4). These authors note significant increases have been observed in concentrations of all major nutrients in the lower Berg since the 1950's (also confirmed by comparison to historic as part of this study).

Nutrient input to the Berg Estuary from the sea occurs mostly during upwelling events which occur mostly in summer (the low flow period) (Slinger & Taljaard 1994). The prevailing southeasterly winds at this time of the year drive surface water offshore allowing nutrient rich waters to well-up from below along the coast (Chapman and Shannon 1985). Tidal processes transport these into the Berg Estuary contributing to nutrient supply particularly in the lower estuary. Corresponding northerly winds that prevail in winter (the high flow season) tend to drive nutrient poor surface waters onshore which in turn provide a very modest contribution to nutrient supplies to the estuary. Coastal upwelling also reportedly provides significant pulses of both DIN and DRS to estuaries in other parts of the world (Dale & Prego 2002, Prego 2002, Prego & Bao 1997, Bianchi 2007).

Typical nutrient concentrations for newly upwelled water and oceanic surface water in the Benguela region are provided in Table 4.3. Nitrate concentrations measured at the mouth of the Berg Estuary peak at around 250-300 $\mu g.l^{-1}$ in the low flow period (Feb, May and November 2005) when southeasterly winds are likely to be blowing and hence upwelling to be occurring. These values correspond well with the range for newly upwelled water reported by Chapman & Shannon (1985, Table 4.3) and it can be deduced that upwelling processes are most likely the primary source of nitrate in the lower estuary at this time. Lower concentrations measured at the mouth in the high flow season (90-160 $\mu g.l^{-1}$) are higher than those for surface waters in St Helena Bay but are probably influenced by higher nutrient concentrations in the outflowing river water.

By contrast peak phosphate (150-300 $\mu g.l^{-1}$) and silicate (2 000-5 000 $\mu g.l^{-1}$) concentrations at the mouth of the Berg in the low flow season are much higher than corresponding values for newly upwelled water in the Benguela region (Phosphate 40-90 $\mu g.l^{-1}$, Silicate 140-1 400 $\mu g.l^{-1}$, Table 4.3).

Table 4.3 Typical values for nitrate, phosphate and silicate concentrations in newly upwelled and oceanic surface waters in the Benguela region (after Chapman & Shannon 1985, Bailey & Chapman 1991).

	Freshly upwelled water ($\mu g.l^{-1}$)	Surface water – St Helena Bay ($\mu g.l^{-1}$)
Nitrate	200-400	112-140
Phosphate	40-90	50-56
Silicate	140-1 400	330-360

This may well be linked with anthropogenic nutrient inputs directly into the lower estuary (e.g. treated sewage from the surrounding urban settlements and waste water from the pelagic fish processing factories situated at the mouth) and/or *in situ* chemical and biochemical processes. These include remineralisation, referring to the process whereby nutrients (total ammonia and DIP) are released from 'labile' organic matter through heterotrophic bacterial decomposition (Eyre, 1994; Eyre and Balls, 1999; Roy *et al*., 2001), and dissolution where by the siliceous remains of certain marine organisms such as diatoms dissolve after dying releasing DRS into the water column (Kamatani *et al*, 1980). Anthropogenic inputs of nutrients along the estuary channel are probably the most important in the case of DIN and DIP but not for DRS.

4.4.4 Seasonal variation in nutrient concentrations

A strong seasonal signal is evident in nutrient distribution patterns of the Berg Estuary linked to changes in the hydrological regime (river inflow patterns), concentrations in source waters (i.e. river and sea) and the relative significance of *in situ* biochemical and biological processes and anthropogenic inputs.

During summer and autumn, the marine environment is clearly a primary source of inorganic nutrients to the estuary, in particular dissolved inorganic nitrogen (DIN) and DIP. The distinct concave curvature of the property-salinity plots for all the DIN species (nitrate, nitrite and total ammonia), shows significant removal of these nutrients from the water column, particularly in the mid-salinity ranges. When residence times are long, as is the case in the middle reaches of the Berg Estuary during low flows, primary production can have a marked influence on nutrient concentrations in the water column - particularly the limiting nutrient – in this case N, as reflected in the near depleted concentrations of DIN (nitrate, nitrite and total ammonium). Significant renewal of nutrients occurs across the estuary-sea boundaries and to a limited extent across the river-estuary boundary. Strong tidal intrusion can push saline, higher nutrient waters far upstream of the mouth during these low flow periods. Results showed that during summer and autumn DIP concentrations in the estuary declines more or less linearly with salinity until reaching levels comparable with that at the head of the estuary at a salinity of between 10 (summer, 30-35 km from the mouth) and 20 (autumn, 20-25 km upstream). This is indicative of a slower but nonetheless significant uptake by primary producers within the estuary, particularly in the upper reaches of the system. As the curvature is not as distinct as for the DIN species, it supports the suggestion that N is the limiting nutrient in the Berg Estuary during low flow periods. During this period (summer and autumn), DRS declined from the seaward boundary (salinity 35) to the head (salinity 0).

This is surprising, as in most systems (including previous studies on the Berg Estuary) a reverse relationship is expected since DRS is usually higher in the freshwater than in the sea (Eagle and Bartlett, 1984).

In winter (high flow season) the situation in the Berg Estuary is somewhat different, in that the river water becomes the primary source for some of the nutrients, in particular nitrate. Levels of nitrate in river inflow at this time are extremely high (in the region of 500-2 000 $\mu g.l^{-1}$, compared with a maxima of 300 $\mu g.l^{-1}$ in summer/autumn).

High nitrate concentrations in river water can probably be attributed to runoff from agricultural activities in the catchment, often a major source of nitrate, particularly at the onset of the high flow season (i.e. the 'first flush' effect). A marked drop in nitrate concentrations in river inflow towards spring/early summer (November 2005) supports the 'first flush' concept. This also points to a significant export of nitrate from the Berg Estuary into the adjacent marine environment during the high flow season.

The convex relationship between salinity and total ammonia concentrations during winter (high flow season) suggests that the nutrient is being introduced to the water column in the mid-salinity ranges (or middle reaches). This pattern is usually indicative of internal processes releasing N into the water column (e.g. remineralisation) or anthropogenic inputs (e.g. N-enriched effluents).

However, these processes and activities are usually not expected to have such marked effects during high flow periods when river water volumes and flushing rates are relatively high. High variability in total ammonia concentrations in river inflow could also result is such distribution patterns (e.g. a pulse of higher nutrient river water may have entered the river just prior to the survey).

The river does not appear to be a major source of DIP, as concentrations in river inflow remained low during the high flow season (mostly < 75 $\mu g.l^{-1}$). Taking into account that extensive agricultural activities are taking place in the catchment this is surprising, but could be linked to P being strongly associated with soils, stronger than for example inorganic N that are very mobile.

During winter results suggested that DRS is introduced to the estuary towards the mid-salinity ranges. This relationship was again surprising, as DRS is typically reintroduced to the water column through the dissolution of diatom skeletons (Kamatani et al, 1980), but such processes usually do not have significant influence during high flow periods (e.g. high flow periods) or at times when residence time of water in the system has not been long (e.g. immediately after high flow season). A high variability in DRS concentrations in river inflow could also result in such distributions (e.g. a pulse of higher nutrient river water may have entered the river just prior to the survey).

4.4.5 Historical change in nutrient concentrations

Historical changes in nutrient concentrations in the Berg Estuary were examined separately for the high and low flow seasons owing to key differences in the primary sources of nutrients at these times. Property-salinity plots showed most nutrients showed similar trends for low and high flow periods, respectively, over the years. However the concentrations entering the estuary across the river-estuary and estuary-sea boundaries did showed marked changes over the years.

Data on nutrient concentrations in the high flow season extend back to 1975 and show a consistent increase in the concentration of nitrate, nitrite, and silicate up to the present day, associated with comparable increases noted in the river (Day 2007 – BRBMP Final Report Volume 2, Chapter 4). These increases are most likely associated with increased use of fertilizer in the catchment (nitrate and nitrite) and soil erosion and disturbance (ploughing) (silicate).

Little change is evident in concentration of DIP at the head of the estuary in the high flow season over time.

Taking into account that extensive agricultural activities are taking place in the catchment this is surprising (and in contrast to results reported for the river - Bath 1993, Day 2007 – BRBMP Final Report Volume 2, Chapter 4). This might be the result of P being strongly associated (bound) with soils, stronger than for example inorganic N that is very mobile.

Comparison with historic data showed a marked change in concentration of dissolved total ammonia and DIP along the seaward boundary particular during the low flow seasons (summer).

This could be associated with more intense upwelling during the 2005 surveys relative to those in 1996 and 1990, although it would be expected that in terms of inorganic N, the signal would have been reflected in nitrate rather than in total ammonia. These changes could be linked to anthropogenic inputs of total ammonia and DIP from industries (e.g. fish factories) near the mouth, although these would have to be confirmed through comparison with effluent volume and concentration data for the corresponding periods.

4.4.6 Comparisons with other west coast estuaries

Along the west coast of South Africa, the Berg Estuary is one of two permanently open systems, the other being the Olifants Estuary.

Other important estuaries along the west coast include the Orange and the Diep estuaries (Eagle and Bartlett 1984; Taljaard *et al.* 1992), but these are temporarily open/closed systems and are expected to have somewhat different nutrient dynamics compared to that of the Olifants and Berg estuaries.

Nutrient dynamics in the Olifants Estuary (DIN, DIP and DRS) have been studied by Taljaard et al. (2006). Comparison of property-salinity plots for DIN (nitrate, nitrite and total ammonia) in this estuary show similar patterns to those observed in the Berg, particular during the low flow season, where a concave curvature suggests significant biological uptake in the middle reaches, with renewal across the river-estuary, and especially the estuary-sea boundaries. Lower values at the seaward boundary of the Olifants than the Berg estuary at this time most likely reflect reduced upwelling intensity at the mouth of the former than at Cape Columbine just south of the Berg estuary mouth. During the high flow season, however, concentrations of DIN in river waters entering the Berg Estuary (2 000 $\mu g.l^{-1}$) is about an order of magnitude higher than for the Olifants system (200-300 $\mu g.l^{-1}$).

Dissolved inorganic phosphate (DIP) concentrations in both estuaries were within the same ranges, during both the low and high flow season, except that in the case of the Olifants Estuary convex curvature suggested the introduction of DIP during extended low flow periods. Although reasons for the introduction of DIP to the water column were inconclusive, it is likely that geochemical processes (e.g. desorption of P from particulate phases) and/or foliar release (associated with the dense *Potamogeton* beds) were contributing factors (Howard-Williams and Allanson, 1981).

For low flow periods, DRS distribution patterns in the Berg Estuary did not show a reverse relationship with salinity as expected, but DRS concentrations increased with increase in salinity, while decreasing with increased salinities in the Olifants Estuary. In both instances the distribution was not linear. Interestingly, both these systems showed a convex curvature in their property-salinity plots during low flow periods (specifically the November 2005 survey on the Berg Estuary) with maximum concentrations at salinities between 15 and 20. Similar features have been observed in three Australian (tropical) and three Scottish (temperate) estuaries, but in the lower salinity range (Eyre & Ball, 1999). These maxima were mainly attributed to dissolution of diatom skeletons at the sediment/water surface.

During the high flow seasons, both systems showed an increase in DRS concentration with a decrease in salinity, suggesting that the river was the main source of DRS during these times.

4.4.7 Nutrient limitations on algal growth

Differences in the rates of uptake of the different nutrients (nitrogen vs. phosphorus and silica), suggests that nitrogen is most limiting in the Berg Estuary, as is generally the case in the marine environment (Chapman & Shannon 1985).

While it is difficult to prove conclusively that nitrogen is indeed limiting in the Berg estuary without accurately measuring rates of algal growth under variable nutrient concentrations, comparing nutrient concentrations in the environment with known half saturation constants does provide a good indication of whether this is the case or not (Fisher *et al*. 1988). The half-saturation constant for a particular nutrient represents the concentration at which nutrient uptake is half its maximum value.

Below this value, uptake rates are reduced potentially to the extent that they limit algal growth rates or biomass accumulation, while above this level nutrient concentration is likely to have a small positive effect on uptake rates (Fisher *et al*. 1988). Half saturation constants reported in the literature for ammonium, nitrate, and nitrite are in the order of 1-2 µM (14-28 $\mu g.l^{-1}$) (MacIsaac & Dugdale 1969, Eppley *et al*. 1969, Murphy 1980, Fisher *et al*. 1981, Priscu & Priscu 1984), phosphate in the order of 0.1-0.5 µM (3-15 $\mu g.l^{-1}$) (Nalewajko & Lean 1980) and silicate in the order of 1-5 µM (28-140 $\mu g.l^{-1}$) (Paasche 1973).

If we examine concentrations of these nutrients in the Berg estuary, it is clear that total nitrogen (TN) reaches levels that are potentially limiting in extensive areas of the middle reaches of the estuary during the low flow period (February and May), while phosphorus is at potentially limiting levels only in the extreme upper reaches of the estuary when flows are low (Feb and May) and silicate probably never reaches levels that could be considered limiting.

Historical increases in the amount of nitrogen entering the estuary with the river runoff must almost certainly have contributed to increased primary production in the system – most likely through an expansion of emergent vegetation (reeds) and phytoplankton biomass in the estuary.

4.4.8 Likely impacts of alterations in freshwater flow on nutrient dynamics

Beck *et al*. (2007 – BRBMPR Volume 2 Chapter 2), predict that mean annual runoff to the Berg Estuary following the construction of the Berg River Dam will decline by approximately 13% from present day. Much of this reduction will take the form of reduced winter base flows and intra-annual floods. The effect of such a change in flow on nutrient dynamics in the estuary is likely to be very modest, but this will have to be confirmed through long-term monitoring programmes.

4.4.9 Future monitoring recommendations

Analysis of nutrient data for the Berg etuary has provided important information on seasonal variation and historic changes within the system, and important insights into factors affecting primary production within the system. Clear historical changes have taken place in the system since monitoring was first undertaken in 1975, and these changes could be tracked through time using the data from sampling events spaced at roughly 5-yearly intervals in between (1989/1990, 1995/1996). The lack of any data between the period 1996 and 2005 is seen as a short coming in this data set. Thus, it is recommended that comprehensive surveys comparable with the survey completed for the Berg River Baseline Monitoring Study in 2005, be completed at least once per annum for at least 5 years following the construction of the Berg River Dam, reduced to bi-annually for 10 years following this, and then to a five-yearly interval thereafter. This would entail collection of water samples for analysis of DIN (nitrate, nitrite, total ammonia) DIP and DRS from at least 15-20 stations up the length of the estuary on at least two occasions during each calendar year corresponding to late summer (February), and at the peak of the winter flows (August). Simultaneous collection of data on water temperature, salinity, dissolved oxygen and chlorophyll a in the estuary is considered essential.

In order to improve understanding of the effects of biological uptake and other biochemical processes (e.g. remineralisation) on the nutrient dynamics of the Berg Estuary, interdisciplinary studies to further investigate these aspects should be undertaken, e.g. as part of Water Research Commission Research Projects.

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CHAPTER 5 - MICROALGAE

G. Bate & G. Snow

5.1 INTRODUCTION

Research on estuarine microalgal ecology has been neglected in South Africa, with the main effort on fish and invertebrate ecology. The result is that our understanding of the microalgal component is small and rather fractured. It has been realised that the phytoplankton and benthic microalgae are important contributors to primary production with the result that there has been an increased research effort in this area in the last ten years. Comprehensive studies relating microalgal biomass to freshwater flow is limited to a few Eastern Cape estuaries and there has been no such study in the Western Cape. As a result, data from once- or twice-off studies will be included for comparative purposes but relating biomass to flow in the Berg will be based on predictions only.

Research by Hilmer & Bate (1990) showed that the highest phytoplankton biomass occurred when flow rate into the estuary was equivalent to a "residence time" of 3 spring tidal cycles. The term "residence time" has been queried (Van Niekerk and Huizinga, Pers. com. CSIR) and now refers to the flow rate that would fill the estuary in 3 spring tidal cycles or 42 days. Working in the Gamtoos Estuary, Snow (2000) especially studied the high chlorophyll *a* that is found at the interface between fresh and saline water. This zone, called the "river estuarine interface zone" or REI normally occurs at a salinity of between 10-15 ppt. The relationship between chlorophyll a and flow rate is shown in Table 5.1. As the flow rate increased in the Gamtoos Estuary, the position of the REI zone moved down the estuary towards the mouth and the vertically averaged chlorophyll a decreased. The data in Table 5.1 indicate that above and below the optimum flow rate for maximum biomass, there is a lower phytoplankton biomass.

Table 5.1 The influence of flow rate on the content of chlorophyll a in the Gamtoos Estuary. (After Snow 2000).

Flow ($m^3 \cdot s^{-1}$)	Chlorophyll *a* ($\mu g \cdot l^{-1}$)
0.3	26.7
0.8	47.6
1	35.7
1.2	49.9
1.25	26.7
2.3	13.5
9.7	15.4
30.5	6.4

There are no data in South Africa to indicate whether there is a diatom species seasonal effect in estuaries, however, Bate *et al.* (2002) showed that there was no seasonal effect in the Swartkops River over a 13-month period. This applied especially to the upper reaches at higher altitudes where the quality of the water had the lowest TDS but where temperatures were more varied. By implication there is good reason to suspect that in South African estuaries, diatom species changes are more likely to be influenced by water quality variables such as salinity and mineral nutrients than by temperature.

The Berg River Dam is expected to affect the quantity and quality of river water entering the estuary. To understand the effects of these changes on microalgae, this study aimed to determine the distribution of phytoplanktonic and benthic microalgal communities in the Berg Estuary. In particular, to determine which groups are numerically dominant in the phytoplankton and which diatoms (generally the dominant microalgal group in estuarine sediment) are numerically dominant in the benthos. In addition, the study aimed to determine the distribution of microalgae in the estuary by using chlorophyll *a* as an index of microalgal biomass. The strength of association between microalgal biomass and environmental variables was tested and the following hypothesis was proposed to test for a significant difference in average biomass between a summer and winter sampling session: Average phytoplankton chlorophyll *a* concentration is highest in winter (~2 $\mu g \cdot l^{-1}$) compared to summer (~0.1 $\mu g \cdot l^{-1}$) due to higher nutrient availability in the fresh water. The results of the study are used to predict the changes in biomass and community composition in response to reduced river input.

5.2 MATERIALS AND METHODS

5.2.1 Study site

The Berg is one of only three permanently open estuaries on the west coast of South Africa. It is a river-dominated estuary with tidal influence measurable up to ~70 km from the mouth (Slinger and Taljaard 1994). In 1966 a new estuary mouth was cut through the sand dunes about 1 km north of the original mouth, which was stabilised between concrete walls (Slinger and Taljaard 1994). The original mouth has silted up and the old channel forms a blind arm running parallel to the coast. The lower 4 km of the estuary is frequently dredged to a depth of at least 4 m to allow for boat navigation. The result of the stabilised mouth and deepened channel is a strong tidal current, particularly in the lower and middle reaches of the estuary. Sediment in the lower reaches (sites 1 to 4, Figure 5.1, were extremely soft, which is usually indicative of a high percentage of fine sediment particles (greater than 30% of <125 µm sediment), high organic content (>3% ash-free dry weight) and a high moisture holding capacity (Snow *unpub. data*). Above the R27 bridge the intertidal sediment was generally compacted and appeared to have a high fine sand content (125 to 250 µm sediment particle size) and a high detritus content. The upper reaches (>28 km) had a thick fringe of the common reed (*Phragmites australis*) with very little to no exposed intertidal area.

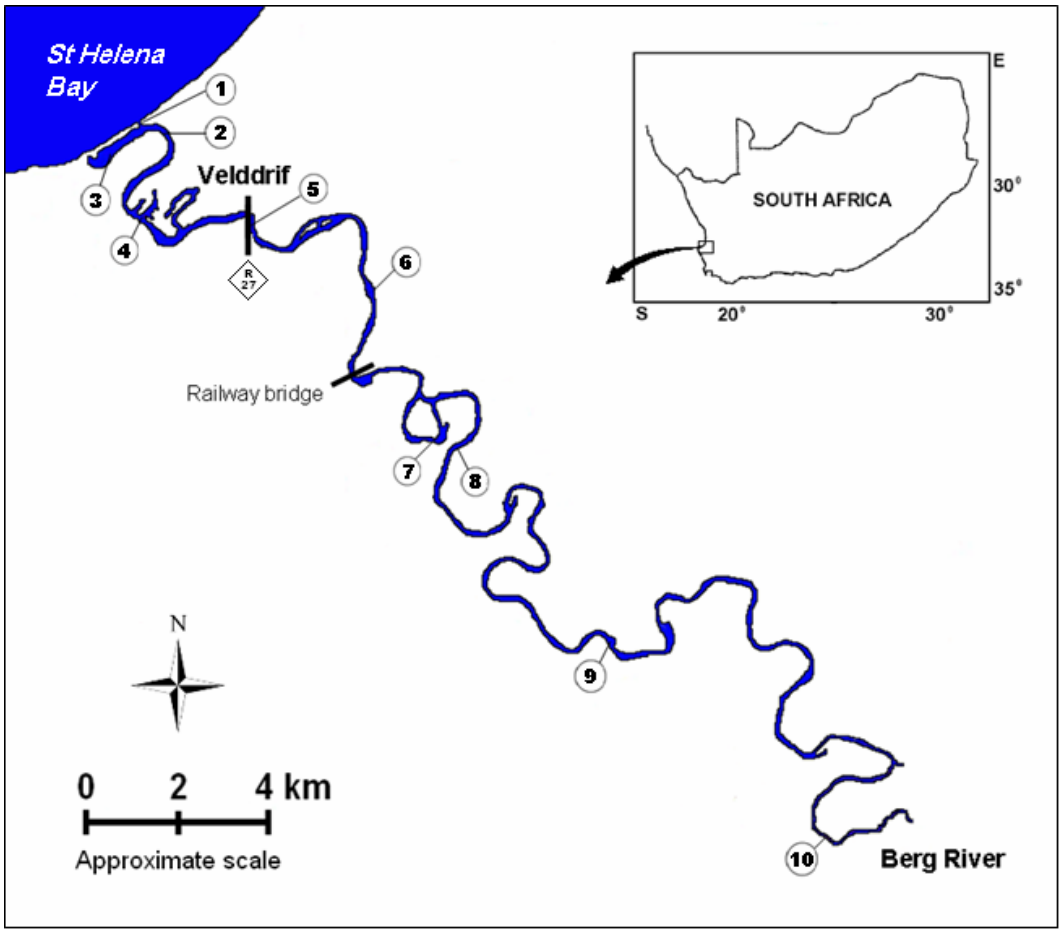


Figure 5.1 Berg Estuary indicating locations of the sampling sites.

River flow into the estuary was strong in August 2005 and, as a result, sampling was limited to the middle and lower reaches of the estuary (sites 1 to 9, Figure 5.1).

The flow was much weaker in November 2005, hence more sampling effort was placed on the upper reaches of the estuary with an additional two sites 16.5 km (site 8) and 43.2 km from the mouth (site 10) (Figure 5.1).

5.2.2 Water quality

Water quality variables were recorded at each site using an YSI 30-10ft CTD (temperature and salinity), an YSI pH100 pH meter and a WTW Oxi330i oxygen meter. A Secchi disc was used to determine light attenuation. The vertical attenuation coefficient was determined as described by Dawes (1981): K (m^{-1}) = (1.7 / secchi depth). Filtered water samples (Whatman GF/C) collected in August 2005 were analysed for total oxidised nitrogen (nitrate + nitrite) using the reduced copper cadmium method as described by Bate and Heelas (1975). Ammonium and soluble reactive phosphorus (SRP) were analysed using standard methods (Parsons *et al*. 1984)

5.2.3 Phytoplankton chlorophyll a

Water samples (500 ml) were gravity filtered through Whatman GF/C filters then stored in the dark of a cooler box until they could be frozen. The chlorophyll *a* was extracted by placing the frozen filters into 10 ml of 95% ethanol (Merck 4111). After extraction for 24 hours, spectrophotometric determinations of chlorophyll a were performed according to Nusch (1980). Absorbance was measured before and after acidification of extracts with 0.1 N HCl.

5.2.4 Phytoplankton identification

Water samples for phytoplankton enumeration were collected at the surface, 0.5 m, 1.0 m and then at 1.0 m intervals to the bottom. The water samples were fixed with 1.5 ml of 1 % (v/v) glutaraldehyde solution. Glutaraldehyde was preferred to a 10% neutral formalin solution as formalin can cause flagellates to lose their flagella making identification difficult (Lund *et al*. 1958, Boney 1989). Samples were then placed in 60 ml settling chambers and allowed to settle for 24 hrs then counted following the Utermöhl method of cell enumeration as modified by Snow et al. (2000). Functional and dominant groups were categorised into flagellates, dinoflagellates, greens, blue-greens, diatoms, and euglenoids. It is important to note that all flagellates and the cyanobacteria (blue-greens) were included as phytoplankton in this study. Many flagellates do not contain chloroplasts and are more correctly classified as protozoans.

5.2.5 Benthic chlorophyll a

Four replicate intertidal benthic samples were collected from premarked locations (20 mm internal diameter circle) at low tide from each site by scraping a known area of surface sediment (<2 mm depth) just above the estuarine water level. Four subtidal samples were collected from each site using a 20 mm internal diameter corer attached to an extension pole and the surface sediment was scraped from the core. Both intertidal and subtidal samples were stored in the dark of a cooler box until they could be frozen. The samples were freeze-dried, approximately 0.1 g was added to 4 ml of 95% ethanol (Merck 4111) and then stored for 24 hours at 0 °C. Once the chlorophyll *a* had been extracted the samples were whirlimixed, filtered through Whatman GF/C filters and the extract was analysed on a Waters M-45 high performance liquid chromatograph (HPLC). Samples collected in November 2005 were analysed spectrophotometrically according to Nusch (1980) before and after acidification of the extracts with 0.1 N HCl.

5.2.6 Benthic diatom collection and identification

The epipelon was sampled based on the method described by Round (1981) and the details described in Bate et al. (2004). Samples were taken using a length of aluminium piping (~5 mm I.D.) that was drawn across the sediment and allowed to fill with a mixture of surface sediment and water.

This process was repeated up to five times in different positions in order to get a sample that was representative of the different micro-habitats. The mixture was stored in a plastic sample container (50 ml). In a field laboratory, some of the settled material was placed in a petri dish and 5 clean degreased cover slips (covering ca. 40% of the sediment surface) were placed on top of the wet sediment.

On the same day (ca. 1-2 hours later) the cover slips were carefully removed with as little sediment as possible. In this way only living cells that had attached to the cover slips were sampled.

The five cover slips from each sample were placed in glass bottles and transported to the laboratory. There is no time limit at this stage to process the diatoms further. To each glass bottle containing the cover slips, 2 ml of saturated $KMnO_4$ and 2 ml of 10 M HCl was added. This mixture was heated on a hot plate at ca. 60°C until the solution cleared (~20-40 mins) and became straw coloured. All acid cleaned samples were washed with distilled water using 5 consecutive spins (2000 rpm for 10 mins). Permanent light microscopy slides were made with 1-2 drops of diatom 'digest', placed onto an acid-washed cover slip (previously stored in ethanol) and allowed to dry in air. Cover slips treated in this manner allow the drop of sample to spread more evenly. Once completely dry, a small amount of Naphrax® mounting medium (Northern Biological Supplies, U.K.) was dotted onto a glass microscopy slide and the cover slip placed over it. Air trapped under the slide and the Naphrax were dispersed by heating the slide on a hot plate (~60°C). The Naphrax was allowed to dry for 2-3 days. The slides were logged and stored in a slide library, to form a permanent record.

Diatom frustules were examined under a Zeiss Axioplan light microscope with Differential Interference Contract (DIC) optics. Using a television camera (JVC KY-F3), images of the dominant taxa were visualised using the AnalySIS image analysis programme (©1999, Soft Imaging System GmbH). Diatom valves were counted in each sample using 1000x magnification until the obvious dominant was established. At least one of every taxon was made into a digital image. All the images were then printed and used in the counting procedure. This achieves two important aspects, (1) a digital image of each taxon and (2) a count of the total number of taxa. The nomenclature of Krammer & Lange-Bertalot (1986-91 and 2000) was used with a few exceptions associated with some taxonomic revisions suggested by Round et al. (1990). Other taxonomic works consulted included Archibald (1983), Hustedt (1976), Lange-Bertalot & Krammer (1989), Simonsen (1987) and various articles by R.E.M. Archibald, B.J. Cholnoky and F.R. Schoeman (e.g. Schoeman and Archibald 1976).

5.2.7 Data analyses

The Student's t-test was used to test for differences between the means of two variables. Analysis of variance (ANOVA) was used to test for differences between the means of more than two variables using the Tukey's Test for all pairwise multiple comparisons. The Pearson product moment correlation was used to measure the strength of association between two or more variables. The statistical software package Statistica (version 7) was used to perform statistical analyses. Surfer for Windows (Golden Software), version 6, was used to create filled contour profiles.

5.3 RESULTS

5.3.1 Water quality variables

Salinity profiles measured along the length of the estuary varied considerably from August 2005 to November 2005 (Figure5.2 and Figure 5.3).

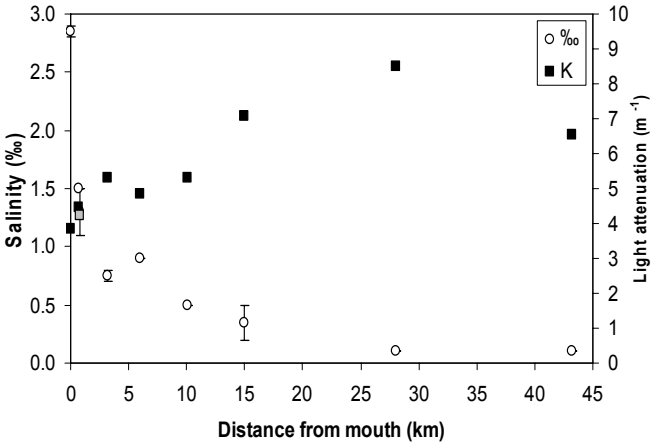


Figure 5.2 Vertically averaged salinity (‰) and light attenuation (K) measured along the longitudinal axis in the Berg Estuary, August 2005. Vertical bars represent standard error of the means. Symbols shaded grey represent samples collected in the blind arm, 0.8 km from the mouth of the estuary.

During August, vertically averaged salinity ranged from 5.1 ± 5.0 ‰ (28 km from the mouth) to 2.9 ± 0.1 ‰ at the mouth of the estuary indicating strong river flow.

The turbulent flow resulted in the water column being well mixed and the vertical salinity gradient never exceeded 0.5 ‰.

In November, there was a strong longitudinal salinity gradient, indicating a reduced river input relative to August, but the water column remained well mixed. Vertically averaged salinity ranged from 0.4 ± 0.0‰ at the head of the estuary (43 km from the mouth) to 32.9 ± 0.0‰ at the mouth of the estuary.

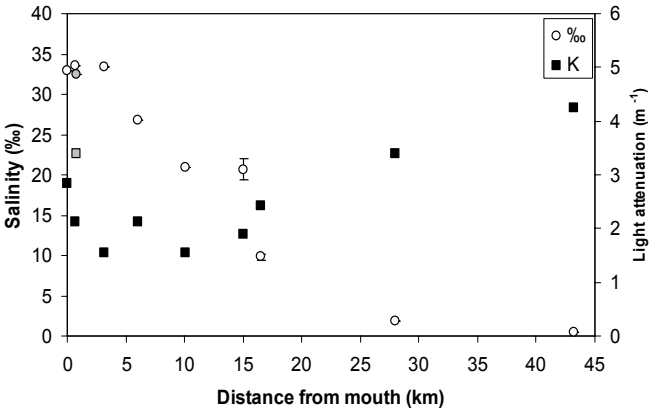


Figure 5.3 Vertically averaged salinity and light attenuation (K) measured along the longitudinal axis in the Berg Estuary, November 2005. Vertical bars represent standard error of the means. Symols shaded grey represent samples collected in the blind arm, 0.8 km from the mouth of the estuary.

Turbidity, expressed as light attenuation (K), was highest at sites nearest to the head of the estuary in August and November (Figures 5.2 and 5.3 respectively) where vertically averaged salinity was less than 10 ppt. Average K in August (5.58 ± 0.50 m^{-1}) was significantly higher than in November (2.56 ± 0.28 m^{-1}) (t = 5.36; p < 0.001; n = 10) as a result of the more turbulent flow. Light attenuation was negatively correlated to salinity in August (r = -0.79; p < 0.05; n = 9) indicating a decrease in turbidity as salinity increases.

A similar trend, although not significant, was found in November.

Temperature in the estuary was generally uniform above 5 km from the mouth, with a slight decrease near to the mouth of the estuary (Figure 5.4). Average temperature in August (15.3 ± 0.3 °C) was significantly lower than in November (20.2 ± 0.8 °C) (t = -5.28; p < 0.001; n = 10). Vertically averaged temperature ranged from 13.7 ± 0.1 °C at the mouth of the estuary to 16.5 ± 0.1 °C (6 km from the mouth) in August, and from 16.3 ± 0.0 °C 0.7 km from the mouth of the estuary to 22.4 ± 0.0 °C (10.1 km from the mouth) in November.

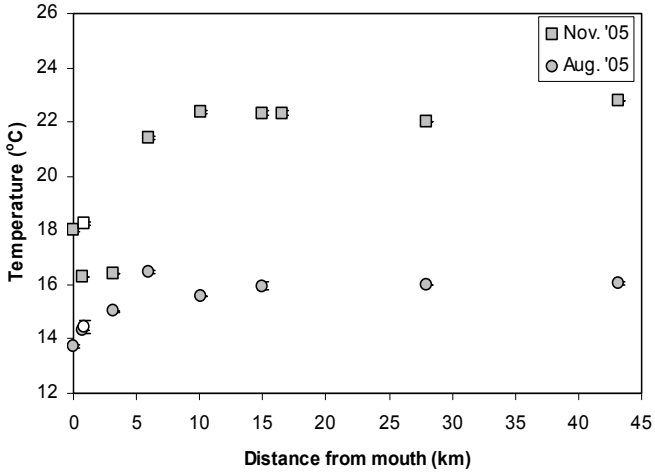


Figure 5.4 Vertically averaged temperature measured along the longitudinal axis in the Berg Estuary, August and November 2005. Vertical bars represent standard error of the means. The unshaded symbols represent measurements in the blind arm, 0.8 km from the mouth of the estuary.

In August, nutrients were measured in samples collected at 0.5 m and the bottom and the concentrations averaged. TOxN (nitrate + nitrite) and soluble reactive phosphorus showed gradual increases in concentrations with distance from the mouth (Figure 5.4).

TOxN and SRP ranged in concentrations from 36.9 to 63.5 µM and 0.1 to 1.2 µM respectively. Ammonium was highest at the mouth (4.8 µM) and closest to the head of the estuary (3.8 µM), and was lowest (1.0 µM) 15 km from the mouth (Figure 5.4).

According to Clark & Taljaard (2007), both NO_x and SRP increased as salinity increased in November 2005, which indicates a marine source of nutrients into the Berg Estuary during this period of low flow (Figure 5.6).

5.3.2 Biotic variables

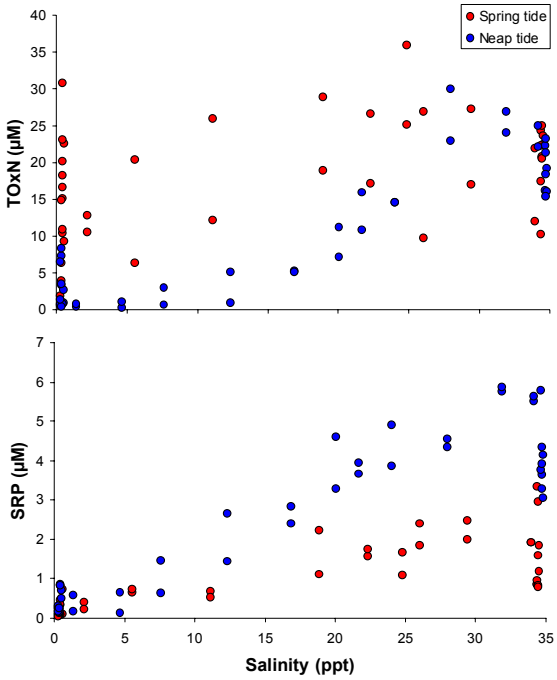


Figure 5.5 Total oxidised nitrogen (TOxN) and soluble reactive Phosphorus (SRP) concentrations in relation to salinity in the Berg Estuary, November 2005 (Data from Clark & Taljaard 2007).

The average concentration was significantly higher in August ($t = -7.88$; $n_{(Nov)} = 38$; $n_{(Aug)} = 78$; $P < 0.001$), particularly in the middle and lower reaches of the estuary. In August there was no discernable pattern and the concentration was evenly distributed throughout the estuary. Chlorophyll *a* concentration ranged from 4.13 ± 0.25 µg·l^{-1}, 15 km from the mouth, to 6.09 ± 0.77 µg·l^{-1} at the mouth.

There was a strong Pearson's correlation between chlorophyll *a* and ammonium ($r = 0.71$; $p < 0.01$; $n = 16$) and a negative correlation with TOxN ($r = -0.52$; $p < 0.05$; $n = 16$). In November there was a distinct increase in concentration with distance from the estuary mouth, ranging from 0.26 ± 0.04 µg·l^{-1} at the mouth to 6.63 ± 1.01 µg·l^{-1}, 43 km from the mouth.

Phytoplankton chlorophyll *a* concentration distribution differed considerably between the August and November 2005 sampling trips as a result of the difference in river flow entering the estuary (Figure 5.7).

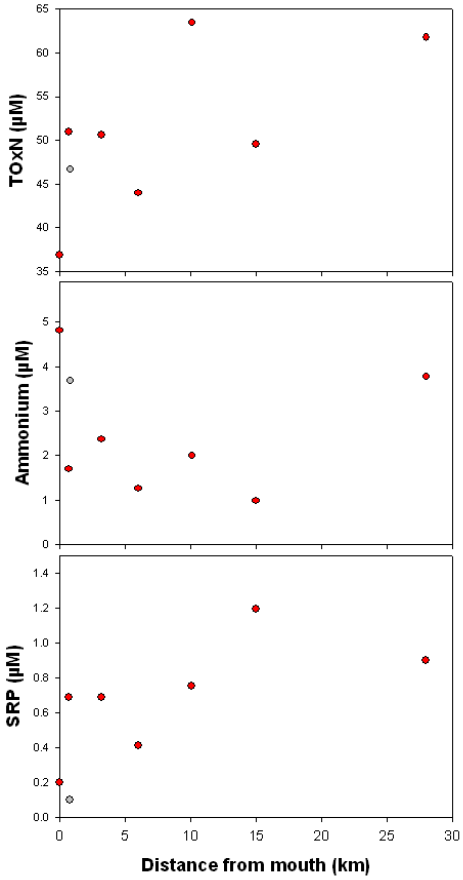


Figure 5.6 Total oxidised nitrogen (TOxN), ammonium and soluble reactive phosphorus (SRP) concentrations measured along the longitudinal axis in the Berg Estuary, August 2005. Concentrations are the average of 0.5 m and bottom samples. The symbols shaded grey represents measurements in the blind arm, 0.8 km from the mouth of the estuary.

Total oxidised nitrogen and soluble reactive phosphorus (Clark & Taljaard 2007) increased with salinity, which was the inverse of the phytoplankton chlorophyll *a*. Vertically averaged phytoplankton chlorophyll *a* measured in November was significantly correlated to light attenuation (r = 0.72; p < 0.05; n = 10) suggesting that phytoplankton cells either contributed to the turbidity, were closely associated to suspended solids or turbulence in the upper reaches of the estuary had resuspended fine sediments that were high in microalgal biomass.

In August 2005 the phytoplankton was dominated by flagellates (80.9%) and diatoms (17.8%).

The remaining three groups contributed less than 2 % of the phytoplankton cell density. The flagellates and diatoms had similar distribution patterns in the estuary and ranged from 5901 ± 1081 cells·ml^{-1} (28 km from the mouth) to 60527 ± 8934 cells·ml^{-1} (10.1 km from the mouth) and 3728 ± 674 cells·ml^{-1} (28 km from the mouth) to 16554 ± 4402 cells·ml^{-1} (10.1 km from the mouth) respectively (Figure 5.7). Using an all pairwise multiple comparison procedure (Tukey's Test) it was found that the density of flagellates at the two sites nearest to the head of the estuary (15 and 28 km) were significantly lower than at the next two sites closer to the mouth (6 and 10.1 km). This result indicates that the high density of flagellates did not enter the estuary, which would otherwise be evenly distributed throughout the upper reaches of the estuary.

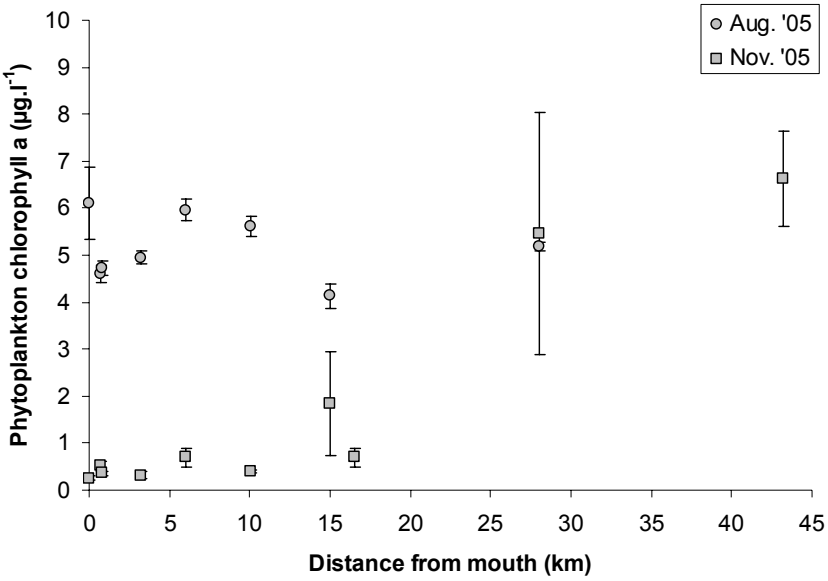


Figure 5.7 *Vertically averaged water column chlorophylla measured along the longitudinal axis in the Berg Estuary, August and November 2005. Vertical bars represent standard error of the means. The unshaded symbols represent measurements in the blind arm, 0.8 km from the mouth of the estuary.*

Instead, there was sufficient residence time for high cell densities to develop in the lower-middle reaches of the estuary (between 3.2 and 15 km from the mouth).

A Tukey's Test on diatom density found no significant differences between the sampling sites. However, the distribution pattern is similar to that of the flagellates, which suggests that the high densities found between 3.2 and 15 km from the estuary mouth also developed within the lower-middle reaches of the estuary.

Of the five phytoplankton groups, only the flagellates (r = 0.97; p < 0.001; n = 39), diatoms (r = 0.79; p < 0.001; n = 39) and cyanobacteria (r = 0.54; p < 0.001; n = 39) were significantly correlated to total cell density in the estuary. This is largely due to the high cell density of these groups in the surface water 10.1 km from the mouth (Figure 5.5). Total phytoplankton density was significantly correlated to phytoplankton chlorophyll *a* in the estuary (r = 0.34; p < 0.05; n = 39), which showed a slight increase in the lower-middle reaches of the estuary and at the mouth of the estuary (Figure 5.9).

Only the diatom group was significantly correlated to chlorophyll *a* (r = 0.44; p < 0.01; n = 39). It is possible that there was a high density of heterotrophic flagellates present resulting in the weak association between flagellate densities and chlorophyll *a*.

In November 2005, phytoplankton at the water surface was dominated by flagellates (79.2%) and diatoms (19.5%). The flagellate: diatom ratio ranged from 3.0 to 175.0 in the lower to middle reaches of the estuary respectively. High densities (21366 to 58429 cells·ml^{-1}) of flagellates were present throughout the estuary (Figure 5.10) and were largely dominated by a 'small' flagellate (Figure 5.11C).

In addition to the 'small' flagellates, a high density of 'large' flagellates (Figure 5.11A) was present in the estuary from 6.0 to 16.5 km from the mouth (3728 to 17714 cells·ml^{-1}), which contributed to the high flagellate: diatom ratio. A bloom of 'small' diatoms (Figure 5.11B) in the middle and upper reaches of the estuary (28 and 43.2 km), with densities in excess of 300 000 cells·ml^{-1} (Figure 5.10), resulted in the low flagellate: diatom ratio at these sites.

Microalgal biomass was highest in the middle and upper reaches of the estuary where chlorophyll *a* concentrations were 5.47 ± 2.59 µg·l^{-1} (28 km) and 6.63 ± 1.01 µg·l^{-1} (43.2 km) (Figure 5.12). The estuary was shallow (< 1 m) 28 km from the mouth, which possibly reduced tidal flow and provided a more stable habitat in the upper reaches of the estuary. There was a strong association between phytoplankton chlorophyll *a* and the diatoms (r = 5.67; p < 5.05; n = 10), dinoflagellates (r = 5.70; p < 5.05; n = 10) and chlorophytes (r = 5.74; p < 5.05; n = 10). This indicates that the peak in chlorophyll *a* in the upper reaches of the estuary, referred to as the river-estuary interface (REI), is primarily the result of chlorophyll *a* pigments from these three phytoplankton groups. As was the case in August, the weak association between flagellates and chlorophyll *a* may be the result of a high proportion of heterotrophic cells within the flagellate group.

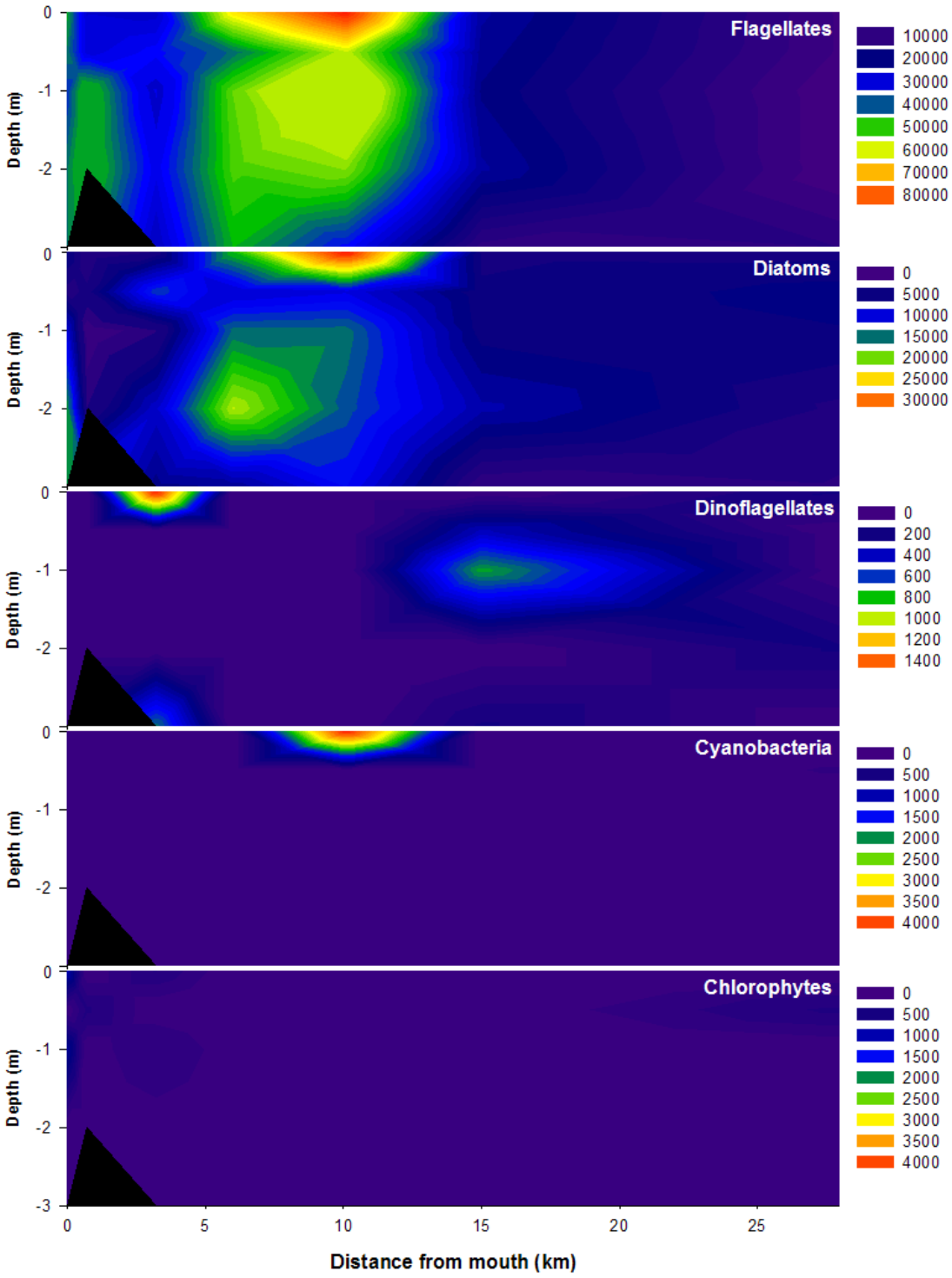


Figure 5.8 Filled contour diagrams of phytoplankton group cell density (cell·ml^{-1}) in the Berg Estuary, August 2005.

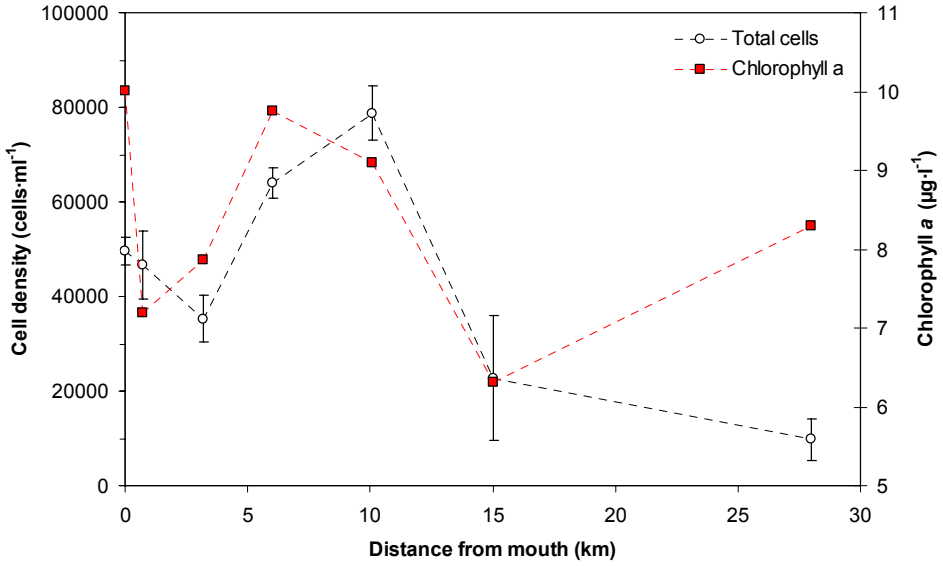


Figure 5.9 *Vertically averaged total phytoplankton cell density (cell·ml^{-1}) and chlorophyll a (µg·l^{-1}) measured in August 2005 along the longitudinal axis of the Berg Estuary. Vertical bars represent standard error of the means.*

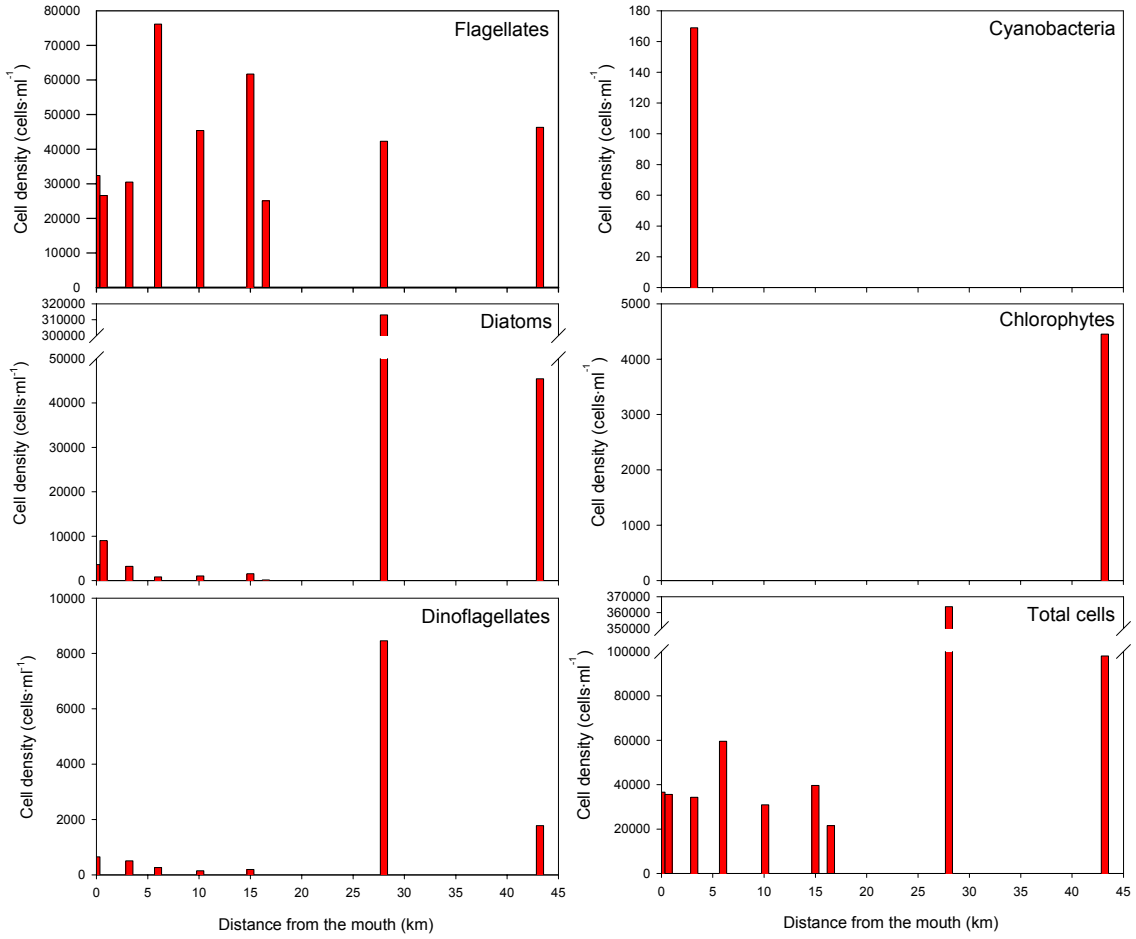


Figure 5.10 *Surface phytoplankton cell density (cell·ml^{-1}) measured in November 2005 along the longitudinal axis of the Berg Estuary.*

Benthic chlorophyll *a* concentration measured in August ranged from 2.6 to 31.5 $\mu g \cdot g^{-1}$ in the intertidal zone and 2.1 to 12.6 $\mu g \cdot g^{-1}$ in the subtidal zone (Figure 5.13). Highest concentrations were measured in the soft sediments in the blind arm near to the mouth of the estuary. In November the concentration ranged from 1.5 to 3.9 $\mu g \cdot g^{-1}$ in the intertidal zone and 5.8 to 14.9 $\mu g \cdot g^{-1}$ in the subtidal zone. Intertidal chlorophyll *a* was lowest at the two sites nearest to the mouth of the estuary and subtidal chlorophyll *a* increased significantly with distance from the mouth (r = 5.84; p <5.01; n = 10).

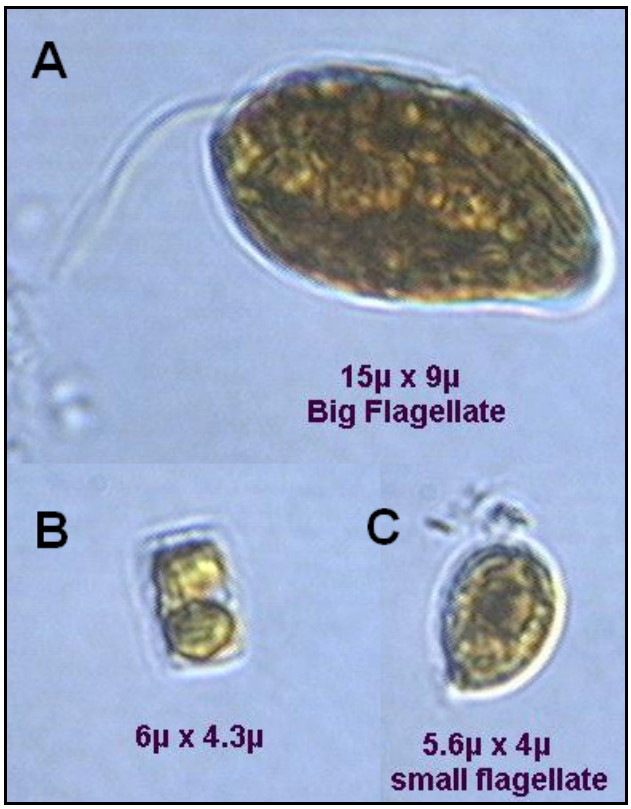


Figure 5.11 Dominant phytoplankton cells collected in November 2005 (A = large flagellate, B = small diatom and C = small flagellate).

There were 18 dominant benthic diatoms in the samples collected in August (Table 5.2) and 13 in November (Table 5.3). *Opephora minuta* was dominant at sites nearest to the mouth of the estuary in August and 15.1 km from the mouth in November. *Bacillaria paxillifer* var. *paxillifer* was present in the middle reaches of the estuary during both sampling sessions, not nearer than 6 km from the mouth. *Hippodonta* sp. was only dominant in the estuary in November at sites in the lower reaches of the estuary (from the mouth to 15.1 km). *Denticula sundaysensis* and *Planothidium delicatula* were examples of taxa dominant exclusively in sediment at sites nearest to the head of the estuary in November and August respectively.

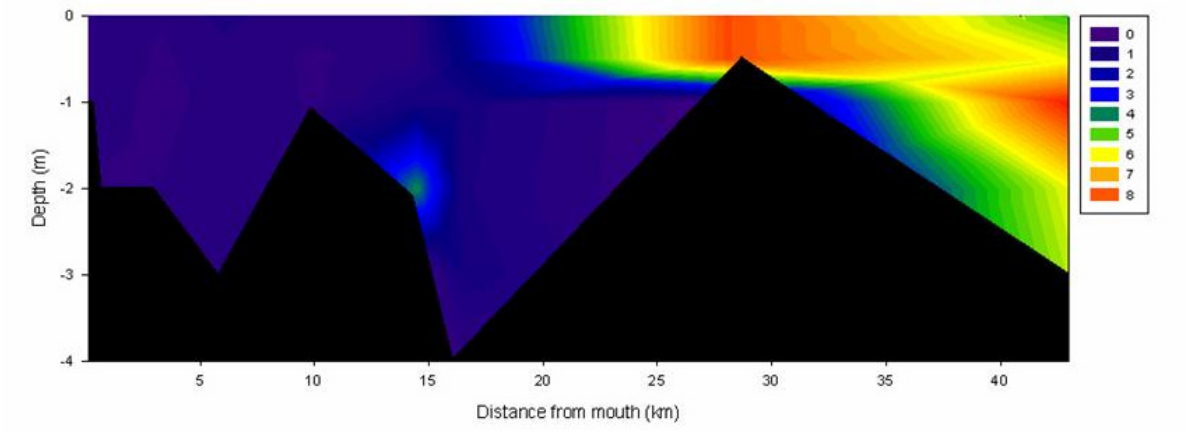


Figure 5.12 Filled contour diagram of phytoplankton chlorophyll a ($\mu g \cdot l^{-1}$) in the Berg Estuary, November 2005.

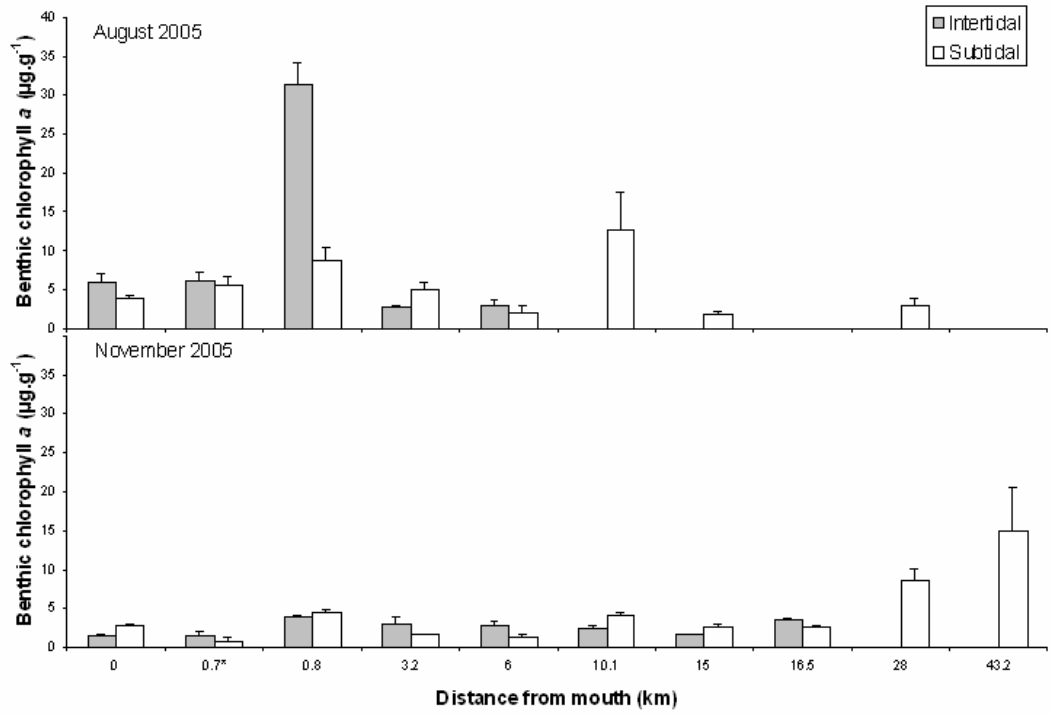


Figure 5.13 Intertidal and subtidal benthic chlorophyll a along the longitudinal axis of the Berg Estuary, August and November 2005.

5.4 DISCUSSION

Based on historical data (1975 to 1996), Clark & Taljaard (2007) described the Berg River Estuary as having a strongly seasonal hydrological regime. During winter, strong freshwater flushing generally limited saline intrusion during the flood tide up to the R27 Bridge (Figure 5.1, Schumann 2007). During summer the river inflow to the estuary was low and the system became marine-dominated. Characteristically estuarine water (salinities between 30 and 5 ppt) occurred between Kliphoek (site 7 in Figure 5.1) and 40 km from the mouth of the estuary.

The Berg Estuary was well mixed in August and November with distinct changes in environmental variables between the sampling sessions. Temperature followed local climatic conditions with highest temperatures recorded in November (~20°C) and lowest temperatures in August (~15°C). The water temperature in the lower reaches of the estuary was lower, by up to 6°C, than in the upper and middle reaches of the estuary because of seawater intrusion.

An important morphological feature in the Berg Estuary is the depth of the channel 28 km from the mouth. The estuary broadens in this area but is very shallow (0.5 m at low tide), which causes a slight bottle-neck in flow. In November the salinity was low at this site (<2 ppt) and increased to 10 ppt at the next site downstream (16.5 km). In addition, the attenuation of light through the water column was highest (>3 m^{-1}) at this site and further upstream.

Nutrient input into the estuary is moderate to high as a result of agricultural inputs. Clark & Taljaard (2007) stated that nitrogen in the estuary is mainly in the form of nitrate (NO_3), as opposed to nitrite (NO_2), which is typical of a well-oxygenated system. Turpie & Clark (2005) estimated that freshwater contains 60 to 90 µM total inorganic nitrogen in winter as opposed to 20 to 40 µM in summer. Under low flow conditions, nitrogen concentration is highest in the lower reaches of the estuary, decreasing upstream and in winter the concentration is highest in the upper reaches. Results of this study have confirmed this finding in August with a high concentration of TOxN (>60 µM) at the head and decreasing to less than 40 µM at the mouth of the estuary.

Soluble reactive phosphorus was generally low in the estuary (<1.2 µM) and the molar DIN:P ratio (i.e. [NO_3 + NO_2 + NH_4]:[PO_4]) was above 40 throughout the estuary and was >500 in the blind arm near to the mouth. This could be indicative of P-limited microalgal growth.

However, at high river flows the residence time of water in the estuary and turbulent currents may be more important limiting factors than nutrient supply.

Table 5.2 List of benthic diatom taxa collected in August 2005. The relative abundances of dominant species (dominance) and total number of species (# taxa) at each site are included.

Distance (km)	Zone	Taxon	Dominance (%)	# Taxa
0	Intertidal	Opephora minuta Cleve-Euler	45	23
		Catenula adhaerens (Mereschk.) Mereschk.	16	
		Odontella aurita (Lyngbye) Agardh	15	
	Subtidal	Fallacia sp. 03 D.G. Mann	38	33
		Catenula adhaerens (Mereschk.) Mereschk.	19	
		Opephora minuta Cleve-Euler	17	
0.7	Intertidal	Navicula gregaria (Donkin)	80	28
	Subtidal	None		10
0.8	Intertidal	Navicula salinicola Hustedt	34	35
		Cocconeis sp. 02 Ehrenberg	13	
		Navicula gregaria (Donkin)	11	
	Subtidal	Opephora minuta Cleve-Euler	23	18
		Catenula adhaerens (Mereschk.) Mereschk.	18	
3.2	Intertidal	Navicula gregaria (Donkin)	70	32
		Nitzschia aff perindistincta Cholnoky	17	
		Amphora subacutiuscula Schoeman	10	
	Subtidal	None		11
6	Intertidal	Amphora sp. 04	28	12
		Navicula gregaria (Donkin)	24	
		Amphora cf. copulata (Kütz.) Schoe. & Arch.	16	
		Fallacia sp. 03 D.G. Mann	12	
	Subtidal	Bacillaria paxillifer var. paxillifer (O.F. Muller) Hendey	35	24
		Amphora ovalis var. affinis (Kützing) V Heurck	13	
10.1	Intertidal	Rhopalodia brebissonii Krammer	15	40
		Fallacia sp. 03 D.G. Mann	10	
15	Intertidal	Navicula salinarum Grunow	22	30
		Fallacia sp. 03 D.G. Mann	15	
		Tryblionella hungarica (Grunow) D.G. Mann	15	
28	Intertidal	Hippodonta hungarica (Grun.) Lange-Bertalot et al.	32	23
		Bacillaria paxillifer var. paxillifer (O.F. Muller) Hendey	22	
		Planothidium delicatula (Kütz) Round & Buktiyarova	14	

Phytoplankton chlorophyll *a* measured in the Berg Estuary during this study was low, around 5-6 $\mu g.l^{-1}$ in winter (August) and mostly less than 1 $\mu g.l^{-1}$ in spring (November), which compares well to other Western Cape estuaries (Table 5.4). However, concentrations measured during this study are considerably higher than those recorded by the CSIR in 1989/1990 (Figure 5.14). Chla concentrations recorded in the latter study were in the region of 1.0-2.5 $\mu g.l^{-1}$ in winter (August) and even lower than this in summer (January: 0.1-0.4 $\mu g.l^{-1}$). The increase in Chla between 1989/1990 ties in well with the observed increase in nutrient concentrations over the same time period (Clark & Taljaard 2007).

It should also be noted that sampling was limited to two sessions, during high and low flow periods and does not include the transition phases between the two flows. The transition phases would be a period of medium flow and would be most likely to occur during spring and autumn, seasons when phytoplankton blooms are most likely to occur.

Table 5.3 List of benthic diatom taxa collected in November 2005. The relative abundances of dominant species (dominance) and total number of species (# taxa) at each site are included.

Distance (km)	Zone	Taxon	Dominance (%)	# Taxa
0	Intertidal	Hippodonta sp. Lange-Bertalot et al.	20	16
	Subtidal	Amphora coffeaeformis (Agardh) Kützing	60	14
0.7	Intertidal	None		
	Subtidal	None		
0.8	Intertidal	Cocconeis scutellum var. scutellum Ehrenberg	28	25
		Hippodonta sp. Lange-Bertalot et al.	22	
	Subtidal	Amphora acutiscula Kützing	85	29
3.2	Intertidal	Hippodonta sp. Lange-Bertalot et al.	80	25
	Subtidal	Hippodonta sp. Lange-Bertalot et al.	35	36
		Navicula sp. Bory	15	
		Navicula paeninsulae Cholnoky	10	
6	Intertidal	Navicula sp. Bory	60	28
		Nitzschia aremonica Archibald	20	
	Subtidal	Hippodonta sp. Lange-Bertalot et al.	33	20
		Bacillaria paxillifer var. paxillifer (O.F. Muller) Hendey	15	
10.1	Intertidal	Opephora minuta Cleve-Euler	85	19
	Subtidal	Bacillaria paxillifer var. paxillifer (O.F. Muller) Hendey	70	
		Hippodonta sp. Lange-Bertalot et al.	10	14
15	Intertidal	None		
	Subtidal	None		
16.5	Intertidal	Nitzschia sigma (Kützing) W.Smith	29	25
		Navicula salinicola Hustedt	23	
		Bacillaria paxillifer var. paxillifer (O.F. Muller) Hendey	20	
	Subtidal	Navicula salinicola Hustedt	90	19
28	Subtidal	Fragilaria elliptica Schumann	70	12
		Bacillaria paxillifer var. paxillifer (O.F. Muller) Hendey	23	
43.2	Subtidal	Fragilaria elliptica Schumann	75	25
		Denticula sundaysensis Archibald	15	

An estuarine freshwater requirement (EFR) study of the Olifants Estuary, a permanently open estuary approximately 125 km north of the Berg, was sampled in March and August 2004. Results showed that the system functions as a permanently open estuary and has a well developed, but not eutrophic, REI region (Bate 2006). The pattern of water-column chlorophyll *a* was similar to the Berg Estuary, decreasing from the head of the estuary to the mouth. Maximum chlorophyll *a* concentrations were low, generally less than 10 $\mu g.g^{-1}$, and were similar in March and August. This pattern of microalgal biomass appeared to be a function of macro-nutrient concentration and grazing pressure (Bate 2006).

In March 2004, flagellates were the most dominant phytoplankton group and, together with dinoflagellates, peaked in the middle reaches of the estuary. Diatoms increased in density with decreasing salinity, reaching a maximum 20.5 km from the mouth.

In August, the slightly higher salinity in the estuary indicated a slightly lower river water input. Flagellates were still the dominant group in the estuary but the density was much lower and, together with the diatoms, were evenly spread throughout the estuary.

Table 5.4 *Range of phytoplankton chlorophyll a concentrations published for South African estuaries (modified from Adams & Bate 1999). Western Cape estuaries are marked with an asterisk.*

	Chlorophyll a ($\mu g.l^{-1}$)		
Estuary	**Min**	**Max**	**Reference**
Olifants*	1.7	10.3	Bate 2006
Palmiet*	2	8	Branch & Day 1984
Bot*	0	6	Bally et al. 1985
Gamtoos	1.6	115.2	Snow 2000
Sundays	12	23	Hilmer & Bate 1991
Sundays	> 100 (bloom)		Hilmer & Bate 1990
Kariega	1	8	Allanson & Read 1995
Great Fish	0	52	Allanson & Read 1995
Great Fish	> 100 (bloom)		Lucas 1986
Keiskamma	0	19	Allanson & Read 1995
Nahoon	1	6	Campbell et al. 1991
Gqunube	5	15	Campbell et al. 1991
Kwelera	0	10	Campbell et al. 1991
St Lucia	0	16	Fielding et al. 1991

Phytoplankton dominance in permanently open estuaries is a function of inorganic nutrient concentration in the river water and favourable water retention times (days to weeks). A study of the Gamtoos Estuary (Snow *et al*. 2000) found that a flow of 1 $m^3 \cdot s^{-1}$ provided the ideal residence time, resulting in the highest vertically averaged chlorophyll *a* concentration (115 $\mu g \cdot l^{-1}$), or REI, in the upper reaches of the estuary. As river flow increased, the position of the REI moved further downstream and the chlorophyll a concentration decreased to 10 $\mu g \cdot l^{-1}$ at a flow of 30.5 $m^3 \cdot s^{-1}$. In this study, phytoplankton chlorophyll *a* in the Berg was highest in the lower reaches of the estuary in August. The highest vertically averaged chlorophyll *a* (10 $\mu g \cdot l^{-1}$) was located at the mouth of the estuary. In November the highest phytoplankton chlorophyll *a* was in the upper reaches of the estuary. There was a distinct decrease in concentration in the middle and lower reaches of the estuary below the shallow 28 km site. The highest vertically averaged chlorophyll *a* concentration (7 $\mu g \cdot l^{-1}$) was at the head of the estuary (43.2 km).

The Swan River Estuary, Western Australia, is similar to the Berg Estuary and could provide an invaluable glimpse into the effects of reduced river input on the phytoplankton community composition in the Berg. The Swan Estuary is in a Mediterranean climate, is micro-tidal and there are moderate to high nutrient loads from urban and rural catchments (Chan *et al*. 2002). The estuary is split into two distinct regions; the lower estuary (the mouth at Fremantle to the narrows near Perth) and the upper estuary (the narrows to the tidal limit).

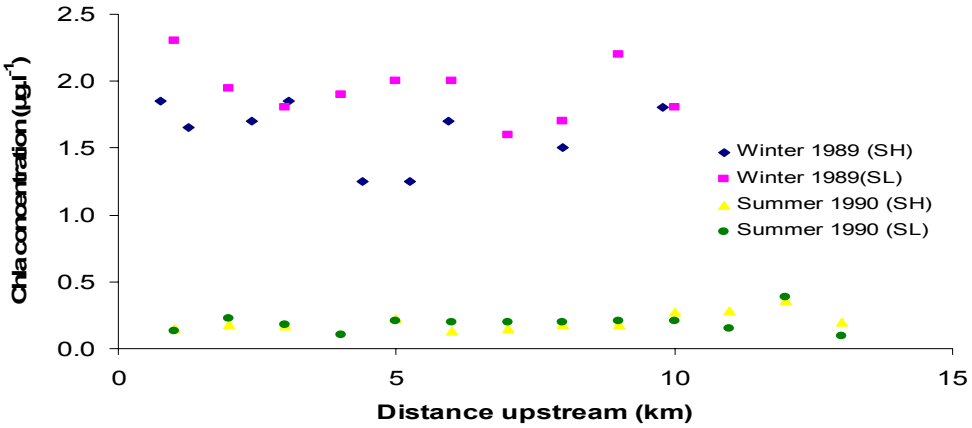


Figure 5.14 *Variation in vertically averaged Chlorophyll a concentrations in the Berg River estuary during September 1989 and January 1990.. SH and SL denotes samples collected at spring high and spring low tide respectively. (Data from CSIR).*

Salinity penetration is generally restricted at the narrows with the result that the upper estuary is much fresher than the lower estuary (Figure 5.15). The upper estuary has a series of deep pockets and these are reported to have higher concentrations of NH_4 and PO_4 (Rosser and Thompson 2001). A recognised pattern of bloom succession has been established within the upper reaches (Rosser and Thompson; Chan et al. 2002). Chlorophyte-dominated blooms occurred in early spring as river flow decreased. In mid summer the salinity in the upper estuary reached ~30 ppt and estuarine diatoms dominated giving way to dinophyte- and cryptophyte-dominated blooms through summer and autumn periods. As flow increased and salinity decreased in the upper estuary, freshwater diatoms became dominant.

A reduction in flow from dam construction and increased nutrient loads from anthropogenic inputs caused an increased occurrence and biomass of cyanobacteria blooms in the inner Neva Estuary, Gulf of Finland (Nikulina 2003).

Flagellates were dominant throughout the Berg Estuary in August and November, during high and reduced river inputs respectively. In August, the estuary was near-fresh throughout (<3 ppt) and a distinct phytoplankton community was present 15.1 km from the mouth, which consisted of flagellates (77%), diatoms (21%), cyanobacteria (1%) and chlorophytes (1%). In November a distinct community occurred 28 km from the mouth and consisted of flagellates (12%), a diatom-dominated bloom (86%) and dinoflagellates (2%).

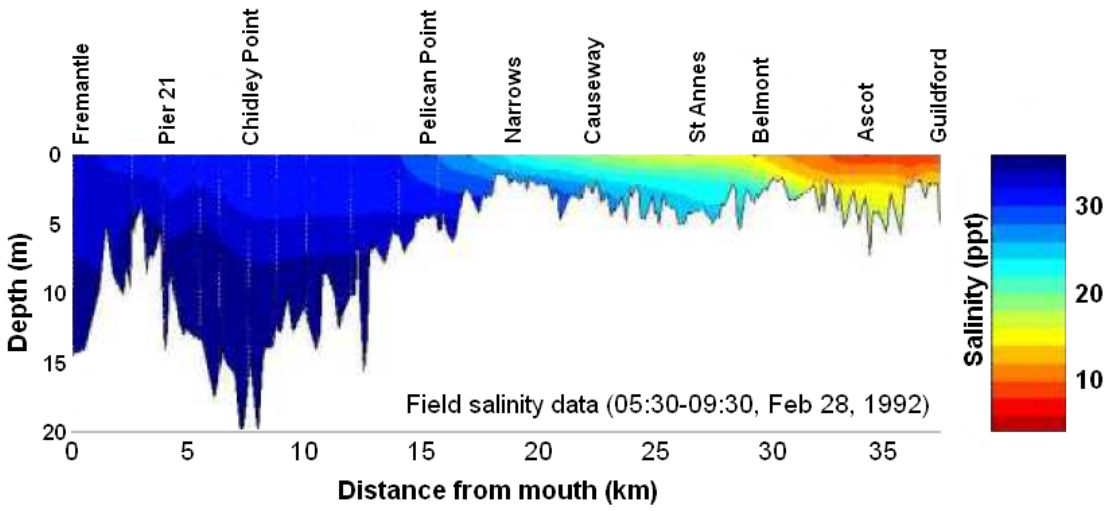


Figure 5.15 Filled contour plot of salinity in the Swan River Estuary, Western Australia (Chan et al. 2002).

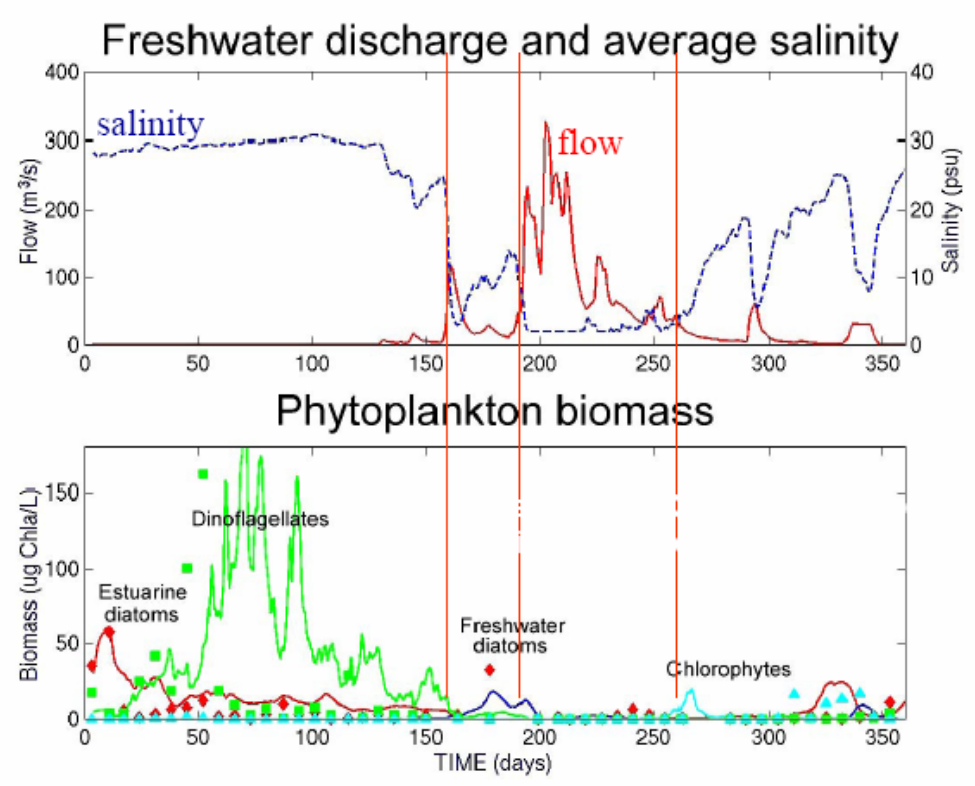


Figure 5.16 Phytoplankton group biomass in the upper reaches of the Swan River Estuary relative to freshwater discharge and salinity, 1995 (Chan et al. 2002).

Recent studies of the Keurbooms, Gamtoos, Swartkops, Sundays, Mngazana and Mngazi Estuaries found an intertidal chlorophyll a range of between 5.5 ± 5.3 $\mu g.g^{-1}$ and 86.6 ± 7.3 $\mu g.g^{-1}$ (Snow unpub. data). Benthic microalgal biomass followed a general distribution pattern based on the distributions of organic matter and fine sediment (<125 µm). Sites closest to the mouth and head of the estuaries were generally dominated by coarse sediment, were low in organic matter (<3% ash-free dry weight) and supported a low microalgal biomass. The process of flocculation, a process well described by Day (1981), leads to the settlement of organic matter, fine sediment particles, nutrients such as phosphorus and microalgal cells as floc in the REI zone. This results in sediment in the middle reaches of the estuaries becoming high in organic matter, dominated by fine sediment and supporting a high microalgal biomass. However, results from the Berg Estuary did not follow this generalised pattern (Figure 5.11) and could be the result of the turbulent tidal currents. The highest biomass was measured in the blind arm during high flow in August, probably because this site was protected from the turbulent currents in the main channel (river water flow and tidal exchange). In November, biomass was highest in the upper reaches of the estuary and decreased towards the mouth. It is possible that suspended microalgal cells were settling out of the water column but it is more likely that benthic microalgal biomass increased as tidal currents, and the associated resuspension of microalgal cells, decreased with distance from the mouth.

5.4.1 Responses to reduced flow

Salinity profiles measured during this study compared well to profiles reported by Schumann (2007). In August 2005, salinity was 2.9 ppt at the mouth and the 1 isohaline was close to site 4 (Figure 5.1). This is similar to the August 2003 spring low salinity profile (Schumann 2007), where flow was estimated to be 126.9 $m^3.s^{-1}$. The salinity profile during the spring low in November 2005 corresponded well with the profile measured during the spring low in November 2003.

Unfortunately, base flows had not been investigated at the time of submitting the 2004 annual report 2004 and had not been updated in the 2005 annual report. However, based on flows reported for May 2003, flow was less than 0.2 $m^3.s^{-1}$.

Data supplied on the Berg Estuary showed that its volume is 12 million m^3. The actual annual average flow for the period 15 Jan 1995 to 1 November 2003 was 17.9 $m^3 \cdot s^{-1}$. The maximum was 892.6 $m^3 \cdot s^{-1}$ while the minimum was 0.8 $m^3 \cdot s^{-1}$. Applying the 42-Day "Optimum Rule", the flow rate that would give the maximum biomass ± 10% is 3.3 $m^3 \cdot s^{-1}$. The actual flow data show that the optimum flow rate is exceeded 84% of the time and only within the optimum range for 6% of the time. For 10% of the time the flow rate is below the optimum.

The implication of this is that during periods of high river inflows, the estuary is freshwater dominated and the "REI" would be out to sea, i.e. water within the estuary would be replaced quicker than the time necessary for an REI to develop. This must be interpreted with caution, however. Studies of freshwater requirements are usually undertaken when there is a necessity to decrease the flow in rivers in order to send it elsewhere. The data provided in this report might easily be interpreted to imply that because the average flow rate is far above the optimum for primary productivity, that by decreasing the flow, the estuary might increase its productivity and therefore improve. Assumptions of this nature are incorrect because there would be a shift from the natural condition and the holistic ecology will be altered in a manner that cannot be predicted without a complete understanding of how it is functioning. For example, if the flow rate were to decrease, there will probably be an increase in the TDS of the water flowing out to sea. In an area already prone to "Red Tides", this could have negative impacts.

Phytoplankton biomass; a reduction in flow during winter is not likely to lead to a change in the phytoplankton biomass peak but the peak is expected to move slightly upstream of the mouth. During summer, a reduction in flow could lead to hypoxic conditions in deeper areas of the estuary, causing the release of PO_4 and NH_4 from the sediment.

This would favour the increased occurrence of phytoplankton blooms as experienced in the Swan-Canning Estuary.

Phytoplankton community structure; an estuarine diatom-dominated bloom occurred during the study so a reduced flow during summer is expected to increase the occurrence of these blooms. Chlorophytes were present in the river water so it is expected that they could bloom in spring as river flow begins to decrease. There has been no evidence of a dinoflagellate bloom but it is likely that this could occur during stable conditions in late summer.

Benthic biomass; Benthic chlorophyll *a* will increase in the estuary by up to 2 $mg \cdot m^{-2}$ in response to a reduction in river flow in winter due to decreased turbulent flow. Reduced flow in summer is likely to increase subtidal chlorophyll *a* in the upper reaches of the estuary but turbulent tide-driven currents will continue to limit benthic microalgal biomass in the lower reaches of the estuary.

Benthic community structure; there are insufficient data to predict the exact change in taxa in the estuary but the increased penetration of high salinity water and the more stable conditions of the water column is likely to support more marine species in the lower reaches and species that are better adapted to fine sediment and increased organic content in the upper reaches of the estuary.

5.4.2 Monitoring recommendations

Lying at the base of the estuarine food chain, micro-algae are a very important component of the estuarine ecosystem. They respond rapidly to changes in physico-chemical conditions particularly temperature and nutrients concentrations in the estuary and as such are good early warning indicators of changes in these parameters. Phytoplankton biomass (measured a chlorophyll a) is also easy and relatively inexpensive to monitor. Regrettably, little historic data on micro-algae is available for the Berg River estuary but changes observed between measurements made in 1989/1990 and the present day suggest that phytoplankton abundance has increased substantially, probably in response to observed increases in nutrient concentration over the same time period (Clark & Taljaard 2007). It is critical that micro-algal abundance is more carefully monitored in the future to isolate any changes induced by construction of the Berg River dam. Thus, it is recommended:

- Surface and bottom water samples are collected for analysis of Chlorophyll a concentration at at least 20 stations up the length of the estuary at the same time intervals (and same time) at which the nutrient samples are collected. This would entail collecting samples at spring high and low tide up the length of the estuary during summer (January) and winter (August) for the first fives years following construction of the Berg River dam, reduced to bi-annually (once every two years) for 10 years following this, and then to a five-yearly interval thereafter.
- Intertidal and subtidal sediment samples are collected from a series of 10 stations up the length of the estuary for analysis of benthic microalgae (measured as Chla concentration) at the same time intervals as for water column chlorophyll a.

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CHAPTER 6 - SUBMERGED MACROPHYTES AND MACROALGAE

B.M. Clark, K. Hutchings, M. Joske & A. Duffel-Canham

6.1 INTRODUCTION

A detailed account of the supra-tidal and emergent vegetation of the Berg Estuary is provided in the next chapter of this volume (Boucher & Jones 2007 – BRBMPR Vol. 3 Chapter 7). This chapter addresses just the intertidal and submerged vegetation, which in the case of the Berg estuary includes four species of algae found predominantly in the intertidal zone and two macrophytes species that occur both in the subtidal and the intertidal.

As is the case with the other components of the Berg River Baseline Monitoring Programme the primary objective of this study was to describe the natural and present state, including the natural variability, of those chemical, physical and biological characteristics of the river and its hydraulically linked systems (i.e. estuary, floodplains and groundwater) that are most likely to be affected by changes imposed after the construction of the Berg River Dam, and to provide future recommendations for monitoring.

6.2 SUBMERGED MACROPHYTES

6.2.1 Background

Seagrasses (or eelgrasses) usually form a conspicuous part of most estuarine flora and are found in all types of environments from arctic to tropical areas (Talbot and Bate, 1987). *Zostera capensis* Setchell (eelgrass) is the only known representative of the genus *Zostera* to occur in Southern Africa (Edgecumbe 1980). It grows in estuaries and mudflats and provides shelter for a number of different organisms and is an important source of nutrients for the ecosystem (Edgecumbe, 1980). It also helps to stabilize marsh sediments. Dense meadows of eelgrass leaves increase rates of sedimentation and the rhizome and root networks bind the substratum together thereby reducing sediment erosion. The roots also allow oxygen to penetrate into otherwise impermeable sediments. The penetration of *Zostera* roots into the sediment aerates the upper layers and provides a more favourable habitat for burrowing animals. Eelgrass beds are widely recognized to be important spawning and nursery areas for many species of fish (Beckley 1983, Hanekom & Baird 1984, Ter Morshuizen & Whitfield 1994).

The flow of freshwater into estuaries creates a salinity gradient which determines the distribution of different macrophyte communities (Adams *et al*. 1992). *Zostera capensis* is usually confined to the lower and middle reaches of permanently open estuaries (Talbot and Bate, 1987) but in systems that experience reduced freshwater input, *Zostera* may spread into the upper reaches (Adams *et al*. 1992). In addition the availability of nutrients and light causes a dynamic relationship between seagrass (and other submerged macrophytes) and phytoplankton. For example, if the nutrient levels are high, phytoplankton tends to bloom thus causing high turbidity and preventing light from reaching the seagrass which then has reduced growth. Nutrient uptake by *Zostera* from the water column usually occurs through the leaves and from interstitial water via the rhizomes. Nitrogen is usually the limiting element and is most often absorbed as ammonium. In sandy sediments, phosphate may be a limiting factor due to adsorption onto sediment particles (Short, 1987). Laboratory studies showed that maximum growth of *Zostera capensis* occurs at a salinity of between 15 and 35 ppt (Adams & Bate, 1994). *Zostera* plants of other species in the UK have been reported to grow optimally in salinities ranging from 10 to 39 parts per thousand (McRoy, 1966)

No previous detailed studies have been done in the Berg River estuary to assess the abundance and distribution of *Zostera capensis.* Owing to its importance in the estuarine ecosystem and its sensitivity to changes in the physico-chemical environment, surveys were made of the distribution and abundance of *Zostera* in the Berg estuary for the Berg River Baseline Monitoring Study.

These data are useful as a benchmark of the current biomass and distributional extent of *Zostera* in the system.

A number of other rooted macrophytes species are known to occur in other estuaries in the region including *Potamageton pectinatus* and *Ruppia cirrhosa* (Adams *et al*. 1999), some of which have actually been reported in the Berg (Boucher & Jones 2007, BRBMPR Vol. 3, Chapter 5). These two species both show a preference for lower salinities than *Zostera capensis*, and a preference for slower flowing waters than are typically found in the Berg (Adams *et al*. 1992, 1999,Adams & Bate 1994). Preliminary surveys in the Berg as part of this study indicated that the abundance of these species was extremely low (present in very small localised patches only) and hence were not surveyed in detail.

6.2.2 Methods

Eleven transects were surveyed in the lower portion of the estuary from near the mouth to 16 km upstream (immediately above the farm Kliphoek (Figure 6.1) during November 2005. Each transect was run from bank to bank across the substratum of the channel, perpendicular to the direction of flow. The position of and distances covered by *Zostera capensis* on each transect was recorded on an underwater slate, and quantitative samples (minimum two) were collected from each patch of *Zostera* encountered by removing the above ground biomass within a 0.0625 m^2 quadrat. These samples were returned to the laboratory, blotted dry and weighed to obtain above ground wet mass, and then dried for 48 hours to obtain an above ground dry mass for each quadrat. Data for individual quadrats were averaged to obtain a mean biomass per square meter along each transect. Start and end points and lengths of each transect are included in Table 6.1.

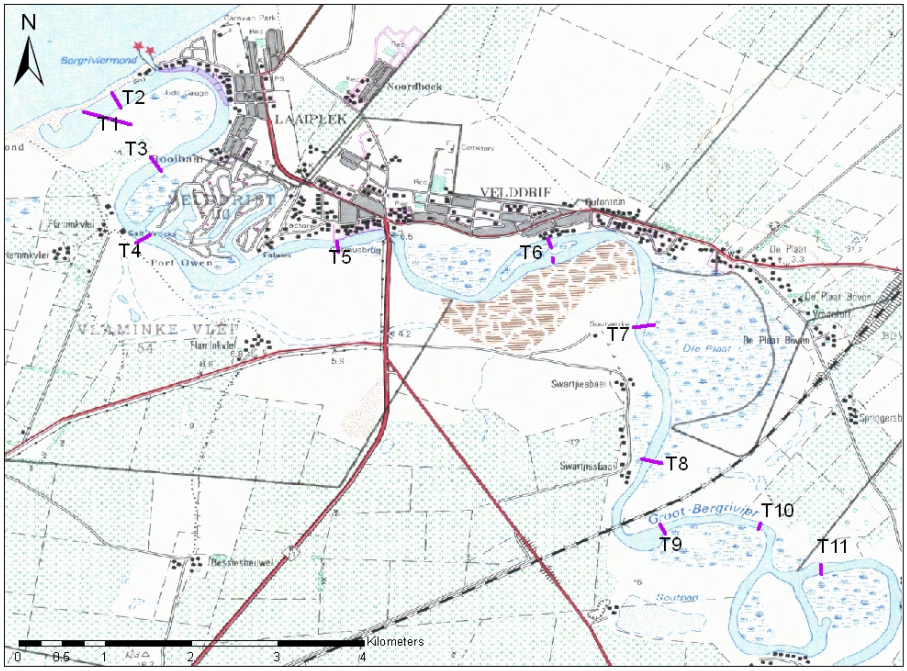


Figure 6.1 Transects used for assessment of the abundance and biomass of Zostera capensis (T1-T11) and various algae species (A1-A5) in the Berg estuary.

Table 6.1 Coordinates of the start and end points, and lengths of the eleven transects used for surveying of Zostera capensis biomass in the Berg estuary.

Transect	North Bank		South Bank		Transect	Distance From
No.	Latitude	Longitude	Latitude	Longitude	Length (M)	Mouth (M)
T1	32.77467[1]	18.13767[1]	32.77600[2]	18.14267[2]	475	800
T2	32.77266[1]	18.14066[1]	32.77433[2]	18.14167[2]	203	525
T3	32.78083	18.14583	32.77933	18.14467	194	1855
T4	32.78750	18.14467	32.78833	18.14317	155	2925
T5	32.78817	18.16417	32.78933	18.16433	132	5130
T6a	32.78783	18.18617	32.78883	18.18650	113	7850
T6b	32.78983	18.18667	32.79033	18.18667	58	7850
T7	32.79683	18.19717	32.79717	18.19500	204	9679
T8	32.81133	18.19800	32.81083	18.19583	208	11300
T9	32.81767	18.19783	32.81867	18.19833	119	12735
T10	32.81750	18.20833	32.81817	18.20800	83	13710
T11	32.82183	18.21450	32.82283	18.21467	113	14825

1. West bank
2. East bank

6.2.3 Result and Discussion

Mean biomass of *Zostera* on each of the 11 transects surveyed in the lower Berg estuary is depicted in Figure 6.2 and Figure 6.3.

Zostera was in fact only recorded on four of the 11 transects, on the edges of the channel only (intertidal and shallow subtidal areas only). Highest biomass of *Zostera* was recorded in what is now a blind lagoon near the mouth of the estuary, but what was once the original mouth of the system (Transects 1 and 2). Above ground wet biomass of Zostera where it was present on these transects averaged 300-2 000 $g.m^{-2}$, whilst dry biomass was in the order of 70-400 $g.m^{-2}$. Further up the estuary (Transects 5 and 6 – 5.130 and 7.850 km up from the mouth respectively), *Zostera* was again recorded on the channel margins. Above ground wet biomass of *Zostera* on these two transects was in the order of 200 – 1 700 $g.m^{-2}$, while dry biomass ranged from 70-430 $g.m^{-2}$. No *Zostera* was recorded on any of the intervening transects at any point further upstream from this point.

Submerged macrophytes are reportedly highly variable both on spatial and temporal scales (Adams *et al*. 1999). Fluctuations in salinity, turbidity, and sediment supply appear to be the primary factors responsible for variations in biomass and distribution of submerged macrophytes. For example, Talbot *et al*. (1990) reports that heavy floods in the Nahoon and Kwelera estuaries (occurring approximately every 15 years) completely eliminated *Zostera* beds in these systems, moderate sized floods (2-3 year frequency) and associated heavy fluvial deposits tended to smother these macrophytes beds, while small intra-annual floods tended to smother beds temporarily impairing growth rates and shortening leaf lengths.

Any reduction in flooding frequency or reduction in fluvial sediment supply (as can be expected in the Berg estuary) can by contrast result in the expansion and increase in growth rate of Zostera as well as other macrophytes species, as has been observed in the Kromme estuary (Adams & Talbot 1992).

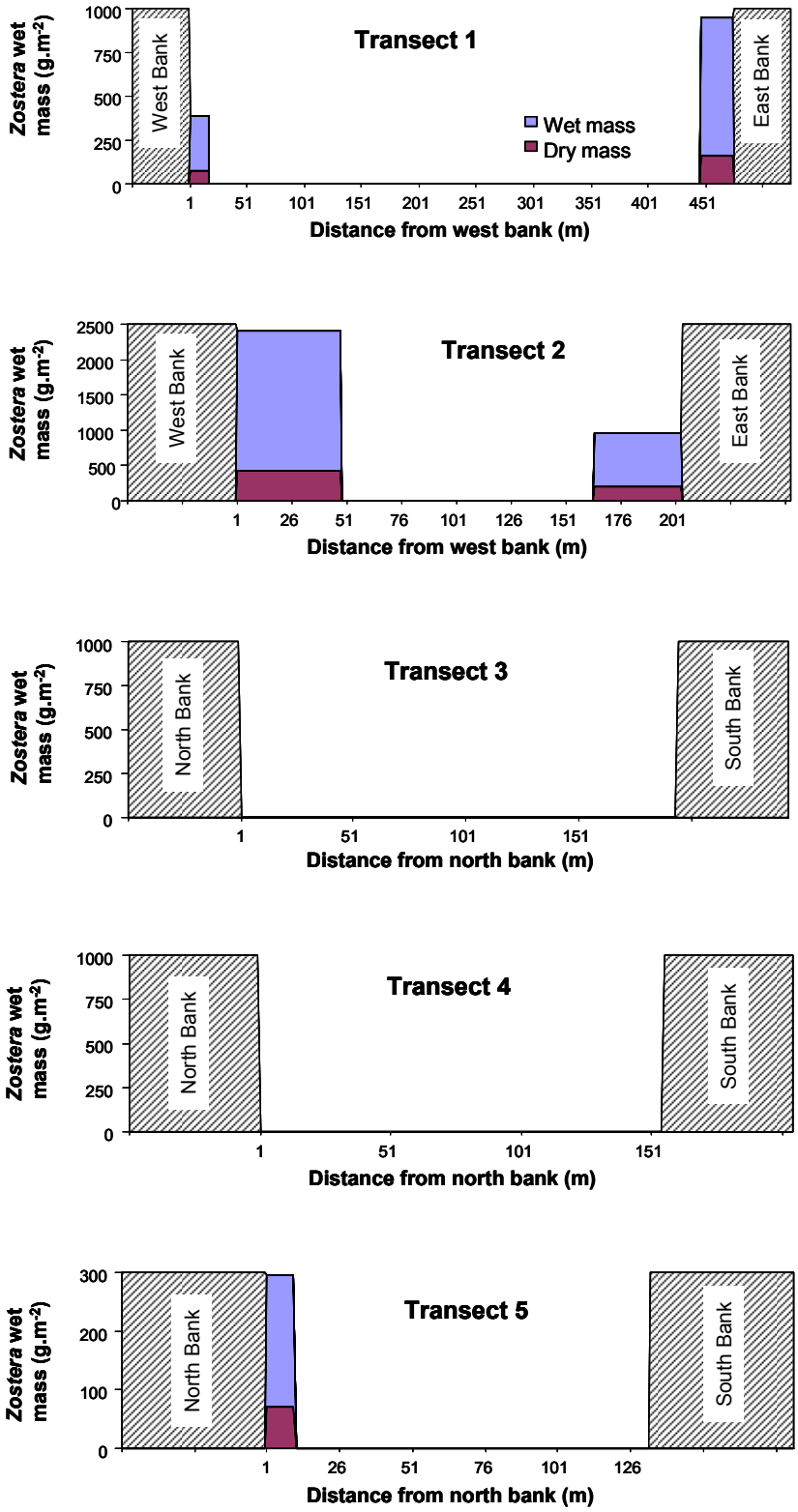


Figure 6.2 Biomass of Zostera capensis on transects 1-5 on the Berg estuary

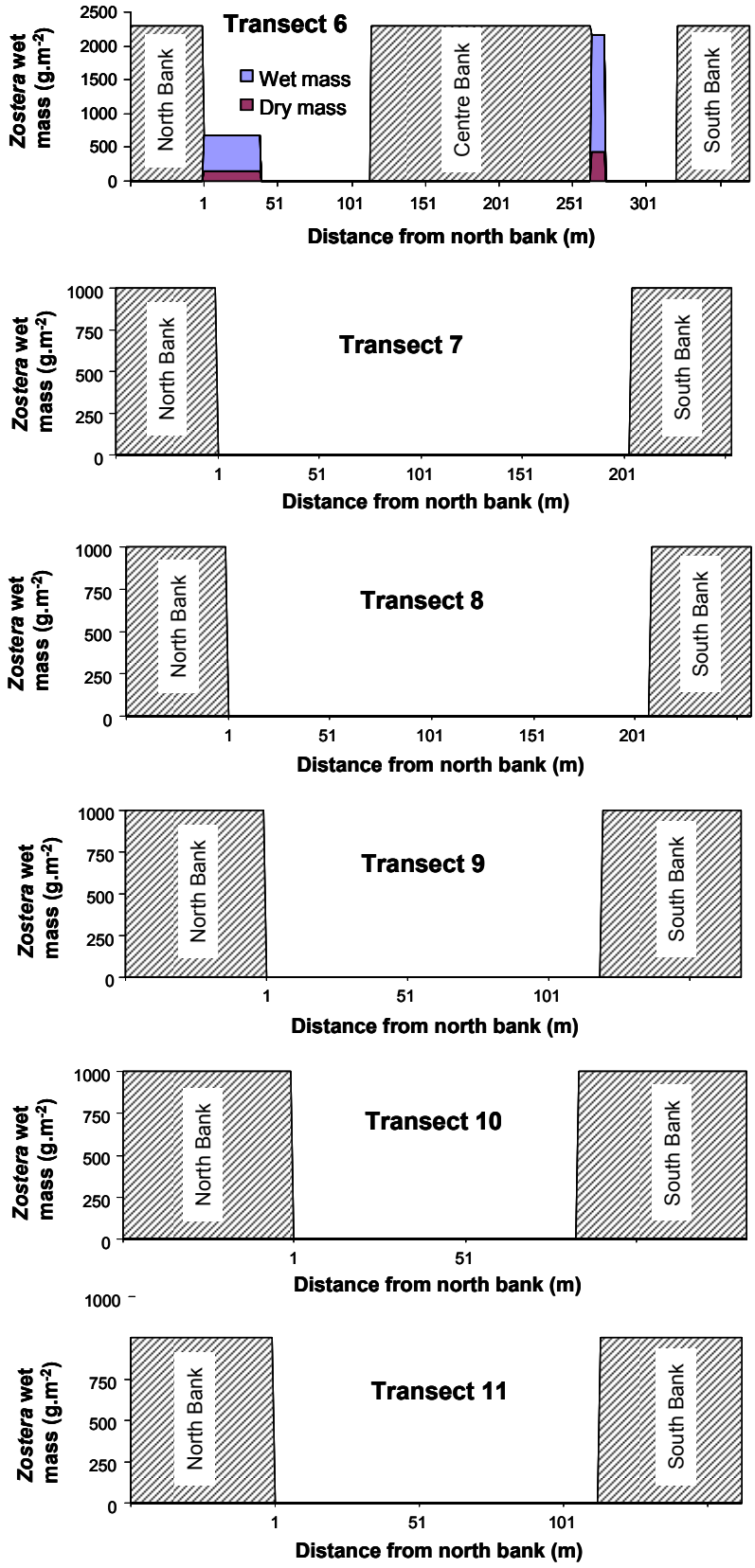


Figure 6.3 Biomass of Zostera capensis on Transects 6-11 in the Berg estary.

Zostera beds in the Berg estuary seem to be confined to the extreme lower reaches of the system and are most abundant in area where flow rates are lowest – i.e. in the intertidal and shallow subtidal areas in the old mouth which is now a blind lagoon and in a subsidiary channel above the Carinus Bridge. The primary factors limiting growth and distribution of *Zostera* in the Berg estuary include high flow rates, turbidity, and salinity.

The construction of the Berg River dam is likely to have a relatively modest impact on the hydrology of the system - changes in base flow are likely to be modest (Howard & Ractliffe 2007), and flood peaks (from small to large floods) are expected to decline by no more than 10% (Beck & Basson 2007). These changes may nonetheless have a significant impact on the distribution and abundance of submerged macrophytes in the Berg estuary, with any change likely to be positive (i.e. an increase in abundance). As such, occasional monitoring (every 5 years) of *Zostera* and other macrophytes beds in the Berg estuary is probably warranted.

6.3 MACROALGAE

6.3.1 Background

Previous scientific research relating to the occurrence of algae in the Berg River, either the estuary or the river itself, is scarce. Kalejta and Hockey (1991) noted that there was a marked cyclical growth of the alga *Cladophora* sp. at some of their study sites in the Berg River estuary, while O'Callaghan (1994) and Morant *et al*. (in press) make no reference to algae in the estuary.

6.3.2 Selection of sites and methods

An initial survey of the Berg River estuary was undertaken in November 2002. Five sampling sites were selected corresponding to the transect positions from which water quality data have been collected (see Figure 3.2, BRBMR Vol. 3 Chapter 3,). Two of these (Sites 2 and 3) are the same as those chosen by Kalejta and Hockey (1991) in their study of benthic invertebrates in the Berg River estuary. Comparison with their findings of algal coverage and dry weight are useful. Sites 4 and 5 are at increasing distances from the mouth and were selected as control sites to reflect probable absolute limits for algal occurrence. The algal sampling sites are shown in Figure 6.4 and basic details of the sites are given in Table 6.2.

Table 6.2 Details of algal sampling sites in the Berg River estuary

Algae site number	Water quality transect equivalent	Description	Distance from the mouth (km)
Site 1	BO2	Jetty at the Fish Factory in Laaiplek	0.6
Site 2	BO7	Riviera Hotel in Velddrif	5.75
Site 3	B10	Die Plaat	11.05
Site 4	B13	Boat wreck at Melkplaas	16.20
Site 5	B14	Jetty at blue awning house	21.50

Sites 1, 2 and 3 have fairly long tidal zones – approximately 20 m. Sites 4 and 5 have very short tidal zones, being steep banks on sides of the estuary channel. There is a minimal tidal range at the latter sites and therefore less area for algae to accumulate.
Sites 4 and 5 are encroached by dense stands of *Phragmites australis* and large seasonal accumulations of the aquatic angiosperm *Eichhornia crassipes* were seen here.
At each site seven $1m^2$ quadrats were spaced evenly along a transect from the spring high to spring low water mark.

The percentage cover of algae was assessed in each quadrat and algae were collected and preserved with a 4% formalin solution for identification in the laboratory. The algae were then dried in an oven at 60^oC and weighed. Algal assessments were done twice monthly on each spring tide.

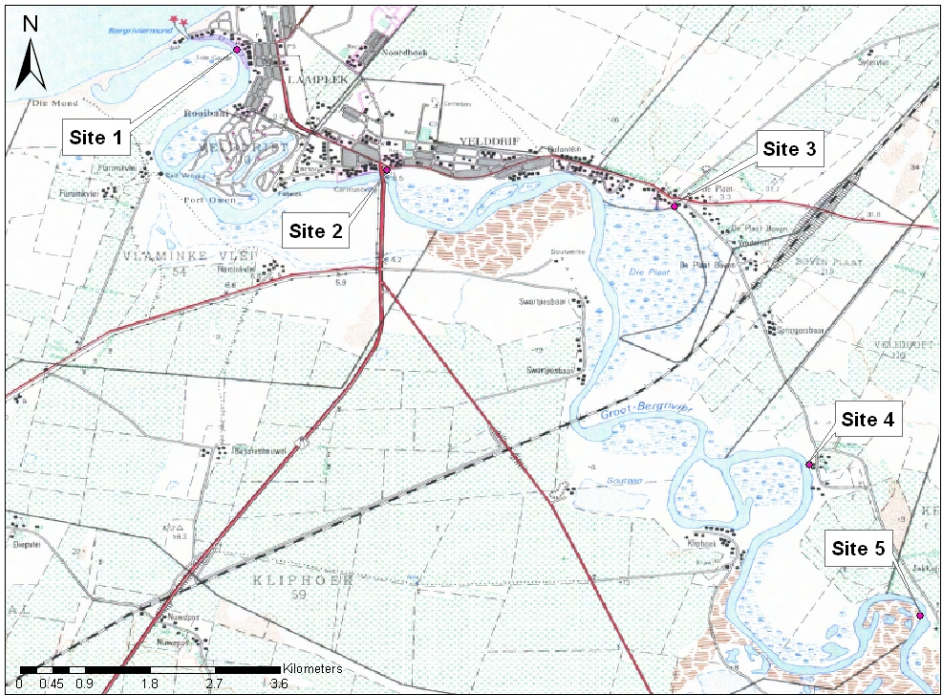


Figure 6.4 Algae sampling sites along the Berg River estuary.

6.3.3 Results

Species composition

Four species of algae have been recorded in this study. These are the marine and estuarine algae – *Enteromorpha prolifera*, *E. flexuosa*, (Chlorophyta), *Ectocarpus siliculosa* (Phaeophyta) and *Caloglossa leprieuri* (Rhodophyta). Identifications were confirmed by Dr Herre Stegenga of the University of Leiden, Netherlands. This study marks the first finding of *E. flexuosa* in southern Africa, although it is a common species in northern European estuaries. The two *Enteromorpha* species always had the greatest percentage cover and the highest biomass. It was not considered necessary to ascertain the difference in biomass of each *Enteromorpha* species, as this can only be achieved by microscopic examination, which is not currently part of this study.

Kalejta and Hockey (1991) noted that the alga found in their study was a *Cladophora* sp. (identified by Mr. Richard Simons in the Sea Fisheries Laboratory, Botany Department, University of Cape Town). The fact that no *Cladophora* sp. has been found to date can not be seen as significant as, unfortunately, the genus *Cladophora* has a number of species both marine and/or freshwater.

Since the original identification did not confirm the actual species found it cannot indicate any salinity change in the estuary over time.

Algal cover and biomass

The average monthly percentage cover and dry mass of algae at sites 1–3 is shown in Figure 6.5 and Figure 6.6 respectively. Algae percentage cover and biomass both increased from sites 1- 3, with 100% cover never recorded at site 1, occasionally at site 2 and frequently occurring at site 3.

Maximum biomass (dry weight) was around 100 $g.m^{-2}$ at sites 1 and 2 and frequently above 500 $g. m^{-2}$ peaking at nearly 1 $kg.m^{-2}$ at site 3.

Variations in both algae cover and biomass were clearly seasonal, peaking during the summer months and being absent from the estuary during the midwinter period.

The duration of the absence of algae at these sites however differed during each year of monitoring (Figure 6.5 and Figure 6.6), being absent from the estuary for much of 2003 (8 months), and persisting for most of the year (8-9 months) during the following two years. The percentage cover and biomass at all three sites was low during the 2002-2003 summer, intermediate during the summer of 2003-2004 and peaked during the 2004-2005 summer period. At sites 1 and 2, algae occurred predominately in the midshore area (quadrats 3-5) whilst at site 3, coverage was frequently 100% in all seven quadrats (Figure 6.5 and Figure 6.6).

Algae occurrence and density at sites 4 and 5 was insufficient to accurately estimate using 1 m^2 quadrats and only presence or absence was recorded. At site 4, 16.2 km from the estuary mouth, algae were recorded during November 2002, February 2003, December 2003-March 2004, July 2004 and October-March 2005. At site 5 over 21 km from the mouth, algae were only observed during July, October and November 2004 and again in March 2005.

6.3.4 Discussion

A variety of environmental factors will influence the distribution and density of algae within the Berg River estuary. The most important will be the temperature, salinity, current strength, availability of light (influenced by day length and water turbidity) and nutrients (inorganic nitrogen, phosphate and silicate).

All algae recorded in this study are common euryhaline estuarine species that tolerate salinities between 15 and 35 practical salinity units (psu) and a range of temperatures. Water temperatures during the summer months (November-February) are usually low at sites 1 and 2 (13-23 ^oC) due to the influence of cool up-welled marine water and generally warmer from site 3 upstream (21-25 ^oC) where solar heating and the mixing of warmer river water takes effect (see Figure 3.17 - Schumann 2007, BRBMPR Vol. 3, Chapter 3). With unlimited light and nutrients, algae growth usually increases with increasing temperature within the tolerable thermal range, and this is a possible contributing factor to the much higher algal percentage cover and biomass observed at site 3 compared to sites 1 and 2. Salinities in the Berg River Estuary from the mouth up to site 3 fall within the range 20-35 psu for most of the year but decrease substantially to less than 10 psu during the winter spates (Figure 3.18 - Schumann 2007, BRBMPR Vol. 3, Chapter 3). Upstream of this, in the region of the estuary where sites 4 and 5 are situated, salinities are frequently less than 20 psu for most of the year, only exceeding this value during the late summer period (Figure 3.18 - Schumann 2007, BRBMPR Vol. 3, Chapter 3). This salinity decrease in the region of sites 4 and 5 are most likely instrumental in limiting the distribution of algae upstream.

Most algae require a firm substrate for initial cell attachment and subsequent filament growth. Commonly, an increase in light and temperature will initiate algal growth.

Once growth commences, the increase in drag on the algal thallus may cause it to be pulled off the initial growth site. The algae continues growing whilst unattached, but its position is now controlled by wind and flow. Almost all the algae seen in the Berg River estuary appeared to be free floating and their major initial growth substrate is not known.

The large intertidal flood plains at Die Plaat (site 3) experiences weak currents under normal summer (low flow) conditions, allowing algae to accumulate whilst stronger tidal currents at sites 1 and 2 probably reduce the quantity of algae by flushing it out the mouth. In a normal estuarine flow regime, algae are flushed from the system at the time of seasonal flows. Re-colonisation by new plants will occur with a seasonal “trigger” of light and temperature.

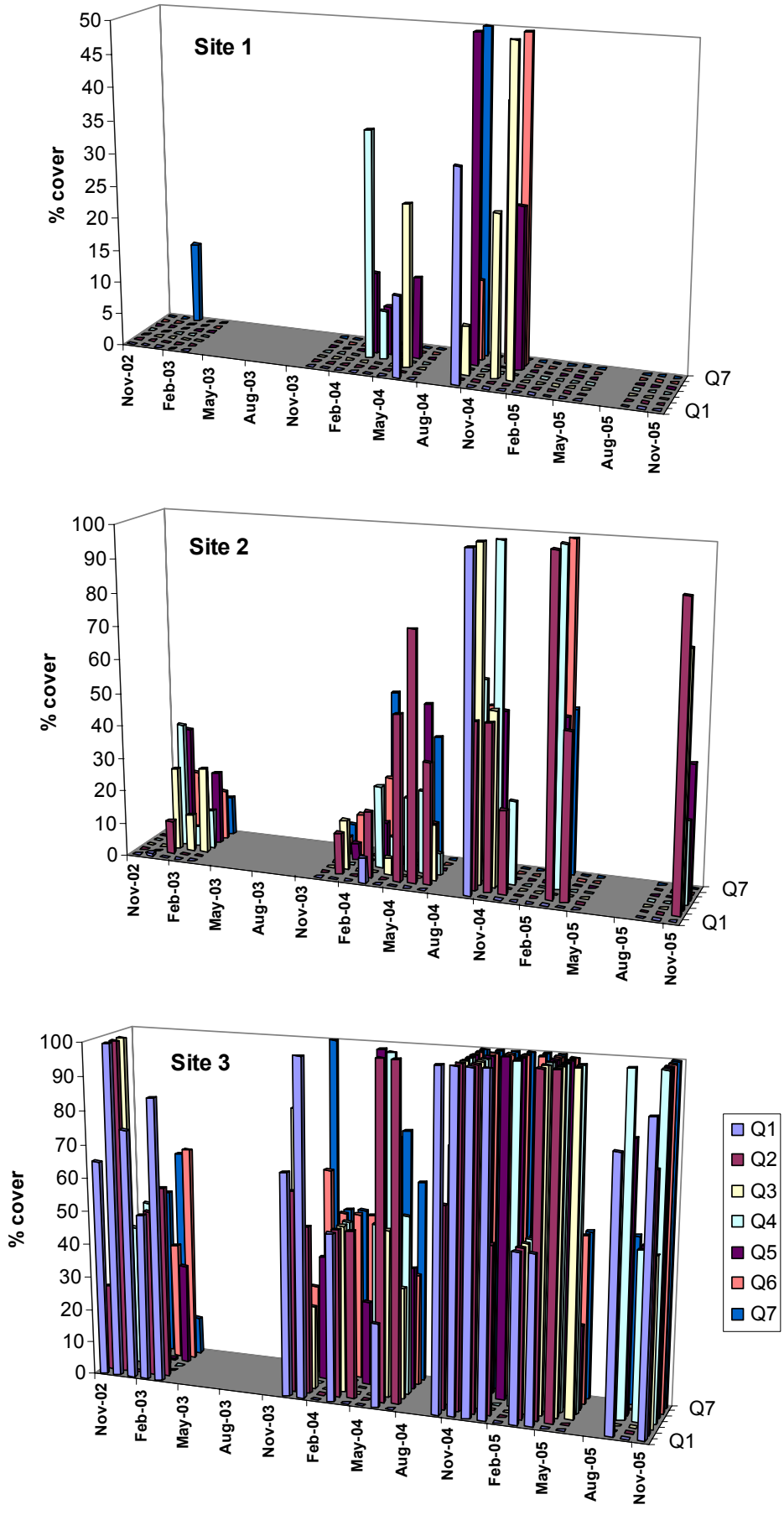


Figure 6.5 Percentage algae cover in 1m^{-2} quadrats (Q1-7) at three sites in the Berg River estuary.

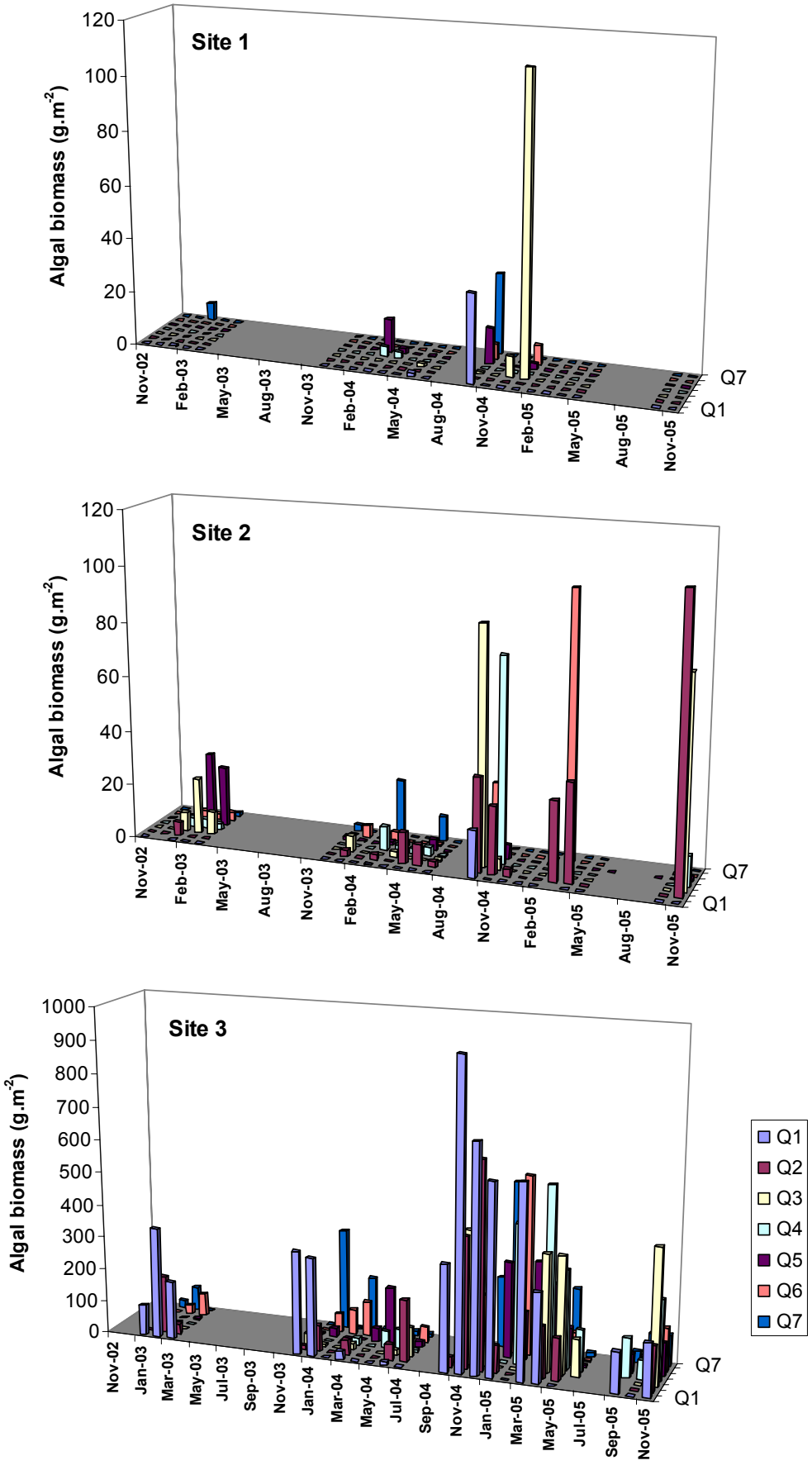


Figure 6.6 Algal biomass (dry weight) at three sites in the Berg River estuary.

All algae require sufficient light for photosynthesis and growth. During the summer period (November and February), secchi depths at all 5 algae sampling sites were typically recorded at 1-2 m (Figure 3.21 - Schumann 2007, BRBMPR Vol. 3, Chapter 3), but decreased substantially from site five upstream. This is due to the influence of muddy river water and its high silt load which effectively cuts out light and inhibits algal growth. During the winter spates, visibility is typically reduced to less than 0.5m at all sites and this shading effect along with shortened day length, strong currents, possible smothering of algae by sediment and reduced salinities and temperatures causes algae to disappear during the winter.

Measurement of nutrients (dissolved silicate, phosphate and nitrogen) within the Berg River estuary showed depleted levels in the middle estuary (from about station B10 upstream) with higher levels on the seaward boundary (marine renewal) during the dry season (Figures 4.4-4.8 - Clark and Taljaard 2007, BRBMPR Volume 3, Chapter 4). Clark and Taljaard (2007, BRBMPR Volume 3, Chapter 4), provide evidence that the nitrogen species (dissolved nitrate, nitrite and ammonia) are limiting in the middle reaches of the estuary during low flow periods. Winter floods provide an input of nutrients from terrestrial sources that elevate nutrients throughout the estuary, but at these times algae are swept out of the system and salinities, temperatures and light availability are unsuitable for new growth. The record dry season and consequently low flow rates during 2003 (see Fig 3.4, Table 3.8 - Schumann 2007, BRBMPR Vol. 3, Chapter 3) possibly resulted in a reduced terrestrial nutrient input into the system. This could explain the low algae cover and biomass observed during the 2003-2004 season relative to that recorded for the following year when flow rates were higher. The nitrogen deficiency in the middle estuarine stretches during the summer is probably a further factor limiting the distribution of macroalgae. In these middle reaches where turbidity is high, phytoplankton probably out-compete macrophytes for the limited available nitrogen.

Large amounts of algal growth are commonly produced by the presence of increased nutrients, in particular nitrates, nitrites and phosphates. Nutrient input from anthropogenic activities for example, runoff from agricultural land, sewage outfalls or commercial effluent. This nutrient over enrichment or eutrophication, as discussed above, can have numerous undesirable impacts on aquatic ecosystems. Nitrogen enrichment from a pelagic fish factory effluent contributed to substantial blooms of the macroalgae *Ulva* sp. in nearby Saldanha Bay (Monteiro *et al.* 1997). Morant, *et al* (in press) proposed that this could cause future problems in the Berg River. Elevated levels of dissolved inorganic phosphate and dissolved total ammonia over historical values were observed on the seaward boundary of the estuary, and Clark and Taljaard (2007, BRBMPR Volume 3, Chapter 4) suggested that this may have anthropogenic origins but cautioned that this would require further investigation in order to quantify the effluent volumes. During the period February 1988-April 1989, Kalejta and Hockey (1991) recorded fairly constant percentage cover of algae (in the range of 50-100%) at sites 2 and 3, with algae only disappearing briefly in January at site 3. Although their sampling technique for determining algae biomass was different (a round core 0.0037m^{-2}), maximum dry weight recorded at sites 2 and 3 was only 20-40 $g.m^{-2}$ (Kalejta and Hockey 1991). During this study, it was found that algae disappeared completely during mid winter for at least two months, whilst the maximum algae biomass recorded during the low flow periods was 4 to 20 times that measured in the earlier study (931 $g.m^{-2}$ at site 3 and 161 $g.m^{-2}$ at site 2). The increase in the amount of algae found in this study compared to that of Kalejta and Hockey (1991), albeit a seasonal occurrence, is a cause for concern and could reflect increased nutrient inputs into the estuary reported by Clark and Taljaard (2007, BRBMPR Volume 3, Chapter 4).

Macro-algae form an integral part of estuarine ecosystems not only as primary producers, but also by altering habitat and providing shelter and feeding areas for numerous species.

Kalejta and Hockey (1991) found that the abundance of benthic invertebrates in the Berg River estuary fluctuated in response to the seasonal growth of *Zostera capensis* and macro-algae. These benthic invertebrates are the primary food source for higher trophic level consumers such as fish and shorebirds (Whitfield 1998, Kalejta and Hockey 1991). Macro-algae also provide shelter from predators for numerous species of juvenile fish that utilize estuaries as nursery areas (Clark *et al.* 1994). Excessive algal growth that may occur under eutrophic conditions however, can have negative impacts by clogging channels thereby impeding water flow and restricting the movements and behaviour of fish and other estuarine fauna. Predicted changes in base flow and flood frequency and timing (Howard & Ractliffe 2007 - BRBMPR Volume 1, Chapter 5, Beck & Basson 2007 - BRBMPR Volume 3, Chapter 1) associated with the construction of the Berg River dam, may allow macro algae to penetrate further up the estuary and lead to changes in biomass in the lower reaches. Given that substantial increases in algae biomass and changes in species composition that appear to have occurred in the last 15-20 years, this should be monitored on a regular basis (at least every 5 years, for at least two full seasons at a time) using similar protocols to those employed in this report.

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CHAPTER 7 - BERG RIVER ESTUARINE AND FLOODPLAIN VEGETATION

C. Boucher and F. E. Jones

7.1 INTRODUCTION

This study was commissioned as part of a baseline study against which impacts on the Berg River and estuary will be monitored following the construction of the Berg River Dam (previously referred to as the Skuifraam Dam). The aims of this study were to compile a report on the vegetation of the estuary and the lower floodplain wetlands using existing and new survey data, which included the following key elements:

- A description of the present status of the river, floodplain and estuary with regard to its vegetation;
- A list of key processes which influence the vegetation of the riverine ecosystem;
- Identification of the future requirements (e.g. key resource quality requirements) for maintenance of riparian, floodplain and estuarine vegetation;
- Predictions of the kinds of changes that might be expected as a result of changes in the flow regime of the river following construction of Berg River Dam.
- A list of parameters that could be used as indicators to measure change in vegetation in the river, floodplain and estuary;

The first part of this chapter summarises information gleaned from historic studies dealing with vegetation communities of the Berg River estuary, while the second section of the chapter is a synthesis of the three-year study (2003-2005) undertaken towards the compilation of the Berg River Baseline Monitoring Programme.

7.2 APPROACH AND METHODS

Vegetation measurement was done using transects, along which plant community data were gathered within an estimated width of 2 m on each side of the transect mid-line (the mid-line was marked in most places by pegs, with precise location fixed by survey during 2004 and 2005). Most transects track plant zonation patterns parallel to the river channel from water's edge to the last recognisable relevant vegetation that was either saltmarsh or directly influenced by annual river flows. The different plant assemblages sampled were identified in the field on the basis of their different floristic content, structural differences and by obvious habitat differences.

The following data were recorded for each transect during the 2003-2005 study period. Data sheets used to collect data for each transect or feature are supplied in Appendix 3.1):

- Data were collected on 10-20 February 2003, 8-12 March 2004 and 14-19 April 2005 to coincide with neap tides as spring high tides inundate a large section of the lower riparian vegetation making it a virtually impassable quagmire in places.
- Locality and applicable site details (2003);
- A simple (not to scale) sketch of the transect profile with additional observations/notes;
- Distance of, and rough slope angles for, each lateral transect zone measured with a differential GPS for the estuary and floodplain (2003). These data points along selected transects were formally surveyed during 2004 and 2005 (refer to Table 7.2);
- On ground identification of different lateral plant assemblages;
- A list of all species observed in each different species assemblages along the transect was compiled and Braun-Blanquet cover-abundance ratings were attributed to each species using the following scale (Boucher, 1987):

  R = Few individuals with a cover of less than 0.1% of the area.
  + = Occasional plants but with a cover of less than 1% of the area.
  1 = Many plants but with a cover of less than 1%, or a few plants but with a cover of 1-5% of the area.
  2 = Many plants with a cover of 1-5% or any number of plants with a cover of 6-25%.
  3 = Any number of plants with a cover of 26-50% of the area.

4 = Any number of plants with a cover of 51-75% of the area.
5 = Any number of plants with a cover of 76-100% of the area.

The Braun-Blanquet method of manual tabular data manipulation to expose species groupings and relationships was used to synthesise the data collected from the study area (Werger 1974).

An initial assessment of 19 transects or features (containing 155 samples listed in Table 7.1 at end of report) were undertaken during 2003 on the estuary and floodplain. These were refined, reduced and in some instances, relocated, to provide a subset of the most readily interpretable and readily monitored transects (see selection rationale notes on transects in Appendix 3.1).

Most of the transects in the estuary build on O'Callaghan's (1994a, b) transects (refer to Table 7.2 & Figure 7.1), while the rest were selected in order to capture features identified from the maps and existing photography (dated 14-12-2001) as potentially demonstrating dynamic vegetation change most effectively and least ambiguously. Data captured deviated from the sampling method used by O'Callaghan in that he captured species data in 1x1 m sized samples placed within each different suite of species he observed (= community) whereas the present study recorded the measured point of change between species suites and then recorded all species within each suite. This was to enable the recording of annual changes to community boundaries as well as to overall species composition. (O'Callaghan found species complements changed seasonally thus all comparisons made to his data here are for February to April, which is the period sampled in the present survey.)

The final subset of eight surveyed and geo-referenced transects (Table 7.2; Figures 7.2 – 7.5 vegetation transects overlying the vegetation map) represent a mixture of all but one (Riparian Woodland) of the natural vegetation types described in Section 7.2.3, although some of the vegetation types, such as xeric floodplain and open pans are less thoroughly represented than halophytic saltmarsh or reed marsh for example. These transects, ordered from downstream to upstream features, are described briefly below with detailed descriptions of each transect being presented in numerical order in Appendix 3.1.

Table 7.2 List of vegetation transects used during the Berg River Baseline Monitoring Study

Locality	Transect code/s	Previously surveyed	Reason for continuing (or not continuing) to capture data even though no survey	Reason for including as a surveyed transect in 2004 and/or 2005	Reason for not including as a surveyed transect
Blind lagoon dune	Est1	O'Callaghan B1	Useful long term information to compare with O'Callaghan's study	n/a	Too far from project transects
Blind lagoon south east	Est2	O'Callaghan B2	Useful long term information to compare with O'Callaghan's study	n/a	Too far from project transects
Cerebos salt works	Est3, Est22, Est25	O'Callaghan B4	Est 22 Included in 2004/5 surveys	Est 3 and Est 25 only included in 2005. This site is close to a project transect and is also a good, long vegetation transect	Ran out of time during 2004, problems with surveying (farmer bulldozed way-station)
Die Plaat	Est4		Only study site on Die Plaat	n/a	Too far from project transects
Kruispad West	Est5 / Est21		Included in 2004 / 2005 surveys	Close to project transect, kept Est 5 & added one more (Est 21) at same locality, on project transect. Surveyed 2004 & 2005	n/a
Port Owen	Est6	O'Callaghan B3	Included in 2005 survey	Useful long term information to compare with O'Callaghan's study	n/a
Kruispad East	Est7 / Est20		Included in 2004 / 2005 surveys	Close to project transect, kept Est 7 and added one more (Est 20) at the same locality. Surveyed both, 2004 and 2005	n/a
Jantjieskraal	Est8		Awkward access & bank too sheer	n/a	Too far from project transects
Zoutkloof East	Est9		Valuable up-river site opposite Caledonia (Est 10)	n/a	Too far from project transects
Caledonia	Est10		Valuable up-river site opposite Zoutkloof East (Est 9)	n/a	Too far from project transects
Langrietvlei	Est11		Close to Kruispad East and West which have 4 surveyed transects	n/a	Too far from project transects
Caltex / Velddrif	Est12	O'Callaghan B6	Useful long term information to compare with O'Callaghan's study	n/a	n/a
Kruispad Pan	Est13		D-GPS co-ordinates available from 2003 - no D-GPS used in 2004/5	n/a	Not a longitudinal transect - and had added 3 long transect (Est20, Est21, Est22)
Bovenplaat -	Est14		D-GPS co-ordinates available from 2003 -	n/a	Not a longitudinal transect - and

Locality	Transect code/s	Previously surveyed	Reason for continuing (or not continuing) to capture data even though no survey	Reason for including as a surveyed transect in 2004 and/or 2005	Reason for not including as a surveyed transect
die Plaat - Phragmites patch			no D-GPS used in 2004/5		had added 3 long transect (Est20, Est21, Est22)
Bovenplaat farm - Phragmites patch	Est15		D-GPS co-ordinates available from 2003 - no D-GPS used in 2004/5	n/a	Not a longitudinal transect - and had added 3 long transect (Est20, Est21, Est22)
Bovenplaat farm - Phragmites patch	Est16		D-GPS co-ordinates available from 2003 - no D-GPS used in 2004/5	n/a	Not a longitudinal transect - and had added 3 long transect (Est20, Est21, Est22)
Bovenplaat Farm - Cyperus textilis patch	Est17		D-GPS co-ordinates available from 2003 - no D-GPS used in 2004/5	n/a	Not a longitudinal transect - and had added 3 long transect (Est20, Est21, Est22)
Kruispad East - Typha patch	Est18		D-GPS co-ordinates available from 2003 - no D-GPS used in 2004/5	n/a	Not a longitudinal transect - and had added 3 long transect (Est20, Est21, Est22)
Kersefontein - Prionium serratum	Est19		D-GPS co-ordinates available from 2003 - no D-GPS used in 2004/5	n/a	Not a longitudinal transect - and had added 3 long transect (Est20, Est21, Est22)

7.3 FLOODPLAIN ZONE OF THE BERG RIVER

This zone begins at the Farm Caledonia near Hopefield, merging with the estuary some 3.2 km below the Farm Kersefontein. The "flood plain" (Harrison & Elsworth 1958) is flooded every winter containing small pans or vleis. Pools between runs are 1-2 m deep, even in summer. The estuary was not separated from the floodplain or studied by Harrison & Elsworth (1958).

7.4 HISTORIC VEGETATION SURVEYS

Three main studies of vegetation in the floodplain and estuary zones of the Berg River have been undertaken prior to the present study. The first by Harrison & Elsworth (1958) described the floodplain zone as the last of the five zones into which they divided the Berg River.

"Day (1981) briefly describes the vegetation of the marshes at Velddrif as deing dominated by *Sarcocornia natalensis* whereas the mud banks between Velddrif and Laaiplek are covered with *Sporobolus pungens* (sic), *Chenolea diffusa, Sarcocornia perennis, Schoenoplectus triqueter, Triglochin bulbosa* and *T. striata*, together with other species. *Zostera capensis* is found below the low tide mark. Further upstream, *Phagmites australis* lines the river and *Zostera* is replaced by *Ruppia* sp." (O'Callaghan 1994a).

McDowell (1993) did not distinguish between estuary and floodplain, but identified ten principal communities in three groups associated with the floodplain and estuary. O'Callaghan (1994a) described the estuary, which he divided into 6 zones, in some detail.

Boucher (1996a) also reported on a helicopter survey of the Berg River. He subdivided the river into 49 x 5 km segments to facilitate evaluation from a helicopter on 12 September 1995. Dominants in each segment were recorded visually during flight. Some 3-5 records were made per segment. The segments that represented the estuary and floodplain were 44-49 (220-249km) – referred to as section F by Boucher (1996a). He noted that the only woody exotics able to survive the higher salinities along the river itself were *Acacia cyclops* and *Eucalyptus camaldulensis.*

Impacts to the vegetation and habitats of the estuary and floodplain include total transformation of the habitat (with near complete loss of vegetation) such as found at Cerebos salt works and Port Owen. Farming activities, including grazing and cropping have reduced vegetation cover to less than 5% in some areas with river banks being seriously affected by livestock passage to water (Boucher 1996a).

Both O'Callaghan (1994a) and McDowell (1993), noted that estuarine areas have been significantly transformed and threatened by anthropogenic disturbance (urban development e.g. Laaipiek, Velddrif and Port Owen, and water storage). The lands adjacent to the upper estuary and river have long been used for agricultural purposes. Over 250 ha of the upper marsh areas on the southern banks are now occupied by evaporation pans from the salt works and the only upper marsh remaining in this region is an approximately 10 ha above Carinus Bridge (also severely disturbed by trampling and grazing).

The mouth of the river was artificially stabilized in 1966 to facilitate the passage of fishing trawlers. O'Callaghan (1994a) cites an estimate by Anderson[2] that marshes in the lower Berg River decreased by only 13% from 1938 to 1986 but notes that this author did not distinguish between salt marshes and reed beds. O'Callaghan estimates that approximately 250 ha of salt marsh (constituting just less than 2% of the salt marshes of the Cape) survive adjacent to the lower estuary.

Distribution and presence of species and communities found during the present study were markedly similar to distribution patterns observed by O'Callaghan (1994a), and although some differences were observed, most of these relate to species identification disparities.

[2] Hydrological / hydraulic study of the Cape Estuaries. Data Report no 8. Groot Berg (CW15).

O'Callaghan sampled along six transects (Figure 7.1) in the estuary using aerial photography to assess vegetation cover along the different zones he identified within the estuary, as follows:

a) Blind Lagoon (Transect B1 – Est1 in the current study)

The marshes consisted of disjunctive patches with some submerged macrophytes (probably *Zostera capensis*) in 1942, which were greatly reduced by 1960 with no evidence of submerged macrophytes (possibly related to extensive dredging activities). By 1971 the new mouth had been open for five years, the old mouth had closed (forming the Blind Lagoon) with much sediment deposition, especially along the northern shores, and development of patches of salt marsh. Continued sediment deposition was visible in 1977 leading to development of a salt marsh cliff at B1 and recognizable marshes at Transect B2. Photographs from 1981 showed increased sedimentation and increased development of salt marshes, especially along the southern shores of the Blind Lagoon, which O'Callaghan postulated might be due to dumping of dredge spoil on marshes opposite Laaipiek and / or dredging activities at Port Owen (since late 1970s).

Distribution of species on the lower parts of Transect B1 was similar to distribution patterns observed at Langebaan Lagoon (O'Callaghan pers. obs.), including *Zostera capensis*. *Spartina maritima, Sarcocornia perennis, Triglochin bulbosa, Sarcocornia pillansii* (x *S. perennis*), *Limonium depauperatum* and *Sporobolus virginicus.* Presence of *Triglochin striata, Romulea tabularis, Cotula eckloniana* and *Crassula glomerata* on the upper parts indicated that salinities in this area decreased to below that of sea water, at least during late winter. Species at the top of the transect indicate a moist dune environment that abuts onto the marsh.

During this study similar vegetation patterns were identified at this transect with few departures indicating that the vegetation may have stabilised to a degree in this part of the estuary since the closing of the estuary mouth (see Appendix 3.1 for details and discussion of similarities and differences).

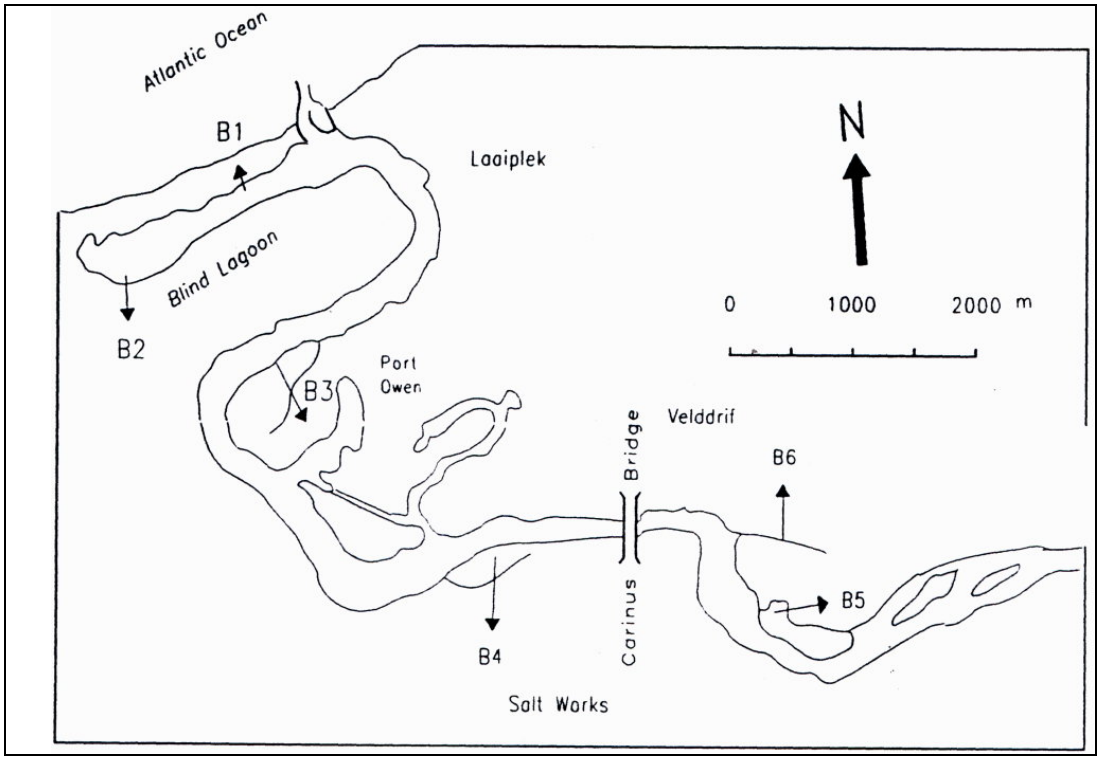


Figure 7.1 Sketch map of Berg River estuary showing location of six transects (B1 to B6) sampled by O'Callaghan (1994a).

b) Transect B2 (Est2 in the current study)

Marshes at B2 are younger than those at B1, dating from 1966 at the earliest, and distinction between the marsh vegetation and adjacent terrestrial vegetation was not as clear as at B1.

Zostera capensis was found to approximately 53 cm below MSL, especially during summer. From -50 cm to 63 cm no angiospermous vegetation was present. These mud flats were rich in microflora and filamentous green algae, especially during early summer. (See Appendix 3.1 for further details and discussion of similarities and differences in the intervening interval till the current study.)

c) Transects B3 (Est6 – this study) and B4 (Est3, Est22 and Est25 in the current study)

A salt marsh erosion cliff-face limited development of the lower marsh along both these transects. The area immediately above this cliff was slightly elevated compared with the rest of the marsh, impeding drainage and numerous creeks of varying size traversed the marsh. With the exception of these creeks, the marsh consisted of flat expanses with little variation in elevation. Under these conditions, species distribution was patchy and possibly related to soil drainage characteristics, rather than changes in elevation alone.

At B3, elevational distributions of most species overlapped to a degree. The salt marsh at B3 can be roughly divided into four sections:

- Deeper creeks containing *Zostera capensis*.
- Zone from *Sarcocomia perennis* to *Limonium depauperatum* constituted 90% of the remaining spatial distribution of the marsh. These areas were flooded relatively frequently, usually from water entering and leaving via creeks.
- *Juncus*/*Spartina* zone found near a smaller creek where soils were almost constantly waterlogged.
- The remainder of the marsh constituted less than 10% of the spatial area of this transect. It was characterized by *Salicomia meyeriana* and, except for *Sarcocomia pillansii* (x *S. perennis*), contained only annual species. These upper areas are seldom flooded although the soils were rather saline. The top of the transect was disturbed by development and was largely devoid of vegetation except after rains, during spring.

Physiographic structure of the marsh at B4 was similar to B3, the lower part of the transect (from *Schoenoplectus triqueter* to *Limonium depauperatum*) constituting more than 90% of the spatial distribution of this transect and elevational distribution of most species overlapped. Despite numerous creeks none were deep enough to support *Zostera capensis*. Decreased salinity was evidenced by the presence of *Schoenoplectus triqueter, Triglochin striata, Scirpus venestulus* and *Juncus kraussii*. The upper part of B4 had been disturbed by the evaporation pans of the Salt Works. Soils were highly saline in summer and vegetation (*Sarcocomia pillansii* x *S. perennis* and *Salicomia meyeriana*) sparse or absent.

These transects were not accurately geographically referenced by O'Callaghan (1994a) consequently the general area only was located and sampled during the current study.

d) Transect B5

Effects of fresher water inputs were evident at this transect. *Schoenoplectus triqueter* and *Juncus kraussii* were recorded in a creek and *Zostera capensis* at the riverine end throughout the year (limited by fresh water influx after the rainy season). Other species supported by lowered salinities included *Crassula natans*, *Samolus porosus* and *Juncus scabriusculus*.

Juncus kraussii covered more than 90% of B5. *Schoenoplectus triqueter* covered more than 70% often forming dense monospecific stands.

Distribution of some species found in more saline marshes (Transect B1) did not overlap with distributions of *Schoenoplectus triqueter* and *Juncus kraussii,* but *Bassia diffusa* and *Sarcocomia pillansii* occurred in association with sedges and more salt-tolerant species. Taller sedges might negatively affect growth of other species. Distribution patterns of the more salt-tolerant species were irregular. Growth of those species co-occurring with the taller sedges was lanky, requiring sedges for mechanical support.

The upper end of the transect would be flooded only occasionally by relatively fresh water during the rainy season and grasses and herbs found here included *Polypogon monspeliensis, Sporobolus virginicus, Disphvma crassifolium and Plantago crassifolia*.

This transect was not accurately geographically referenced by O'Callaghan (1994a) consequently the general area only was located and sampled during the current study.

e) Transect B6 (Est12 in the current study)

This transect starts at a creek traversing the marsh south of Velddrif. The banks of the creek lined with *Phragmites australis.* The bottom of this creek was constantly filled with fresher water in which *Potamogeton pectinatus* was found.

Most of this transect was dominated by *Sarcocomia pillansii*, which was not often flooded with riverine water as the area immediately adjacent to the creek was slightly elevated. Water that might have entered the marsh through rain, surface drainage or storm surges, could not easily drain away. The relatively saline soils required for domination by *S. pillansii* would have resulted from salt deposition by evaporation rather than flooding by saline water. *Juncus kraussii* co-dominated with *Sarcocomia pillansii* in areas where the soils were slightly less saline (e.g. immediately adjacent to the creek). The remaining species (including most of *Juncus kraussii*) were concentrically arranged around a depression seasonally filled with rainwater. The majority of these species germinated and grew during spring and died back by mid-summer.

Phragmites australis was again found on the top of the transect where it was supported by fresh water run-off from adjacent hard surfaces.

This transect was not accurately geographically referenced by O'Callaghan (1994a) consequently the general area only was located and sampled during the current study.

O'Callaghan (1994a) primarily documented the relationship between species occurrence and height above sea-level (elevation gradient) in an attempt to relate their distribution to inundation level, however local salinity differences proved to be a prime determining feature for the occurrence of some saltmarsh species. O'Callaghan concluded that no typical salt marsh can be recognized at the Berg River. Marshes in the Blind Lagoon showed the clearest zonation patterns, whereas the zonation patterns higher up the estuary were less easily discernible.

Conditions prevailing in the Blind Lagoon were somewhat different to those in the other parts of the estuary. There was no unidirectional riverine flow in this part of the estuary. Vegetation was subject only to tidal inundation from the mouth of the estuary.

Distribution patterns of species along the elevation gradients in the remainder of the Berg River estuary were patchy with regard to elevation above sea level. This inconsistent relationship between species distributions and elevation might be attributed to a number of factors:

a. Relatively flat topography: flooding and drainage related to elevation relative to the surrounding marsh. Local depressions result in longer periods of inundation.
b. Numerous creeks of varying sizes traversed the marshes, adding to complexity of inundation patterns.
c. Fresh water input increased as one moved up the river. The effects of salinity on salt marsh plants thus varied tidally as well as seasonally.

The complexities result in an inconsistent relationship between salinity and tidal inundation, affecting relative distribution and competition between the various species. The species composition of the marshes might vary according the period of inundation.

7.5 VEGETATION MAP AND MAPPING UNITS APPLIED IN CURRENT STUDY

The communities recorded on the Berg River Estuary, are arranged in four groups using McDowell (1993) terminology (marshes, pans, floodplain flats, and estuarine saltmarsh). These units were used to compile the vegetation map of the estuary and floodplain produced for this study which are based on information gathered as notes during fieldwork and particularly from the analysis of the transects sampled and described in Figures 7.2–7.5. A detailed electronic version of the vegetation map was produced in this project.

The initial intention was to compare spatial changes from the McDowell (1993) study to the present. Unfortunately this could not be achieved because it transpired that McDowell did not produce a georeferenced map. The phytosociological communities described in the next section are distributed in a fine-scale complex mosaic, such that they could not be mapped individually at the mapping scale applied in this project although their location along each transect is indicated in Appendix 3.1. Phytosociological community names, derived from the analysis of the data collected during the 2003 baseline study, are indicated in Table 7.1 and are also included in each of the descriptions below (Appendix 3.1).

The projection system used for mapping vegetation units in the Berg River Estuary was Transverse Mercator, Lo 19, based on WGS84. All spatial data inputs were therefore projected as WGS84, Lo19. Similarly, the output format of the vegetation layer generated during this project is projected as WGS84, Lo19 (see Table 7.3 for details).

Vegetation units as defined originally by McDowell (1993), were digitised in ArcView 3.3 using visual cues from orthophotos flown at a scale of 1:30 000. The presence of indicator vegetation communities/species detected during field assessments were generally used to guide the interpretation of the orthophotos.

Table 7.3 Metadata for Vegetation Map of the Berg River Estuary

FILE DETAILS		
File name:	Est_vegmap.shp	
Data Source:	On screen digitizing of vegetation units (originally identified by McDowell (1993) from orthophotos flown at a scale of 1:30 000	
Copyright Holder:	Department of Water Affairs and Forestry (DWAF)	
Scale Digitized at: 1:30 000	Extent: Berg River Estuary and floodplain	Data date: 2006
LEGEND AND FEATURE PROPERTIES		
Legend Title: No legends generated	Feature Type: Vector Polygon (shapefile)	
PROJECTIONS & DATUMS		
Projection Name: Transverse Mecator -WGS 84		Datum name: Lo 19
RELEVANT ATTRIBUTE FIELDS		
FIELD	DESCRIPTION	
Shape	Polygon	
Berg_Id	Vegetation type or landscape feature (originally described by McDowell (1993)	
Value	Provided a reference number for each vegetation type or landscape feature	
Comment	Features described where relevant	
Unique_Id	Provides a numerical identifier for each separate unit or feature	

Table 7.4 Areas occupied by mapping units

MAPPING UNIT	TOTAL AREA IN HA	% OF AREA
Agricultural lands	5 907.929	29.4%
Dam	7.441	0.0%
Denuded lands	61.197	0.3%
Exotic trees	145.514	0.7%
Farm road	52.548	0.3%
Farmstead	94.343	0.5%
Grassland	40.999	0.2%
Halophytic floodplain	1 546.764	7.7%
Halophytic saltmarsh	128.860	0.6%
Inundated mud-flats	205.656	1.0%
Main Roads	42.742	0.2%
Open pan	1 161.668	5.8%
Railway	14.884	0.1%
Reed marsh	514.586	2.6%
Reed marsh - short	73.059	0.4%
Riparian woodland	139.603	0.7%
River	792.817	3.9%
Salt works	345.693	1.7%
Sedge marsh	375.975	1.9%
Sedge pan	1 000.767	5.0%
Strandveld	6 182.506	30.7%
Urban	293.984	1.5%
Xeric floodplain	998.001	5.0%
Total area mapped	**20 127.536**	**100.0%**

The total area included in the maps (Figures 7.2 - 7.5) is 20 128 ha, with the Strandveld, the natural vegetation type occupying the terrestrial areas, and agricultural lands being the most abundant, each occupying 30% of the area (Table 7.4). Halophytic floodplain, Open pans, Sedge pans and Xeric floodplain together occupy another 24% of the area. The rest of the units have a low incidence together occupying in total only 16% of the area.

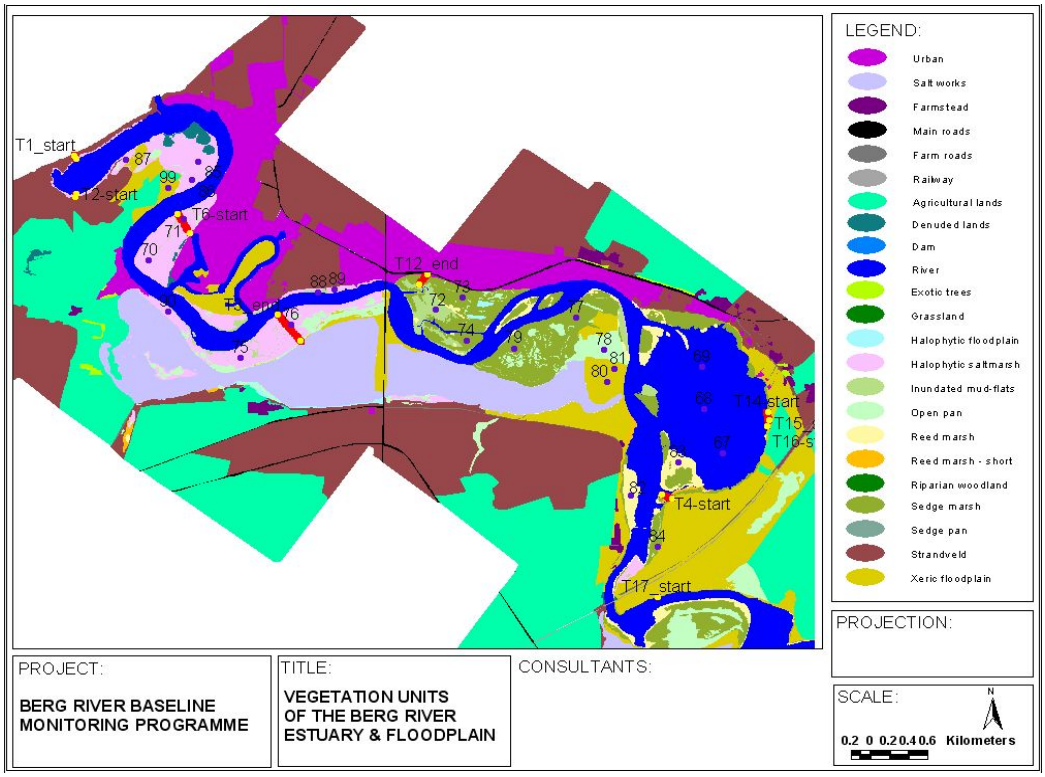


Figure 7.2 *Vegetation map of the bottom section of the Berg River estuary and immediate surround based on units recognised by McDowell (1993) and showing transects sampled in the present study.*

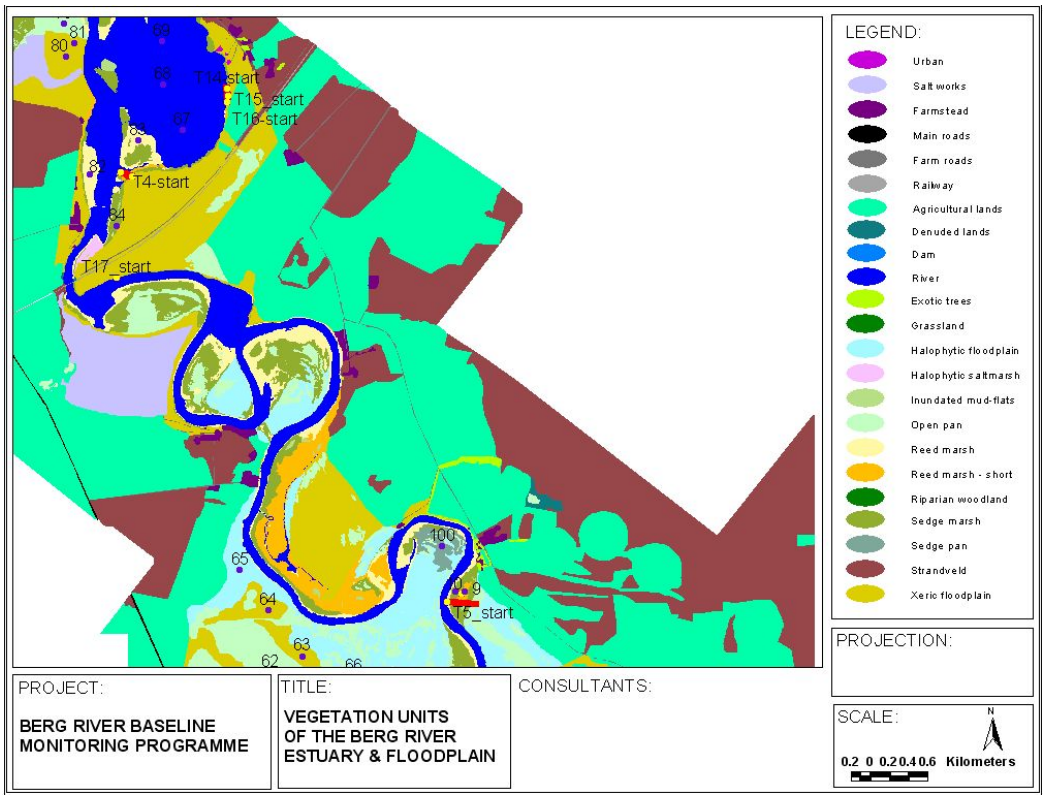


Figure 7.3 *Vegetation map of the lower middle section of the Berg River estuary and immediate surround based on units recognised by McDowell (1993) and showing transects sampled in the present study.*

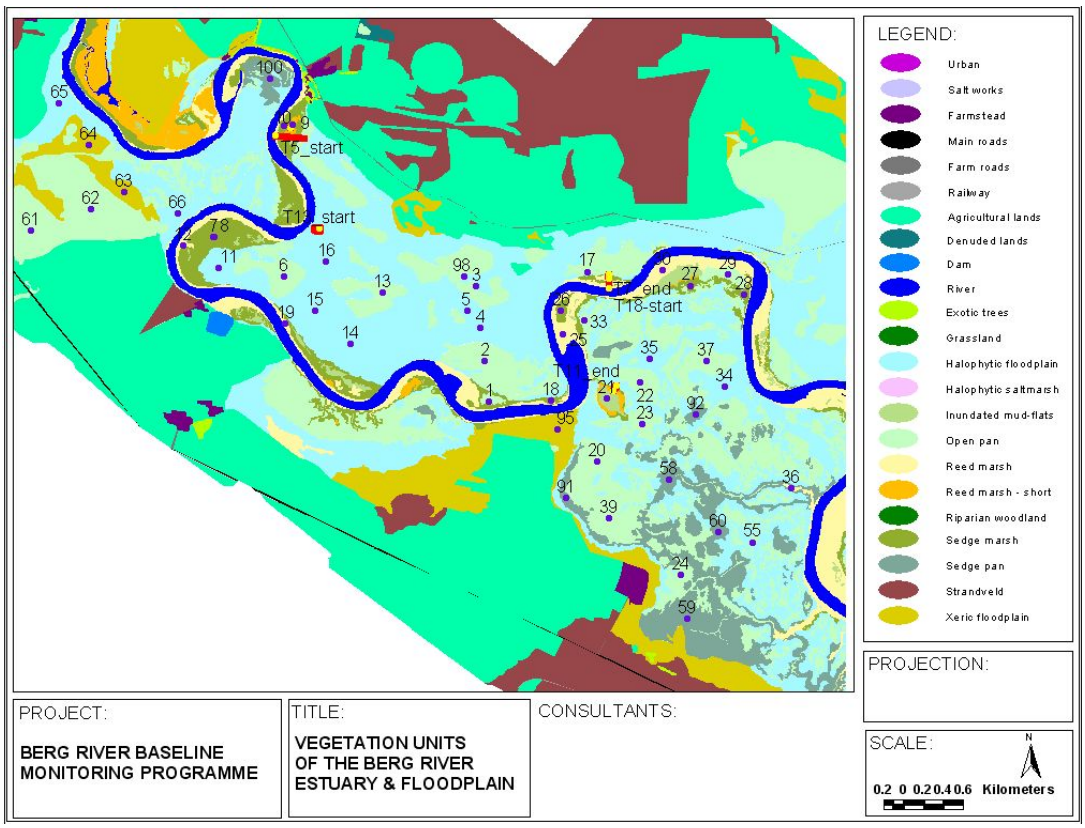


Figure 7.4 Vegetation map of the upper middle section of the Berg River estuary and immediate surround based on units recognised by McDowell (1993) and showing transects sampled in the present study.

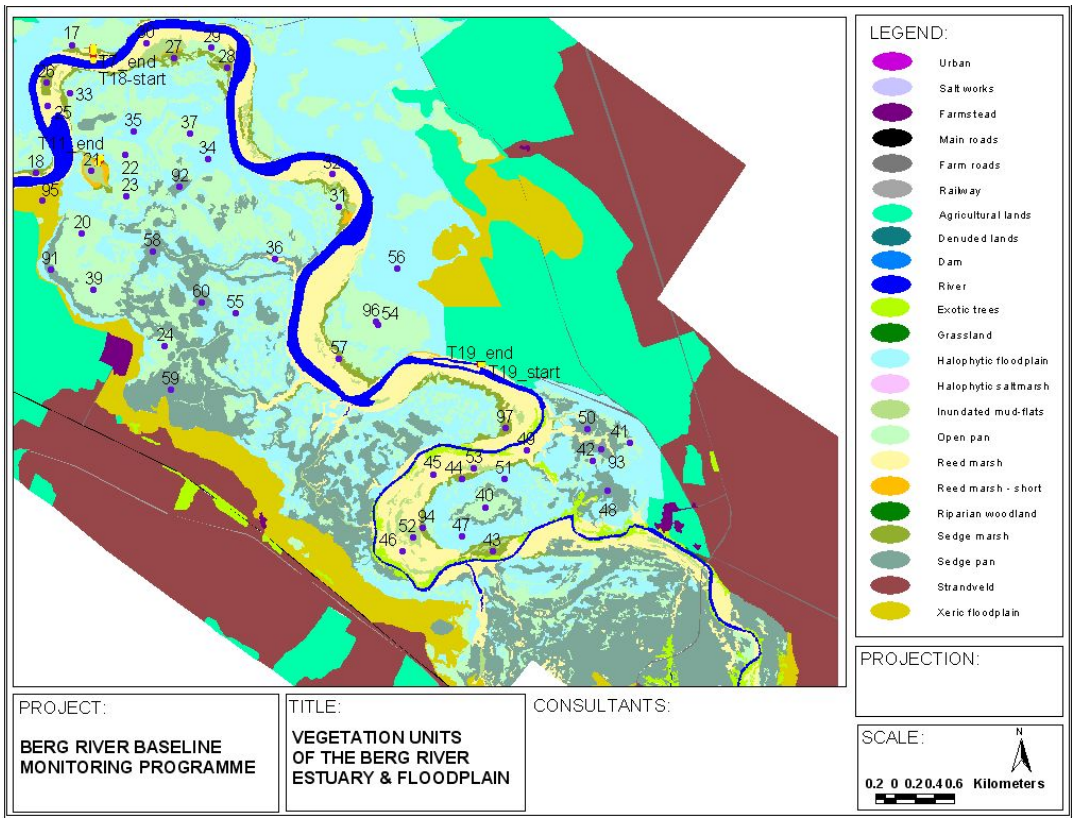


Figure 7.5 Vegetation map of the top section of the Berg River estuary and immediate surround based on units recognised by McDowell (1993) and showing transects sampled in the present study.

The different mapped vegetation types (Figures 7.2 - 7.5) are examined in respect of the author's perceptions of inundation frequencies (arranged from high to low frequency) and then related to graphs drawn using the hydrodynamic model (Basson & Beck 2007 – BRBMP Vo. 3 Ch 2) for 100 selected points (indicated in Figures 7.2 - 7.5) distributed through all the vegetation types. The individual graphs are presented in Appendix 3.2 and are grouped according to their vegetation mapping categories in Table 7.5, together with explanations for each graph pattern exhibited by the group over the selected wet and dry periods. Sites with inundation graphs that differ from the norm for the group are also indicated in this table. The mapping units are arranged from wettest to driest in Table 7.5.

Table 7.5 Assessment of mapped vegetation unit response to inundation predicted by Hydrogeographic Model graphs (Appendix B) of 100 sites (Figures 7.2–7.5)

Map unit	Group	Author perception of normal inundation periods	Sites in group	Evaluation of model for 23 April to 23 Sept 1999 inundation period	Evaluation of model for 23 April to 23 Sep 2003 inundation period	Samples with unusual inundation patterns
1. River	1	Permanently inundated.	67, 68, 69	Deeply permanently inundated.	Shallowly permanently inundated.	
2. Halophytic Saltmarsh	2a	Outer limits determined by spring high tide mark. Partially flooded by each spring tide. Lower estuary.	70, 71, 76, 85, 86, 87, 89	Always inundated.	Always inundated.	Sites 88 (Inundated mudflats) and 99 (Xeric floodplain) match the pattern of Group 2a.
	2b		75, 90	Inundated each spring high tide and dry during neap tide	Inundated each spring high tide and dry during neap tide	
3. Inundated Mudflats	3a	Generally always inundated except partially exposed at spring & totally exposed at spring equinox low tides.	21, 52, 53	Permanently inundated	High tide inundation 13 Aug–9 Sept only, rest no inundation	Site 88 is different from the rest being permanently deeply inundated with a pattern matching Group 2a
	3b		72		Tidal spikes through whole period, virtually never dry	
4. Sedge Marsh	4a	Outer limits determined by equinox spring high tide mark. Partially flooded by each spring tide. Upper estuary.	73, 77, 79	Always inundated.	Inundated each spring tide for extended periods and dry for short period during neap tide.	
	4b		7, 10, 26, 27, 57	Always inundated.	Mainly not inundated, except shallowly during end winter.	
	4c		8, 18, 28, 43, 94	Extended spring tide inundation, mainly dry during neap tides.	One inundation period over 2–3 spring tide events at end of winter.	
	4d		44, 74, 84	Spring high just inundates on a few occasions (1–3).	None to one inundation event through whole period	

Map unit	Group	Author perception of normal inundation periods	Sites in group	Evaluation of model for 23 April to 23 Sept 1999 inundation period	Evaluation of model for 23 April to 23 Sep 2003 inundation period	Samples with unusual inundation patterns
5. Sedge pans (sedgefields)	5	Wet season flooded each spring tide top. Dry season lower incidence of flooding probably around equinox only. Fringe channels with slow flows.	48, 50, 58, 59, 60, 91, 92, 93	Always inundated.	Few (1–3) spring tide inundation events at end winter.	Site 100 (mapped as Sedge pan) differs having the pattern of Group 9.
6. Open pans	6a	Two kinds:- one with permanent open water amongst sedges close to river and other only inundated during annual winter floods during spring high on floodplain.	2, 6, 13, 20, 22, 24, 29, 33, 37, 39, 41, 42, 54, 96	Permanently inundated.	One very small short inundation event.	
	6b		61, 62, 98	Permanently inundated.	No inundation events.	Site 80 (Xeric floodplain) graph is similar to that of Site 98.
	6c		1, 78	Permanently to regularly inundated except during neap tides.	Inundated each spring tide for and dry during neap tide.	
	6d		17, 23, 31, 40	Inundated during spring tide events in winter.	Single late winter to no inundation event.	
7. Short Reedbeds	7	Flooded by top of each high tide	9	Always inundated.	Two short inundation events.	Sites 45 & 83 (Reed marsh) and Sites 4 & 15 (Halophytic floodplain) exhibit similar inundation patterns to Group 7.
8. Reed marsh (Tall Reedbeds)	8a	Winter season flooded each high tide. Dry season lower incidence of flooding probably around spring high only. Fringes channels with rapid flows. Pioneer in disturbed riverine areas e.g. it benefits from fire.	45, 83	Permanently inundated.	Few (0–4) spring high tide inundation events during late winter to early spring.	Sites 45 & 83 exhibit similar inundation pattern to Group 7 (Short reedbeds).
	8b		12, 19, 25, 30, 32, 36, 38, 46, 49, 82	Inundated during 1–8 spring tide events mainly in winter.	Few (0–2) spring tide inundation events at end winter.	No 2003 inundations at Sites 32, 46, 49
9. Halophytic Floodplain	9	Equinox spring high during flood events.	3, 5, 11, 14, 16, 34, 35, 47, 51, 55, 56, 65, 66	Few (0–3) short spring tide inundation events in late winter.	Few (0–1) short spring tide inundation events in late winter.	Sites 4 & 15, mapped as Halophytic floodplain, has Group 7 pattern (Short reed marsh). Site 100 (mapped as Sedge pan) has the pattern of Group 9.

Map unit	Group	Author perception of normal inundation periods	Sites in group	Evaluation of model for 23 April to 23 Sept 1999 inundation period	Evaluation of model for 23 April to 23 Sep 2003 inundation period	Samples with unusual inundation patterns
10. Xeric Floodplain	10	Very large floods during equinox.	63, 54, 81, 95	None to few (0–1) spring tide inundation events.	No inundation event.	Graphs for Site 80, mapped as Xeric floodplain, exhibit the inundation pattern of Group 6b, while Site 99 (also Xeric floodplain), exibits that of Group 2a.

7.5.1 Marshes

i. Inundated Mudflats, supporting aquatic species such as *Eichhornia crassipes* (water hyacinth), *Potamogeton pectinatus* (fountain grass) and *Zostera capensis* (sea grass) (Figure 7.6). *Zostera* occurs downstream of *Potamogeton*. This community is identified phytosociologically as *Zostera capensis* Aquatic Beds in Table 7.1. The inundated mudflats occupy 206 ha or 1% of the area mapped in Figures 7.2 - 7.5.

Increased salinities through increased water abstraction imply displacement of *Potamogeton* by *Zostera*. These perennial wetlands include occasionally tidally exposed mud flats and natural pools on the river's edge. The mudflats are generally inundated by lower estuary water except for partial exposure during spring and totally exposure during equinox spring low tides (see inundation graphs in Appendix 3.2 and mapping unit group pattern explanations in Table 7.5).



Figure 7.6 Zostera capensis (eelgrass beds- top left) fringing the saltmarsh vegetation (right foreground) on the mudflats in the Blind Lagoon on Transect 1 is immersed except at spring low tides.

ii. Normal or Tall Reed Marsh, Consists of virtually monospecific stands of *Phragmites australis* (fluitjiesriet) from two to four metres in height (Figure 7.7). This community is identified phytosociologically as *Phragmites australis* Reedland in Table 7.1, where it occurs in pure stands. *Phragmites australis* can occur in other riparian or saltmarsh communities as an accompanying species. According to McDowell (1993), in less dense stands these tall reeds overtop mats of the aquatic herb *Potamogeton pectinatus* (fonteingras). Reed Marsh is found mainly on depositional, saturated silt-rich soils on inner riverine bends although it fringes most channels with rapid flows in them. It is a pioneer in disturbed riverine areas and benefits from being burnt at intervals. It occupies 515 ha or 2.6% of the area mapped in Figures 7.2 - 7.5.

These Tall Reed Marshes are usually inundated by each high tide during a wet season with a lower incidence of flooding probably around spring high only during the dry season (see inundation graphs in Appendix 3.2 and mapping unit group pattern explanations in Table 7.5).



Figure 7.7 Phragmites australis (fluitjiesriet) lines the banks of the Berg River in a Reed Marsh community. A mat of Eichhornia crassipes (water hyacinth) floats at the base of the stand of tall reeds.

iii. Short Reed Marsh.

These virtually monospecific stands, ranging from one to two metres in height, consist mainly of *Schoenoplectus triqueter* (formerly *Scirpus triqueter)* (a sedge). Stands of medium height reeds such as *Schoenoplectus scirpoideus* (formerly *Scirpus littoralis)* (papgras) and *Cyperus textilis* (matjiesgoed) are also to be found less frequently in zones subject to greater fresh water influences (Figure 7.8), otherwise it occupies a similar niche to Reed Marsh. It is inundated by most high tides (see inundation graphs in Appendix B and mapping unit group pattern explanations in Table 7.5). This community is identified phytosociologically as *Schoenoplectus scirpoideus* Sedgeland and *Cyperus textilis* Sedgeland in Table 7.1. It occupies 73 ha or 0.4% of the area mapped in Figures 7.2 - 7.5.



Figure 7.8 *Short Reed Marsh at Kruispad Farm, comprising a mixture of Cyperus textilis (majiesgoed), Schoenoplectus triqueter (an invasive sedge) and Schoenoplectus scirpoideus (papgras). This area is grazed frequently and the reeds show some evidence of recent grazing activity.*

7.5.2 Pans

i. Open Pan, represents a saltpan community. This community is identified phytosociologically as the *Triglochin striata - Salicornia meyeriana* Dwarf Shrubland in Table 7.1. These "salt deserts" generally lack macrophytes or larger perennials (Figure 7.9). Scattered *Salicornia meyeriana* (glasswort) shrublets (to about 0.25 metres) often comprise the only noticeable groundcover during the dry season. There are two kinds of Open pans in this mapping unit. One with permanent open water amongst sedges nearer to the river channel and another which is only inundated during annual winter floods during spring high and is located on the floodplain (see inundation graphs in Appendix 3.2 and mapping unit group pattern explanations in Table 7.5). The unit occupies 1 162 ha or 7.8% of the area mapped in Figures 7.2 - 7.5.



Figure 7.9 *An Open Pan at the farm Kruispad during the dry summer months. Fringed with a Halophytic Saltmarsh / Halophytic Floodplain mosaic (grey), the reeds visible in the background are from both the Tall Reed Marsh and Short Reed Marsh, communities.*

ii. Sedge Pan has characteristic monospecific stands of *Juncus maritimus* (sareegras) in Summer while *Aponogeton distachyos* (waterblommetjie) is conspicuous when in flower in late winter (after the rains) (Figure 7.10). This community was not sampled during the 2003 survey on which the phytosociological communities are based. Height ranges from 0.25 - 0.5 metres. This community would be adversely affected by higher salinities. During the wet season it is inundated at each spring high tide. Dry season lower incidence of flooding probably around equinox spring high only. The Sedge pans fringe channels with slow flows (see inundation graphs in Appendix 3.2 and mapping unit group pattern explanations in Table 7.5). It occupies 1 001 ha or 5% of the area mapped in Figures 7.2 - 7.5.



Figure 7.10 *A Sedge Pan community dominated by Juncus rigidus (sareegras) across the river from Jantjieskraal. In the background a Reed Marsh community (dominated by Phragmites australis (fluitjiesriet) is overshadowed by tall Eucalyptus (gum) trees lining the river banks in a Riparian Woodland community (refer to community 3(iii) below).*

7.5.3 Floodplain Flats

i. Halophytic Floodplain.

Perennial cover consists almost entirely of fleshy-leaved chenopods; mainly *Sarcocornia pillansii* (brakbos). This community is identified phytosociologically as the *Sarcocornia pillansii* Dwarf Shrubland in Table 7.1. These shrubs may be interspersed with open patches colonised by ephemeral growth during spring but appearing as mud patches during summer (Figure 7.11). Height is normally 0.5 to 0.75 metres. These areas are normally inundated by equinox spring high during flood events (see inundation graphs in Appendix B and mapping unit group pattern explanations in Table 7.5). It occupies 1 547 ha or 7.7% of the area mapped in Figures 7.2 - 7.5.

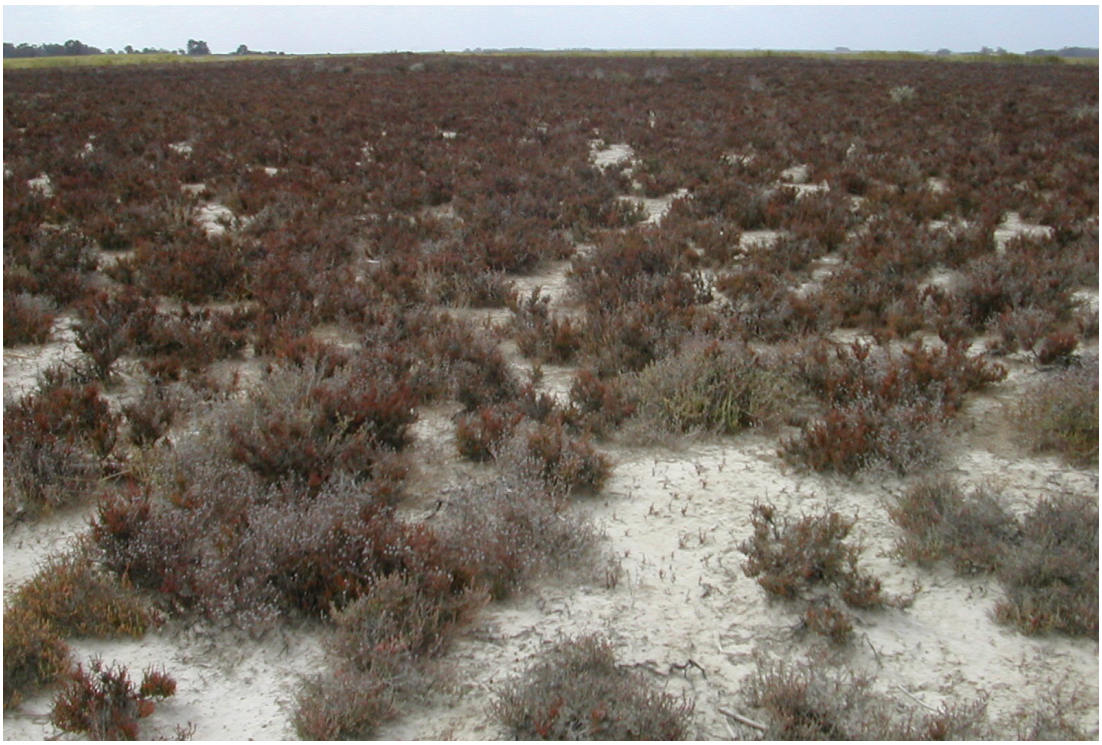


Figure 7.11 Sarcocornia pillansii (brakbos) dominates this Halophytic Floodplain community. In the background, a fringe of Reed Marsh (refer to Community 2 above) is visible below the crest of Eucalyptus trees, which line the river course in a Riparian Woodland community (refer to community 3(iii) below).

ii. Xeric Floodplain Community.

Cover consists of a greater diversity of xerophytes (drought-adapted species) than that defined for the Halophytic Floodplain; being transitional between the latter and terrestrial Strandveld (Figure 7.12). This community is identified phytosociologically as the *Chrysanthemoides incana* Shrubland in Table 7.1. This vegtation grows to roughly 1.5 metres tall dominated by succulent species, such as the Aizoaceae (formerly Mesembryanthemaceae, the vygie family which are leaf succulents) and Asparagaceae (the asparagus family with succulent tubers). Xeromorphs (plants with drought adapted morphology) include *Rhus* spp. (taaibos) and *Lycium ferocissimum* (boksdoring). Geophytes and therophytes (drought-avoiding bulbous and annual groups) appear in spring. The community is dependant on a short inundation period during Berg River floods only, which reduce salinity levels and deposit sand and mud (see inundation graphs in Appendix B and mapping unit group pattern explanations in Table 7.5). It occupies 998 ha or 5% of the area mapped in Figures 7.2 - 7.5.



Figure 7.12 Dormant (leafless) Asparagus species appear to be dead amongst the Sarcocornia pillansii shrubs in this Xeric Floodplain community. In the far background a tall Reed Marsh community (green) is visible along the riverbank.

iii. Riparian Woodland, up to 3 m tall lines the river along the upper part of the zone (Figure 7.13). Presently mainly alien woody species including *Acacia* spp. (acacia), *Populus* spp (poplar), and *Eucalyptus* spp. (eucalyptus). This community is identified phytosociologically as the *Athanasia trifurcata* Shrubland in Table 7.1. These may be interspersed with occasional woody indigenous species such as *Salix mucronata* (Cape willow), *Rhus tomentosa* (taaibos), *Olea europaea* subsp*. africana* (wild olive) and *Metrosideros angustifolia* (smalblad). Normally attains a height of greater than 3 metres. Further from the coast this community gradually replaces the niche occupied by Sedge Marsh. This community is not salt tolerant, requiring a continuous freshwater input. It occupies 140 ha or 0.7% of the area mapped in Figures 7.2 - 7.5.



Figure 7.13 A Riparian Woodland community lines the banks of the Berg River on the farms Zoutkloof East and Caledonia. On the far bank Salix mucronata (Cape willow) is dominant while on the near bank, Olea europaea subsp africana (wild olive) and Salix mucronata are dominant. Some woody alien species such as Sesbania punicea (red sesbania) are also present.

7.5.4 Estuarine saltmarsh

i) Halophytic Saltmarsh

This low-growing community, less than 0.5 metres in height, includes an estuarine community of mainly fleshy-leaved salt-tolerant species (Figures 7.14 & 7.15). This community is identified phytosociologically as the *Sarcocornia perennis* Dwarf Shrubland comprising a fine-scale mosaic of a number of subcommunities, including the *Triglochin striata - Salicornia meyeriana* Dwarf Shrubland, *Triglochin striata* Herbland, *Sporobolus virginicus* Grassland, *Juncus kraussii* Sedgeland and *Leptochloa fusca* Grassland in Table 7.1. Typical low-growing dominants include *Sarcocomia perennis* (brakbos), *Cotula coronopifolia* (gansies), *Bassia diffusa* (formerly *Chenolea diffusa*) (soutbos) and *Spartina maritima* (cord grass). It is exposed to regular tidal flooding and its distribution is determined by salinities (see inundation graphs in Appendix 3.2 and mapping unit group pattern explanations in Table 7.5). The outer limits of the community are determined by the spring high tide inundation level in the lower estuary. It occupies 129 ha or 0.6% of the area mapped in Figures 7.2 - 7.5.

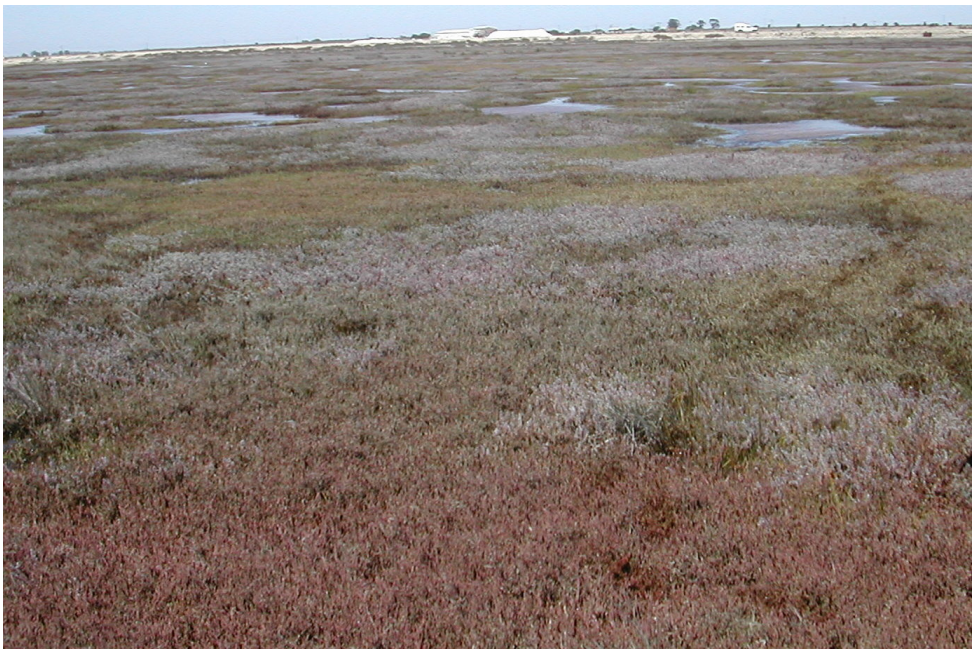


Figure 7.14 *Halophytic saltmarsh between the Cerebos saltworks (in the background) and the Berg River. Recently inundated by the tide, the pools of water are small hyper-saline open pans (refer to community 2(i) below).*



Figure 7.15 *Halophytic saltmarsh at Port Owen near the Berg River mouth. The pink-grey species dotted in amongst the brighter green Sarcornia perennis, on the right of the photograph is Bassia diffusa, while the darker brown-purple species on the left is Limonium depauperatum (papierblom).*

ii) Sedge Marsh, 0.7-1.0 m tall, characterized by *Juncus kraussii* (biesie) with other species, including, *Sarcocornia pillansii* (brakbos), *Samolus porosus*, *Nidorella foetida* and *Sporobolus virginicus* (brakgras) (Figure 7.16). Normally 0.5 to one metre tall, this community includes several sedge species and is exemplified by the invariable presence of *Juncus kraussii* (biesie). Smaller sedge species occur in a varied mosaic, which often include non-sedge species - especially *Sarcocomia perennis* (brakbos) as well as *Samolus porosus* (samolus), *Nidorella foetida* (nidorella) and *Sporobolus virginicus* (brakgras). Typical saltmarsh species are a minor element. Regular estuarine submersion ameliorated by freshwater drainage and river flooding. Outer limits determined by equinox spring high tide mark. Partially flooded by each spring high tide (see inundation graphs in Appendix 3.2 and mapping unit group pattern explanations in Table 7.5). It is found in the upper section of the estuary. Increased salinities would have an adverse effect on this community. It occupies 376 ha or 1.9% of the area mapped in Figures 7.2 - 7.5.



Figure 7.16 A Sedge Marsh/Halophytic Saltmarsh mosaic between Cerebos saltworks and the Berg River. In the foreground is the Halophytic Saltmarsh (refer to community 4 above), while the distinct reed clumps of Juncus kraussii (biesie) further behind indicate the Sedge Marsh community.

7.6 DETAILED VEGETATION DESCRIPTION

Over the three years of this study 23 sites were examined. Some are traditional linear transects, some are of specific habitat features such as pans, while others are detailed size delimitations of isolated clumps of indicator species.

An initial assessment of 19 transects or features were undertaken during 2003 on the estuary and floodplain. These were refined and reduced to provide a subset of the most readily interpretable and readily monitored transects. Most of the transects on the estuary build on O'Callaghan's (1994a, b) transects (refer to Table 7.2), while the rest were selected in order to capture features identified from the maps and existing photography as potentially demonstrating dynamic vegetation change most effectively and least ambiguously. The final subset of eight surveyed and geo-referenced transects (Table 7.2; Figures 7.2–7.5 vegetation transects overlying veg map) represent a mixture of all but one (Riparian woodland) of the natural vegetation types described in §7.5, although some of the vegetation types, such as xeric floodplain and open pans are less thoroughly represented than halophytic saltmarsh or reed marsh for example. These transects, ordered from downstream to upstream features, are described briefly below with detailed descriptions of each transect being presented in numerical order in Appendix 3.1.

Each plant assemblage recorded along each transect (see methods above) was recorded as a sample plot and then manipulated subjectively, following accepted phytosociological tabular manipulation processes (Werger 1974), to expose natural groupings, or plant communities, as presented below, based on the data ordered in Table 7.1. The coarser vegetation units described and mapped in §7.5 above contain the detailed plant communities named below within them. The description of these detailed units along each transect are presented below and their distribution along transects in Appendix A. The mapping unit name for each plant community, as used in §7.5, is given in brackets after the name.

1. *Zostera capensis* Aquatic beds (Inundated Mudflats)
2. *Sarcocornia pillansii* Dwarf Succulent Shrubland (Xeric Floodplain)
3. *Sarcocornia perennis* Saltmarsh (Sedge Marsh and Halophytic Saltmarsh)
    - 3.1 *Bassia diffusa-Sarcocornia perennis* Dwarf Shrubland typicum (Halophytic Saltmarsh)
    - 3.2 *Limonium depauperatum-Triglochin striata* Herbland (Halophytic Saltmarsh)
    - 3.3 *Salicornia meyeriana-Triglochin bulbosa* Dwarf Shrubland (Open pan)
    - 3.4 *Sporobolus virginicus-Sarcocornia perennis* Grassland (Sedge Marsh)
    - 3.5 *Juncus kraussii-Sarcocornia perennis* Sedgeland (Sedge Marsh)
    - 3.6 *Leptochloa fusca-Sarcocornia perennis* Grassland (Short Reed Marsh)
4. *Schoenoplectus scirpoideus* Sedgeland (Short Reed Marsh)
5. *Phragmites australis* Reedland (Reed Marsh)
    - 5.1 *Phragmites australis* Reedbed typicum (Tall Reed Marsh)
    - 5.2 *Cyperus textilis-Cotula coronopifolia* Sedgeland (Sedge Marsh)
6. *Eleocharis limosa* Inland Sedge Marsh (Sedge Marsh)
7. Azonal Riparian Woodland
    - 7.1 *Xanthium strumarium-Paspalum distichum* Riparian Herbland (Riparian Woodland)
    - 7.2 *Athanasia trifurcata- Rhus angustifolia* Riparian Woodland (Riparian Woodland)
8. Sand Strandveld
    - 8.1 *Chrysanthemoides incana-Lycium ferocissimum* Alluvium Strandveld (Strandveld)
    - 8.2 *Chrysanthemoides monilifera-Cladoraphis cyperoides* Grassy Dune Strandveld (Strandveld)
    - 8.3 *Nylandtia spinosa--Cladoraphis cyperoides* Grassland Grassy Flats Strandveld (Strandveld)

The plant communities on the estuary are found in lateral zones that appear to be linked directly to altitude and thus to varying levels of inundation along a water salinity gradient rather than to distance from the channel.

The tabular analysis of the 2003 estuarine data (Table 7.1) indicates zonation patterns and responses (i.e. indicator plant communities and species) that will enable vegetation monitoring.

Appendix 3.1 contains details of the vegetation and of changes that have occurred along the transects over the 2003-2005 period. (It must be noted that no data were ever collected for Transects 23 and 24.)

7.6.1 Zostera capensis Aquatic beds

Surveys of submerged aquatic vegetation of the Berg River estuary are reported on in detail in Chapter 6 of the BRBMP (this volume) and are dealt with in a superficial manner only in this chapter. *Zostera capensis* Aquatic bed (Figure 7.6) were only recorded on the seaward margin of Transect 1 during the present study (community numbered 1 in Table 7.1). The distribution of this community in the study area is illustrated in Figures 7.2–7.5, where it is called Inundated Mudflats. This marine vegetation is exclusively dominated by 0.25 m tall mid-dense (estimated cover of 40%) beds of the eelgrass, *Zostera capensis*. It is usually only exposed at spring low tides. The substrate was recorded on fine sand with scattered shells visible, although these perennial wetlands are usually associated with occasionally exposed mud flats and natural pools under saline conditions in estuaries.

7.6.2 Sarcocornia pillansii Dwarf Succulent Shrubland

The *Sarcocornia pillansii* Dwarf Succulent Shrubland (Figures 7.11 & 7.12) was recorded in Transects 1, 2, 4, 5, 7 and 11 (community numbered 2 in Table 7.1). The distribution of this community in the study area is illustrated in Figures 7.2–7.5, where it is called Halophytic and Xeric Floodplain. This dwarf shrubland, from 0.3—0.5 m tall with a low to moderate cover (10-60%), is dominated by, *inter alia*, *Drosanthemum floribundum*, *Sarcocornia pillansii* and *Spergularia media*. It occurs on fine silty saline soil along the lower river and estuarine floodplain. It is utilized by domestic stock for grazing.

7.6.3 Sarcocornia perennis Saltmarsh

Six different communities belonging to the *Sarcocornia perennis* Saltmarsh were identified in this study.

i. *Bassia diffusa-Sarcocornia perennis* Dwarf Shrubland typicum (Figure 7.15) was recorded on Transects 1, 3 and 11. The distribution of this community in the study area is illustrated in Figures 7.2 - 7.5, where it is called Halophytic Saltmarsh. This dwarf shrubland, from 0.1 - 0.2 m tall, usually has a dense cover (90-100%), dominated by *Sarcocornia perennis*, almost to the exclusion of other species.

ii. *Limonium depauperatum-Triglochin striata* Herbland (Figure 7.16) was recorded on Transects 2, 3, 6 and 12. The distribution of this community in the study area is illustrated in Figures 7.2 - 7.5, where it is called Halophytic Saltmarsh. This dwarf shrubby herbland from 0.1 - 0.25 m tall, usually has a dense cover (90-100%) dominated by, *inter alia*, *Bassia diffusa*, *Limonium depauperatum, Sarcocornia perennis* and *Triglochin striata*.

iii. *Salicornia meyeriana-Triglochin bulbosa* Dwarf Shrubland was recorded on Transects 3, 6 and 11. The distribution of this community in the study area is illustrated in Figures 7.2 - 7.5, where it is called Open Pan. This dwarf shrubland, from 0.1 - 0.2 m tall, usually has a cover that varies seasonally from sparse to moderate (5 - 40%), is dominated by *Salicornia meyeriana* together with mixtures of, *inter alia*, *Bassia diffusa*, *Limonium depauperatum* and *Sarcocornia perennis*. The silty soil in this community can become hypersaline in summer.

iv. *Sporobolus virginicus-Sarcocornia perennis* Grassland was recorded on Transects 5, 7, 11, 12 and 17. The distribution of this community in the study area is illustrated in Figures 7.2–7.5, where it is called Sedge Marsh.

This dwarf shrubby grassland, from 0.1 - 0.20 m tall, usually with a dense cover (90-100%), is dominated by, *inter alia*, *Juncus kraussii*, *Sarcocornia perennis* and *Sporobolus virginicus*. This community is usually found near the inland edge of the saltmarsh.

v. *Juncus kraussii-Sarcocornia perennis* Sedgeland (Figure 7.16) was recorded on Transects 3, 4, 7, 12 and 14. The distribution of this community in the study area is illustrated in Figures 7.2 - 7.5, where it is called Sedge Marsh. The 0.3 - 0.5 m tall spiky sedge *Juncus kraussii* is dominant, usually with *Sarcocornia perennis*, and forms dense stands, in this community.

vi. *Leptochloa fusca-Sarcocornia perennis* Grassland (Figure 7.8) was recorded on Transect 7. The distribution of this community in the study area is illustrated in Figures 7.2 - 7.5, where it is called Short Reed Marsh. The highly palatable grass *Leptochloa fusca* is dominant in local clumps in the saltmarshes.

7.6.4 Schoenoplectus scirpoideus Sedgeland

The *Schoenoplectus scirpoideus* Sedgeland (Figure 7.8) was recorded on Transects 4 and 7. The distribution of this community in the study area is illustrated in Figures 7.2–7.5, where it is called Short Reed Marsh. This 0.5 m tall sedgeland, dominated virtually exclusively by *Schoenoplectus scirpoideus*, dies back during the cold winter months to appear devoid of living vegetation.

7.6.5 Phragmites australis Reedland

Two different communities belonging to the *Phragmites australis* Reedlands were recorded in this study.

i. *Phragmites australis* Reedbed typicum (Figure 7.7) was recorded on Transects 5, 7 and 8. The distribution of this community in the study area is illustrated in Figures 7.2-7.5, where it is called Tall Reed Marsh. This 3-5 m tall dense reedland, dominated almost exclusively by *Phragmites australis* and sometimes also additionally with *Bolboeschoenus maritimus*, usually lines open channels. It is often burnt in the summer to stimulate regrowth, as the young shoots are preferred for grazing by domestic stock.

ii. *Cyperus textilis-Cotula coronopifolia* Sedgeland (Figure 7.8 & 7.16) was recorded on Transects 5, 7, 11 and 19. The distribution of this community in the study area is illustrated in Figures 7.2-7.5, where it is called Sedge Marsh. This is a less dense to open and shorter (1.5-2.5 m tall) form of reedland dominated by, *inter alia*, *Cotula coronopifolia, Cyperus textilis* and *Phragmites australis*, which is usually found in regularly flooded areas that are disturbed by cattle grazing. *Phragmites australis* appears to be an invasive pioneer in this habitat.

7.6.6 Eleocharis limosa Inland Sedge Marsh

The *Eleocharis limosa* Inland Sedge Marsh (Figure 7.16) was recorded on Transect 8. The distribution of this moderately dense, 0.4 m tall community, dominated virtually exclusively by *Eleocharis limosa*, is illustrated in Figures 7.2 - 7.5, where it is called Sedge Marsh.

7.6.7 Azonal Riparian Woodland

Two different communities belonging to the Azonal Riparian Woodland (Figure 7.13) were recorded in this study. The distribution of these communities in the study area are illustrated in Figures 7.2 - 7.5, where they are called Riparian Woodland.

i. *Xanthium strumarium-Paspalum distichum* Riparian Herbland was recorded on Transects 8, 9, 10 and 11. This community, which is dominated by grasses and weedy herbs, such as, *inter alia*, *Paspalum distichum* and *Xanthium strumarium*, and occasionally also together with *Bolboeschoenus maritimus* and *Cynodon dactylon*, is found in moist sandy disturbed areas lining the water's edge.

ii. *Athanasia trifurcata- Rhus angustifolia* Riparian Woodland was recorded on Transects 8, 9 and 10. This is a 1.0—3.0 m tall fairly dense woodland dominated by, *inter alia*, *Athanasia trifurcata*, *Lolium multiflorum* and *Paspalum distichum*, that is regularly found lining water courses on the Western Cape plains.

7.6.8 Sand Strandveld

Three different communities belonging to the Sand Strandveld were recorded in this study. The distribution of these communities in the study area is illustrated in Figures 7.2–7.5, where they are collectively mapped as Strandveld.

i. *Chrysanthemoides incana-Lycium ferocissimum* Alluvium Strandveld was recorded on Transect 19. This 1-2 m tall shrubland, dominated by, *inter alia*, *Asparagus rubicundus*, *Chrysanthemoides incana*, *Euclea tomentosa* and *Lycium ferocissimum*, is found on inland sand fringing the lower slightly saline reaches of rivers on the western Cape plains.

ii. *Chrysanthemoides monilifera-Cladoraphis cyperoides Grassy Dune Strandveld was recorded on Transect 1. This 0.5 m tall mid-dense community is dominated by the spiky grass Cladoraphis cyperoides. It is found on recent white littoral dunes along the west coast.*

iii. *Nylandtia spinosa-Cladoraphis cyperoides* Grassland Grassy Flats Strandveld was recorded on Transect 2. This 1-2 m tall open shrubland is found on relatively stable saline alluvium and coastal dune sand. A spiny grassland understorey of *Odyssea paucinervis* under *Nylandtia spinosa* shrubs occurs on the estuary fringes where it is dominant.

7.7. DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

This study was designed to provide a basis for the monitoring of changes that might occur to the floodplain and estuarine vegetation of the Berg River after the construction of the Berg River dam at Franschhoek. Transects or samples were located in the major vegetation types found on the estuary and floodplain firstly to document and map the different species assemblages observed and secondly to record the detailed location of these assemblages along transects precisely to ensure repeatable comparative sampling in the future.

7.7.1 Methods

The mapping units used during earlier studies of the Berg River estuary vegetation by McDowell (1993) were used by Ms Jones in the compilation of the present vegetation map which is now available in a comprehensive GIS version. Unfortunately no direct comparison could be made to spatial distribution changes in units identified McDowell's (1993) map, as originally planned, because it later became apparent, on receipt of his data, that his electronic map had not been geo-referenced. Changes to the vegetation since he sampled the area some 10 years previously could thus not be assessed with any confidence.

The current study includes repeated some sampling of the general area sampled by O'Callaghan (1994a) (see Table 7.2), who also used transects, but, unfortunately, he did not give the co-ordinates for his transect locations indicated on his maps, although he did provide distance locations for his samples along his transects, so no precise conclusions can be drawn about changes since his sampling some 10 years earlier. The location of O'Callaghan's transects, in most instances did not coincide with transects through the main channel as used in the present study. (Transects 1 and 2 are closest to his transects and comparisons are drawn in Appendix 7A.) Some of the transects (Transects 3, 6 & 12) intended to repeat the general location of O'Callaghan's transects were relocated to coincide with through channel profiles used by other disciplines in the present study, consequently, in these instances, no comparison to O'Callaghan's work is possible.

Aerial photography is very useful to pick up macro-changes as is indicated by the vegetation maps produced in this study, but this type of photography is inadequate to determine fine-scale changes along transects. Fixed-point vertical digital photography would require precise field location to be useful. This has considerable potential in flat areas with low vegetation. It cannot be used effectively in vegetation over about 1m tall or where the substrate erodes or accumulates to any large extent as on river banks. Inundation profiles proved to be of little use to correlate to vegetation differences except where information was provided along transects. Regular field monitoring of precise limits to each tidal event gives excellent insight into, vegetation as a predictive tool. This was particularly evident during a spring high tide event on Transects 1 and 2 on the Blind Lagoon and 5 at Kruispad West where precise co-incidence of tidal inundation to community boundaries was observed (Appendix 3.1).

Various issues relating to the precise location of monitoring transects arose during this study. Where possible thick wire stakes were used to mark boundaries recorded. These were regularly found in succeeding years and proved a cheap and effective, albeit rather primitive tool. Unfortunately, losses of pegs occurred through not finding them again in dense vegetation, through corrosion if they were not replaced annually, through human removal, by cattle treading on and burying them, by bank collapse covering them and leading to complete loss of the pegs when they get washed away. Alternatively, testing hand-held GPS apparatus also had difficulties, such as inadequate precison to pin-point sub-meter changes. These are critical for picking up annual changes in community boundaries, such as occur in riparian and estuarine system. D-GPS systems are extremely costly to hire, are rather bulky and are not easy to use in inundated, slippery, loose muddy areas where it is difficult to walk under normal conditions, particularly where cattle leave deep hoofprints that are not visible through the muddy water. Steep, eroded slopes of 1 - 4 m bordering on deep pools, such as are common in the floodplain section, are not measurable using a D-GPS system transported on your back. A D-GPS system has similar inadequacies to a hand-held GPS in measuring altitudinal changes. No GPS system is suitably accurate amongst dense bush. This type of restriction with apparatus makes it imperative that sufficient funding is provided annually for conventional surveying of all monitoring transects.

It is apparent that there are some differences between the inundation periods considered usual by the authors compared to the more extreme wet periods presented in the graphs from the hydrodynamic models, yet there is a similar trend in expectations of inundation frequency. A few of the hydrodynamic model graphs are very dissimilar to the rest in particular groups as are high-lighted in Table 7.5. These differences could be attributed to inaccuracies in the models or to inaccuracies in the mapping units or both simultaneously due to local small-scale topographic variations causing vegetation differences. Loss of inundation frequency and degree through abstraction could imply a negative trend with plant communities changing toward the drier spectrum unless adequate (volume and duration) releases are made to coincide with selected natural flow events.

It is essential that flood heights flood similar vegetation units as it is an important driver of ecological function, such as flushing salt build-ups from shallow depressions to prevent dust bowls developing.

Saltmarsh reaction to change is subtle because of the flat topography. Changes to inundation levels is similar to slight changes in topography, both causing changes in species composition, or only in their dominance, with relatively rapid lateral stand boundary changes. Precise surveying and *in situ* recorded flood records of tidal flooding perimeters are essential to accurately record and to explain these types of changes to ascertain the accuracy of the models developed in this project.

Pegs inserted at the places reached by neap and spring low and high tides on a single occasion along selected Transects (see monitor group 1 in paragraph 7.7.4) would probably explain more than 90% of the saltmarsh and floodplain community variation (inversions as described by O'Callaghan (1994a) excluded). Adequate provision must be made to accommodate for the expenses related to these essential surveys.

Unforeseen and unavoidable destruction or disruption of sites can occur (e.g. Transect 10 which was burnt and was bulldozed by the farmer). Long-term monitoring programmes must therefore be designed with extra sites included from the start to absorb unplanned disturbances.

7.7.2 Estuarine Vegetation

This study found that the lower river can be subdivided into two main clear sections (see vegetation map Figures 7.1-7.4). The Sishen-Saldanha Railway Bridge is approximately the upper limit of Typical Estuarine Mudflats Saltmarsh communities (3.1 to 3.3 in the classification above), including *Zostera capensis* beds on the Plaat. These communities are referred to as Cape Estuarine Salt Marshes by Mucina & Rutherford (2006).

Marshes in the Blind Lagoon showed the clearest zonation patterns, whereas the zonation patterns higher up the estuary were less easily discernible. The findings from this study support O'Callaghan's findings possibly because the blind lagoon is the original natural Berg River outlet to the sea.

Debris accumulations occur in two areas along the transects through the saltmarshes (Transects 1 & 2 (Blind Lagoon); 3, 22 & 25 (Cerebos Saltworks) and 6 (Port Owen)), namely, (a) along the top inundation edge of the spring high tides and (b) some older deposits occur at the back of the marsh where maximum floods reach during equinox high flows in winter. The transects measured here all started above the highest debris accumulation line.

The banks along the main channel and the large subsidiary channels are collapsing. Some drainage channels within the saltmarsh are filling with remnant channels visible as a series of depressions or only as covered holes in the marsh.

The prevalence of single species dominance (e.g. sample 6A) is a typical adaptation by a single species to avoid competition by adapting to an area with a particularly severe stress such as that caused by hypersalinity or by long periods of immersion.

The high degree of similarity between samples in a saltmarsh such as this is because the coefficients of similarity applied here are based solely on species content and not on abundance. Saltmarsh communities are regularly distinguished by changes in dominance rather than by changes in species content. Saltmarsh conditions that suit one species more than another give it a competitive advantage and it rapidly becomes dominant (e.g. *Sarcocornia perennis* in sample 6J (2003 to 2004). Changes to particular conditions quickly result in a change in the community. This reaction makes a saltmarsh a very sensitive indicator of changing environmental conditions.

For example, the changes experienced in this saltmarsh could be attributed to the saltmarshes reacting to a generally drier cycle prevailing over the 2003-2004 period.

Juncus kraussii forms dense patchy emergent stands in conjunction with typical saltmarsh species (see composition of communities and location along transects in Appendix 3.1). These patches, albeit with varying species compositions, occur in saltmarshes elsewhere in the region, such as at Langebaan (*Juncus kraussii* Dense Sedgelands of Boucher & Jarman 1977), Kleinmond (Short Sedge Marsh of O'Callaghan 1994a), Uilkraal (*Samolo porosi-Juncion kraussii* of Mucina *et al.* 2003), Western Cape (*Sarcocornio-Juncetalia kraussii* of Boucher 1987); and in general terms as Cape Estuarine Salt Marshes (Mucina & Rutherford 2006); in Namaqualand (Arid Estuarine Salt Marshes of Mucina and Rutherford 2006); in the Southern Cape e.g., in Knysna Lagoon (Grindley 1985); in the Eastern Cape and even in Australia and New Zealand (Mucina *et al.* 2003).

Spartina maritima regularly lines channels through the lower Berg River estuary saltmarshes, as in this transect and through the Western Cape (e.g., the *Spartina-Triglochin* community at Langebaan by Boucher & Jarman 1977). This exotic species is widely distributed fringing estuarine channels through the Western and Eastern Cape estuaries (Pierce 1982).

Salicornia meyeriana is usually associated with bare patches in saltmarshes here, such as those associated with local hypersaline conditions. A hypersaline zone occurs along the Cerebos Saltworks dam walls bordering on main saltmarsh that is largely devoid of plant life. *Salicornia meyerana* can withstand highest salinity conditions as it is short-lived and dies back under very dry summer months or under physiological drought conditions.

This community has been identified and described as the *Chenolea-Salicornia* Dwarf Succulent Shrubland at Langebaan (Boucher & Jarman 1977) and more generally as the *Sarcocornio-Salicornietalia meyerianae* for the Western Cape (Boucher1987).

7.7.3 Floodplain Vegetation

This vegetation is described in broad regional terms as Cape Lowland Alluvial vegetation by Mucina & Rutherford (2006). The present study presents the most detailed description of floodplain vegetation in the region.

The lower river floodplain section, which has a tidal influence, stretches from this railway bridge upstream to and includes Kersefontein Farm, ends approximately at the bridge and road to Bergrivier Station is the upper end of the floodplain. The riparian and floodplain vegetation in this upper floodplain section of the Berg River supports different vegetation from the true lower estuarine section, although it does also contain elements from the upstream non-tidal parts.

Some general observations about the vegetation recorded on the floodplain, particularly about Transects 5 & 21 (Kruispad West) and 7 & 20 (Kruispad East), are useful to develop an understanding of this system in addition to the information provided in Appendix 3.1 where changes that have occurred over the 2003-2005 period are dealt with in detail.

These are very flat marshes associated with the lower floodplain having slightly lower salinity levels than the downstream saltmarshes. These floodplain marshes remain wet for a number of days after inundation by spring high tides with shallow pans spread through them. See Sites 9 and 10 in Volume 3 Chapter 3 for inundation profiles located on Transect 5 for wet and dry periods. These floodplain marshes are heavily utilized by cattle for grazing during the summer months when they are generally drier and less grazing is available in the non-riparian inland vegetation. Heavy grazing, with accompanying trampling, reduced the grazable grass cover in these wetlands at 7E, 7F 7H, 20E and 20G.

Over the monitoring period a general reduction in *Phragmites australis* occurred with large scale reduction in cover and deaths being prevalent (5M – P, 7J), but with 5S, 5AB, 5T developing as a new bed of *Phragmites australis*. These changes are probably related to a generally drier climatic cycle with less flooding as *Phragmites* generally occupies the fringes of more permanent water bodies unless the cover of natural vegetation has been disturbed, such as through fire, in which case it can advance into drier riparian fringes. Shorter growing *Cyperus textilis* in sample 7J decreased as a river fringing stand of tall *Phragmites australis* became denser and more mature. After a period, farmers periodically set dense *Phragmites australis* patches alight to rejuvenate them to increase young grazable shoots after a fire the cover of *Cyperus textilis* would increase initially under these conditions. Downward movement of species less tolerant of lengthy inundation occurred in sample 5C into 5B, as evidenced by *Juncus kraussii, Samolus porosus* and *Sarcocornia perennis* in particular, with *Typha capensis* moving upward from 5A to 5B. *Phragmites australis* was the most commonly recorded species in samples along the floodplain transects over the three years.

Specific isolated clumps of *Phragmites* were measured on the Bovenplaat Farm to provide some future indication of the dynamics of this species (Transects 14 – 16). Transect 17 provides patch outlines of *Cyperus textilis* and Transect 18 of *Typha capensis*. Unfortunately the outlines of these individual patches could not be resurveyed in 2004 and 2005 because of surveying facility constraints.

Samples 5W and 5Z along the inner margin of the floodplain marsh became devoid of plants by 2005, presumably either disturbances increased (heavy grazing occurred in these marshes) or inundation levels decreased (see decrease in general inundation levels in graphs for Sites 9 and 10 in Volume 3 Chapter 3) or salinities have increased over the 2004 – 2005 period making these parts unsuitable for vegetation (probable as this phenomenon is generally associated with a reduction in flooding).

Individually marked populations or clumps of species such as *Cyperus textilis, Phragmites australis* and *Prionium serratum* are essential for monitoring purposes. The performance of the floristic elements from the low salinity upstream parts, such as *Prionium serratum* and *Cyperus textilis*, are particular useful to monitor salinity and flow changes in the floodplain section. An increase in them indicates a tendency for the system toward becoming fresher but with less flushing flows such as annual floods, while in contrast, a decrease in clump size and condition may indicate an increase in salinitiy. A decrease in *Prionium serratum* numbers and condition has also be linked to increased shading such as through an increased invasion of riparian fringes by alien trees such as *Acacia mearnsii* and *Eucalyptus camaldulensis*. The alien trees increase because of environmental stress placed on the natural vegetation in riparian systems through physical human-origin disturbances, including reduction of natural vegetation cover and abstraction related problems such as over-abstraction or disruption of flow variability.

A degradation in *Phragmites australis* clump size and condition could be indicative of increased salinities in the estuarine section and of a lack of periodic flushing flows, together with an increase in physical disturbance from cattle grazing, for instance. *Phragmites australis* patches are burnt periodically to open the clumps, thereby increasing their floristic diversity and also to provide young shoots and leaves for grazing. Cattle graze dryland areas more in winter-spring and the tidally inundated floodplains during summer-autumn. Cattle would tend to concentrate in the riparian tidally flooded areas on the floodplain if insufficient grazing was available in dryland areas because of generally lower and poorly distributed annual rainfall resulting in less dryland grazing and if the floodplain was inundated less resulting in more grasses and less sedges and reeds. Predicted global warming changes, with a generally drier climate in the Western Cape, would tend to result in increased usage on the tidally inundated floodplain.

A general lowering in inundation levels and in frequency of inundation results in a migration of saltmarsh species downward and an increase in salinity levels in backwater pools. Changes in species composition and dominance accompany these environmental changes as are illustrated in Transects 12. The saltmarsh salinity increases are alluded to by O'Callaghan but not the consequences to the floodplain, which is an increase in saline bare pans similar to dust bowls as the rainfall is insufficient to leach away the salts that accumulate in these hollows. As the pans develop high salinities, fewer and fewer plants are able to survive in them, until they becomes devoid of any vegetation. As the vegetation cover becomes less, wind blows the friable soil away, increasing the size of the pans. This process is also speeded up by ploughing on these lower river floodplains as this also removes the vegetation which would have stablised the soil and provided remedial organic material to the topsoil that is then lost through wind erosion. No agricultural activities, other than carefully managed light stock farming, should occur on the lower floodplain, particularly with the predicted lower rainfalls attached to the global warming scenario.

7.7.4 Monitoring recommendations

The transects studied in this survey are assessed below in respect of their potential for future monitoring although ideally all should be monitored annually as this would provide better long-term monitoring data. Note that different scales of monitoring are possible. Survey vegetation in Autumn (February-April) annually under neap tide conditions.

1. Record precise changes to communities annually to monitor for natural pattern change for baseline record. Formally survey successive community boundary positions. Record species complement and cover-abundance of each species in successive communities along transect annually. Monitor change laterally from transects using new air photography as it becomes available. Use overhead digitial photographs of pegged 1x1 m plots located on boundaries between selected communities to compare change (mark and evaluate community changes using GIS). Take general lateral photographs throughout.

   Peg (then survey location) of outer limits reached by neap and spring, low and high tides on single occasion and relate to community boundaries as tidal rise occurs, then introduce levels on botanical profiles through sites.

   Transect 2 – Short transect with typical straightforward transect pattern of variation. Subject to sedimentation.

   Transect 5 – Formally surveyed and monitored over 3 years with complex interplay related to exposure between spring tide flooding. Would be sensitive to river level fluctuations but influenced to a degree by trampling from stock grazing.

   Transect 6 – Typical complex variations through saltmarsh over extended distance. Typical bank collapse along main channel. Channels through saltmarsh are dynamic. Use as baseline as does not suffer from adjacent agricultural or direct industrial disturbance. Does have adjacent urban development but this only has indirect effects.

   Transect 7 – Typical complex variations through floodplain over relatively short distance. Does suffer from agricultural disturbance (stock grazing) but less than Transect 5 as more distant from homestead with kraals thus useful monitor of interplay between river processes and heavier stock grazing and trampling as shown by Transect 5.

   Transect 12 – Repetition of general area monitored by O'Callaghan and repeated annually in present study.

   Although not done in present study, it should be formally surveyed as the depostional and erosional changes along it are dynamic, possibly from the presence of the Carinus Bridge.

   Transect 22 with 25 ending – Typical complex variations through saltmarsh over extended distance. Bank collapse prevalent. Channels through saltmarsh are dynamic. Monitor effect of saline leakage from saltworks dams. Adjacent to in-stream profile. Serves as confirmation to patterns apparent in Transect 6.

2. Survey community boundaries on single occasion then only record the species and their cover-abundance in each successive community on an annual basis. When changes are considerable and warrant it then resurvey community boundaries or detailed monitoring can be undertaken when funds become available. Monitor change laterally from transects using new air photography as it becomes available. Use overhead digitial photographs of pegged 1x1 m plots located on boundaries between selected communities to compare change (mark and evaluate community changes using GIS). Take general lateral photographs throughout.

   Transect 1 – Short transect with typical straightforward transect pattern of variation. Subject to sedimentation.

Transect 3 – Placed in full annual monitoring category for baseline monitoring. Superceded by Transect 22/25.

Transect 4 – Short transect with typical straightforward transect pattern of variation. Sensitive to changes in salinities and frequency of inundation by saline waters.

Transect 20 – Formally surveyed and monitored over 2 years with complex interplay related to exposure between spring tide flooding. Would be sensitive to river level fluctuations but influenced to a degree by trampling from stock grazing.

Transect 21 – Formally surveyed and monitored over 2 years with complex interplay related to exposure between spring tide flooding. Would be sensitive to river level fluctuations but influenced to a degree by trampling from stock grazing.

3. Only record successive communities along the transect annually to determine whether any changes in species assemblages have occurred. These transects are too distant from the others to warrant surveying community boundaries. Monitor change laterally from transects using GIS techniques with new air photography as it becomes available. Take general lateral photographs throughout.

   Transect 11 – Only transect through a pan on floodplain.

   Transect 13 – Useful to assess changes from sporadic flooding and possibly climate change effects on pans on flats. Stock-grazing does have an additional influence.

4. Monitor boundaries annually using hand-held GPS to document changes to environmentally sensitive stands. Take general lateral photographs. Illustrate spatial changes from GPS records on new air photography as it becomes available using GIS techniques. Monitor all individual indicator species that are possibly sensitive to salinity/freshwater ratio changes that have been examined in special transects in this study (see Appendix 3.1).

   Transects 14, 15 & 16 – Isolated and sensitive Phragmites stands

   Transect 17 – Evaluate presence of Cyperus textilis and take GPS reading of ends of clumps

   Transect 18 - Isolated and sensitive Typha stands

   Transect 19 - Isolated and sensitive Prionium stands

5. Do not monitor as main active processes not tidally related and too distant to monitor

   Transect 8 - This plateau was only sampled during 2003.

   Transect 9 – Fire, stock-grazing and major bank collapse through under-cutting. Adjacent to Transect 10 on opposite bank.

   Transect 10 – Physical man-made disturbance. Major sand deposition. Adjacent to Transect 9 on opposite bank.

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CHAPTER 8 - INVERTEBRATES

T.H. Wooldridge

8.1 INTRODUCTION

8.1.1 General characteristics of the Great Berg River

The Great Berg is the largest river in the Western Cape having a Mean Annual Runoff of 693 x 10^6 m^3 (Berg 1993, quoted in Bennett 1994). The river flows northwards from its source near Franschhoek, draining a catchment area of about 7715 km^2 (Slinger & Taljaard 1994). Stream flow in the 294 km long river is highly seasonal, varying between 0.2-2.0 m^3s^{-1} in summer (November-February) and 15-60 m^3s^{-1} during winter (May-August). At times of flooding, flow rates may increase to 700 m^3s^{-1} (Berg 1993, quoted in Bennett 1994). Two major impoundments are currently located on (Voelvlei Dam - full capacity 168 x 10^6 m^3) or adjacent to the river; (Wemmershoek Dam - 59 x 10^6 m^3) (Dept of Water Affairs 1986). The latter receives diversions from the Klein Berg and the Twenty Four River, both tributaries of the Great Berg.

8.1.2 General characteristics of the Great Berg estuary

The estuary (Figure 8.1) is river-dominated and sediment dispersal occurs seaward of the river mouth. Only two other South African estuaries have large offshore mud deposit centres, namely the Orange or Gariep and the Thukela (Cooper 2001). Besides the Great Berg, numerous other examples of river-dominated estuaries occur in South Africa. In all of them, river flow is critical to the maintenance of an outlet channel and the impact of impoundments is especially notable in these systems (Cooper 2001).

The estuarine floodplain is extensive and tidal influence is measurable up to 70 km from the mouth (Slinger & Taljaard 1994). Over the last 50 km, the estuary bed falls only 1 m (Day 1981). Near the mouth, the estuary bypasses Veldrif, a marina and the fishing harbour of Laaiplek (Figure 8.1). In 1966, a new estuary mouth was cut through the sand dunes about 1 km north of the original mouth (Slinger & Taljaard 1994).

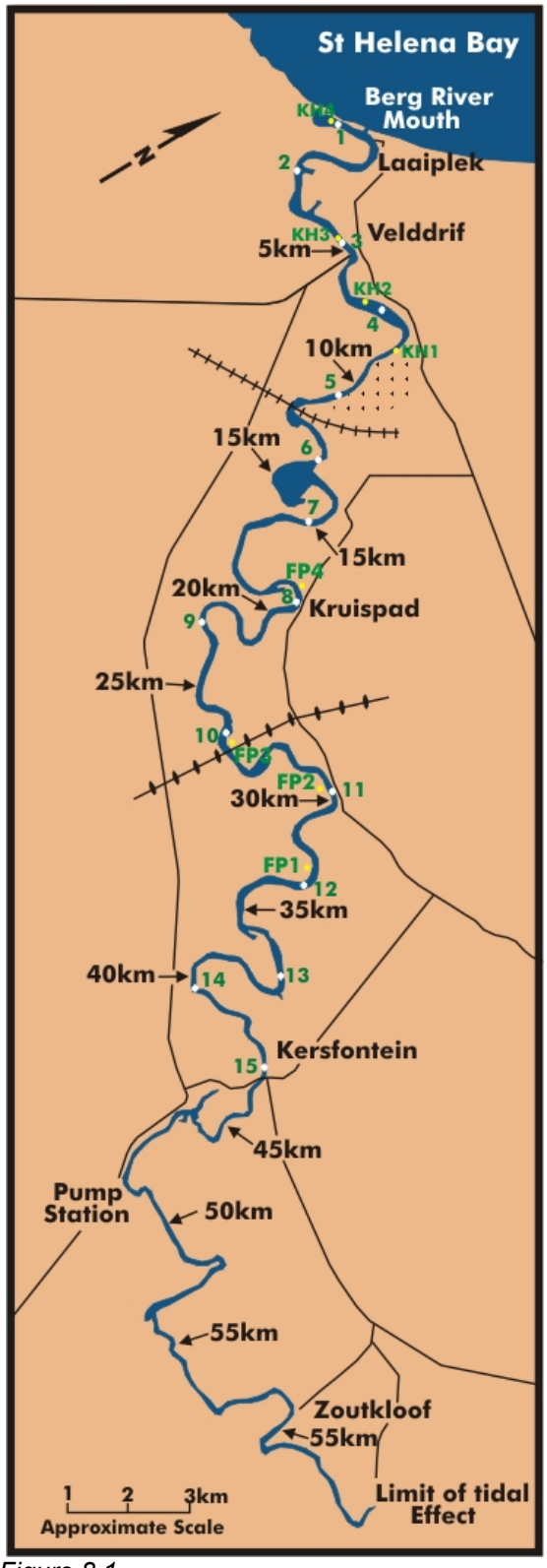


Figure 8.1
Map of the Great Berg estuary. Distance from the mouth indicated in kilometres. Sites 1 to 15 refer to the subtidal invertebrate sampling stations in the monitoring programme, 2003 - 2006. KH1-KH4 represent the intertidal sites; FP1-FP4 represent the floodplain sampling sites (Modified from Bennett 1994). Co-ordinates are given in Table 8.1

The new mouth was stabilized between concrete walls and fishing vessels are now able to enter the port safely. The original mouth has silted up and the former channel currently forms a blind arm or lagoon running parallel to the coast. The lower 4 km of the estuary is also dredged to a depth of at least 4 m to allow for boat navigation.

The main channel at Veldrif is about 100-200 m wide, becoming progressively narrower and shallower upstream. Average width and depth of the channel is about 100 m and 3 m respectively. In the uppermost 15 km, steep banks covered in riparian woodland bound the estuary. Downstream, the estuary is flanked by a floodplain that varies in width from 1.5 to 4 km in the middle reaches to <1.5 km in the lower 15 km. This floodplain is seasonally inundated and supports large numbers of wading birds.

8.2 SAMPLING METHODS

Fifteen subtidal invertebrate sampling sites were located along the estuary (Figure 8.1). A further four intertidal sites (KH1-KH4) and four floodplain pan sites (FP1-FP4) were sampled in September 2003 and February 2006. The channel beyond Kersfontein is relatively shallow and choked with debris. It is therefore difficult to deploy sampling equipment effectively along these reaches. In order to more accurately document changes in biological communities along the estuary, a relatively large number of sites were chosen (15).

Table 8.1 Co-ordinates for sampling stations (1-15) and K & H sites shown in Figure 8.1

Station	Latitude	Longitude
1	32°46.414'S	18°08.456'E
2	32°47.319'S	18°08.697'E
3	32°47.329'S	18°09.821'E
4	32°47.301'S	18°11.152'E
5	32°48.541'S	18°11.826'E
6	32°49.053'S	18°12.465'E
7	32°49.650'S	18°13.337'E
8	32°50.515'S	18°14.217'E
9	32°51.694'S	18°13.594'E
10	32°52.234'S	18°15.155'E
11	32°51.489'S	18°16.779'E
12	32°52.452'S	18°17.914'E
13	32°53.402'S	18°18.722'E
14	32°54.240'S	18°17.964'E
15	32°54.309'S	18°18.900'E
K & H1	32°46.430'S	18°08.348'E
K & H2	32°47.283'S	18°09.872'E
K & H3	32°47.285'S	18°10.261'E
K & H4	32°48.017'S	18°11.927'E

8.2.1 Biological sampling

Collection of samples was done from the deck of a 4.5 m twin-hull fibreglass boat equipped with a 40 hp outboard motor at sites 1 – 15. Core samples were collected at intertidal and floodplain pan sites (KH1 – KH4, FP1 – FP4). Approximately five days were spent in the field on each sampling occasion. Seven series of samples were collected (Table 8.1). Three series were collected in summer, one series in autumn, two series in winter and one series in spring. On each occasion, macrozooplankton (nocturnal), hyperbenthic (diurnal) and zoobenthic (diurnal) samples were collected.

Analysis of samples was completed in the laboratory. Invertebrates were identified to species level wherever possible and the data analysed using multivariate statistics from the statistical package, PRIMER V.5 (Plymouth Routines in Multivariate Ecological Research). If multivariate techniques were not appropriate, other packages using MS Excel or Statistica for Windows were used.

Macrozooplankton

Samples were all collected after dark using two slightly modified WP2 plankton nets (57 cm diameter and 200 µm mesh), fitted with calibrated Kahlsico flowmeters. Two replicates were collected per station. Each net was attached to a 1 m boom extending laterally on either side of the bow of a flat-bottomed boat (4.5 m length).

Midwater net tows continued for 2 to 3 minutes (at a speed of 1 to 2 knots) at all 15 stations indicated in Figure 8.1. Although finer nets may be used, this usually leads to excess clogging of the mesh. Filtration efficiency is reduced and larger organisms such as small shrimps (e.g. mysids – often extremely abundant in estuaries) are then under-represented in samples because of increased net avoidance. Animals retained by nets were stored in 10% formaldehyde solution in 500 ml plastic bottles. In the laboratory animals were identified to species level under a microscope and final abundance expressed as the average number per m^3 of water calculated from the two replicates collected at each site.

Table 8.2 Sampling dates and season when invertebrates were sampled in the Great Berg Estuary. The estuary was sampled on seven occasions.

Session	Sampling dates	Season
1	10 – 14 February 2003	Low flow, summer
2	16 – 20 September 2003	High flow, winter
3	25 – 29 February 2004	Low flow, summer
4	24 – 29 April 2005	Low flow, autumn
5	15 – 19 July 2005	High flow, winter
6	14 – 18 November 2005	Low flow, spring
7	17 – 22 February 2006	Low flow, summer

Hyperbenthos

Hyperbenthic animals were sampled at all 15 subtidal stations (Figure 8.1) using a sled mounted on broad skids. Two replicates were collected at each site. The rectangular opening to the sled measured 75 x 70 cm, to which is attached a 500 µm mesh net. A calibrated flow meter mounted in the entrance quantified water volume passing through the net. Animals collected were then stored in 500 ml plastic bottles and preserved in 10% formaldehyde solution. In the laboratory animals were identified to species level under a microscope and final abundance expressed as numbers per m^3 of water calculated from the two replicates collected at each site. Animals captured in sled samples are usually fairly large, measuring up to 1-2 centimetres. Most of the smaller organisms such as copepods escape through the mesh and were therefore not enumerated or identified in sled samples.

Subtidal benthic invertebrates

Subtidal benthic invertebrates were collected using a Van Veen type grab and the contents sieved through a 500 µm mesh screen bag. The grab has a 200 cm^2 bite that penetrated the sediment down to about 10 cm depth. Six replicates were collected in February 2003, while nine replicates were collected on all other sampling occasions. Replicates were collected over an area of about 10 m^2 in the channel area at each site. Animals retained by the sieve were stored in 500 ml plastic bottles and preserved with 10% formaldehyde solution. Final abundance was expressed as the average number of each species per m^2 of substratum at each site, obtained from the six or nine replicates respectively.

Intertidal benthic invertebrates

Intertidal benthic organisms were sampled on the 20th September 2003 and 20th February 2006 at four sites just above the low tide level. Sites KH1 to KH4 (Figure 8.1) represent the same sites sampled by Kalejta & Hockey (1991). Four other sites (FP1 – FP4, Figure 8.1) were located in temporary pans on the floodplain adjacent to the estuary and were sampled in September 2003 only (wet season). At each site a corer having an internal diameter of 10.3 cm was pressed into the sediment to depth of ±25 cm and the contents sieved through a mesh bag (500 µm mesh).

Animals retained by the sieve were stored in 500 ml plastic bottles and preserved with 10% formaldehyde solution.

Final abundance was expressed as the average number of each species per m^2 of substratum at each site, obtained from the six replicates. Each core sample therefore represents ca $1/120^{th}$ m^2.

8.2.2 Abiotic measurements

A YSI 6600 multi-parameter sonde was deployed at all 15 stations (Figure 8.1) during a continuous run up the estuary each trip. Variables were measured near the surface, at 0.5 m depth, at 1 m and thereafter at 1 m depth intervals. The following parameters were recorded at every depth level sampled: Dissolved oxygen (percent saturation and in mg per litre), salinity (ppt), temperature (^oC), conductivity (mS per cm), turbidity and pH.

A sediment sample collected at each station provided information on particle size distribution and percent organic content. Dry samples (dried at 60^{o}C for a minimum of 48 h and then weighed) were incinerated at 550 ^{o}C for 12 h to burn off the organic matter. The difference in weight of the sample after incineration provided information on organic content, expressed as a percentage. Three replicates from each sediment sample were used to obtain a final value. Samples were then soaked in distilled water for 24 h to remove salts. Excess water was carefully siphoned off and the sample again dried at 60^{o}C for 72 h. Dried sediment was then vibrated through a series of metal test sieves (2 mm, 1 mm, 500 µm, 355 µm, 250 µm, 180 µm, 125 µm, 90 µm, 63 µm and <63 µm). General descriptive categories of particle size classes are shown in Table 8.3.

Table 8.3 General description of the different categories of particle size classes.

Particle size class	Category
< 2 mm	Very coarse sand
<1 mm	Coarse sand
<500 µm	Medium sand
<250 µm	Fine sand
<125 µm	Very fine sand
<0.63 µm	Silt/mud

Percent organic content was obtained after incinerating pre-weighed dry sediment samples (dried at 60^{o}C) for 24 hrs at 660^{o}C.

8.3 RESULTS

Abiotic and biotic spreadsheet data are presented separately in 4.1 and Appendices 4.2-4.5 respectively. Abiotic data may reflect a mean value for all water column readings at each station (integrated) as well as values recorded for near-surface and/or near-bottom horizons. This allows for a more sensitive analysis to detect possible relationships between abiotic driving forces and different taxa within invertebrate groups (e.g. zooplankton is more likely to respond to integrated water column values while the benthos may be more sensitive to bottom salinity values).

8.3.1 Abiotic structures

Salinity

Clear seasonal patterns were apparent for salinity, with marine penetration extending further upstream compared to winter (Fig. 8.2). Using Stations 6 and 12 as guidelines, salinity values during low-flow periods (summer) were around 30 and 10- 25 respectively. The corresponding salinity value at the same stations during high-flow periods (winter) was around zero for both sites. In spring (November), salinity was around 20 at Site 6 and near-zero at Site 12.

The water column in the lower 10 km of the estuary (Stations 1 – 5) tended to be relatively well mixed (the difference between surface and bottom values was usually <2), except in September 2005 when strong stratification persisted below Station 4 (<8 km from the mouth).

Above Station 4, strong freshwater flow resulted in salinity values of close to zero. Similar values were recorded in July 2005.

Stratification was maximal in the middle and upper estuary, decreasing again at the uppermost stations. A maximum difference between near-surface and bottom waters of 13 was recorded in April at Station 12.

Temperature

The water column was generally well mixed, with relatively little difference in the vertical temperature profile. On most occasions the difference did not exceed 0.5°C. A strong temperature gradient was evident along the estuary, with the uppermost stations in mid-summer (February) averaging 6.2°C warmer than the mouth. Winter temperatures (July) ranged between 0.1 and 3.7°C warmer in the upper estuary compared to the lower stations. Maximum difference was recorded in November 2005 (Δ 7.4°C). The most rapid change occurred at lower stations.

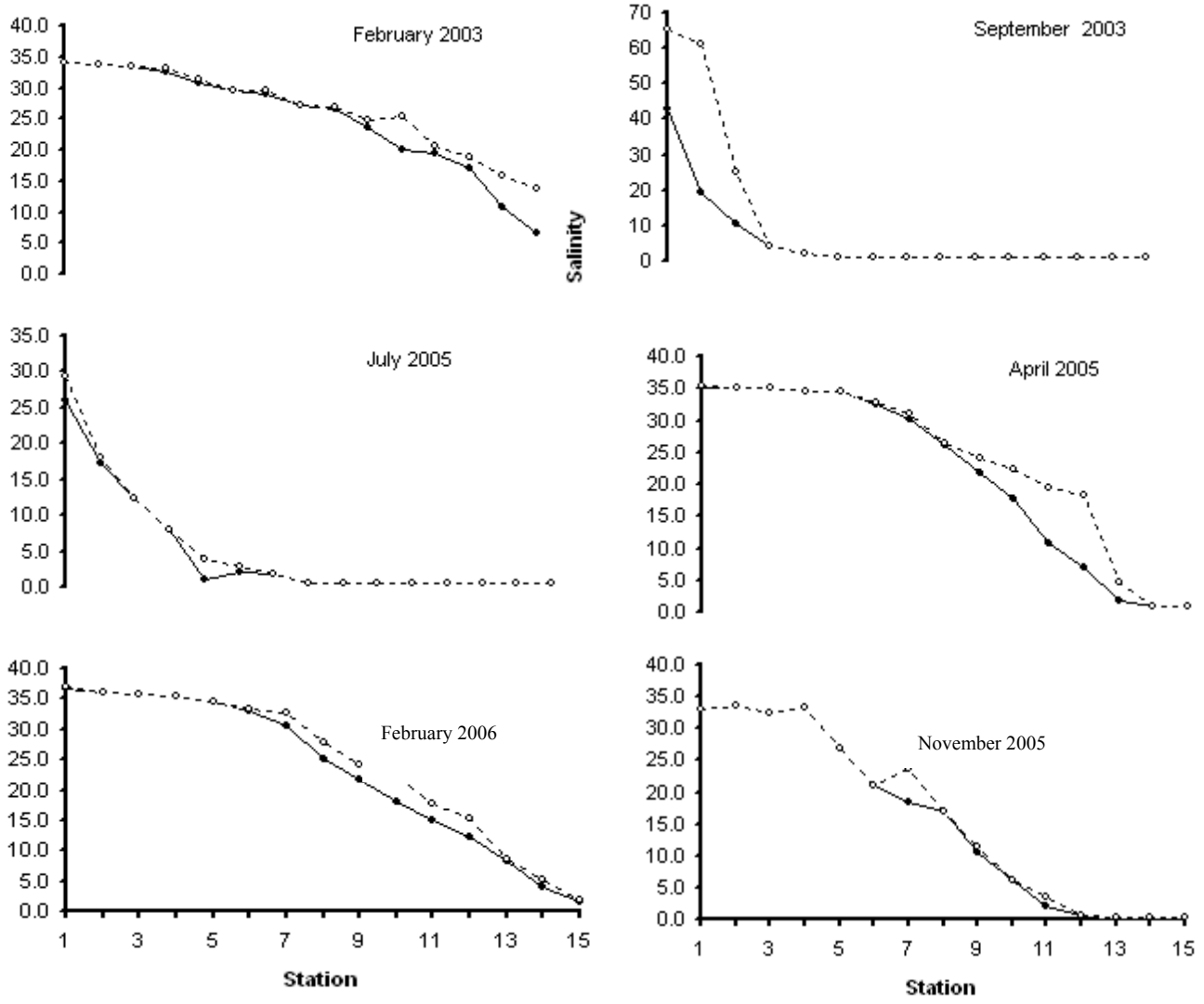


Figure 8.2 Salinity values recorded in near-surface (solid line) and bottom waters (dashed line) at 15 stations in the Great Berg estuary. Seven series of samples collected between February 2003 and February 2006.

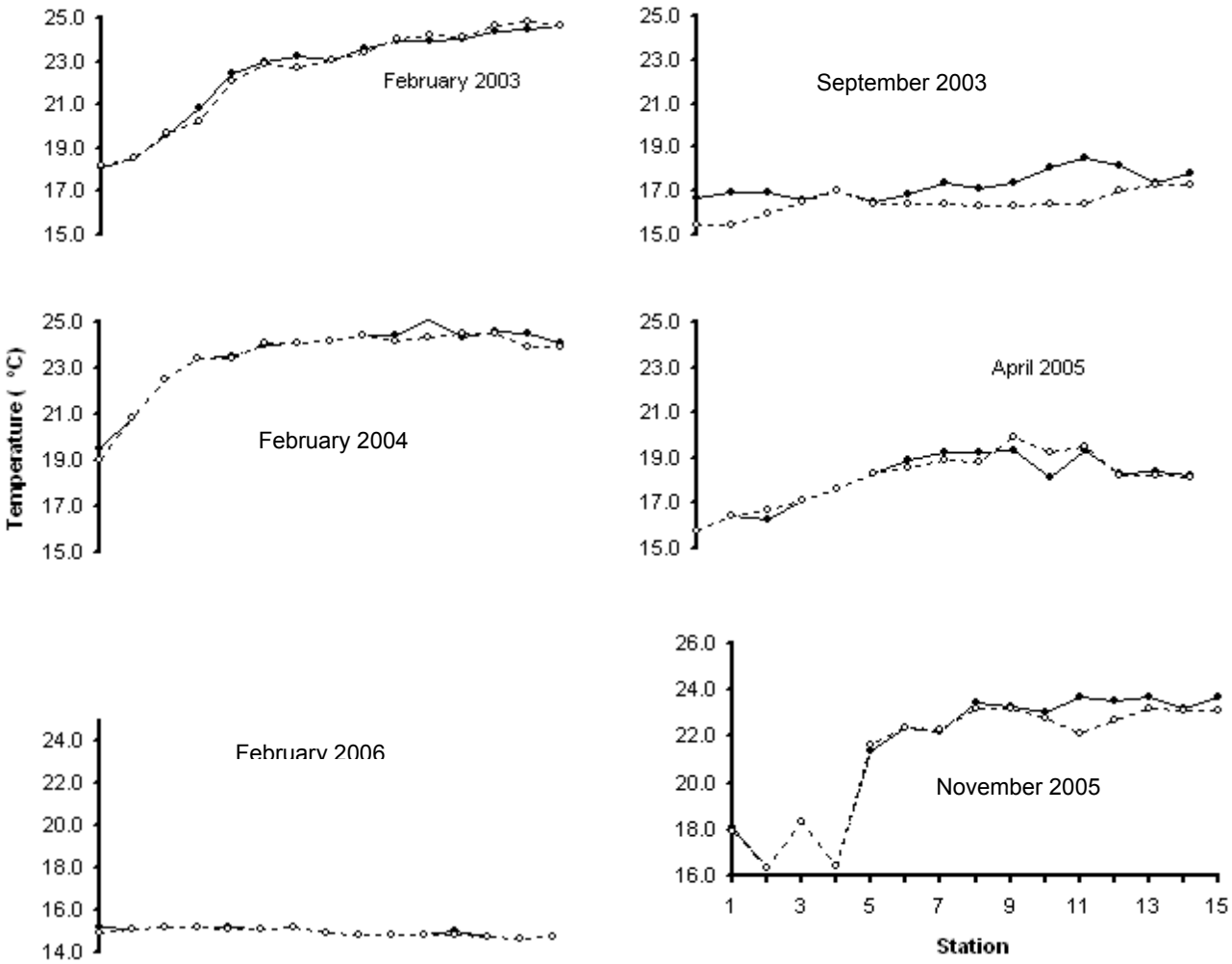


Figure 8.3 Temperature values recorded in near-surface (solid line) and bottom waters (dashed line) at 15 stations in the Great Berg estuary. Seven series of samples collected between February 2003 and February 2006.

Figure 8.2 represents the percentage mud (<0.065 mm) and organic matter along the estuary, averaged for six visits where data are available. The two parameters mirror the same pattern along the estuary, with maximum values recorded in the blind arm at the mouth and in the middle estuary (Stations 1, 10, 11 and 12 respectively).

Mean water turbidity (Figure 8.6) was similar at the first ten stations (20 - 40 NTU's), increasing to a maximum of 143 NTU's at the uppermost station. Variability was lowest near the mouth (Stations 1-4) and in the upper estuary (Stations 13 – 15).

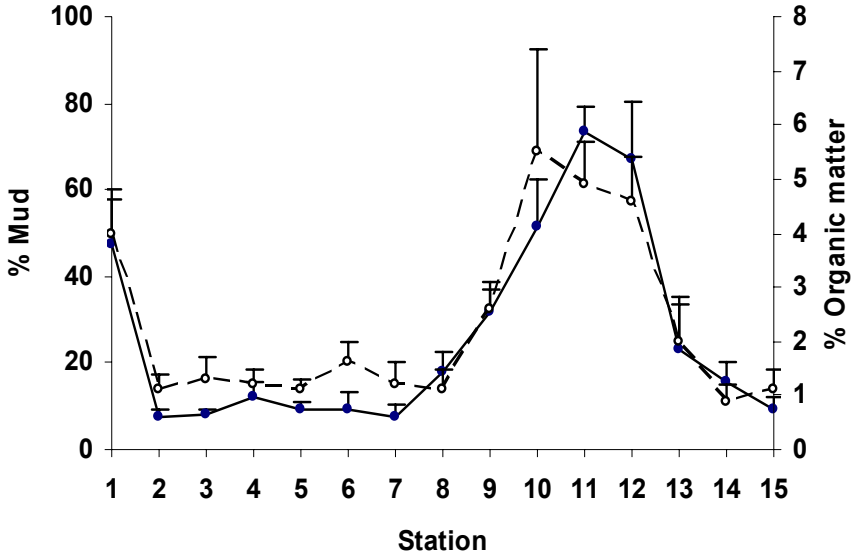


Figure 8.4 Percentage mud (solid line) and percentage organic matter (broken line) at 15 stations in the Great Berg estuary, Data are the average for five visits. +1SE.

8.3.2 Biotic species composition and abundance

Zooplankton species composition and abundance for the seven series is given in Appendix 4.2. Forty-nine taxa were identified, with copepods numerically dominating the zooplankton. The contribution of copepods to total abundance (14 taxa) only fell below 85% on a single occasion (Table 8.4), with *Pseudodiaptomus hessei* usually exceeding 60% of copepod numbers.

Table 8.4 Total contribution of copepods (%) to total abundance of all zooplankton collected in the Great Berg Estuary.

Sampling dates	% copepod contribution to total zooplankton abundance	% contribution of *P. hessei* to total copepod abundance
February 2003	99	68
September 2003	98	81
February 2004	97	75
April 2005	92	68
July 2005	47	22
November 2005	87	89
February 2006	91	92

If copepods are removed from the data base, then peracarid crustaceans (mysids, isopods and amphipods) and crab larvae (mainly *Hymenosoma orbiculare*) were the most abundant zooplankter groups (Figure 8.5).

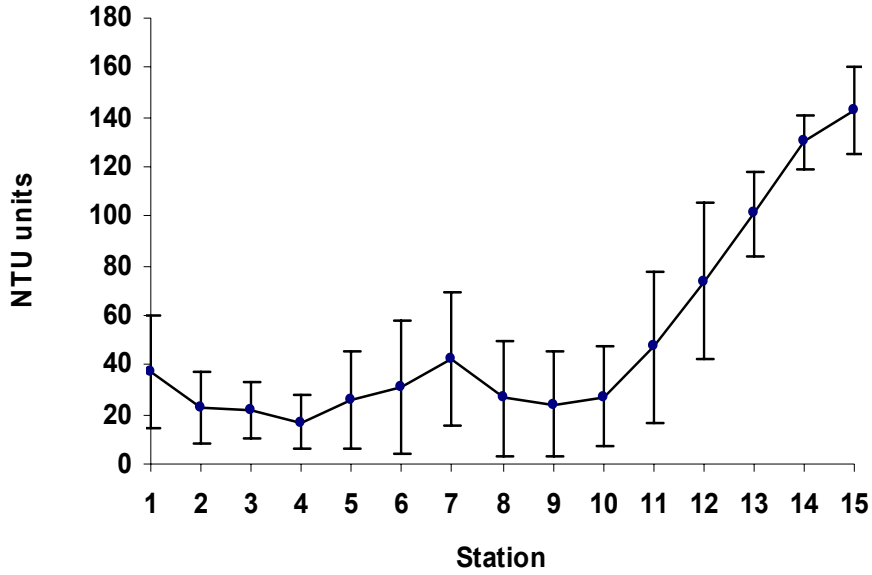


Figure 8.5 Mean turbidity at 15 stations in the Great Berg estuary, Data are the average for three visits, ±1SE (data not available for all visits).

Pseudodiaptomus hessei was the most abundant species in the zooplankton and was recorded at all stations. This species is described as a pioneer species, attaining maximum abundance after floods or strong freshwater pulsing (Wooldridge 1999) that may occur during any season. Although distribution along the Great Berg estuary was variable between trips (Figure 8.7), variation in abundance and distribution could not be explained by salinity ($P>0.5$). Abundance was least in July 2005 (Figure 8.7E) when freshwater dominated much of the estuary (<10 above Station 4). Such low abundance is probably explained by flushing effects during winter when zooplankton is lost to the system.

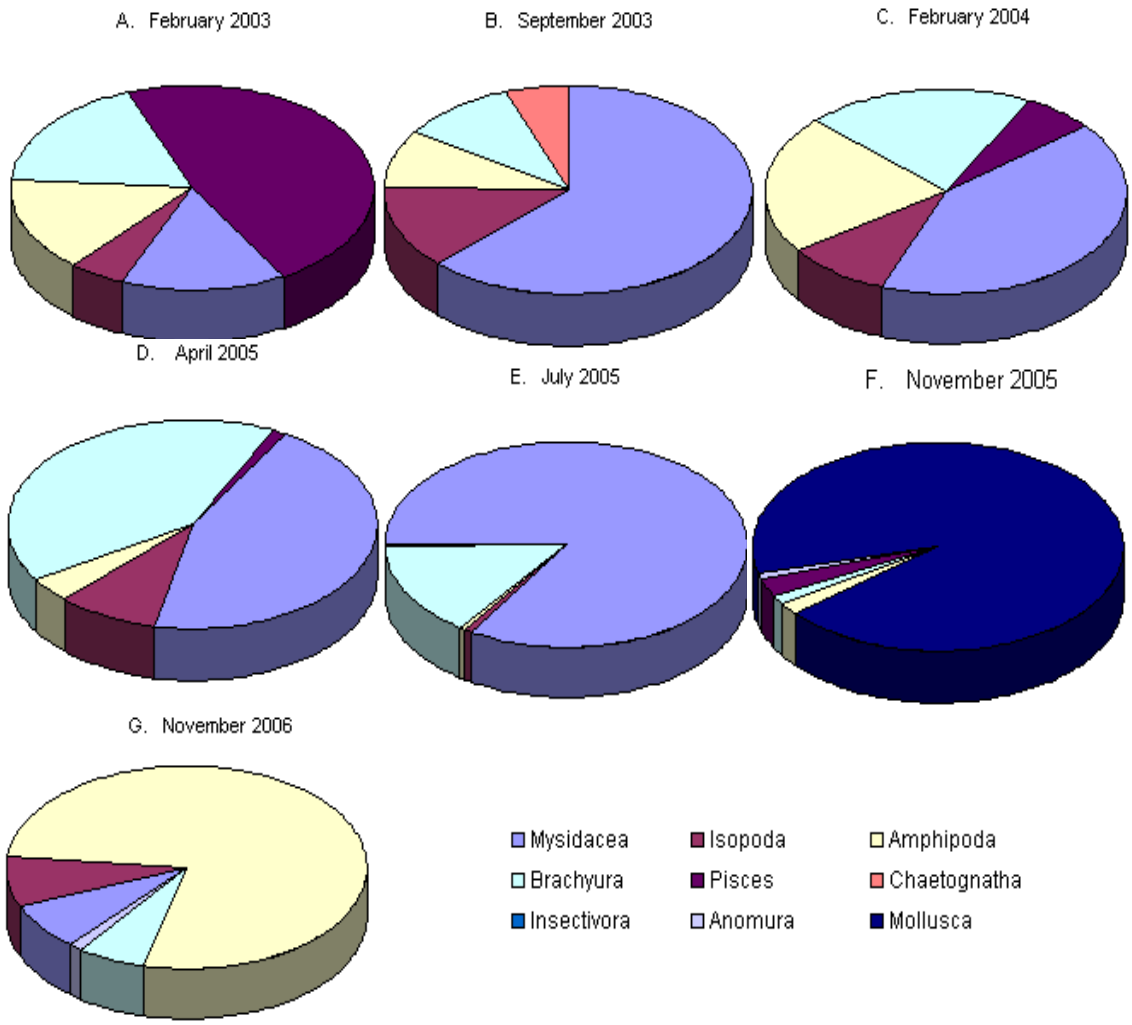


Figure 8.6 *After removal of copepods from the zooplankton assemblage, peracarid crustaceans (mysid shrimps, isopods and amphipods) were regularly represented in abundance. Fish larvae and small gastropods were each common on a single occasion (February 2003 and November 2005 respectively).*

Maximum abundance of *P. hessei* exceeded 52000 ind.m^{-3} in November 2005 at Station 6 (salinity 21) following the high-runoff period in winter. Relatively high abundance when numbers exceeded 25000 m^3 was recorded on three other occasions; at Station 5 in September 2003 (Figure 8.7B) and at the same station in February 2006 (Figure 8.7G). Salinity at these sites was ca 2 and 35 respectively. On the third occasion, *P. hessei* abundance exceeded 25000 ind.m^{-3} in February 2003 at Station 11 (Figure 8.2A).

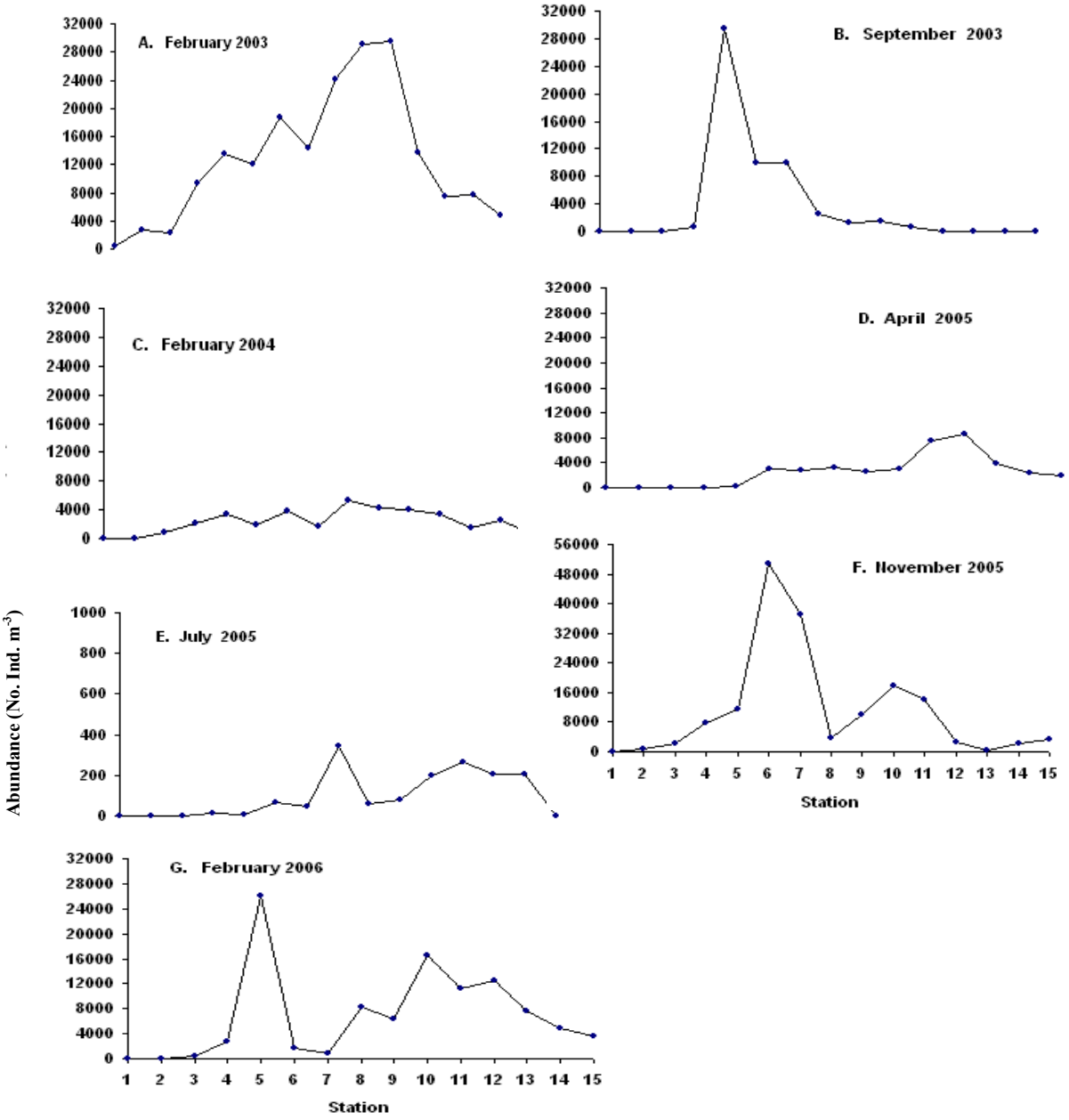


Figure 8.7 Distribution of the copepod Pseudodiaptomus hessei at 15 stations in the Great Berg estuary. P. hessei was the most abundant species recorded in the zooplankton. Seven series of samples collected February 2003 – February 2006.

Other numerically important copepods in the estuary were *Acartia longipatella* (abundance >15 000 ind.m^{-3} at Station 3 and >5 500 at Station 8 in February 2003, Appendix 4.2), an unidentified species of *Halicyclops* (abundance exceeded 13000 ind.m^{-3} in February 2003 at Station 9, 4.2) and an unidentifired *Daphnia* species (abundance exceeded 28 500 ind.m^{-3} in February 2003 at Station 13).

Acartia longipatella is associated with relatively high salinities while the other two species are linked to freshwater. Numerous marine associated species were recorded in the lower estuary (particularly *Paracalanus* and *Oithona* species).

Mysid shrimps were represented by four species and of these, only *Mesopodopsis wooldridgei* and *Rhopalophthalmus terranatalis* were common. Highest numbers of *M. wooldridgei* were recorded in July 2005 when numbers exceeded 2 800 ind.m^{-3} of water. The center of abundance of *R. terranatalis* was usually recorded further upstream compared to *M. wooldridgei,* peaking at over 250m^3 in April 2005. Such levels of abundance are high when compared to other estuaries around the coast.

The amphipods, *Corophium acherusicum*, *Grandidierella lutosa* and *Melita zeylanica* were occasionally common in the plankton, *C. triaeonyx* exceeding 45 00 ind.m-3 in February 2006. Both species are more benthic in distribution and most of the individuals recorded in the plankton were juveniles.

Mudprawn larvae (*Upogebia africana*) were relatively abundant in the plankton on a single occasion (November 2005) when over 200 ind.m^{-3} were recorded at Station 1. This species breeds during the warmer months and requires a marine phase of development. Stage 1 larvae are flushed from estuaries on the nocturnal ebb tide, eventually returning as postlarvae.

Larvae of the crown crab *Hymenosoma orbiculare* were sometimes very common in the lower estuary (numbers exceeded 1 600 ind.m^{-3} in April 2005 at Station 1), particularly during the warmer months. The life history strategy of this species is uncertain and it is still not clear whether the species also requires a marine phase of development following the pattern shown for many other estuarine crab species.

The estuarine roundherring *Gilchristella aestuaria* is one of a few fish species that spends its entire life cycle in estuaries (Whitfield & Marais 1999). In the present study larvae were relatively abundant in the zooplankton during the warmer months and in the middle and upper estuary.

Hyperbenthic species composition and abundance recorded during each survey are given in Appendix 4.3. Thirty-four taxa were identified. The five most common taxa on each sampling occasion are shown in Fig. 8. Mysids were generally the most common group numerically, although larvae of the crown crab *Hymenosoma orbiculare* (Figure 8.8A), gobiid and estuarine roundherring larvae (*Gilchristella aestuaria,* Figure 8.8F and the amphipod *Corophium acherusicum (*Figure 8.8G) were relatively abundant on occasions.

Mesopodopsis wooldridgei attained maximum abundance at Station 2 in February 2003 (>700 ind.m^{-3}) and was the most common mysid encountered in samples. *Rhopalophthalmus terranatalis* exceeded 300 ind.m^{-3} of water in April 2005 at Station 12. Maximum recorded density of *M. wooldridgei* in the hyperbenthos was recoded at a different time during the year on and was an order of magnitude less when compared to its peak abundance in the zooplankton. This is not unexpected in a relatively deep estuary since the species may occupy a horizon above the sampling level of the sled during the day. No clear pattern in seasonal distribution was evident in the data, although numbers were lower during periods of high flow. Larva of the crab *Hymenosoma orbiculare* was the most common brachyuran (564 m^{-3} at Station 5 in February 2003). *Gilchristella aestuaria* larvae were more common upstream, also peaking in February 2003 (>250 m^{-3} at Station 9).

Composition and abundance of subtidal benthic species for the seven series is given in Appendix 4.3. The average number of species recorded for all surveys was 23-24, with the maximum recorded in February of 2003 (33 species).

The lowest number of species recorded was 20 (February 2004). No seasonal pattern was evident in the data. Forty-three taxa were identified in total, with amphipods and polychaetes numerically dominating the community.

The contribution of amphipods ranged from 18% (February 2006) to 79% (February 2003).

On average, the contribution of amphipods to total abundance was 54% for the seven series, with no seasonal pattern evident in the data. The contribution of polychaetes ranged from 9% (November 2005) to 60% in February 2006. The switch in dominance from amphipods in November 2005 to polychaetes in February 2006 occurred over three months and illustrates the dynamic nature of community change in the benthos.

On average, polychaetes contributed 32% to total abundance for the seven series of samples. The third most important group were isopods, contributing on average 9% to total abundance (range 2% - 17%). In summary, no seasonal pattern was evident in the number of species, nor in the dominance pattern at higher taxonomic levels (polychaetes and amphipods, for example).

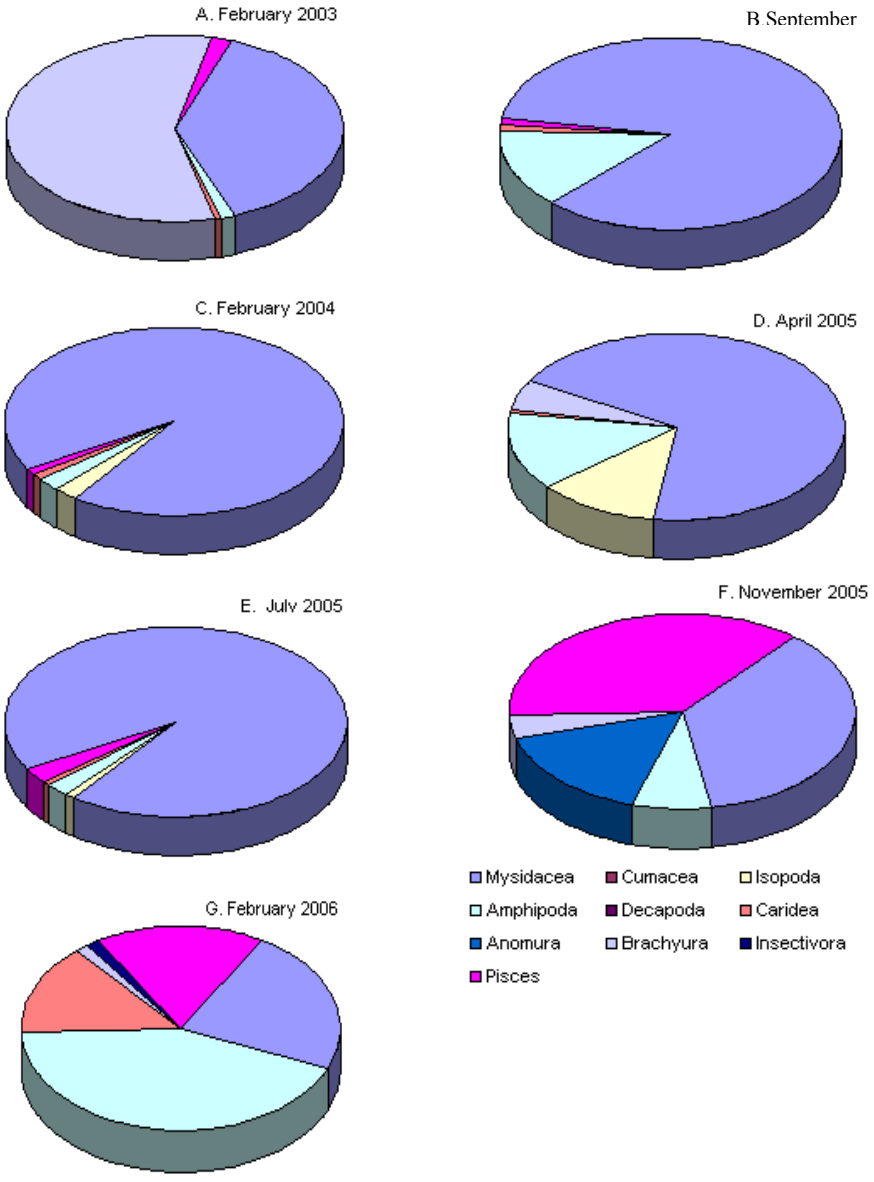


Figure 8.8 *Mysid shrimps (Mesopodopsis wooldridgei and Rhopalophthalmus teranatalis) were the most common group in the hyperbenthos. Larvae of the crown crab Hymenosoma orbiculare, fish larvae and the amphipod Corophium acherusicum were relatively abundant on occasions. Seven series of samples collected February 2003 – February 2006.*

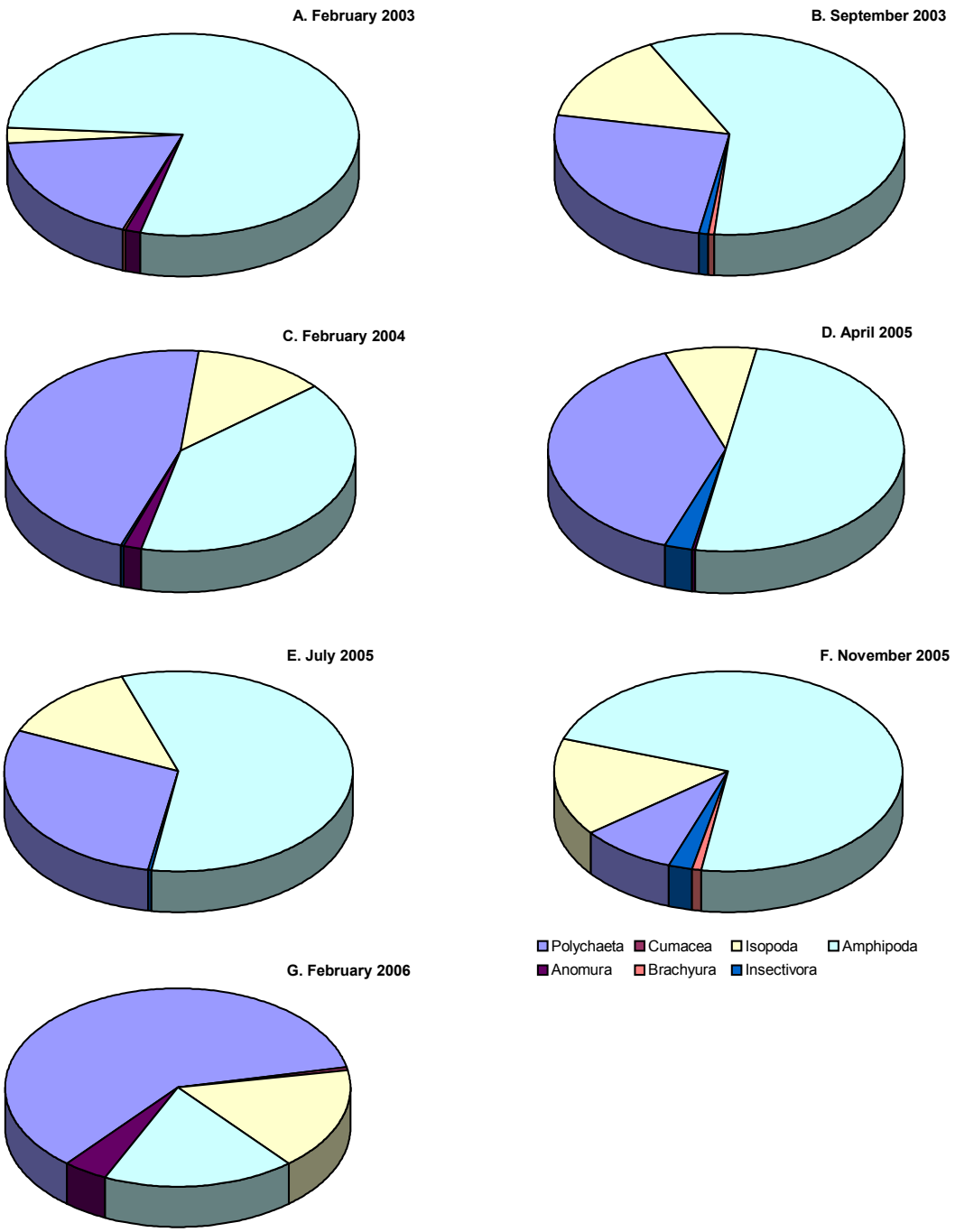


Figure 8.9 *Amphipods (Grandidierella lutosa and Corophium acherusicum) and polychaete worms were the most common group in the subtidal benthic community. Larvae of the crown crab Hymenosoma orbiculare, fish larvae and the amphipod Corophium acherusicum were relatively abundant on occasions. Seven series of samples collected February 2003 – February 2006*

Polychaete worms were most common at Stations 5 – 6 and 9 - 10 (Figure 8.10). The data reflect high variance between sampling trips ascribed largely to river flow patterns. During high flow periods, numbers were generally much lower compared to the dry season (Appendices XXII – XXVIII). Four species dominated the polychaete assemblage on most occasions (*Boccardia* sp. *Ceratonereis keiskama, Capitella capitata* and *Desdemona ornata*), although spatially, abundance levels of any of the four species did not reflect any consistent pattern. Highest numbers of any species occurred at the end of a dry season ((*Capitella capitata* (16150 m^{-2}) and *Ceratonereis keiskama* (14166 m^{-2}) in April 2005)).

Amphipod distribution and variance (Figure 8.11) reflects the same general pattern shown for the polychaetes. The most abundant amphipods were *Grandidierella lutosa* and *Corophium acherusicum,* with maxima exceeding 16 000 ind. m^{-2} (Station 5 in February 2004) and 84 000 ind. m^{-2} (Station 8 in February 2003 respectively (Figure 8.11). *C. acherusicum* was also the most abundant of all species on most occasions in the subtidal benthos (Appendix 4.3). *G. lutosa* was consistently more abundant at lower sites, while *C. acherusicum* occurred further upstream (Figure 8.12). The center of the population of both species occurred nearer the mouth during the wet season when numbers also tended to be lowest.

The sandprawn *Callianassa kraussi* was also relatively common in the lower estuary (Stations 5 - 7) in summer, attaining a maximum abundance 867 ind. m^{-2} and 972 ind. m^{-2} in February 2006 and February 2004 respectively.

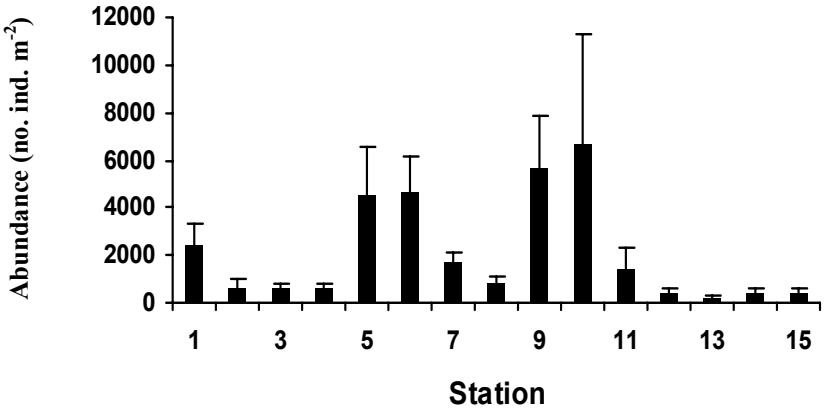


Figure 8.10 Distribution and abundance of polychaete worms in the Great Berg estuary. Data reflect mean values for seven series of data (collected February 2003 – February 2006) +1SE

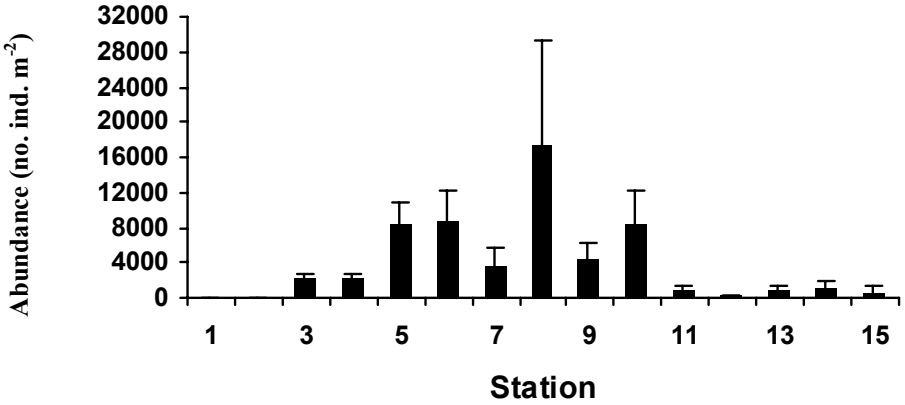


Figure 8.11 Distribution and abundance of amphipods in the Great Berg estuary. Data reflect mean values for seven series of data (collected February 2003 – February 2006) +1SE

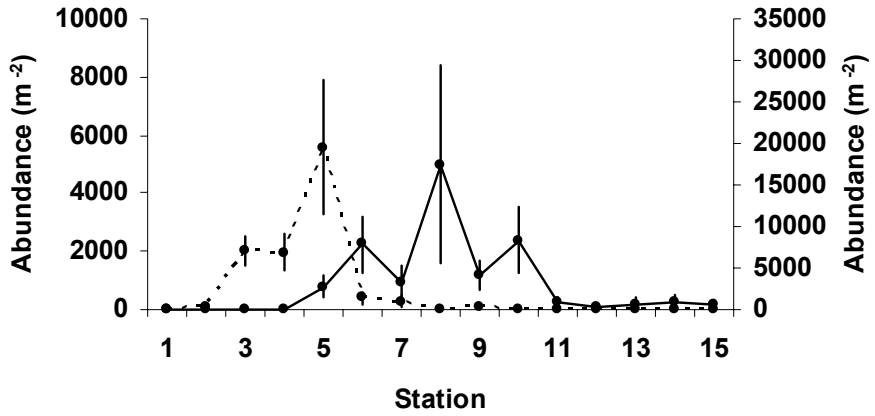


Figure 8.12 *Distribution of the amphipods Grandidierella lutosa (dashed line, Y1 axis) and Corophium acherusicum (solid line, Y2 axis) at 15 subtidal stations in the Great Berg estuary. Data are mean values for the seven data series ± 1SE.*

8.3.3 Classification and ordination of biotic assemblages

Macrozooplankton

The zooplankton assemblage of tidal estuaries having full horizontal salinity gradients is grouped into three categories:

- a marine associated fauna (salinity values above ca 28),
- a freshwater-brackish community (salinity values <4) and
- a typical endemic estuarine fauna found at salinity values ranging between 4 and 28.

The marine-associated group is characterized by having a relatively large number of species. The typical estuarine assemblage has fewer species, but numbers of individuals within species tends to be very high compared to the marine group. Freshwater species are also high in number, although in the Great Berg estuary only the transitional fringe was sampled. Bray-Curtis similarity analysis using group average mode on square-root transformed data (Appendix 4.3) clearly showed distinct clusters of sites representing the three major groups noted above for the seven series of samples collected (Figure 8.12). Group linkages shown by the Bray-Curtis similarity matrix in Figure 8.13 is also closely reflected by non-metric multi-dimensional scaling (MDS) plots (Figure 8.14). Whereas similarity analysis provides the level of similarity (%) in the species assemblage between sites, the MDS plots group the sites as a 2-dimensional matrix. The relative distance between sites in an MDS plot is a reflection of the degree of similarity between them, based on the species assemblage. The further the distance between points, the greater the difference in the species assemblage between them. In the later method, low stress levels indicate a high degree of confidence in the relationships between groups (Clark & Warwick 1994).

In Figure 8.13 and Figure 8.14, the marine associated fauna sometimes extended up to Station 4, linked to the state of the tide and amount of freshwater runoff from the catchment into the estuary. Uppermost sites reflect the brackish water community that penetrates downstream in relation to the amount of freshwater runoff. The typical estuarine community extends over much of the estuary, particularly during summer when runoff is relatively low (extending to Station 15 in April 2005). Between these major groups, transitional communities exist, as indicated in Figure 8.13 and Figure 8.14.

Environmental variables (Appendices I - VII) were then linked to the biotic assemblages recorded for each trip (Appendices VIII – XIV) using the PRIMER package BIO-ENV to best explain linkages. Abiotic data is first analyzed on its own. The multivariate pattern is then compared to species data to identify the extent of matching patterns that reflect the degree to which environmental data 'explains' the biotic pattern for each set. A Draftsman Plot was first used to identify environmental variables that were highly correlated. For example, integrated salinity, surface salinity and bottom salinity were usually highly correlated leading to the exclusion of surface and bottom salinity readings from further analysis. A similar process of potential elimination was undertaken for other variables where multilevel readings were taken.

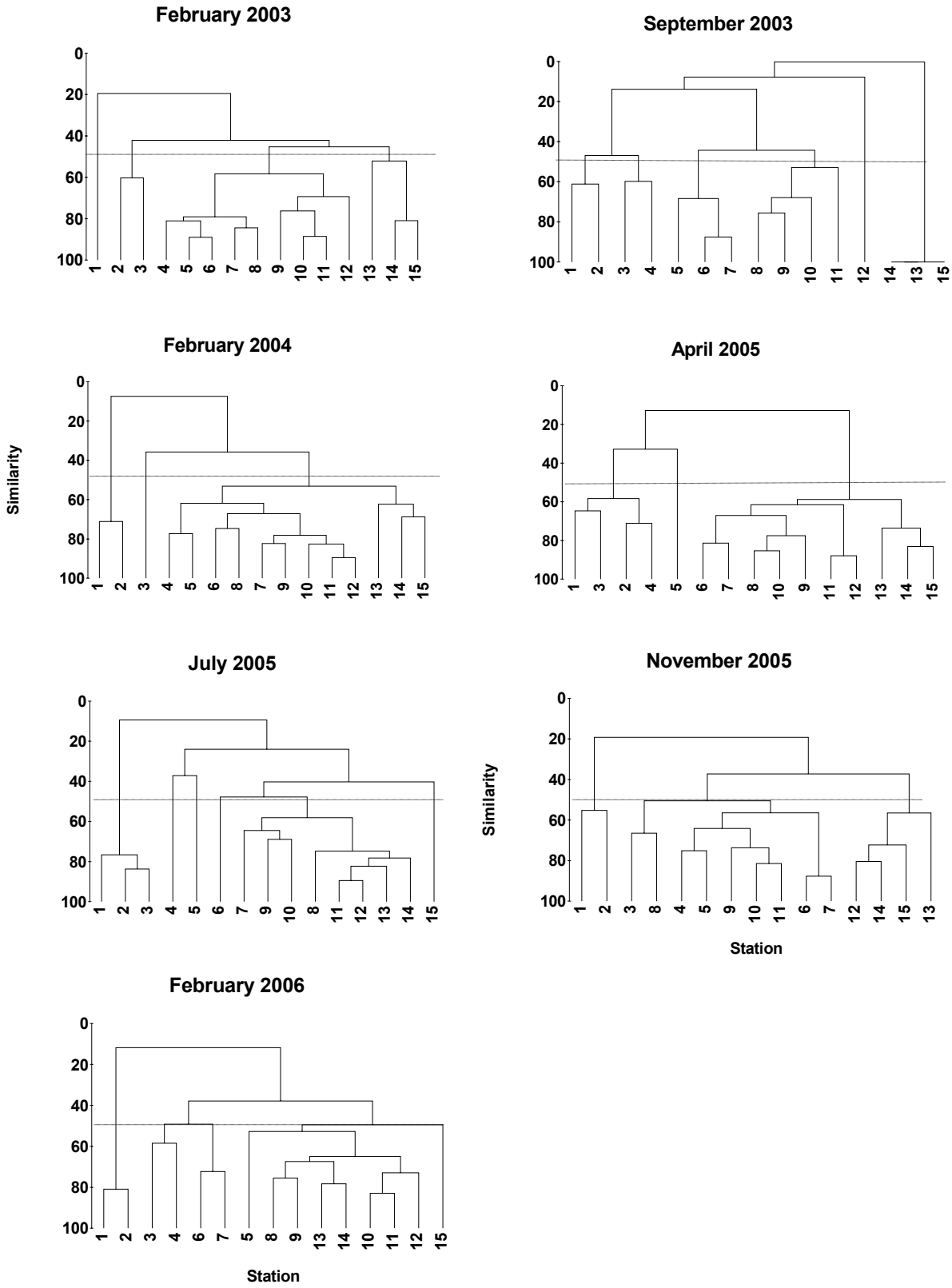


Figure 8.13 Dendrogram for Bray-Curtis similarity clustering of sites based on zooplankton composition and abundance. Data for seven series, collected between February 2003 and February 2006. The dotted line represents the arbitrary 50% cut-off used to delineate groups within the community.

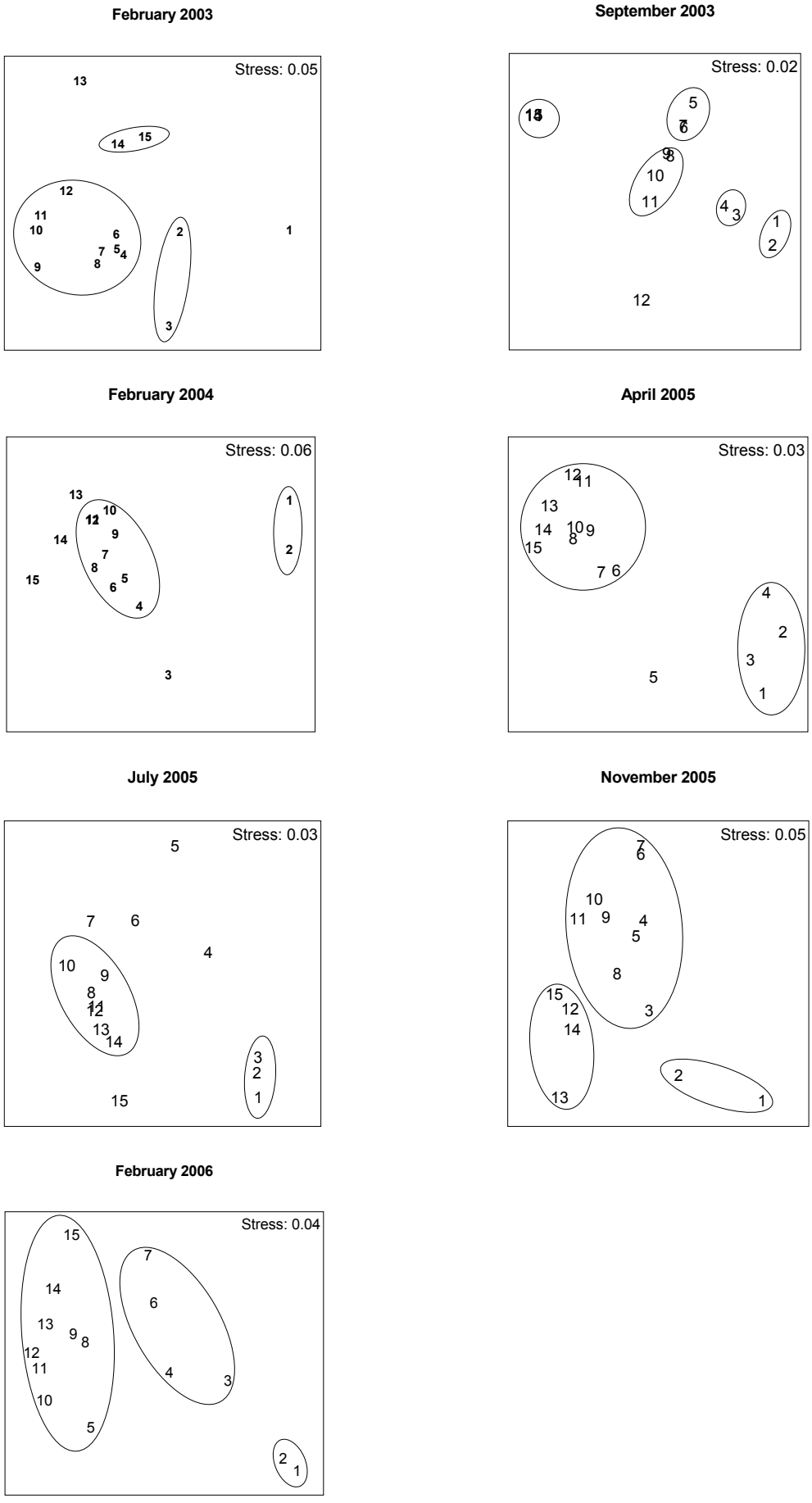


Figure 8.14 2-dimentional MDS configuration of zooplankton community structure in the Great Berg estuary, based on the 50% cut-off similarity index shown in Fig 8.12.

Although up to five variables explained much of the correlation between environmental parameters measured and zooplankton community structure along the estuary (Table 8.5), salinity consistently emerged as the most important. The contribution of salinity as a factor explaining zooplankton distribution and structure ranged between 67 and 94.1%. Other variables identified usually explained <10% of the correlations as individual entities, although some were probably surrogates of variables not measured, e.g., sediment structure responds to water current velocity. In turn, estuarine zooplankton avoids strong currents in order to reduce being flushed from the estuary.

Table 8.5 Correlation between the zooplankton species assemblage and environmental variables for each of the seven sampling trips to the Great Berg estuary.

	Variables	**Correlation**	**Comments**
February 2003	Integrated salinity, sediment characteristics	94.2%	Integrated salinity on its own accounted for 80% of the correlation
September 2003	Integrated salinity	94.1%	Salinity highly correlated
February 2004	Integrated salinity, sediment characteristics	77.5%	Integrated salinity on its own accounted for 67.2% of the correlation
April 2005	Integrated salinity, integrated temp, NTU surface, NTU integrated, sediment characteristics	88.5%	Integrated salinity on its own accounted for 80% of the correlation.
July 2005	Integrated salinity, NTU surface, NTU bottom Ch-*a* integrated, % coarse sand	94.5%	Integrated salinity (71.5%), surface & bottom turbidity (15.4%) account for most of the correlation
November 2005	Integrated salinity, sediment organic matter	79.3%	Integrated salinity on its own accounted for 75.7% of the correlation
February 2006	Integrated salinity, NTU integrated, Ch-*a* integrated, sediment characteristics	93.7%	Integrated salinity on its own accounted for 81.1% of the correlation

SIMPER analysis identifies species that primarily account for the assemblage (a posteriori) within cluster groups that are typically estuarine or brackish in composition (refer to Figs. 12 & 13). An arbitrary cut-off level of <50% similarity is used to define the major groups. Tables 8.6 – 8.12 rank the species in order of numerical dominance up to a cut-off cumulative contribution of 90%. The marine group (lower stations nearer the mouth) is excluded from all comparisons. Typically, estuarine communities are dominated by relatively few species, but numbers are high and this is in contrast to the marine component where the number of species is relatively high, but abundance levels of any species are low (refer to Appendices VIII – XIV).

Table 8.6 SIMPER analysis of the numerically dominant zooplankton species (ranked) in the estuarine and brackish water cluster groups shown for February 2003 in Figure 8.13 andFigure 8.14. Columns represent average numerical abundance within a cluster, average similarity between sites, Similarity Standard deviation, Contribution of each species to total numerical abundance and the cumulative contribution (up to the 90% cut-off value).

Species	Av. Abund.	Av. Sim.	Sim/SD	Contrib%	Cum %
Stations 4 – 12					
Pseudodiaptomus hessei	18295.67	28.02	9.35	44.27	44.27
Halicyclops sp.	2582.61	9.70	2.06	15.32	59.59
Acartia longipatella	2185.50	6.80	0.79	10.75	70.34
Gilchristella aerstuaria larvae	163.50	3.56	1.04	5.63	75.97
Rhopalphthalmus terranatalis	11.17	3.10	1.77	4.90	80.87
Corophium acherusicum	48.50	2.73	1.15	4.31	85.18
Mesopodopsis wooldridgei	33.22	2.13	1.12	3.37	88.55
Exosphaeroma hylocoetes	8.78	1.52	0.80	2.40	90.95
Average similarity between stations in the group: 63.29%					
Stations 13 – 15					
Pseudodiaptomus hessei	6599.17	40.93	4.87	58.68	58.68
Daphnia sp.	9740.17	16.50	5.35	23.66	82.34
Gilchristella aestuaria larvae	9.50	8.01	4.47	11.48	93.83
Average similarity between stations in the group: 69.75%					

Table 8.7 SIMPER analysis of the numerically dominant zooplankton species (ranked) in the estuarine and brackish water cluster groups shown for September 2003 in Figure 8.13 and Figure 8.14. Columns represent average numerical abundance within a cluster, average similarity between sites, Similarity Standard deviation, Contribution of each species to total numerical abundance and the cumulative contribution (up to the 90% cut-off value).

Species	Av. Abund.	Av. Sim.	Sim/SD	Contrib%	Cum %
Stations 5 – 7					
Pseudodiaptomus hessei	16414.67	36.33	8.30	45.90	45.90
Exosphaeroma hylocoetes	71.67	9.48	7.74	11.98	57.88
Rhopalphthalmus terranatalis	56.67	7.46	4.88	9.42	67.30
Hymenosoma orbiculare	29.33	6.47	4.97	8.18	75.48
Mesopodopsis wooldridgei	6.33	5.59	11.67	7.06	82.54
Melita zeylanica	11.67	5.01	7.63	6.33	88.86
Halicyclops sp.	546.33	4.35	0.58	5.49	94.35
Average similarity between stations in the group: 79.15%					
Stations 8 – 11					
Pseudodiaptomus hessei	1495.75	35.60	13.09	63.10	63.10
Corophium acherusicum	8.00	4.25	3.88	7.54	70.64
Rhopalophthalmus terranatalis	59.50	3.28	0.41	5.82	76.45
Hymenosoma orbiculare	4.30	2.95	0.79	5.23	81.69
Halicyclops sp.	76.25	2.65	0.41	4.69	86.38
Chironomid larvae	0.65	2.37	0.90	4.20	90.58
Average similarity between stations in the group: 56.41%					
Stations 13 – 15					
Chironomid larvae	0.10	100.00		100.00	100.00
Average similarity between stations in the group: 100.00%					

Table 8.8 SIMPER analysis of the numerically dominant zooplankton species (ranked) in the estuarine and brackish water cluster groups shown for February 2004 in Figure 8.13 and Figure 8.14. Columns represent average numerical abundance within a cluster, average similarity between sites, Similarity Standard deviation, Contribution of each species to total numerical abundance and the cumulative contribution (up to the 90% cut-off value).

Species	Av. Abund	Av. Sim.	Sim/SD	Contrib%	Cum %
Stations 4 – 12					
Pseudodiaptomus hessei	3290.11	28.38	7.90	44.99	44.90
Rhopalphthalmus terranatalis	64.67	7.01	1.48	11.10	56.09
Halicyclops sp.	109.11	6.15	1.11	9.74	65.84
Acartia longipatella	161.89	4.70	0.80	7.45	73.28
Exosphaeroma hylocoetes	5.89	4.04	1.67	6.40	79.68
Gilchristella aestuaria larvae	7.56	3.43	1.13	5.44	85.12
Mesopodopsis wooldridgei	2.78	2.01	0.83	3.19	88.31
Corophium acherusicum	13.89	1.82	0.57	2.88	91.20
Average similarity between stations in the group: 63.09%					
Stations 13 – 15					
Pseudodiaptomus hessei	1520.00	28.77	21.76	42.55	42.55
Halicyclops sp.	128.33	16.47	22.68	24.36	66.92
Chironomid larvae	10.00	7.19	13.64	10.63	77.55
Daphnia sp.	144.33	6.17	0.58	9.13	86.68
Other insect larvae	13.67	5.84	13.84	8.64	95.32
Average similarity between stations in the group: 67.60%					

Table 8.9 SIMPER analysis of the numerically dominant zooplankton species (ranked) in the estuarine cluster group shown for April 2005 in Figure 8.13 and Figure 8.14. The brackish water community was not represented on this occasion. Columns represent average numerical abundance within a cluster, average similarity between sites, Similarity Standard deviation, Contribution of each species to total numerical abundance and the cumulative contribution (up to the 90% cut-off value).

Species	Av. Abund.	Av. Sim.	Sim/SD	Contrib%	Cum %
Stations 6 – 15					
Pseudodiaptomus hessei	3880.80	32.47	5.60	56.37	56.37
Rhopalphthalmus terranatalis	71.10	4.75	0.99	8.24	64.62
Melita zeylanica	8.00	4.52	1.8	7.84	72.45
Corophium acherusicum	10.30	4.23	1.16	7.34	79.80
Exosphaeroma hylocoetes	10.90	3.19	0.91	5.53	85.33
Hymenosoma orbiculare larvae	25.90	2.18	0.69	3.78	89.11
Uromunna sheltoni.	32.50	1.74	0.47	3.03	92.13
Average similarity between stations in the group: 57.60%					

Table 8.10 SIMPER analysis of the numerically dominant zooplankton species (ranked) in the estuarine cluster group shown for July 2005 in Figure 8.13 and Figure 8.14. The brackish water community was only present at one station and it was therefore not possible to perform a SIMPER analysis. Columns represent average numerical abundance within a cluster, average similarity between sites, Similarity Standard deviation, Contribution of each species to total numerical abundance and the cumulative contribution (up to the 90% cut-off value).

Species	Av. Abund.	Av. Sim.	Sim/SD	Contrib%	Cum %
Stations 7 – 14					
Pseudodiaptomus hessei	176.25	26.76	7.17	37.58	37.58
Halicyclops sp.	23.88	15.50	4.52	21.77	59.35
Corophium acherusicum	4.50	10.30	11.86	14.46	73.81
Copepod sp.	50.63	9.49	1.04	13.33	87.14
Melita zeylanica	1.33	4.02	0.93	5.65	92.79
Average similarity between stations in the group: 71.20%					

Table 8.11 SIMPER analysis of the numerically dominant zooplankton species (ranked) in the estuarine and brackish water cluster groups shown for November 2005 in Figures 8.12 and 8.13. Columns represent average numerical abundance within a cluster, average similarity between sites, Similarity Standard deviation, Contribution of each species to total numerical abundance and the cumulative contribution (up to the 90% cut-off value).

Species	Av. Abund.	Av. Sim.	Sim/SD	Contrib%	Cum %
Stations 4 – 7, 9 - 11					
Pseudodiaptomus hessei	21327.43	25.52	7.09	38.54	38.54
Acartia longipatella	2176.29	6.82	0.92	10.30	48.84
Gastropod spat	3858.71	6.49	0.92	9.80	58.64
Gobiid larvae	14.14	4.45	6.13	6,72	65.36
Gilchristella aestuaria larvae	32.29	3.48	1.45	5.26	70.62
Gilchristella aestuaria eggs	39.42	3.00	1.36	4.53	75.15
Melita zeylanica	11.57	2.83	1.51	4.27	79.42
Corophium acherusicum	8.29	2.71	1.47	4.09	83.51
Rhopalphthalmus terranatalis	8.86	1.95	0.90	2.95	86.46
Exosphaeroma hylocoetes	11.29	1.90	0.90	2.87	89.33
Mesopodopsis wooldridgei	7.57	1.70	0.90	2.57	91.89
Average similarity between stations in the group: 66.22%					
Stations 12 – 15					
Pseudodiaptomus hessei	2268.00	32.02	7.06	44.76	44.76
Halicyclops sp.	107.25	13.76	7.22	19.24	63.99
Chironomid larvae	4.75	7.50	8.84	10.48	74.47
Other insect larvae	4.75	7.48	10.60	10.46	84.93
Corophium acherusicum	8.00	7.37	6.71	10.30	95.25
Average similarity between stations in the group: 71.54%					

Table 8.12 SIMPER analysis of the numerically dominant zooplankton species (ranked) in the estuarine cluster group shown for February 2006 in Figure 8.13 and Figure 8.14. The brackish water community was not represented on this occasion. Columns represent average numerical abundance within a cluster, average similarity between sites, Similarity Standard deviation, Contribution of each species to total numerical abundance and the cumulative contribution (up to the 90% cut-off value).

Species	Av. Abund.	Av. Sim.	Sim/SD	Contrib%	Cum %
Stations 8 – 15					
Pseudodiaptomus hessei	2939.78	29.21	9.56	51.70	51.70
Halicyclops sp.	140.33	10.01	1.65	17.72	69.42
Rhopalphthalmus terranatalis	58.78	4.72	0.92	8.35	77.77
Corophium acherusicum	35.89	3.63	0.81	6.43	84.20
Gilchristella aestuaria larvae	8.00	2.78	0.83	4.91	89.11
Exosphaeroma hylocoetes	3.56	1.50	0.60	2.65	91.76
Average similarity between stations in the group: 56.49%					

8.3.4 Hyperbenthos

Bray-Curtis similarity analysis on the hyperbenthos (Appendix 4.3) using group average mode on square-root transformed data showed at least seven clusters at the 50% cut-off level (Figure 8.15), reflecting a high degree of dissimilarity between site groupings on all sampling occasions. At lower resolution (20 -40% similarity level), the three broad categories (marine, estuarine and a brackish water community) were identified, but variability within these broad groups was also high between sampling sessions. High variability in community composition and structure is also reflected in the irregular pattern shown by station sequence along the X-axis on all occasions. This may in part also reflect the presence of few species at many sites. MDS plots performed on the data further emphasized the absence of any distinct pattern (Figure 8.16). Consequently, no further data analysis is performed on the data.

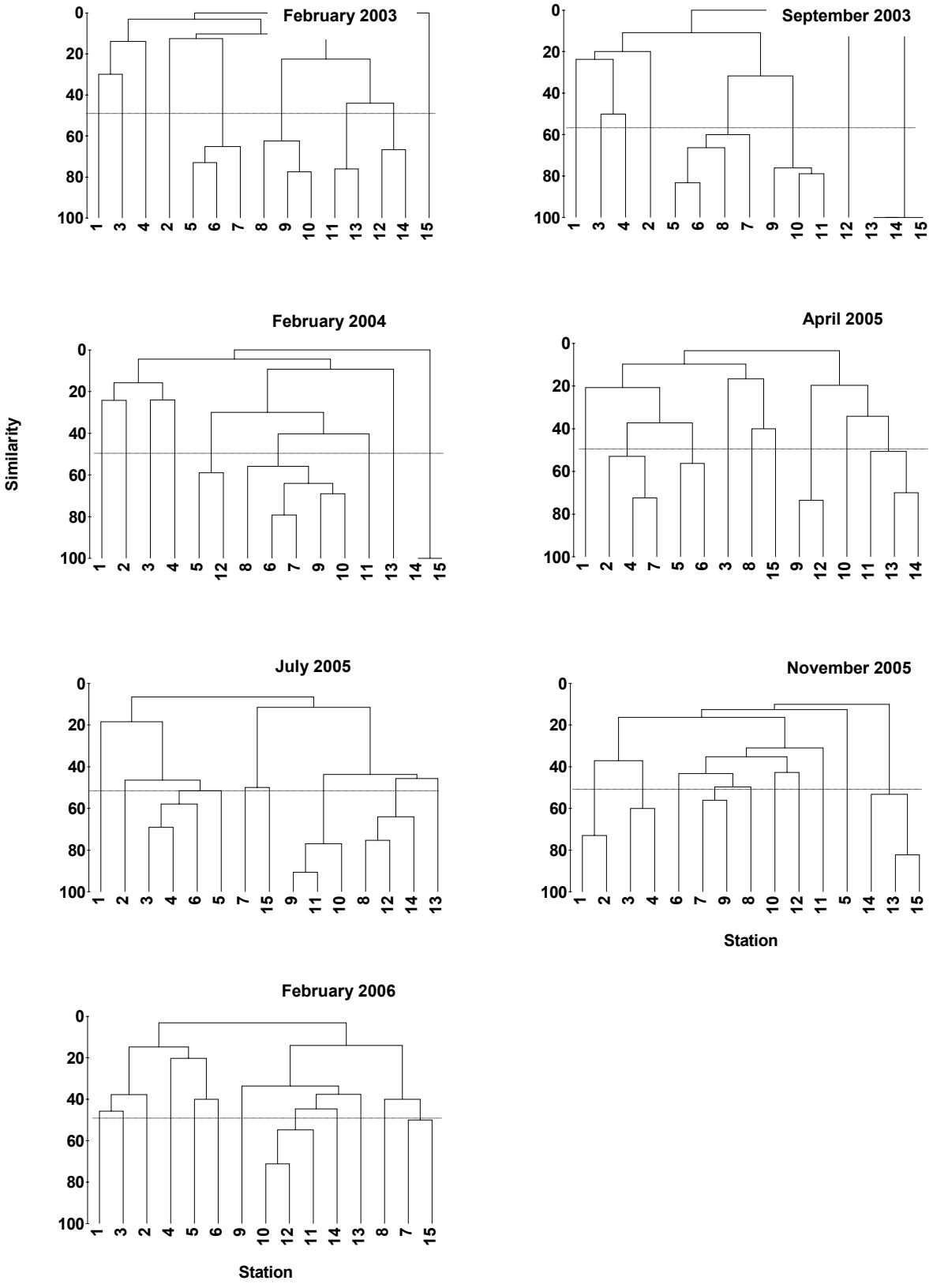


Figure 8.15 Dendrogram for Bray-Curtis similarity clustering of sites based on hyperbenthos composition and abundance. Data for seven series, collected between February 2003 and February 2006. The dotted line represents the arbitrary 50% cut-off used to delineate groups within the community.

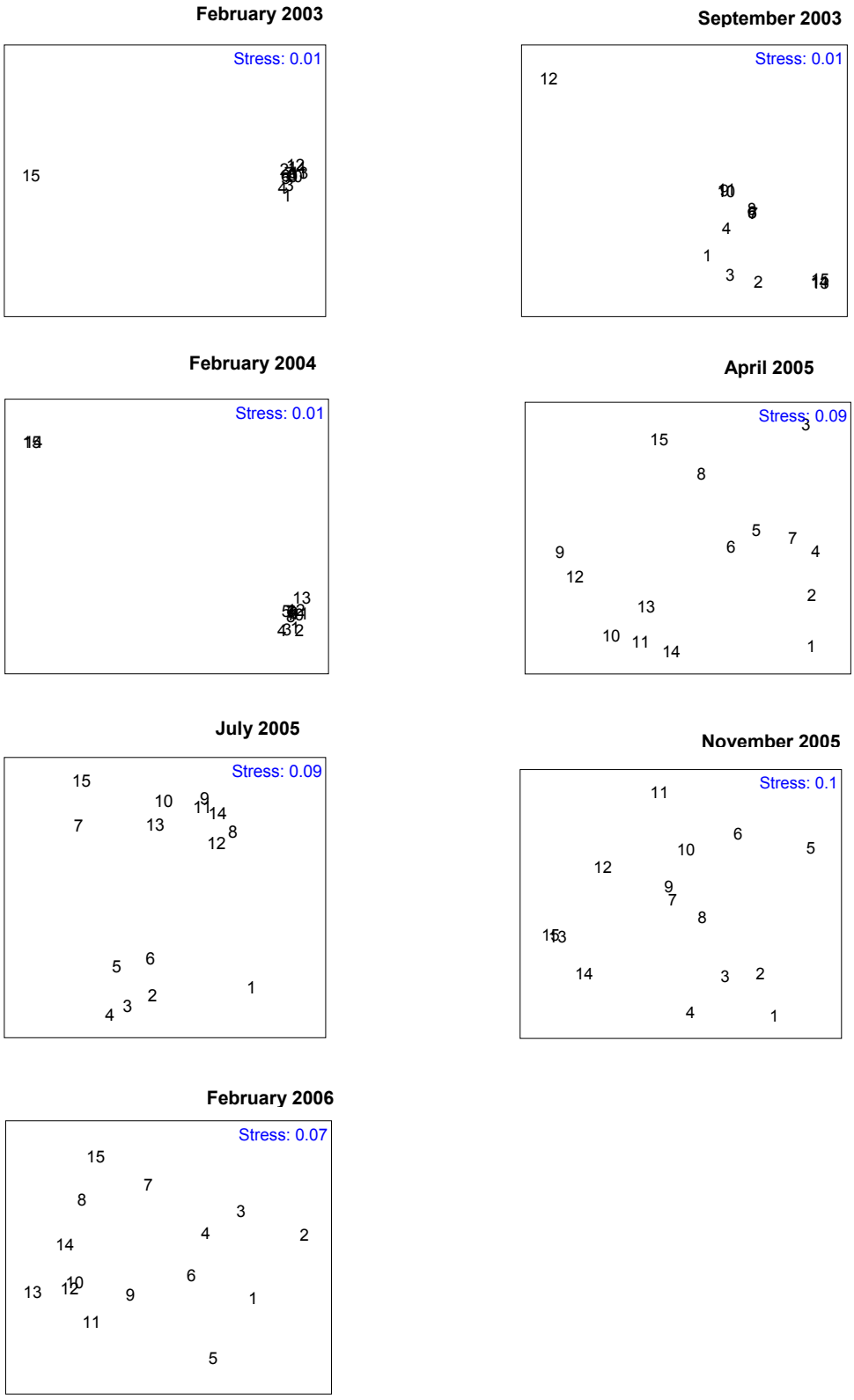


Figure 8.16 *2-dimentional MDS configuration of hyperbenthic community structure in the Great Berg estuary. Data for seven series, collected between February 2003 and February 2006.*

8.3.5 Subtidal benthos

Bray-Curtis similarity analysis on the subtidal macrobenthos (Appendix 4.4) using group average mode on square-root transformed data exposed between four (September 2003) and 10 clusters (July 2005) at the 50% cut-off level (Figure 8.17), reflecting a high degree of dissimilarity between site groupings on most sampling occasions. At lower resolution (20 -40% similarity level), the three broad categories (marine, estuarine and a brackish water community) were identified, but variability within these broad groups was moderately high between sampling sessions. Composition of the community consistently showed a major change upstream of Stations 9 - 11, with <20% similarity to downstream stations. These upper sites represent a brackish water community that also reflected fewer species. MDS plots performed on the data further emphasized the high degree of variability between sites and sampling trips (Figure 8.18).

Environmental variables (Appendix 4.1) were then linked to the subtidal benthic assemblages recorded for each trip (Appendix 4.4) using the PRIMER package BIO-ENV to best explain linkages. A Draftsman Plot was first used to identify environmental variables that were highly correlated. For example, integrated salinity, surface salinity and bottom salinity were usually highly correlated leading to the exclusion of surface and bottom salinity readings from further analysis. A similar process of potential elimination was undertaken for other variables where multilevel readings were taken.

Although up to three variables explained much of the correlation between environmental parameters measured and the subtidal benthic community composition and structure along the estuary (Table 8.13), salinity emerged as the most important on most occasions. However, salinity did not show any correlation with the biotic community at times of high river flow (September 2003 and July 2005, Fig. 2). In July 2005, Ch-*a* emerged as an important factor that explained the correlation. No chlorophyll data are available for the initial three sampling trips. Highest correlation between salinity distribution and the community occurred during summer (February 2003, February 2004 and February 2006, exceeding 70% on all three occasions.

SIMPER analysis identifies species that primarily account for the assemblage (*a posteriori*) within cluster groups that are typically estuarine or brackish in composition (refer to Figure 8.17). An arbitrary cut-off level of <50% similarity is used to define the major groups as indicated in the figure. Table 8.14- Table 8.20 rank the species in order of numerical dominance up to a cut-off cumulative contribution of 90%. The marine group associated with stations nearer the mouth usually had a similarity level of <50% between sites due to the rapid transition from marine to a typically estuarine community. These lower sites are excluded from all comparisons. Typically, estuarine communities are dominated by relatively few species compared to the marine component, although abundance levels of individual species are relatively high (refer to Appendix 4.4).

In general, the typical estuarine community supported more species up to a 90% cumulative cut-off level (ca 6 -8 species) compared to the brackish water community (ca 2 -3 species). An increase in salinity at uppermost sites (Figure 8.2, April and February 2006) during the dry months led to an increase in the number of euhaline species, with a concomitant decrease in the brackish water assemblage.

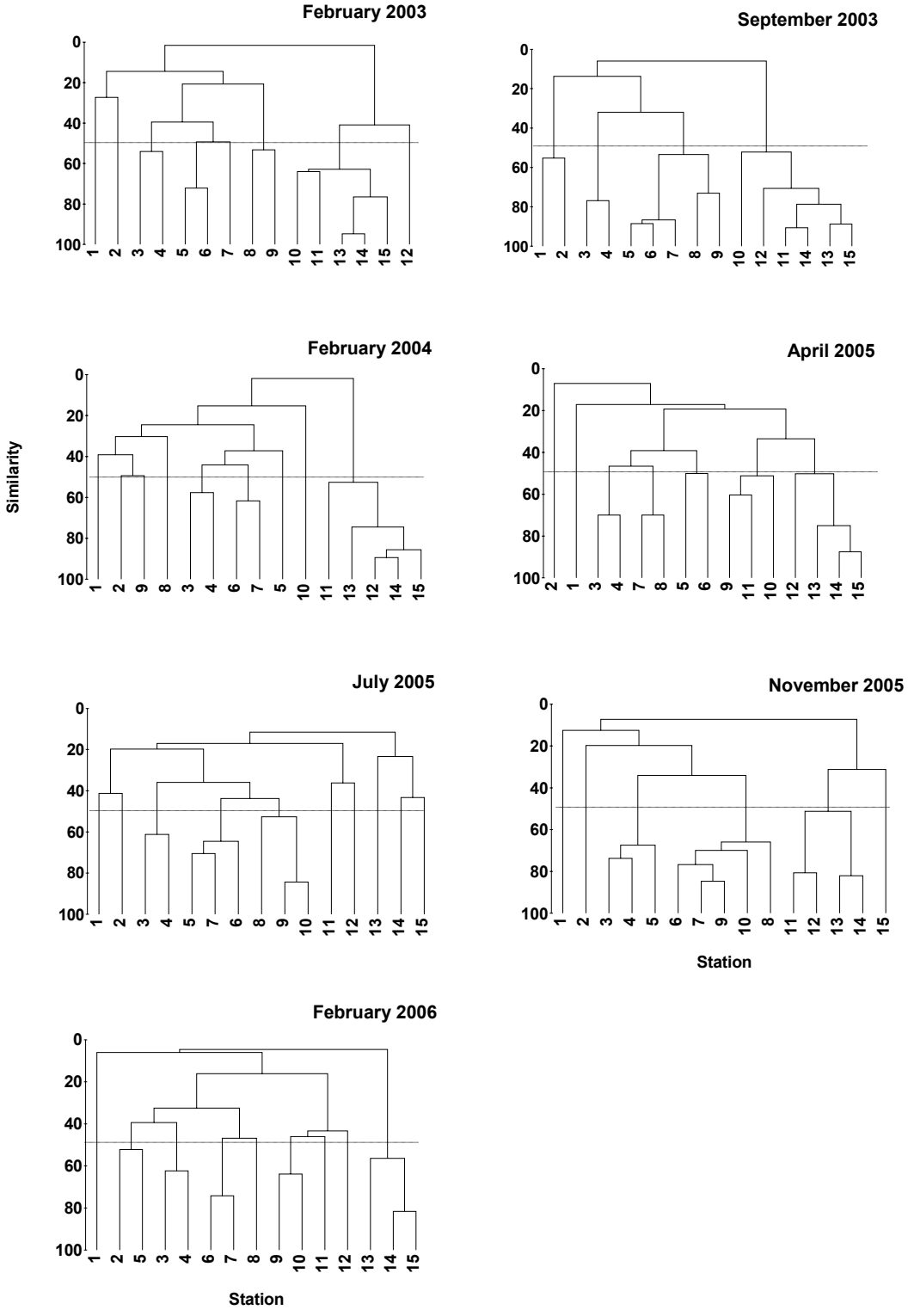


Figure 8.17 Dendrogram for Bray-Curtis similarity clustering of sites based on subtidal benthic composition and abundance. Data for seven series, collected between February 2003 and February 2006. The dotted line represents the arbitrary 50% cut-off used to delineate groups within the community.

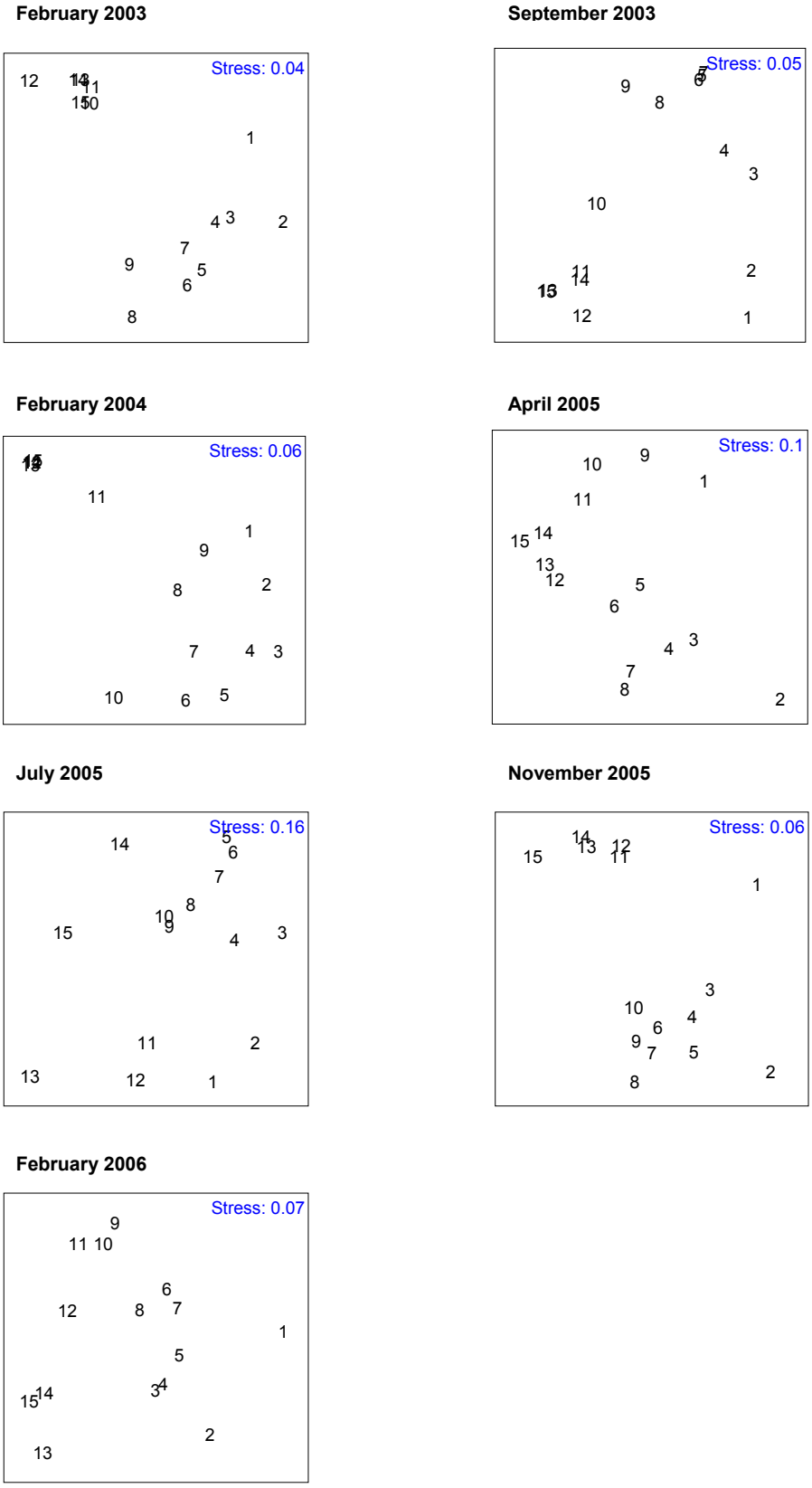


Figure 8.18 2-dimentional MDS configuration of subtidal benthic community structure in the Great Berg estuary. Data for seven series, collected between February 2003 and February 2006.

Table 8.13 Correlation between the subtidal benthic species assemblage and environmental variables for each of the seven sampling trips to the Great Berg estuary.

	Variables	**Correlation**	**Comments**
February 2003	Integrated salinity	70.8%	Integrated temperature, percentage sand, and salinity correlates at the 69.8% level.
September 2003	Integrated temperature, Integrated O2 saturation	72.0%	Correlation with salinity relatively low (<40%).
February 2004	Integrated salinity	80.2%	Correlation with salinity high
April 2005	Integrated salinity, Integrated temperature, Integrated O_2 (mg/l),	71.2%	Salinity on its own correlates at the 55.1% level. Salinity, temperature, oxygen and coarse sand correlate at the70.7% level
July 2005	Integrated Ch-*a*, Integrated temperature Sediment (percentage coarse sand and mud)	69.2%	Integrated Ch-*a* on its own accounts for 56.3% of the correlation
November 2005	Integrated salinity, Integrated pH	75.0%	Integrated salinity on its own accounted for 68.7% of the correlation
February 2006	Integrated salinity, Integrated temperature, Integrated NTU	80.7%	Integrated salinity on its own accounted for 74.8% of the correlation

Table 8.14 SIMPER analysis of the numerically dominant subtidal benthic species (ranked) in the estuarine and brackish water cluster groups shown for February 2003 in Figure 8.17. Groups represent sites >50% similarity. Columns represent average numerical abundance within a cluster, average similarity between sites, Similarity Standard deviation, Contribution of each species to total numerical abundance and the cumulative contribution (up to the 90% cut-off value).

Species	Av. Abund.	Av. Sim.	Sim/SD	Contrib%	Cum %
Stations 5 – 9					
Corophium acherusicum	16152.17	12.92	1.81	33.96	33.96
Ceratonereis keiskama	345.83	7.43	1.31	19.52	53.49
Anthurid sp.	330.56	4.93	1.14	12.96	66.45
Desdemona ornata	2397.22	4.13	0.73	10.87	77.31
Boccardia sp.	98.61	2.76	0.78	7.27	84.58
Melita zeylanica	12.50	1.92	0.78	5.05	89.64
Callianassa kraussi	187.50	1.37	0.47	3.61	93.24
Average similarity between stations in the group: 38.03%					
Stations 11 – 14					
Oligochaete sp.	148.44	46.79	7.73	70.91	70.91
Chironomid larvae	50.52	19.20	0.87	29.09	100.00
Average similarity between stations in the group: 69.75%					

In general, a similar species assemblage dominated the euhaline and brackish water communities on all sampling occasions. The crustaceans *Corophium acherusicum, Grandidierella lutosa* and *Apseudes digitalis* were on average the most important contributors to the euhaline assemblage during low and high river runoff periods, contributing on average 48% and 43% respectively. The polychaete worms *Ceratonereis keiskama*, *Boccardia* sp and *Desdemona ornata* contributed on average about 29-30% to total abundance during high and low runoff periods (Table 8.14 – Table 8.20). The brackish water community when present in samples was represented by Chironomid larvae and polychaete worms.

Table 8.15 SIMPER analysis of the numerically dominant subtidal benthic species (ranked) in the estuarine and brackish water cluster groups shown for September 2003 in Figure 8.17. Groups represent sites >50% similarity. Columns represent average numerical abundance within a cluster, average similarity between sites, Similarity Standard deviation, Contribution of each species to total numerical abundance and the cumulative contribution (up to the 90% cut-off value).

Species	Av. Abund.	Av. Sim.	Sim/SD	Contrib%	Cum %
Stations 5 – 8					
Corophium acherusicum	7014.93	21.77	18.43	27.58	27.58
Ceratonereis keiskama	575.17	11.81	7.42	14.96	42.54
Anthurid sp.	1681.60	10.80	2.50	13.68	56.22
Desdemona ornata	1342.53	9.90	2.71	12.54	68.76
Boccardia sp.	238.02	6.83	5.57	8.66	77.42
Prionospio bocki	144.44	6.38	5.01	8.09	85.51
Chironomid larvae	23.78	4.22	3.83	5.34	90.85
Average similarity between stations in the group: 78.93%					
Stations 13 – 15					
Chironomid larvae	303.70	75.04	10.35	100.00	100.00
Average similarity between stations in the group: 75.04%					

Table 8.16 SIMPER analysis of the numerically dominant subtidal benthic species (ranked) in the estuarine and brackish water cluster groups shown for February 2004 in Figure 8.17. Groups represent sites >50% similarity. Columns represent average numerical abundance within a cluster, average similarity between sites, Similarity Standard deviation, Contribution of each species to total numerical abundance and the cumulative contribution (up to the 90% cut-off value).

Species	Av. Abund.	Av. Sim.	Sim/SD	Contrib%	Cum %
Stations 4 – 12					
Ceratonereis keiskama	1244.74	11.81	1.27	38.39	38.39
Desdemona ornata	1798.61	3.92	0.56	12.72	51.11
Corophium acherusicum	2805.95	3.78	0.89	12.25	63.36
Anthurid sp.	1187.30	2.94	0.55	9.52	72.89
Boccardia sp.	1006.65	2.44	0.59	7.90	80.79
Capitella capitata	1254.66	1.98	0.37	6.41	87.19
Grandidierella lutosa	2356.45	1.06	0.39	3.44	90.63
Average similarity between stations in the group: 30.83%					
Stations 14 – 15					
Oligochaete sp.	94.44	60.97	-	65.50	65.50
Chironomid larvae	8.33	32.11	-	34.50	100.00
Average similarity between stations in the group: 93.08%					

Table 8.17 SIMPER analysis of the numerically dominant subtidal benthic species (ranked) in the estuarine and brackish water cluster groups shown for April 2005 in Figur. Groups represent sites >50% similarity. Columns represent average numerical abundance within a cluster, average similarity between sites, Similarity Standard deviation, Contribution of each species to total numerical abundance and the cumulative contribution (up to the 90% cut-off value).

Species	Av. Abund.	Av. Sim.	Sim/SD	Contrib%	Cum %
Stations 2, 4 – 7					
Anthurid sp.	2227.78	9.39	1.11	21.23	21.23
Grandidierella lutosa	2551.12	7.63	2.43	17.26	38.49
Corophium acherusicum	4907.78	5.17	0.99	11.70	50.19
Callianassa kraussi	88.89	5.08	1.04	11.48	61.67
Ceratonereis keiskama	291.11	4.35	1.07	9.85	71.52
Prionospio sexoculata	215.56	3.60	1.09	8.15	79.67
Exosphaeroma hylocoetes.	121.11	3.48	1.14	7.87	87.54
Desdemona ornata.	158.89	1.36	0.59	3.08	90.62
Average similarity between stations in the group: 44.22% up to here					
Stations 11, 13 – 14					
Corophium acherusicum	4566.67	28.99	8.05	44.81	44.81
Oligochaete sp.	731.48	16.22	9.30	25.07	69.88
Chironomid larvae	588.89	6.85	0.58	10.59	80.47
Ceratonereis keiskama	1350.00	5.55	0.58	8.57	89.04
Capitella capitata	718.52	4.74	o.58	7.33	96.37
Average similarity between stations in the group: 64.70%					

Table 8.18 SIMPER analysis of the numerically dominant subtidal benthic species (ranked) in the estuarine and brackish water cluster groups shown for July 2005 in Figure 8.17. Groups represent sites >50% similarity. Columns represent average numerical abundance within a cluster, average similarity between sites, Similarity Standard deviation, Contribution of each species to total numerical abundance and the cumulative contribution (up to the 90% cut-off value).

Species	Av. Abund.	Av. Sim.	Sim/SD	Contrib %	Cum %
Stations 3 – 6					
Grandidierella lutosa	1748.61	11.26	3.34	23.93	23.93
Anthurid sp.	1611.11	9.19	3.47	19.53	43.46
Prionospio sexoculata	*313.89*	*7.32*	*2.14*	*15.56*	*59.01*
Desdemona ornata	*1697.22*	*7.32*	*2.91*	*15.56*	*74.57*
Corophium acherusicum	7002.78	5.54	0.59	11.77	86.34
Ceratonereis keiskama	144.44	2.82	1.58	5.99	92.33
Average similarity between stations in the group: 47.05%					
Stations 8, 12 & 14					
Corophium acherusicum	8.7.41	13.57	0.58	56.99	56.99
Ceratonereis keiskama	277.78	6.84	0.58	28.74	85.74
Oligochaete sp.	5.56	2.42	0.58	10.18	95.92
Average similarity between stations in the group: 23.80%					

Table 8.19 SIMPER analysis of the numerically dominant subtidal benthic species (ranked) in the estuarine and brackish water cluster groups shown for November 2005 in Figure 8.17. Groups represent sites >50% similarity. Columns represent average numerical abundance within a cluster, average similarity between sites, Similarity Standard deviation, Contribution of each species to total numerical abundance and the cumulative contribution (up to the 90% cut-off value).

Species	Av. Abund.	Av. Sim.	Sim/SD	Contrib%	Cum %
Stations 3 – 6					
Corophium acherusicum	18570.14	21.07	16.29	27.80	27.80
Anthurid sp.	3259.95	14.19	22.23	18.72	46.52
Desdemona ornata	*13.77.78*	*10.81*	*13.84*	*14.26*	*60.78*
Grandidierella lutosa	222.92	6.96	16.43	9.18	69.97
Ceratonereis keiskama	147.45	6.57	16.94	8.67	78.64
Hymenosoma orbiculare	*149.31*	*5.84*	*4.33*	*7.71*	*86.35*
Boccardia sp.	235.19	2.76	0.58	3.64	89.98
Prionospio bocki	149.07	2.12	0.58	2.80	92.78
Average similarity between stations in the group: 75.78%					
Stations 13 - 15					
Chironomid larvae	564.81	35.11	2.96	55.98	55.98
Oligochaete sp.	237.04	27.61	7.08	44.02	100.00
Average similarity between stations in the group: 62.72%					

Table 8.20 SIMPER analysis of the numerically dominant subtidal benthic species (ranked) in the estuarine cluster group shown for February 2006 in Figure 8.17. The group represents sites >50% similarity. Except for sites 7 and 15, no other clusters exceeded 50% similarity. Columns represent average numerical abundance within a cluster, average similarity between sites, Similarity Standard deviation, Contribution of each species to total numerical abundance and the cumulative contribution (up to the 90% cut-off value).

Species	Av. Abund	Av. Sim.	Sim/SD	Contrib%	Cum %
Stations 3 – 6					
Corophium acherusicum	1514.81	34.21	5.53	61.12	61.12
Ceratonereis keiskama	87.04	13.62	1.88	24.33	85.46
Capitella capitata	*524.07*	*8.14*	*0.58*	*14.54*	*100.00*
Average similarity between stations in the group: 55.97%					

Diversity measures

Three diversity indices were measured: Total number of individuals (N), Margalef's species richness (d) and Pielou's evenness index. The maximum number of individuals in the zooplankton was generally recorded in the middle estuary and was linked to the distribution of *Pseudodiaptomus hessei*, although peak in abundance shifted downstream at times of strong freshwater inflow (e.g. September 2003 and July 2005, Figure 8.19). When abundance of *P. hessei* was relatively low, patterns were mostly associated with species in the high salinity lower estuary (e.g. *Acartia longipatella* and *Paracalanus* sp., Appendix 4.2). Species richness was generally maximal in the lower estuary (Figure 8.20), while Pielou's eveness index (Figure 8.21) peaked in the lower and upper estuary where no species dominated the community in terms of abundance.

No diversity trends were apparent for the hyperbenthos and no diversity plots are provided for this group.

Diversity indices for the subtidal benthic community followed similar patterns (Figure 8.22 & Figure 8.23), except for Pielou's eveness index (Figure 8.24) that reflected a variable pattern. This was probably linked to the variable ranking of the amphipods (*Grandidierella lutosa* and *Corophium acherusicum*), polychaete worms (*Ceratonereis keiskama* and *Desdemona ornata*) and the species of anthurid isopod that dominate different reaches of the estuary (Table 8.14 – Table 8.20).

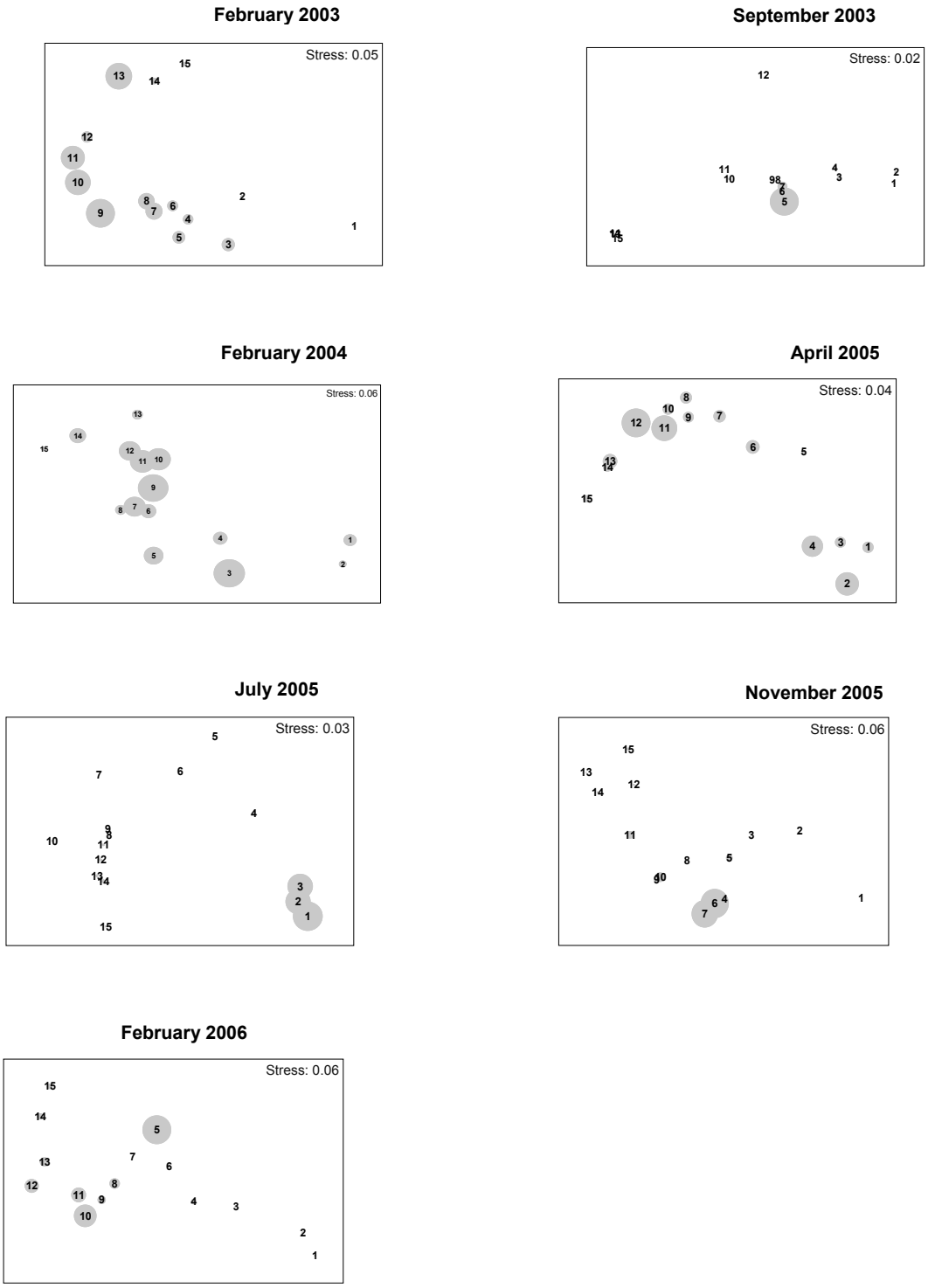


Figure 8.19 Total number of individuals of all species (N) for the zooplankton at 15 stations in the Great Berg estuary. Data for seven series, collected between February 2003 and February 2006. Circle size is a relative measure between sites.

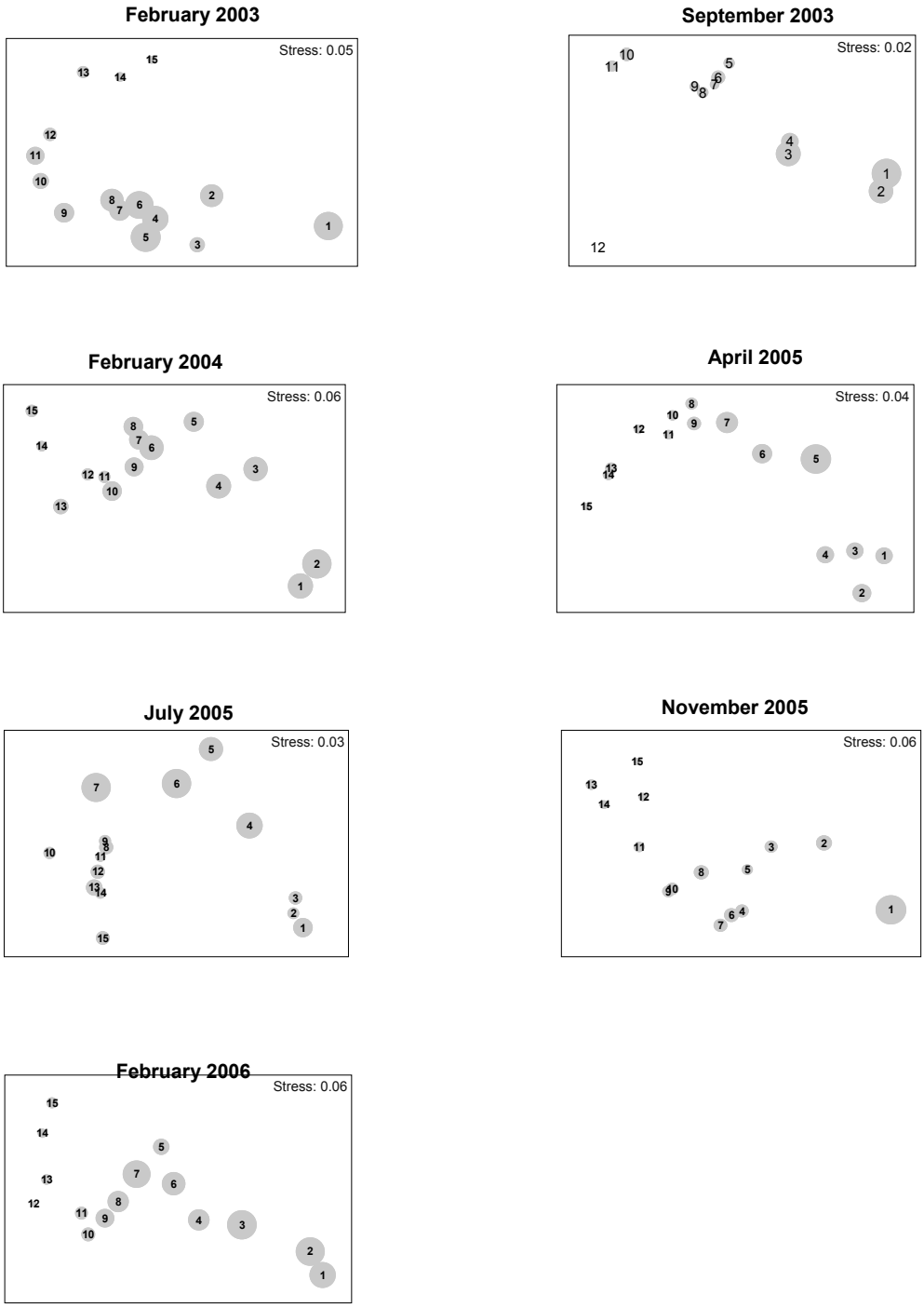


Figure 8.20 Margalef's index (d) of species richness for the zooplankton at 15 stations in the Great Berg estuary. Data for seven series, collected between February 2003 and February 2006. Circle size is a relative measure between sites.

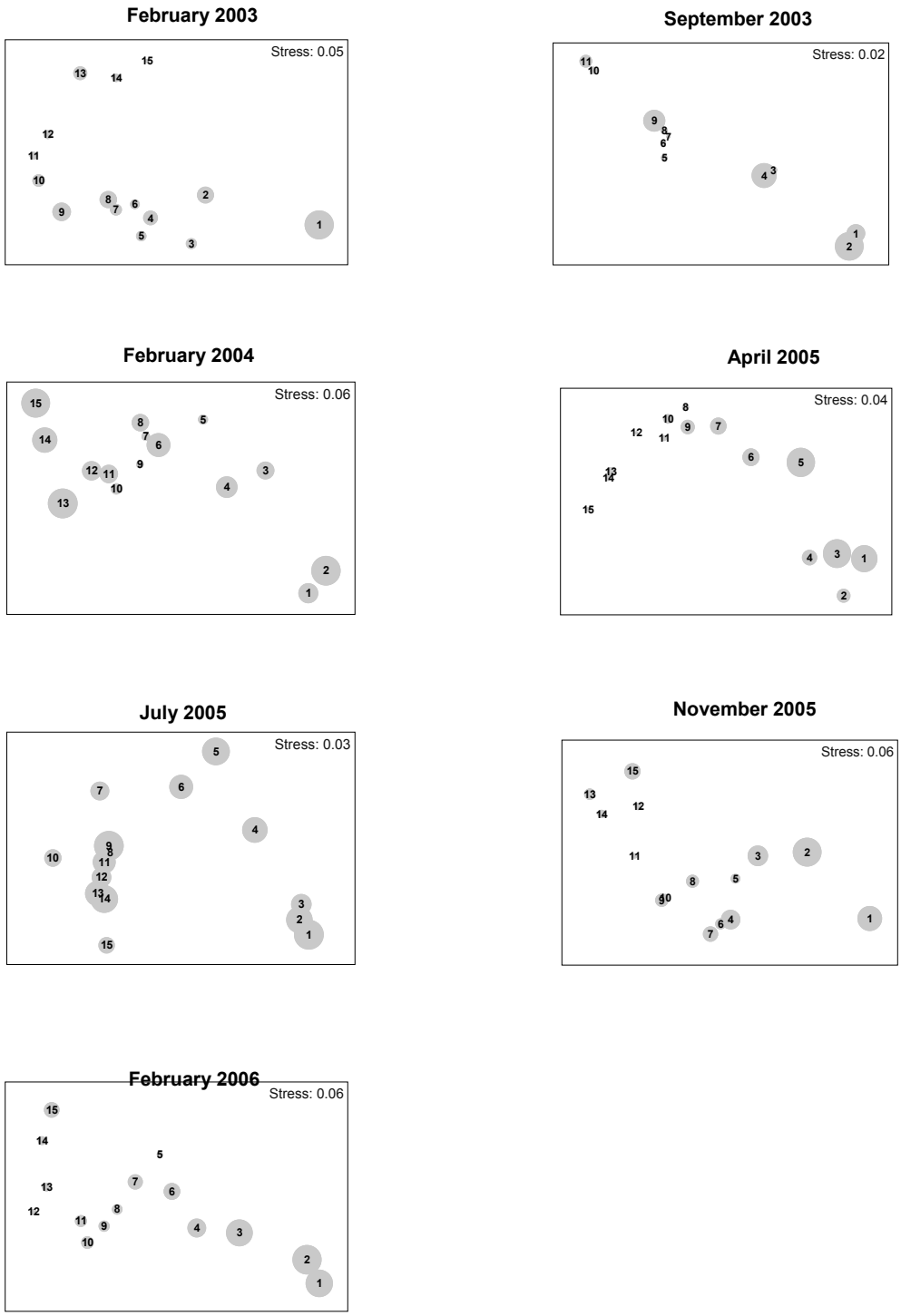


Figure 8.21 Pielou's eveness index (J') for the zooplankton at 15 stations in the Great Berg estuary. Data for seven series, collected between February 2003 and February 2006. Circle size is a relative measure between sites.

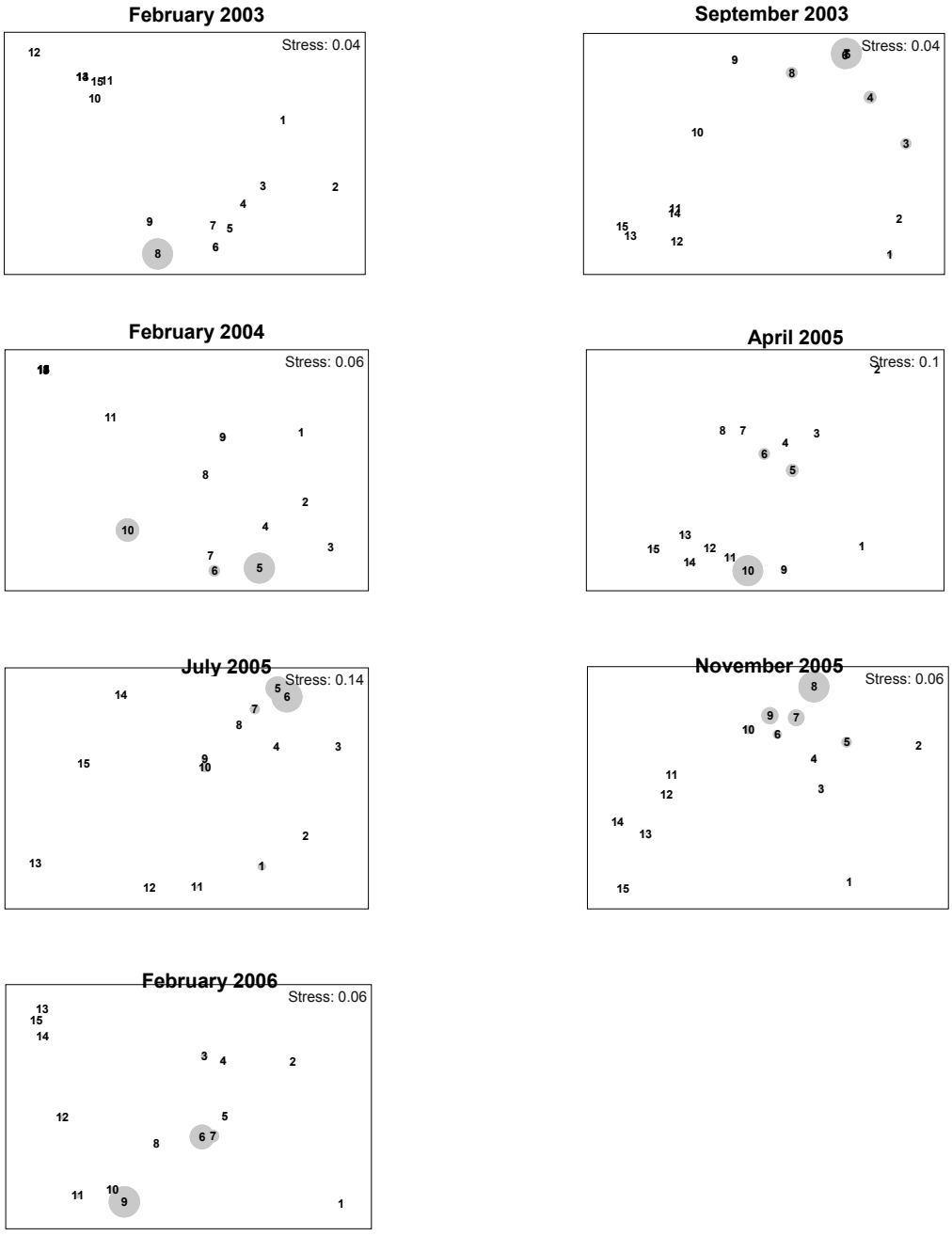


Figure 8.22 Total number of individuals of all species (N) for the subtidal benthos at 15 stations in the Great Berg estuary. Data for seven series, collected between February 2003 and February 2006. Circle size is a relative measure between sites.

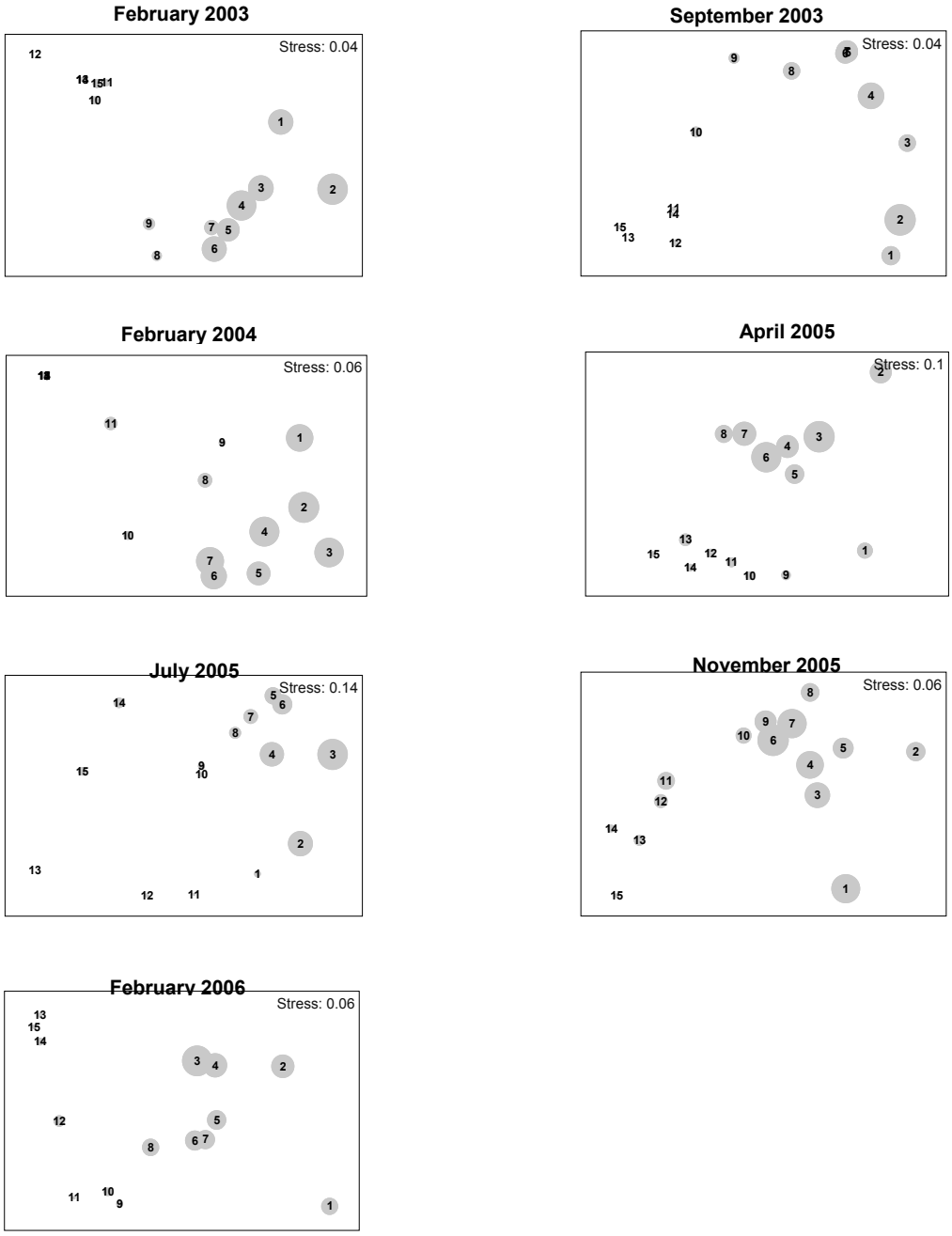


Figure 8.23 Margalef's index (d) of species richness in the subtidal benthos at 15 stations in the Great Berg estuary. Data for seven series, collected between February 2003 and February 2006. Circle size is a relative measure between sites.

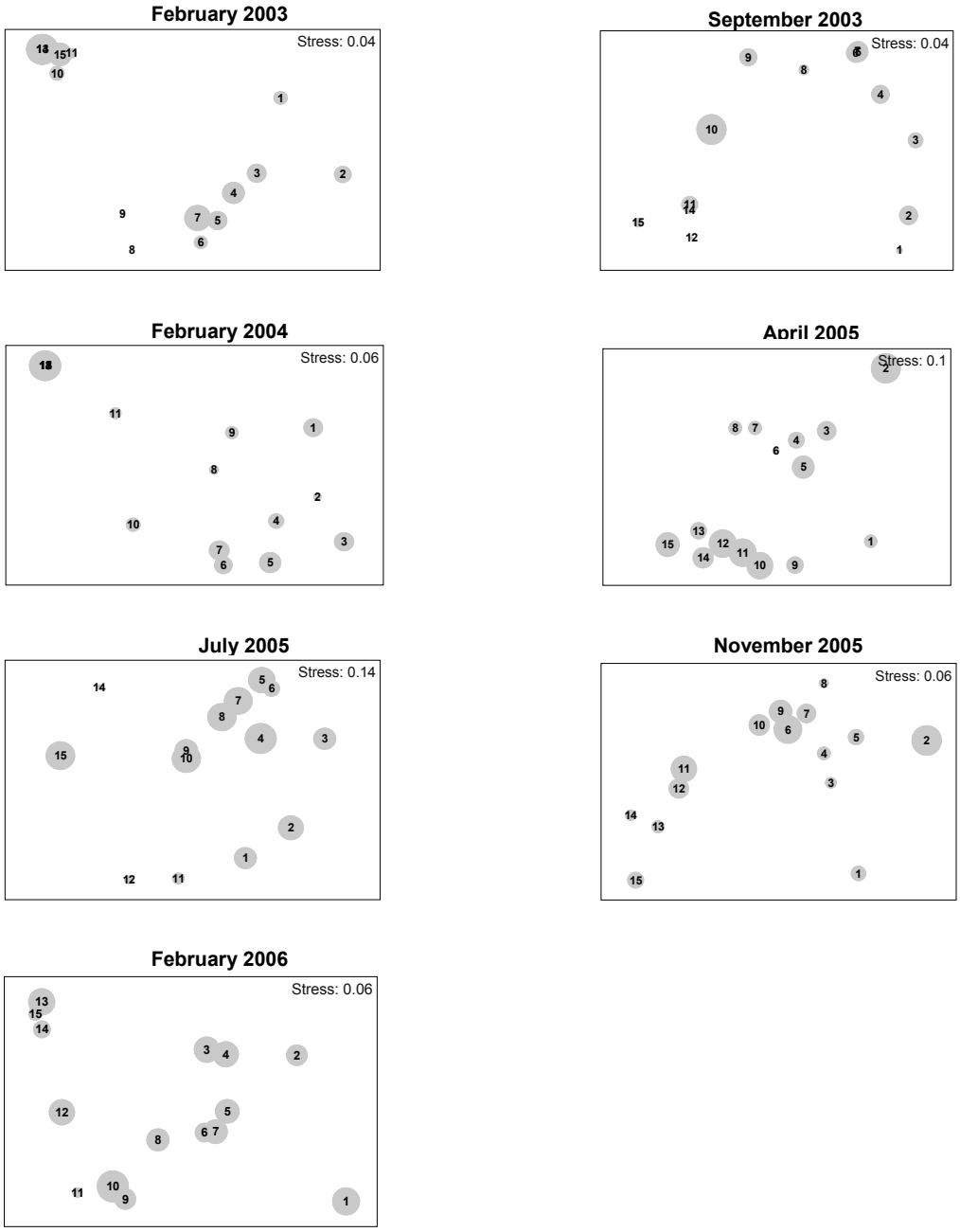


Figure 8.24 Pielou's eveness index (J') for the subtidal benthos at 15 stations in the Great Berg estuary. Data for seven series, collected between February 2003 and February 2006. Circle size is a relative measure between sites.

8.3.6 Intertidal benthic community

Intertidal benthic species composition and abundance recorded in September 2003 and February 2006 is given in Appendix 4.5. On the latter occasion, saltpans were not sampled. Sixteen and twelve taxa were identified on the two occasions. Polychaetes and amphipods clearly dominated from a numerical viewpoint (Figure 8.25). Only insect larvae (chironomids) were recovered in samples collected in two of the freshwater pans (FP1 – FP2, Appendix 4.5).

The polychaetes *Ceratonereis erythraeensis*, *Boccardia* sp. and *Capitella capitata* were the most common species in September 2003 at Stations KH1 – KH3 (82% of total abundance). *C. erythraeensis* and *C. capitata* were most abundant at KH3 (Figure 8.26), while *Boccardia* sp. attained maximum abundance at KH1. Only one polychaete species (*Namalycasatis* sp.) was recorded at KH4.

The latter site was instead characterized by relatively high numbers of amphipods (*Melita zeylanica* and a species of *Talorchestia*) and the isopod *Exosphaeroma hylocoetes*.

In February 2006, *C. erythraeensis* and *C. capitata* were the only polychaetes present in samples (67%). On this occasion, the amphipod *Grandidierella lutosa* contributed 30% to total abundance, compared to 11% in September 2003. Abundance levels *C. erythraeensis*, *C. capitata* and *Grandidierella lutosa* were significantly higher compared to September 2003, with the latter species attaining a density exceeding 15000 ind.m^{-2} at KH3 (Figure 8.26).

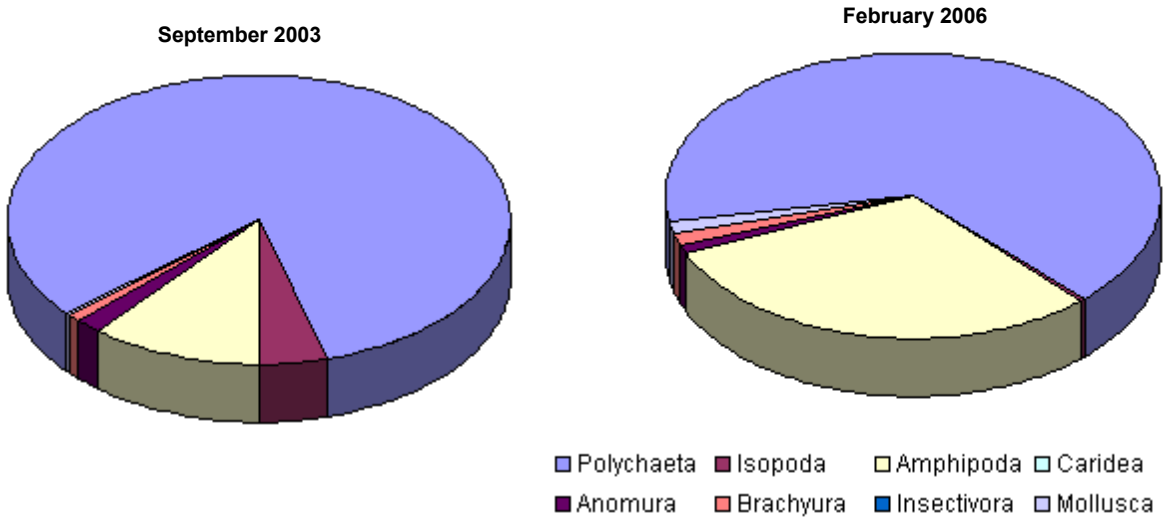


Figure 8.25 Pie-diagram showing the numerical dominance of polychaetes and amphipods in the intertidal benthos (Sites KH1 to KH4) of the Great Berg estuary, September 2003 and November 2006.

Bray-Curtis similarity analysis of intertidal sites using group average mode on square-root transformed data (Appendix 4.5) showed three clusters in September 2003 and two clusters in February 2006 at the 50% cut-off level (Figure 8.27). In September 2003, composition of the community showed a high degree of dissimilarity between Floodplain pan sites (FP1 - FP4) and the downstream sites (KH1 to KH4). Station KH4 also showed little similarity to KH1, KH2 and KH3, separating at about the 10% level. In February 2006, there was greater similarity between sites.

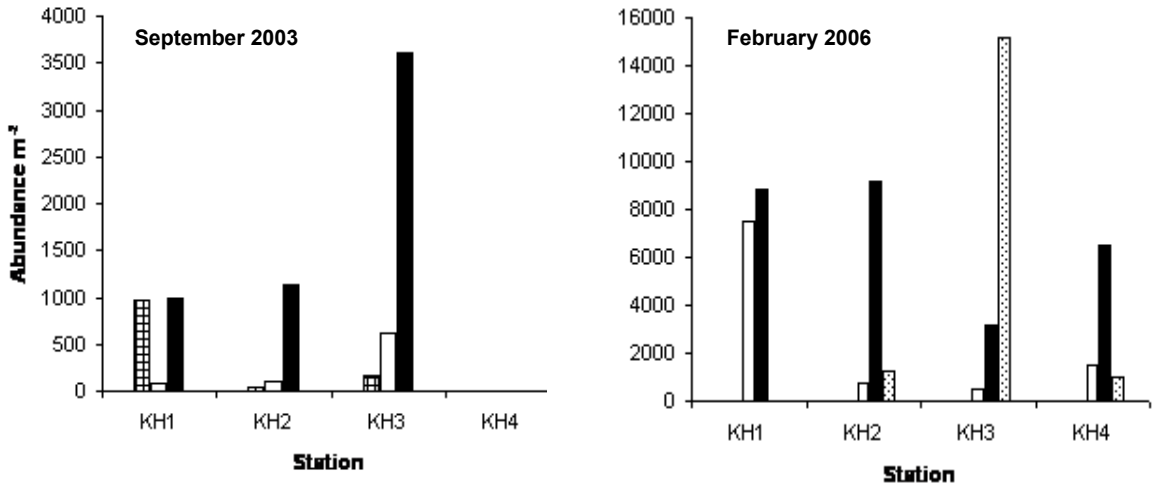


Figure 8.26 Abundance of Ceratonereis erythraeensis (solid bars), Capitella capitata (open bars), Boccardia sp. (squared bars) and Grandidierella lutosa (stippled bars) at intertidal sites (K1 to K4) in the Great Berg estuary, September 2003 and February 2006.

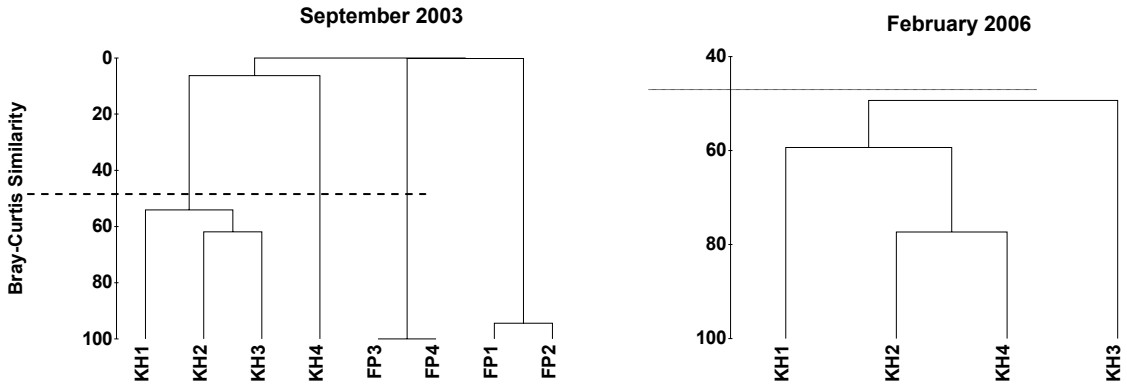


Figure 8.27 Dendrogram for Bray-Curtis similarity clustering of intertidal sites based on composition and abundance. Data for the Great Berg estuary, September 2003 and February 2006. The dotted line represents the 50% cut-off line.

8.4 DISCUSSION

Estuaries are dependent on marine and freshwater links in order to function optimally. A salinity gradient becomes established that typically ranges from freshwater at the tidal head (near-zero salt content) to seawater at the mouth (salt concentration around 35 parts per thousand or 35 ppt). However, a number of factors operating over different time scales lead to temporal variations in the horizontal salinity profile. For example:

- the ebb and flow of the tides operate over time scales of a few hours,
- seasonal changes in evaporation and rainfall operate over time scales of months, and
- shifts between wet and dry cycles operate over time scales of years.

Vertical differences in salinity are also common. The volume of freshwater inflow, the degree of tidal mixing and the topography of the estuary structure the vertical salinity profile. Tide-generated currents also have a major influence on sediment characteristics and the type of organisms found along the estuary. Where strong currents prevail, the substratum will be coarse (sand or gravel). Finer particles (e.g. silt) settle where waters are calm and the currents weak.

The variable nature of estuarine habitats, especially defined by fluctuating salinity and substratum type, make estuaries a stressful and rigorous environment in which to live. Estuarine organisms must cope with problems unlike those of plants and animals living in purely marine or fresh waters. It is therefore not surprising that in general, estuaries are environments inhabited by far fewer species compared to other marine ecosystems, but they rank among the most productive environments on earth. This is only possible if estuaries maintain functional links with both rivers and the sea. Very few organisms are able to tolerate the full salinity range found in estuaries and are broadly separated into three groups:

A marine component is the largest in terms of the number of species and includes two subgroups:

Stenohaline marine animals are typical marine forms that either are unable to tolerate, or barely able to tolerate salinity changes. This component is restricted to the tidal inlet region where salinity remains close to that of seawater. These animals are often the same as those found in the marine nearshore.

Euryhaline marine animals can tolerate varying degrees of salinity reduction below 30 ppt and can penetrate some distance up-estuary. Many can tolerate salinity values down to about 15 ppt, with a few hardy species tolerating levels down to 3 ppt.

A brackish water or true estuarine component comprises those species that are found in the middle reaches of estuaries where salinity varies between 5 ppt and 20 ppt. This category includes endemic species.

A third component is derived from freshwater, with species usually restricted to a zone where salinity does not exceed 5 ppt in the upper reaches.

The Great Berg Estuary is classified as a river-dominated system where sediment dispersal occurs seaward of the river mouth. Only two other South African estuaries are characterized by having offshore mud deposit centres, namely the Orange or Gariep and the Thukela (Cooper 2001). Besides the Great Berg, numerous other examples of river-dominated estuaries occur in South Africa. In all of them, river flow is critical to the maintenance of an outlet channel and the impact of impoundments is especially notable in these systems (Cooper 2001). River dominance in the Great Berg is clearly apparent in the present study with horizontal salinity distribution in the estuary following seasonal changes in river flow. In summer, salinity penetrated relatively far upstream compared to winter. Exceptionally high salinity values were recorded at Stations 1 and 2 (>60 ppt in bottom waters) in February 2003, possibly due to breaching of saltpan levees following heavy rains at the time, but this was not substantiated. These conditions were of short duration and had disappeared a few days later when further measurements were taken (Strydom, pers. com.). The general estuarine salinity regime between summer and winter therefore follows a pattern described by Slinger & Tajaard (1994), with salinity measurements in January or February at Kersfontein showing comparable values to those reported by other authors (Table 8.21). These values naturally vary between years, depending on rainfall pattern and volume of fresh water flowing in to the estuary. (See also report by Schumann 2007 – BRBMPR Vol. 3, Chapter 3).

All three major groups linked to the salinity gradient and described above were identified in the Great Berg Estuary. Marine associated invertebrates did not penetrate far up the estuary and were rapidly replaced by euryhaline forms. The latter group are highly tolerant of salinity fluctuations and only hardy species survive. This would partly explain the relatively low number of species recorded in the zooplankton and benthos as species number is partly controlled by physical characteristics (de Villiers et al. 1999).

Day (1964) previously noted that the composition of the fauna of South African estuaries is more dependent on the physical characteristics of an estuary (depth, condition of the mouth, salinity regime, nature of the bottom sediments etc) than on geographical location.

Table 8.21 Salinity readings documented by different authors at Kersfontein (40 – 45 km from the mouth) during low-flow periods (January or February). (S) surface and (B) bottom reading.

Date	Salinity	Source	Comments
1979	9	Day (1981)	No details provided
1990	1-2	Slinger & Taljaard (1994)	Well mixed water column
1993	0	Bennett (1994)	No details provided
2003	(S) 6.7 (B) 13.8	Wooldridge (this study)	Stratified water column
2004	(S) 0 (B) 0	Wooldridge (this study)	Well mixed water column
2006	(S) 1.6 (B) 1.7	(Wooldridge (this study)	Well mixed water column

However, the relatively low number of species recorded in samples from the Great Berg may also be linked to the biogeographical location of the estuary. Although it is possible to compare west and east coast estuaries directly, it is more realistic to group all surveyed estuaries within a specific region and then to compare results with data from other biogeographical regions of South Africa (Day 1974). Based on this approach, Day (1974) noted that South coast estuaries supported the richest number of intertidal macrofaunal species and the west coast estuaries the least (Table 8.22).

Table 22 clearly shows the paucity of species from west coast estuaries. Included in this relatively small sample are data from Milnerton estuary (Millard & Scott 1954) and the Orange River estuary (Brown 1959), supplemented by unpublished data from the Great Berg and Olifants estuaries (Day 1974). Such low species richness was ascribed to the inability of species to tolerate sharp water temperature changes near the mouth during tidal ebb and flow. This is particularly true at times of upwelling in summer when upwelled water reduces water temperatures in the lower estuary considerably (Day 1974). However, de Villiers et al. (1999) point out that such temperature changes are also experienced in south coast estuaries. Three of the estuaries in Day's (1974) analysis are river-dominated systems (Orange, Great Berg and Olifants) and this must also influence the species assemblage present. In effect, the low species number reflected in the table may be more of a response to river dominance rather than the temperature effect as suggested by Day (1974). This suggests that the number of species may increase if river dominance decreases in these west coast systems.

Table 8.22 Summary of the combined totals of intertidal macrofaunal species (main groups only) identified from all estuaries sampled by Day (!974) and his co-workers. Data for the Morrumbene estuary in Mozambique provided for further comparison (Data extracted from Table 8, Day 1974).

	Morrumbene Estuary	KZN-Transkei estuaries	Southern Cape estuaries	Atlantic coast estuaries
Number of species	378	237	357	59

Invertebrates recorded in the Great Berg may generally be described as typical estuarine species tolerant of wide variation in the physico-chemical environment. This is born out by BIO-ENV analysis that showed salinity and temperature to best explain the correlation between biological data at the community level Table 8.5 and Table 8.13 - zooplankton and subtidal benthos) and the environmental variables measured. In addition, sediment characteristics and chlorophyll-*a* values were also important parameters that explained distribution and abundance of the subtidal benthos. Salinity is often described as the major factor determining distribution patterns of estuarine benthic fauna (e.g. Day 1964, Carricker 1967, Hill 1981, Wolf 1983 among others), although sediment is also known to be a major factor in structuring communities (Day 1964, Holland, Shaughnessy & Hiegel 1987, Teske & Wooldridge 2003). Clearly, factors that structure invertebrate communities are inter-related in complex ways, with the relative importance of any particular factor linked to the magnitude of river domination, degree of sediment change and other drivers along the estuary.

The number of species recorded in the estuary for all three invertebrate groups generally reflected fewer species during high flow periods (September 2003 and July 2005) compared to summer when freshwater runoff was relatively low (Table 8.23). However, the summer pattern is augmented by breeding activity of benthic forms that supplement the zooplankton and hyperbenthos since their larvae are temporarily planktonic.

Table 8.23 The range in the number of species recorded during the low flow period (summer) and high flow (winter) for the zooplankton, hyperbenthos and subtidal benthic communities in the Great Berg estuary.

	Summer	Winter
Zooplankton	30-32	25-27
Hyperbenthos	15-21	13-14
Subtidal benthos	20-32	21-23

Low water temperatures characterize the cool temperate biogeographical province on the west coast. In the Great Berg estuary, colder water in summer dominates the lower estuary where marine influence is high. Water temperatures increased from ca 15 to >25^{o}C upstream, with temperatures rising relatively steeply up to Station 5. Summer water temperatures in the middle and upper reaches are more influenced by the river flowing across the hot interior of the country and not the colder marine water. These data therefore support Day (1974) who concluded that summer temperatures in the upper reaches of west coast estuaries are not much different from estuarine water temperatures on the east coast. However, water temperatures at least in the lower estuary fall sharply at times of upwelling (Day 1974). During winter, water temperatures in the estuary are influenced by colder inflowing river water and cold marine water, such that temperatures may be maximal in the middle-upper estuarine reaches.

Figure 8.28 illustrates estuarine water temperatures from four estuaries around the South African coast, extending from the cool temperate zone (Olifants and Great Berg estuaries), around the south-east coast (Keiskamma estuary) and in to the transitional zone between the warm temperate and subtropical provinces (Mngazana estuary). All are permanently open systems and illustrate the relatively close similarity in upper estuarine water temperatures in summer. Lower reaches illustrate cooler marine influence, particularly on the west coast. In winter, water temperatures in the four estuaries reflect little variation along the lengths of each estuary and all range between 14.5 and 19^0C.

The composition of the euryhaline community is similar to community composition found in estuaries on the south and east coasts of South Africa. Day (1974) noted that none of the benthic species recorded in Atlantic coast estuaries is restricted to the Atlantic coast. Polychaetes such as *Capitella capitata* and *Glycera tridactyla*; crustaceans and molluscs such as *Hymenosoma orbiculare*, *Palaemon perengueyi*, *Upogebia africana*, *Melita zeylanica* and *Nassaria kraussiana* even extend in to Mozambique. The present study on the estuarine zooplankton, hyperbenthos and subtidal benthos supports the notion that most species are not unique to the west coast, although non-benthic marine species that temporarily move in to the lower estuary on flood tides do not all follow this pattern. Elevated summer water temperatures in the middle-upper estuarine reaches and the relatively narrow range between the estuaries in winter may in part explain the similarity between these euryhaline communities, although recent work by Peter Teske and Isabelle Papadopoulos using DNA techniques may alter distribution patterns for some species that are currently perceived to be ubiquitous around the coast.

Although the number of species appears relatively low in the Great Berg estuary, total abundance of some euryhaline species is very high. The estuarine invertebrate fauna (zooplankton, hyperbenthos and benthic subtidal components) reflects the expected pattern where strong marine influence in the lower estuary leads to high species number and low dominance or high eveness near the mouth.

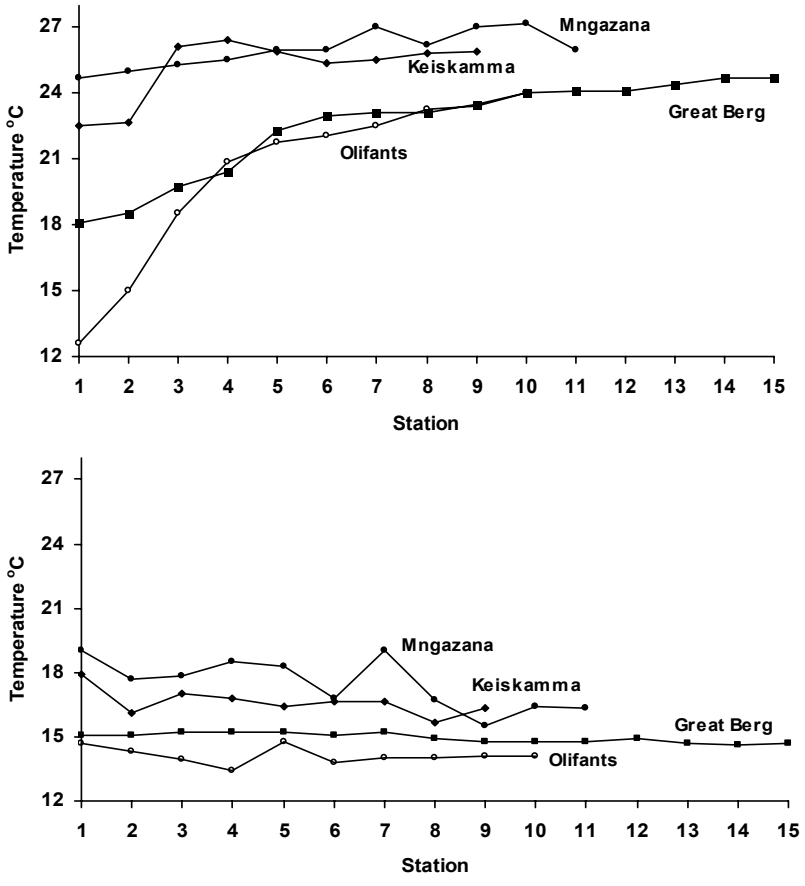


Figure 8.28 *A comparison of summer (A) and winter (B) water temperatures between four permanently open estuaries around the South African coast. The Olifants and Great Berg are located in the cool temperate region, the Keiskamma is located in the warm temperate province and Mngazana occurs further east in the transition zone between the warm temperate and subtropical provinces. Data are extracted from January-February (summer) and June-July data (winter). Data are integrated for the water column at each station along the length of each estuary.*

The converse holds true for the euryhaline fauna that reflects low species number and high dominance or low eveness (see section 8.2.4).

Dominant euryhaline forms in the zooplankton were *Pseudodiaptomus hesse*i and mysid shrimps (*Mesopodopsis wooldridgei* and *Rhopalophthalmus terranatalis*); in the hyperenthos mysid shrimps dominated while in the benthos, polychaete worms (e.g. *Ceratonereis keiskama*) and amphipods (*Corophium acherusicum*) attained very high population abundance levels. The upper reaches of the Great Berg estuary had a relatively depauperate fauna, probably due to fluctuating salinity values that respond to variable freshwater inflow volumes over different time scales (tidal and seasonal particularly). A brackish water faunal community therefore does not have sufficient time to establish itself at the fixed sampling stations. Should future freshwater abstraction levels reduce intra- and interannual variability in salinity distribution along the estuary, faunal communities will follow a trajectory towards increased species richness and lower dominance in an upstream direction. In extreme cases, estuarine communities change significantly in response to a reducing supply of freshwater as documented in the next section.

Many of the dominant zooplankton species in the Great Berg estuary also dominate in south and east coast estuaries. The copepod *Pseudodiaptomus hessei* is endemic to estuaries and is widespread around southern Africa (Wooldridge 1999). It attains high population densities, especially under conditions of relatively high freshwater inflow. In the Gamtoos estuary, maximum abundance was attained in regions of the estuary where salinity ranged between 10 and 25 ppt. In the Great Berg, maximum abundance occurred at salinity values between 20 and 26 ppt relatively high up in the estuary. *P. hessei* is described as a pioneer species (Wooldridge & Melville-Smith 1979), responding to flooding or strong freshwater discharges through marked increases in population density. Although population recovery is extremely rapid, a decline in density may be equally abrupt. This was shown in numerous other estuarine studies (Wooldridge 1999) that leads to high variability in density over time. Such a pattern is typical for the species. The relative abundance of *P. hessei* in South African estuaries that experience contrasting inputs of freshwater is shown in Table 8.24. Data reflect the population response (measured as numbers m^{-3}) to freshwater rich conditions and freshwater starved conditions. Salinity *per se* does not explain the high variability, but correlative evidence suggests that freshwater pulsing leads to nutrient enrichment, increased phytoplankton biomass and hence a greater food supply for the developing zooplankton community. Because of its ability to colonize 'new estuarine' water, the initial absence of predators would also exacerbate the rapid recovery of the population. Predators include numerous other species of zooplankton such as mysid shrimps, crab larvae and larvae of the round herring (*Gilchristella aestuaria*).

Table 8.24 *Maximum abundance levels (number m^{-3}) recorded for the copepod Pseudodiaptomus hessei from different southern African estuaries. Estuaries with strong inflow of freshwater have strong horizontal salinity gradients (Group 1); estuaries with low or no freshwater inflow have weak or reverse horizontal salinity gradients (Group 2). The salinity range shown refers to values recorded at all sampling stations along each estuary.*

Estuary	Salinity range (ppt)	Max. abundance recorded to-date	Reference
Group 1			
Sundays	7-35	33 500	Wooldridge & Bailey (1982)
Great Fish	0-35	91 500	Unpublished records
Keiskamma	0-35	117 000	Unpublished records
Great Berg	7-34	52 000	This study
Olifants	0–34	41 000	Unpublished records
Group 2			
Gqutywa	35-40	12 250	Unpublished records
Kariega	25-36	4 800	Unpublished records
Kromme	31-42	6 000	Wooldridge 1999

Salinity distribution (linked to the volume of freshwater inflow) was identified as the single most important factor explaining zooplankton community patterns in the Great Berg estuary (Table 8.5). A marine associated fauna dominated the zooplankton up to ca 2-3 km chainage (Station 2-3) where salinity remains above ca 30. A brackish water assemblage distinguishes the upper zooplankton community where salinity does not exceed 3 – 5 (Chainage 38-40 km). Between these extremes, a typical estuarine community develops. Although the number of species is typically low, abundance and biomass attain very high levels. The community is euryhaline and because of high biomass, provides a major linkage between primary producers and secondary consumers in the water column.

Although three communities typify the zooplankton, boundaries are not fixed as previously described. Under conditions of low freshwater inflow, salinity values increase generally that may lead to a concomitant upstream shift of the euryhaline community as the brackish zone recedes (Table 8.10, April 2005). By contrast, high riverine inflow leads to flushing of the zooplankton from the estuary. At the species level, *Pseudodiaptomus hesse*i was identified as the single most important copepod in the estuary from a numerical point of view on all sampling occasions. This follows the typical pattern shown for many other South African estuaries. The species is extremely euryhaline and is described as a pioneer species. It is interesting to note that no correlation was found between salinity distribution and population abundance, although strong correlations exist between salinity and species at the community level. Similar descriptions probably also apply to species at population and community levels in the subtidal benthos, but research is still ongoing.

8.5 CONCLUSIONS

Invertebrates identified from the Great Berg estuary are not unique to the west coast of South Africa. However, the number of species present in the estuary may be low compared to communities on the south and east coasts, at least for intertidal organisms. Insufficient information is currently available to test biogeographical trends for other groups (zooplankton, hyperbenthos and subtidal benthos) in the Great Berg, but the causal factors driving observed patterns are sometimes difficult to isolate. For example:

Because of river dominance, salinity values are reduced to relatively low levels most of the time. Consequently, a species-rich invertebrate community does not establish itself in the lower estuary. However, an incursive marine zooplankton component enters the lower estuary on the flood tide. Species are again flushed out on the ebb tide.

Although biogeographical patterns relating to intertidal organisms suggest that Atlantic coast estuaries have fewer species compared to south and east coast estuaries, the effects of river dominance on community composition may exacerbate this pattern. River dominated systems on the east and south coasts also have relatively few species (e.g. Thukela and Breede estuaries). Only two other major estuaries occur on the west coast (Orange and Olifants) and both are river dominated. The larger west coast estuaries are therefore characterized as river dominated systems and can be expected to have relatively low species richness.

Sampling approach may lead to an underestimate of composition and abundance of species. For example, techniques used by different researchers have varied over time.

The use of different types of sampling gear (corers, sleds, nets), or different mesh sizes to separate animals from water or sediment will provide different answers. Smaller animals are often more abundant, but these may pass through a relatively coarse net or sieve.

The number of species in each of the three groups investigated (zooplankton, hyperbenthos and subtidal benthos) was lower in winter compared to summer.

This may be partly explained by increased river runoff (some species may not tolerate reduced salinity levels that result), although species richness may be augmented in summer by seasonal breeding patterns of benthic species whose larvae or juveniles exhibit different lifestyles compared to adults.

Crustaceans dominated three of the four groups investigated (zooplankton, hyperbenthos and subtidal benthos).

Major groups representing the zooplankton were copepods, mysids and fish larvae (particularly larvae of *Gilchristella aestuaria*). Crab larvae and mysids were particularly abundant in the hyperbenthos. The subtidal benthos was numerically dominated by amphipods in both summer and winter. However, the pattern changed along the estuary. Amphipods were more prevalent in the middle estuary and polychaetes nearer the mouth. The intertidal benthos was dominated by polychaetes.

Species numerically dominating communities in the Great Berg are also dominant species in estuaries on the south and east coast of South Africa. In the Great Berg, maximum population densities of zooplanktonic, hyperbenthic and subtidal benthic species were mostly present in the middle estuary (Stations 7 – 11).

Water temperature distribution and its influence on estuarine communities remains an unknown factor. Water temperatures in the middle and upper estuary were relatively high in summer, due to warming of river water as if flowed across the landscape. Little variation existed along the length of the estuary in winter. It is possible that the general similarity between invertebrate community composition in the Great Berg and those in south and east coast estuaries may be partly linked to estuarine water temperatures.

Increased freshwater abstraction has the potential to increase marine dominance in the Great Berg estuary. Canalization and regular dredging of the estuary mouth will maintain a strong link with the marine environment, exacerbating tidal penetration up the estuary. Increased marine dominance is likely to lead to a change in invertebrate community structure, causing an upstream shift towards a more marine associated fauna. The level of marine penetration upstream will determine the extent of change in the fauna. In addition, increased marine dominance upstream may lead to lower water temperatures in summer and this could also influence community structure and estuarine processes.

The subtidal benthic community was an important component of the invertebrate fauna of the Great Berg estuary. This group has received comparatively less attention from estuarine researchers to date and little comparative data exists. Levels of amphipod abundance in the middle estuary for example, are considered very high and they are likely to play an important role in estuarine processes. The subtidal benthic community is unique, having a different assemblage of species not found in other communities above the substratum.

Dominant species in all groups (zooplankton, hyperbenthos and subtidal benthos) are highly tolerant of fluctuations in the physico-chemical environment, having a range of adaptations that aid survival, including avoidance mechanisms that reduce the possibility of being flushed from the estuary.

8.6 MONITORING RECOMMENDATIONS

Invertebrates form an important part of the estuarine ecosystem, particularly in their contribution to sustaining populations of predatory fish and birds. However, there is little historic information on abundance and diversity of invertebrates in the Berge estuary and the brief snapshot of their dynamics in this three-year baseline study does not provide a very firm baseline against which future changes can be assessed. Collection and processing of invertebrate samples is also time consuming and hence cannot realistically be undertaken as frequently as with other faunal components.

Thus, it is recommended that detailed surveys such as those undertaken for this study are repeated at approximately five-yearly intervals. These surveys should include all components of the invertebrate fauna including intertidal and subtidal benthos, hyperbenthos, and zooplankton, to be sampled at at least 10 stations extending up the length of the estuary.

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CHAPTER 9 - ESTUARINE FISH

B.M. Clark

9.1 INTRODUCTION

9.1.1 Background

With the approval to proceed with construction of the Berg River Dam (formerly the Skuifraam Dam) in the Franschhoek catchment area of the Berg River, the Department of Water Affairs and Forestry (DWAF) commissioned Anchor Environmental Consultants CC and The Freshwater Consulting Group to conduct a Baseline Monitoring Programme for the Berg River. The three-year Baseline Monitoring Programme is aimed at describing the present-day condition and natural variation of the Berg River, the Berg estuary and other hydraulically linked systems. The Baseline Monitoring Programme aims to provide a clear understanding of changes occurring in the system due to natural fluctuations *vs.* those induced by water impoundment in the upper reaches of the river. The programme was initiated in October 2002 and was completed in June 2007. This document serves as the estuarine ichthyofauna Final Report. It contains results from the estuarine fish surveys conducted as part of the baseline monitoring programme, reviews relevant ichthyofaunal literature and earlier research on the Berg estuary.

9.1.2 Importance of estuaries for fish

Estuaries in South Africa represent an extremely important habitat for fish in the region. The vast majority of coastal habitat in southern Africa is directly exposed to the open ocean, and as such is subject to intensive wave action throughout the year (Field & Griffiths 1991, Beckley 1984). Estuaries in southern Africa are thus disproportionately important relative to other parts of the world, in that they constitute the bulk of the sheltered, shallow water inshore habitat in the region. Juveniles of many marine fish species in southern Africa have adapted to take advantage of this situation, and have developed the necessary adaptations to enable them to persist in estuaries for at least part of their life cycles. Whitfield (1998) has identified at least 100 species that show a clear association with estuaries in South Africa. Most of these are juveniles of marine species that enter estuaries as post-flexion larvae, remain there for a year or more before returning to the marine environment as adults or sub-adults where they spawn and hence complete the cycle. Several other species also use estuaries in southern Africa including some that are able to complete their entire life cycles in these systems, as well as a range of salt tolerant freshwater species, and euryhaline marine species. Whitfield (1994) has developed a detailed classification system of estuary associated fishes in southern Africa. He recognized 5 major categories of estuary associated fish species and several subcategories:

i. Estuarine species breeding in estuaries, further divided into:
   a) Resident species not recorded spawning in marine or freshwater environment
   b) Resident species also having marine and/or freshwater breeding populations

ii. Euryhaline marine species usually breeding at sea with juveniles showing varying degrees of dependence on estuaries, further divided into:
   a) Juveniles dependent on estuaries as nursery areas
   b) Juveniles occurring mainly in estuaries, but also found at sea
   c) Juveniles occur mainly at sea, but also found in estuaries

iii. Marine species that occur in estuaries in small numbers but are not dependent on estuaries

iv. Euryhaline freshwater species whose penetration into estuaries is determined primarily by salinity tolerance. Includes some species which may breed in both freshwater and estuaries

v. Catadromous species which use estuaries as transit routes between the marine and freshwater environments but may also occupy estuaries in certain regions, further divided into:

a) Obligate catadromous species which require a freshwater phase in their development

b) Facultative catadromous species which do not require a freshwater phase in their development but use estuaries as nursery areas

Fish species in categories I, II, and V as defined by Whitfield (1994) are all wholly or largely dependent on estuaries for their survival and are hence the most important from an estuary conservation perspective. These species will receive most attention in this study.

9.2 METHODS

9.2.1 Study Area

The Berg River estuary is situated at 32°46'S, 18°09'E, approximately 120 km north of Cape Town near the towns of Laaiplek and Velddrif. The Berg River is the largest river in the Western Cape with the region experiencing long, dry summer seasons followed by elevated river flows driven by winter rainfall (Bennett 1994). The effects of the ocean tidal cycle can be measured up to 65 km from the mouth (Day 1981). The upper 15 km of river have a narrow channel and are bounded by steep banks vegetated with riparian woodland. The middle reaches flow through a seasonal flood plain of between 1.5 and 4 km wide. The lower reaches (last 15 km towards the mouth) have a narrower channel (< 1.5 km) dominated with tidal mudflats (Bennett 1994).

Until 1966 the Berg River mouth was naturally located approximately 1 km to the south of its current position (Harrison 1997). In order for the estuary to be used as a fishing harbour, a new mouth was cut through the sand dunes in 1966 and the channel stabilized between three concrete breakwaters. The new channel is dredged to a minimum depth of 4 m allowing the passage of purse-seine boats into the estuary (Bennett 1994). The original mouth rapidly silted up and created a lagoon running parallel to the coast (Eagle & Bartlett 1984).

9.2.2 Sampling Procedure

Fish populations in the Berg estuary were sampled on nine occasions for the BRBMP:

- Feb 2003 (Summer)
- August 2003 (Winter)
- Feb 2004 Summer
- August 2004 (Winter)
- Feb 2005 (Summer)
- May 2005 (Autumn)
- August 2005 (Winter)
- November 2005 (Spring)
- Feb 2006 (Summer)

On each occasion, between 42 and 46 sites, covering a distance of 64 km, were sampled with a 30-m long, 12 mm stretched-mesh beach seine net (Figure 9.1). The net was laid from a small rowing boat, parallel to the shore and hauled shorewards by 5-8 persons. The distance at which the net was laid offshore, and hence the size of the sampling area, varied depending on the prevailing conditions at each site. All fish were removed from the net after it had been hauled to the shore, sorted into species, counted, weighed and measured (up to 100 individuals of each species). Large catches were sub-sampled on site to avoid unnecessary mortality of fish.

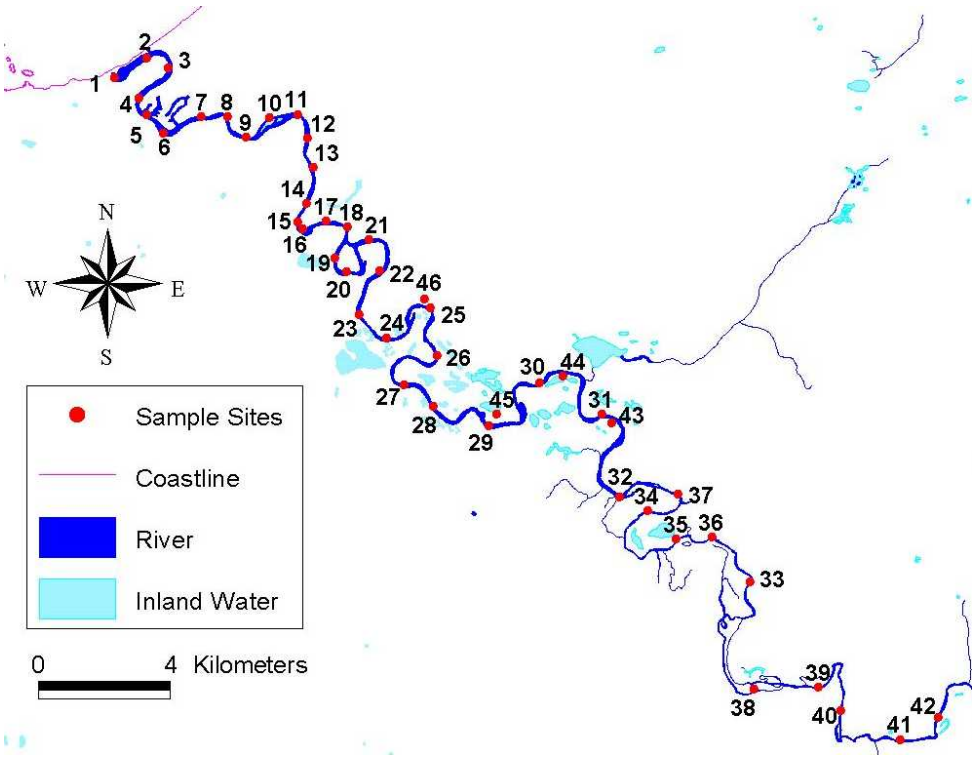


Figure 9.1 Fish sampling sites along Berg River estuary for the BRBMP.

Historical estuarine ichthyofaunal data from the Berg River were obtained from a number of discreet studies that examined the abundance, size frequency and distribution of fishes within the Berg River estuary. Some of these (a total of four studies) represented detailed surveys in which > 30 samples were collected, and the whole, or at least the greater part of the estuary was sampled. These provided data comparable with that collected during the baseline study and were analysed in conjunction with the baseline data. For simplicity and clarity in this report the four historical studies are referred to as Winter 1992 and Summer 1993 (from Bennett 1994) and Summer 1994 and Summer 1996 (S. Lamberth & B. Clark unpublished data). Other published studies that provided less comprehensive data, including those by Day *et al*. 1981 and Harrison 1997, were also used in compiling a description of the Berg estuary ichthyofauna, but were not used for detailed comparisons.

Attempts were made to align the sampling methods employed for the current Berg River Baseline Monitoring Programme with that of the historical sampling procedures. For this reason, the sampling procedures for both current and historical sampling events were identical, as described above. The number of hauls taken (sites sampled) varied between the seasons (due to additional floodplain sampling during winters) and between the different studies. The exact location of sites sampled also varied between studies conducted by different researchers and for analysis and comparative purposes, data were analysed in relation to distance upstream. Details of the current and historical studies referred to in this report are tabulated in Table 9.1.

9.2.3 Data Analysis

Analysis of all data for this study was undertaken using Microsoft Excel and the PRIMER (V5) software package. Data were root-root transformed for the Primer multivariate analyses, and similarity matrices constructed using the Bray-Curtis index and group average linkages as per recommendations from Clarke and Warwick (1994).

9.3 RESULTS

9.3.1 Physico-chemical characteristics of the estuary

Physico-chemical characteristics of the Berg estuary are reported on in detail by Beck *et al.* (2007, BRBMPR Vol. 3 Chapter 2), Schumann (2007, BRBMPR Vol. 3 Chapter 3) and Clark & Taljaard (2007, BRBMPR Vol. 3 Chapter 4). Freshwater flows to the estuary are strongly seasonal, being lowest from Dec-March and peak between July and September (Figure 9.2).

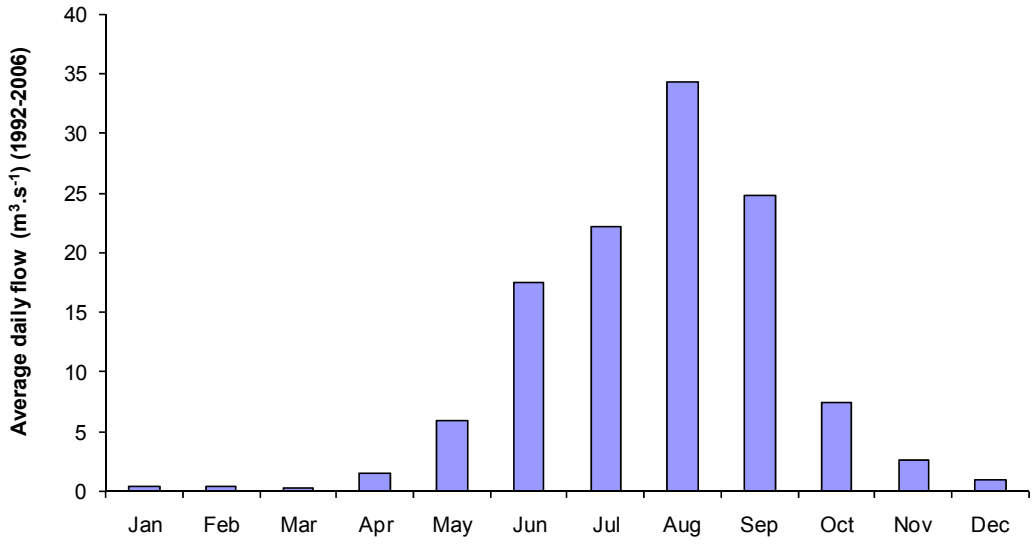


Figure 9.2 Variation in average daily freshwater discharge to the Berg River Estuary, 1992-2006, measured at Misverstand. (Data from Department of Water Affairs)

The salinity structure of the system responds strongly to the seasonal patterns in flow, with saltwater influences extending as far as 45 km upstream in summer but changing to a highly compressed system in winter with salt water influences extending not more than 10 km upstream.

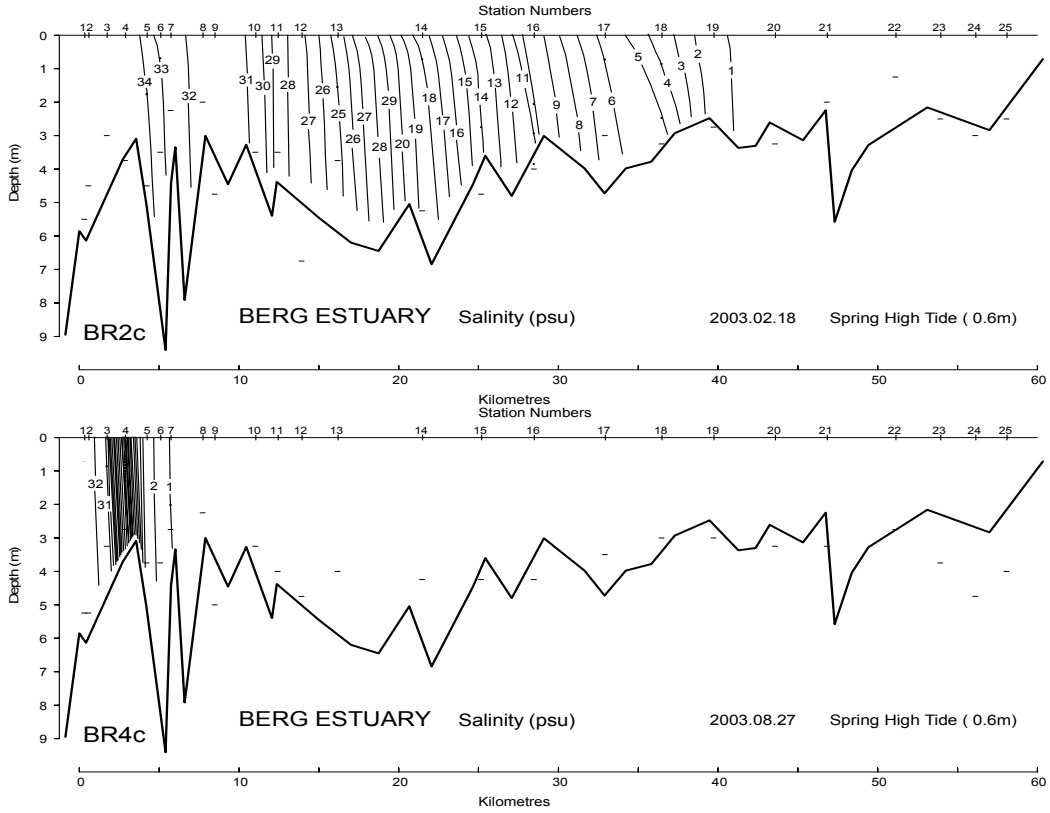


Figure 9.3 Typical salinity structure of the Berg River Estuary in Summer (top) and winter (bottom) (after Schuman 2007).

The timing of the sampling events in relation to the freshwater flow in the estuary is indicated in Figure 9.4. Winter sampling events generally corresponded with high flow periods, while the summer, autumn and spring sampling events corresponded with low flow periods.

9.3.2 Species composition and abundance – seine net hauls

Available data on fish composition in the Berg River estuary includes seven summer (1993, 1994, 1996, 2003, 2004, 2005, 2006), four winter (1992, 2003, 2004, 2005), one spring (2005) and one autumn (2005) collection. The number of sites sampled on each occasion ranged from 55 (Summer 1993) to 32 (Summer 1994 and 1996) with the maximum distance of 64 km upstream being sampled during Summer 2003, Winter 2003, Winter 2005, Spring 2005 and Winter 2006, and a minimum distance of 37 km upstream being sampled during Summer 1994 and 1996. The total area sampled in each study also varied considerably from 7 325 to 15 975 m^2 (Table 9.2). The total number of fish collected during each sampling event varied by more than 10-fold, from 20 402 (Summer 1996) to 243 226 (Summer 2006) (Table 9.2, Appendices 1-13). Biomass of fish landed (only recorded from 2003 onwards) was similarly variable, ranging from 80-490 kg, while the number of species recorded ranged from 14-23 species (Table 9.2). A number of interesting trends were evident in these three parameters (abundance, biomass and species richness) over the course of the study period (Figure 9.5). Firstly, abundance (measured as no. ind. m^{-2}) seems to have increased over the study period with an initial modest increase from 2004 onwards followed by a more marked increased from winter 2005 onwards. Species richness (measured as number of species recorded) exhibited a modest increase over the entire study period, from around 14-18 species between 1992 and 2003, rising to between 17 and 23 species from 2004 onwards.

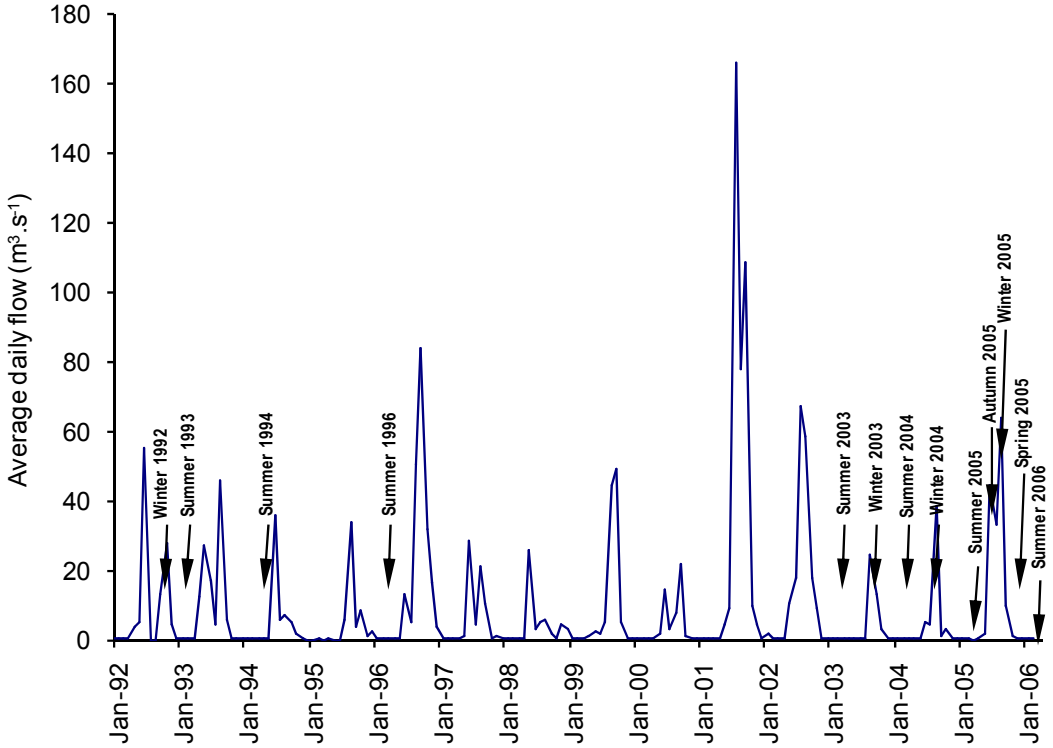


Figure 9.4 Timing of fish sampling events in relation to freshwater discharge into the estuary.

Table 9.1 Detailed historical and current ichthyofauna monitoring studies of the Berg River estuary.

Researcher	Bennett (1993)	Bennett (1993)	Lamberth & Clark (unpubl.)	Lamberth & Clark (unpubl.)	BRBMP	BRBMP	BRBMP	BRBMP	BRBMP	BRBMP	BRBMP	BRBMP	BRBMP
Year	1992	1993	1994	1996	2003	2003	2004	2004	2005	2005	2005	2005	2006
Season	Winter	Summer	Summer	Summer	Summer	Winter	Summer	Winter	Summer	Autumn	Winter	Spring	Summer
Month	Sep	Jan	Mar	Feb	Feb	Aug	Feb	Aug	Feb	May	Aug	Nov	Feb
No. seine hauls	34	55	32	32	42	46	41	41	39	39	42	40	42
No gill net sets	-	-	-	-	-	-	-	-	9	9	9	9	9
Total area (m^2)	12 210	16 385	9 950	9 125	15 975	13 175	8 440	7600	8 588	7 325	7 950	9 750	9 225
No. species	16	18	14	16	18	15	22	16	20	17	15	22	17
Total fish*	32 234	49 431	52 297	20 402	47 310	27 227	50 599	45 622	50 241	36 396	58 351	105 040	243 226
Total biomass (g)	-	-	-	-	164689	56 019	422 824	79 762	189 936	102 521	92 581	460 722	490 051
Distance upstream sampled (km)	64	59	37	37	64	64	62	54	62	62	64	64	64

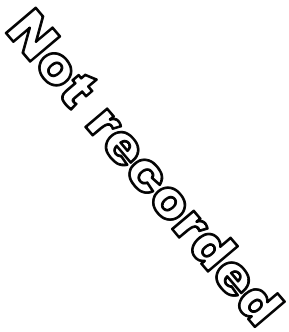
Table 9.2 Summary of the species composition and abundance of fish in beach seine hauls from the Berg River estuary between 1992 and 2006.

			Month	Sep	Jan	Mar	Feb	Feb
			Season	Winter	Summer	Summer	Summer	Summer
Family	Species	Common name	Year	1992	1993	1994	1996	2003
Number								
Clupeidae	*Gilchristella aestuaria*	estuarine round herring	Ia	5216	7959	5337	7841	15011
Gobiidae	*Caffrogobius multifasciatus*	prison goby	Ia					
Atherinidae	*Atherina breviceps*	silverside	Ib	167	12199	2406	684	2139
Clinidae	*Clinus superciliosus*	super klipvis	Ib	6	453			35
Gobiidae	*Caffrogobius nudiceps*	nude goby	Ib					
Gobiidae	*Caffrogobius sp.*	nude goby	Ib	1451	7470	1738	2098	2589
Gobiidae	*Psammogobius knysnaensis*	Knysna sand gobi	Ib	960	334	1069	286	143
Syngnathidae	*Sygnathus acus*	pipefish	Ib	127	166	126	259	46
Carangidae	*Lichia amia*	Leervis, garrick	IIa		2		3	
Mugilidae	*Mugil cephalus*	flathead mullet	IIa	2	103			46
Sparidae	*Lithognathus lithognathus*	sea barbel	IIa				5	14
Sparidae	*Rhabdosargus holubi*	Cape stumpnose	IIa					2
Ariidae	*Galeichthyes feliceps*	white seacatfish	IIb			58		3
Soleidae	*Solea bleekeri*	blackhand sole	IIb		11	9	26	24
Mugilidae	*Liza richardsonii*	harder	IIc	23656	19926	40336	8395	20529
Pomatomidae	*Pomatomus saltatrix*	elf	IIc		20	35	68	56
Sparidae	*Rhabdosargus globiceps*	white stumpnose	IIc	1		1	7	18
Chaetodontidae	*Chaetodon marleyi*	butterfly fish	III				1	
Clupeidae	*Engraulis capensis*	anchovy	III					
Clupeidae	*Sardinops sagax*	sardine	III					
Dasyatidae	*Dasyatis marmorata*	blue stingray	III					
Myliobatidae	*Myliobatos aquila*	eagle ray	III					
Rhinobatidae	*Rhinobatos annulatus*	Sandshark	III	1	27			
Rhinobatidae	*Rhinobatos blockii*	bluntnose guitar fish	III					
Scyliorhinchidae	*Haploblepharus pictus*	dark shy shark	III					
Sparidae	*Sarpa salpa*	streepie	III					
Triglidae	*Cheilidonichtyes capensis*	gurnard	III		6			
Tetraodontidae	*Amblyrhynchotes honkenii*	Blassop	III	4				
Ariidae	*Clarias gariepinus*	sharptooth catfish	IV					
Centrarchidae	*Lepomis macrchirus*	Bluegill sunfish	IV	23	48			
Cichlidae	*Oreochromis mossambicus*	Mozambique tilapia	IV	1	564	1157	674	6543
Cyprinidae	*Cyprinus carpio*	carp	IV	3	32	7	30	92
Galaxiidae	*Galaxias zebratus*	Cape galaxias	IV	5				
Poeciliidae	*Gambusia affinis*	mosquito fish	IV		1	17	4	12
Salmonidae	*Micropterus dolomieu*	small-mouth bass	IV	7	110	1	21	8
		All species		**31630**	**49431**	**52297**	**20402**	**47310**
		No species		**16**	**18**	**14**	**16**	**18**
		No. hauls		**36**	**55**	**32**	**32**	**42**
		Area sampled		**12210**	**16385**	**9950**	**9125**	**15975**

Aug Winter 2003	Feb Summer 2004	Aug Winter 2004	Feb Summer 2005	May Autumn 2005	Aug Winter 2005	Nov Spring 2005	Feb Summer 2006	All Samples
15791	15689	16411	17965	17777	13138	35402	5984	179522
		88	440	28	121	135	1799	2610
466	6914	403	10233	8887		12408	5097	62004
181	64	93	36	79		14	200	1161
		1416	1370	465	390	1174	13983	18797
2324	2907							20577
1393	347	3444	392	615	3664	5214	3522	21383
125	156	84	249	90	94	309	107	1939
	6		37			8		56
	235	11	1960	19	2	13	2132	4524
	20	2	107		3	63	56	270
								2
								61
5	25	20	45		1	75	1608	1849
6871	20836	23594	15340	7244	40849	48486	206300	482362
4	243	1	333	9		708	821	2299
19	46					3		95
								1
1			2	4				7
							1	1
	25					3		28
	6							6
	8		2	1		1	10	50
				1				1
	7							7
	1							1
				1	11	3		21
		1						5
			2			5		7
					1			72
8	2961	12	1627	1140	54	393	1512	16645
35	80	18	89	8	17	490	92	993
			11		3	7		26
2	21	3		28	2	125		215
2	2		2			2	1	156
27227	**50599**	**45622**	**50241**	**36396.4**	**58351**	**105040**	**243226**	817772
15	**22**	**16**	**20**	**17**	**15**	**23**	**17**	227
46	**41**	**41**	**39**	**39**	**43**	**41**	**40**	527
13175	**8440**	**7600**	**8588**	**7325**	**7950**	**9750**	**9225**	135698

Table 9.3 Biomass (g) of fish in beach seine hauls from the Berg River estuary between 1992 and 2006.

			Month	Sep	Jan	Mar	Feb	Feb
			Season	Winter	Summer	Summer	Summer	Summer
Family	Species	Common name	Year	1992	1993	1994	1996	2003
Mass								
Clupeidae	*Gilchristella aestuaria*	estuarine round herring	Ia					12026.0
Gobiidae	*Caffrogobius multifasciatus*	prison goby	Ia					
Atherinidae	*Atherina breviceps*	silverside	Ib					1140.0
Clinidae	*Clinus superciliosus*	super klipvis	Ib					23.0
Gobiidae	*Caffrogobius nudiceps*	nude goby	Ib					
Gobiidae	*Caffrogobius sp.*	nude goby	Ib					5566.0
Gobiidae	*Psammogobius knysnaensis*	Knysna sand gobi	Ib					47.0
Syngnathidae	*Sygnathus acus*	pipefish	Ib					120.0
Carangidae	*Lichia amia*	Leervis, garrick	IIa					
Mugilidae	*Mugil cephalus*	flathead mullet	IIa					442.0
Sparidae	*Lithognathus lithognathus*	White steenbras	IIa					458.0
Sparidae	*Rhabdosargus holubi*	Cape stumpnose	IIa					48.0
Ariidae	*Galeichthyes feliceps*	white seacatfish	IIb					3.0
Soleidae	*Solea bleekeri*	blackhand sole	IIb					148.0
Mugilidae	*Liza richardsonii*	harder	IIc					112427.0
Pomatomidae	*Pomatomus saltatrix*	elf	IIc					4072.0
Sparidae	*Rhabdosargus globiceps*	white stumpnose	IIc					312.0
Chaetodontidae	*Chaetodon marleyi*	butterfly fish	III					
Clupeidae	*Engraulis capensis*	anchovy	III					
Clupeidae	*Sardinops sagax*	sardine	III					
Dasyatidae	*Dasyatis marmorata*	blue stingray	III					
Myliobatidae	*Myliobatos aquila*	eagle ray	III					
Rhinobatidae	*Rhinobatos annulatus*	Sandshark	III					
Rhinobatidae	*Rhinobatos blockii*	bluntnose guitar fish	III					
Scyliorhinchidae	*Haploblepharus pictus*	dark shy shark	III					
Sparidae	*Sarpa salpa*	streepie	III					
Tetraodontidae	*Amblyrhynchotes honkenii*	Blassop	III					
Triglidae	*Cheilidonichtyes capensis*	gurnard	III					
Ariidae	*Clarias gariepinus*	sharptooth catfish	IV					
Centrarchidae	*Lepomis macrchirus*	Bluegill sunfish	IV					
Cichlidae	*Oreochromis mossambicus*	Mozambique tilapia	IV					18347.0
Cyprinidae	*Cyprinus carpio*	carp	IV					8874.0
Galaxiidae	*Galaxias zebratus*	Cape galaxias	IV					
Poeciliidae	*Gambusia affinis*	mosquito fish	IV					4.0
Salmonidae	*Micropterus dolomieu*	small-mouth bass	IV					632.0
		All species						**164689.0**
		No species		**16**	**18**	**14**	**16**	**18**
		No. hauls		**36**	**55**	**32**	**32**	**42**
		Area sampled		**12210**	**16385**	**9950**	**9125**	**15975**



Aug Winter 2003	Feb Summer 2004	Aug Winter 2004	Feb Summer 2005	Nov Autumn 2005	Aug Winter 2005	May Spring 2005	Feb Summer 2006	All Samples
10030.4	16509.0	12154.1	11354.1	8747.3	6599.2	63104.8	3461.9	143986.8
		424.1	985.7	126.8	607.9	691.5	3928.7	6764.6
384.1	5675.0	390.5	9482.3	6582.4		34373.6	3175.0	61202.9
112.4	119.0	48.5	77.0	205.2		4.0	165.6	754.7
		1376.7	3784.3	1636.4	1723.4	3721.8	52999.8	65242.4
3115.3	3366.0							12047.3
1021.2	181.0	2407.2	183.7	932.6	2674.3	4953.9	798.7	13199.6
102.1	140.0	117.9	1830.2	154.4	139.8	614.2	66.0	3284.5
	13.0		2789.0			1000.0		3802.0
	6002.0	367.3	4760.9	734.0	127.3	1121.6	35646.4	49201.5
	3750.0	205.0	6566.7		485.0	1029.0	4535.0	17028.6
								48.0
								3.0
10.5	268.0	222.9	581.3		10.1	584.0	13630.8	15455.6
23615.7	287453.0	52755.1	94068.0	57303.5	48531.1	242153.4	333637.4	1251944.2
198.9	16929.0	220.0	12519.0	355.9		25517.5	18927.3	78739.6
67.0	131.0					200.1		710.1
								0.0
5.5			3.0	3.1				11.6
							78.8	78.8
	45500.0					675.0		46175.0
	4750.0							4750.0
	14500.0		5500.0	2200.0		325.0	3615.0	26140.0
				2800.0				2800.0
	12.0							12.0
	29.0							29.0
		10.0						10.0
		1.0		2.1	4.8	10.9		18.8
			169.0			952.4		1121.4
					43.7			43.7
565.9	5955.0	220.0	6733.0	2229.0	11137.9	14066.3	5076.5	64330.5
16729.3	11428.0	8845.0	28193.0	18500.0	20490.0	65390.6	13377.4	191827.3
					5.4	58.0		63.4
0.8	29.0	1.0	3.0	8.2	0.8	12.0		58.8
59.5	85.0		353.0			162.1	1201.0	2492.6
56018.6	**422824.0**	**79762.3**	**189936.0**	**102520.8**	**92580.7**	**460721.9**	**490051.3**	2059104.6
15	**22**	**17**	**20**	**17**	**15**	**23**	**17**	
46	**41**	**41**	**39**	**39**	**43**	**41**	**40**	
13175	**8440**	**7600**	**8588**	**7325**	**7950**	**9750**	**9225**	135697.5

Some seasonal variability was also evident in the catches with typically fewer species and lower biomass recorded in the winter and autumn samples compared with summer and spring catches. No seasonal trend was evident in abundance, however.

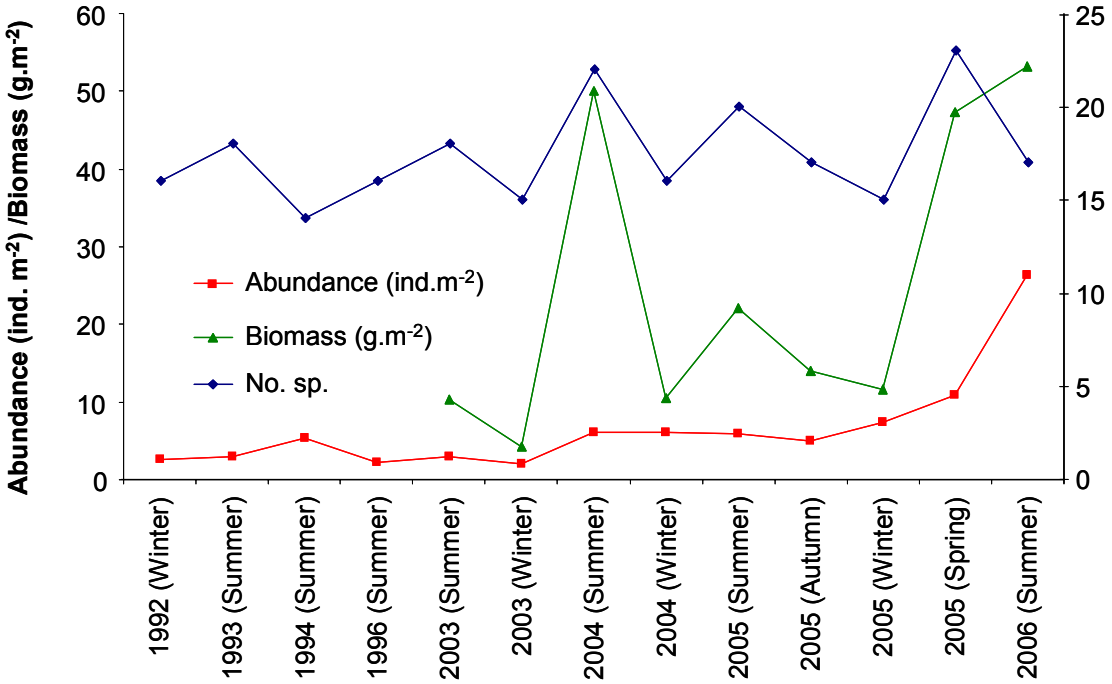


Figure 9.5 Variation in abundance, biomass and species richness recorded in seine net surveys of the Berg River Estuary between 1992 and 2006.

Variation in abundance and species richness of the various categories of estuary associated fish species over the period 1992 to 2006 is shown in Figure 9.6. Abundance of estuarine resident species (Category 1 of Whitfield 1994) were relatively constant throughout the study period and between seasons. Category 1b species (those able to breed in estuaries and the sea) showed a consistent increase in abundance with time while the Category 1a species were slightly elevated in 1993 and 2004. By contrast, the marine migrant species (particularly the category IIc species – those whose juveniles are more abundant at sea than in estuaries) varied dramatically in abundance over the study period accounting for much of the variability observed in the overall abundance of fish in the estuary. Abundance of these species varied without any apparent link to season at modest levels (0.5-6.7 ind. m^{-2}) between 1992 and 2005 but rose dramatically in the last year of sampling (2006 – up to 85.2 ind. m^{-2}). Variation in species richness (number of species) of the various categories of estuary associated fish species is shown in Figure 9.7. The numbers of estuary associated marine species (categories IIa-c) recorded in the estuary varied considerably over the 14 year period, mostly in an asynchronous manner, while the numbers of resident (category 1a and b) and freshwater species (category IV) remained relatively constant over this period.

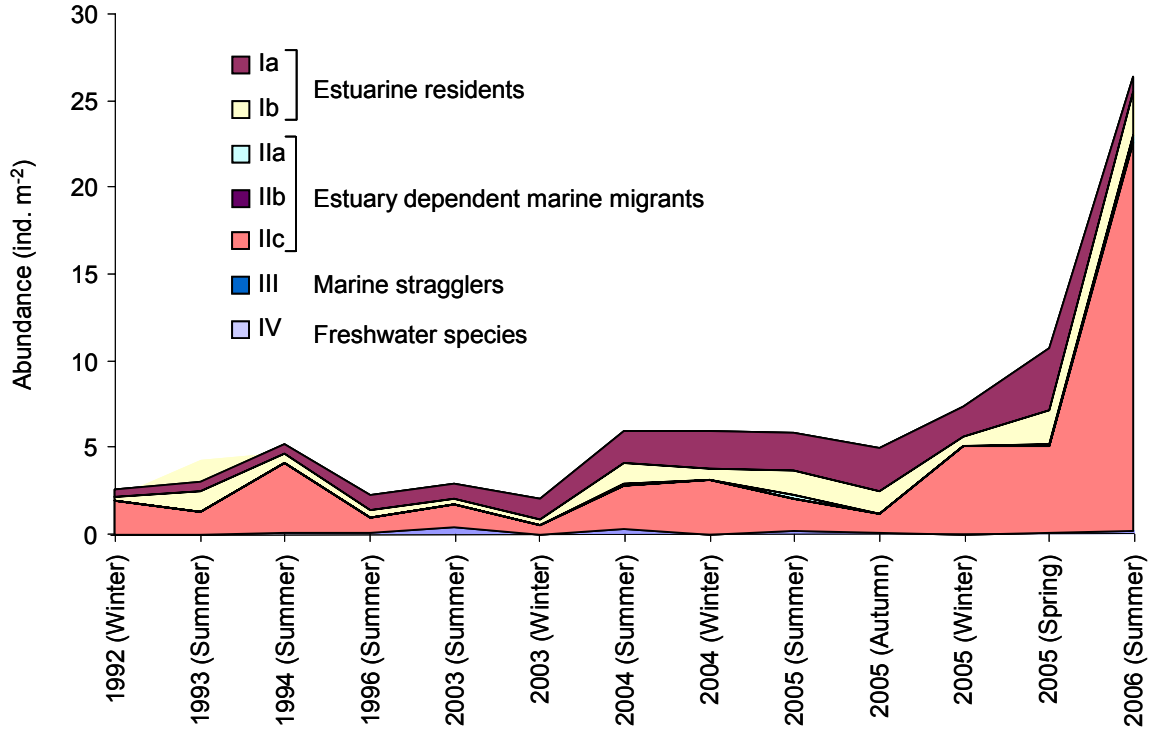


Figure 9.6 *Contribution by various categories of estuary associated fish species (sensu Whitfield 1994) to total abundance in the Berg River estuary 1992-2006.*

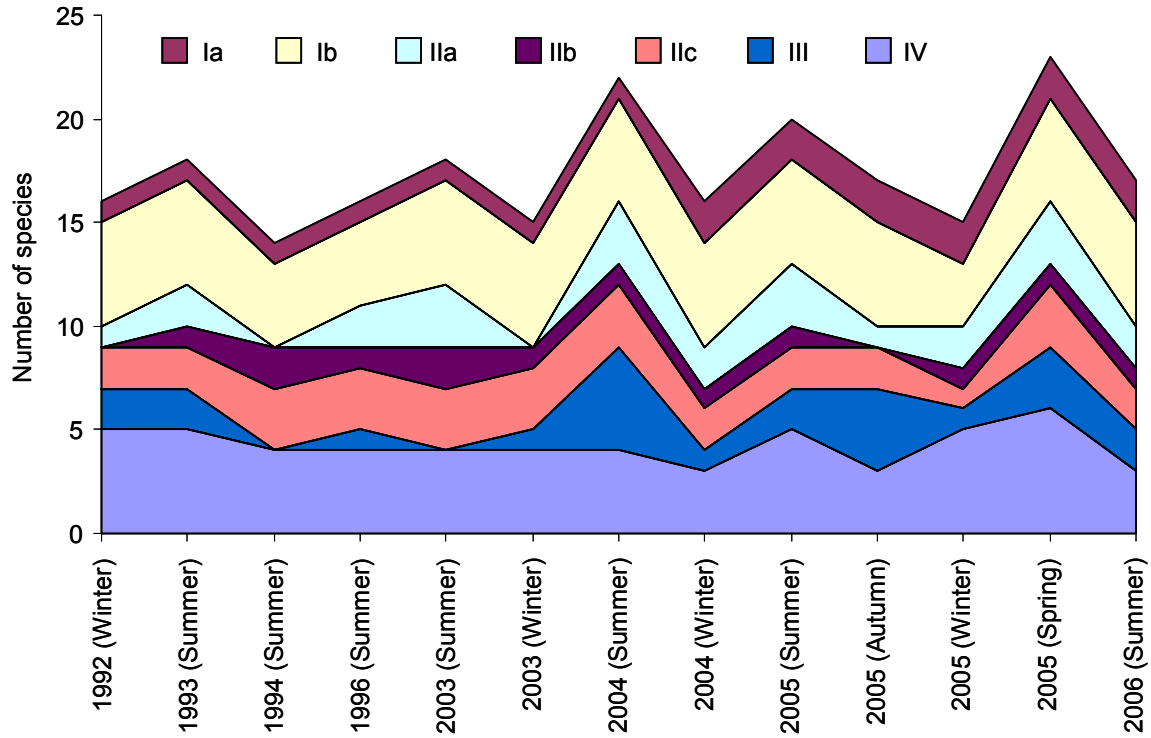


Figure 9.7 *Variation in species richness (number of species) of the various categories of estuary associated fish species in the Berg River estuary 1992-2006.*

In terms of species composition, *Liza richardsonii* (southern mullet) was the most abundant species overall, making up 25-85% of the catches (overall average: 59%), followed by *Gilchristella aestuaria* (estuarine round herring) (3-58% of the catches, 22% overall), *Atherina breviceps* (silverside) (0-25%, 8% overall), *Psammogobius knysnaensis (*Knysna sand goby) (0-8%, 3% overall), *Caffrogobius nudiceps* (nude goby) (0-6%, 2% overall) and *Oerochromis mossambicus* Mozambique tilapia (0-14%, 2% overall) (Table 9.2, Figure 9.8). Together these six species accounted for 93-99% of the catches in each year (overall average: 97%). Contributions by the different species to total abundance varied from year to year and between seasons without any clearly discernable patterns (Figure 9.8). The relative contribution by numbers of fish in the various estuary dependence categories defined by Whitfield (1994) also exhibited no clearly discernable pattern from year to year, or between seasons (Figure 9.8). However, variations in the relative abundance of the various categories of estuarine associated fish species were clearly a function of variations in the abundance of the dominant fish species themselves rather than in the component species as a whole (Figure 9.8).

In terms of biomass, a slightly different suite of species predominated compared with the abundance assessment, with *L. richardsonii* providing the greatest contribution (42-68%, 62% overall), followed by *Cyprinus carpio* (carp) (3-30%, 9% overall), *G. aestuaria* (1-18%, 7% overall), *Pomatomus saltatrix* (elf) (0-6%, 4% overall), *C. nudiceps* (0-11%, 3% overall), *O. mossambicus* (1-22%, 3% overall), *A. breviceps* (0-8, 3% overall). These seven species together made up 66-91% of the biomass in each survey (78% overall) (Table 9.3).

The floodplain surrounding the upper parts of the Berg estuary was sampled during four of the sampling excursions - Winter 1992, 2003, 2004, 2005, and Spring 2005 – being the only time when significant parts of the floodplain were covered with water. Number of species captured in these floodplain samples varied from 1-6 and included mostly freshwater species (*Lepomis macrochirus, O. mossambicus, C. carpio* and *Galaxias zebratus*) but also some estuarine residents (*P. knysnaensis* and *C. nudiceps*) and a marine migrant species (*L. richardsonii*) (Appendices 1-13). Densities of fish at the floodplain sites were all very low (generally <0.3 fish.m^{-2} except for two large catches of small *L. richardsonii. G. zebratus* is the only species considered to show a strong association with the floodplain areas, as it was not recorded in the main part of the estuary at all.

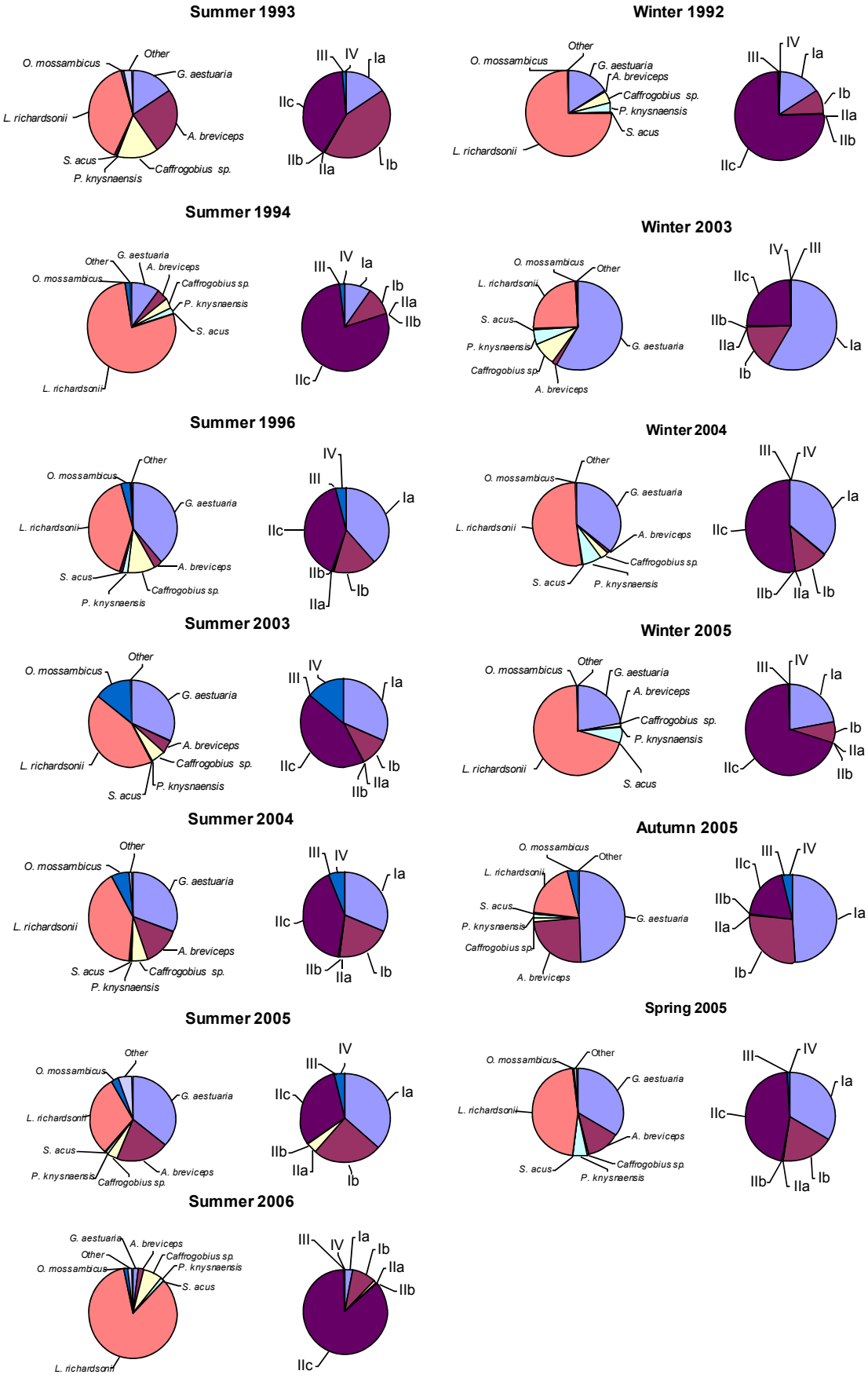


Figure 9.8 Variation in fish community composition (abundance of the six most dominant species and in terms of estuary dependence categories sensu Whitfield 1994) in seine net hauls from the Berg River estuary from 1992-2006.

9.3.3 Species composition and abundance – gill net catches

A total of only 1 260 fish were captured in the gill net sets in the study period (Table 9.4, Appendices 14-17). Each gill net set entailed setting a fleet of variable size gill nets (44, 48, 51, 54, 75, 100, 145 mm stretched mesh). This was done at 9 sites during each of the 2005 and 2006 field excursions. Catches were dominated by *L. richardsonii* (69% of the total), followed by *Mugil cephalus* (16%), *Pomatomus saltatrix* (8%) and *O. mossambicus* (1%). These were amongst the largest species recorded in the seine net catch, and were mostly marine migrants and freshwater species. Estuarine residents (which are mostly small species) were notably absent from the catches. No additional species not recorded in the seine net catches were found in the gill nets.

9.3.4 Species' distribution patterns

Some species displayed clear and consistent distribution patterns up the length of the estuary (Figure 9.9 – Figure 9.11). Some species (*G. aestuaria* and *M. cephalus*, Figure 9.9) showed no clear preference for any particular portion of the estuary. Some (*P. knsynaensis, Caffrogobius multifasciatus, P. saltatrix, Lichia amia, Lithoganthus lithoganthus* and *Solea bleekeri, Figure 9.9*) showed a clear preference for the middle reaches of the estuary. Some (*A. breviceps, L. richarsonii, Syngnathus acus, C. nudiceps, Clinus superciliosus, Rhabdosargus globiceps,* and *Rhinobatos annulatus*, Figure 9.10, while others (*O. mossambicus, C. carpio, Gambusia affinis,* and *Micropterus dolomieu*, (Figure 9.11) showed a clear preference for the lower reaches of the estuary. All of those favouring the upper reaches of the estuary were freshwater species, while those favouring the whole or other portions of the estuary comprised a mixture of estuarine resident and marine migrant species.

Table 9.4 Species composition and abundance of fish caught in a fleet of variable size gill nets (44, 48, 51, 54, 75, 100, 145mm stretched mesh) in 2005/2006

Family	Species	Common name	Month / Season / Year	Feb Summer 2005	May Autumn 2005	Aug Winter 2005	Nov Spring 2005	Feb Summer 2006	All Samples
Clinidae	*Clinus superciliosus*	super klipvis	Ib					1	1
Carangidae	*Lichia amia*	Leervis, garrick	IIa	1	1			7	9
Mugilidae	*Mugil cephalus*	flathead mullet	IIa	20	38	3	103	39	203
Ariidae	*Galeichthyes feliceps*	barbel		1	1		3		5
Mugilidae	*Liza richardsonii*	harder	IIc	232	181	83	190	170	856
Pomatomidae	*Pomatomus saltatrix*	elf	IIc	35	21		15	25	96
Ariidae	*Clarias garipinus*	sharptooth catfish	IV	4				3	7
Cichlidae	*Oreochromis mossambicu*	Mozambique tilapia	IV	2	3	1	10	2	18
Cyprinidae	*Cyprinus carpio*	carp	IV	41	5	1	16	2	65
		All species		336	250	88	337	249	1260

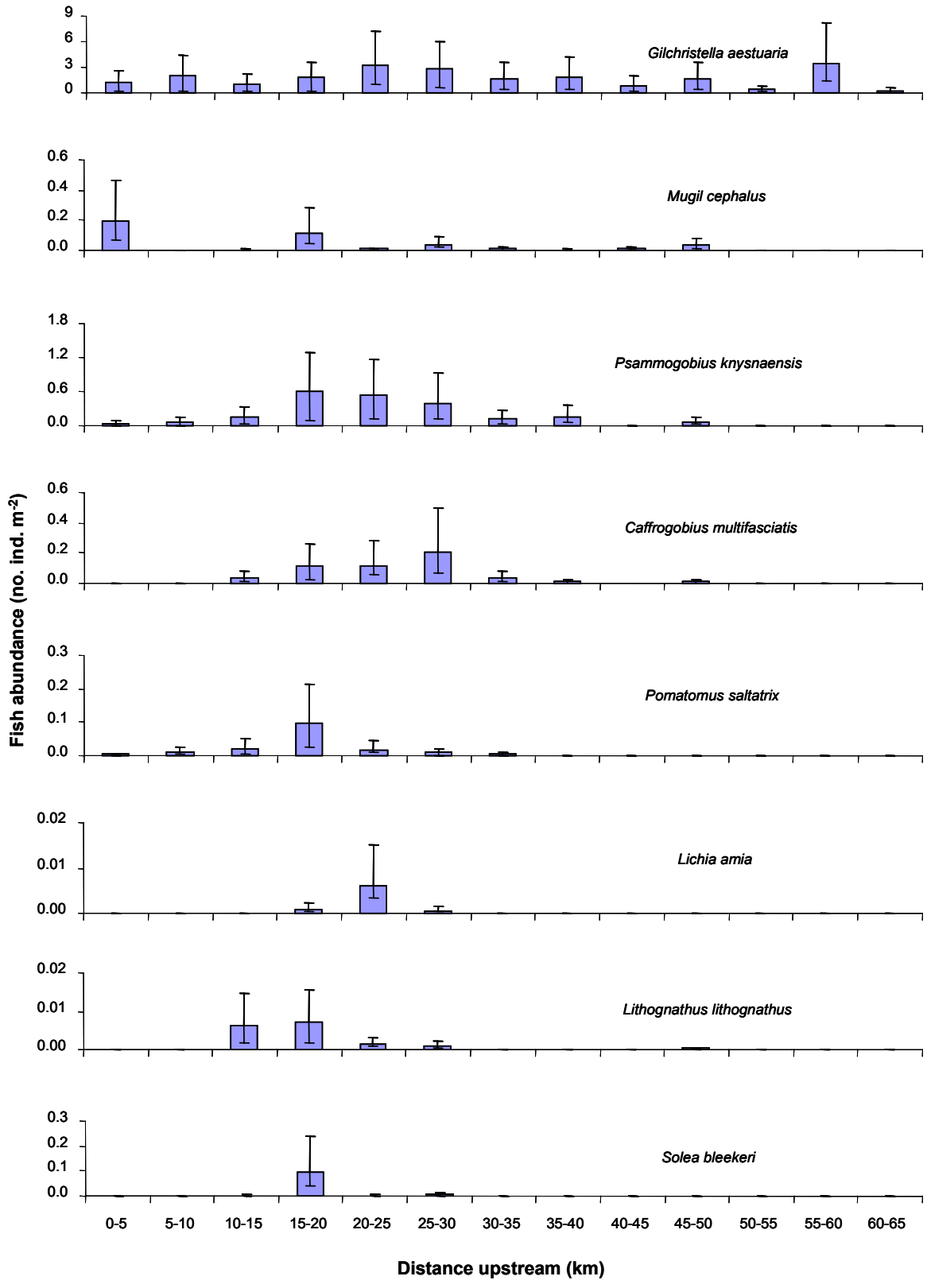


Figure 9.9 Variation in abundance of key fish species with distance upstream (l). Species distributed throughout the estuary and those favouring the middle reaches.

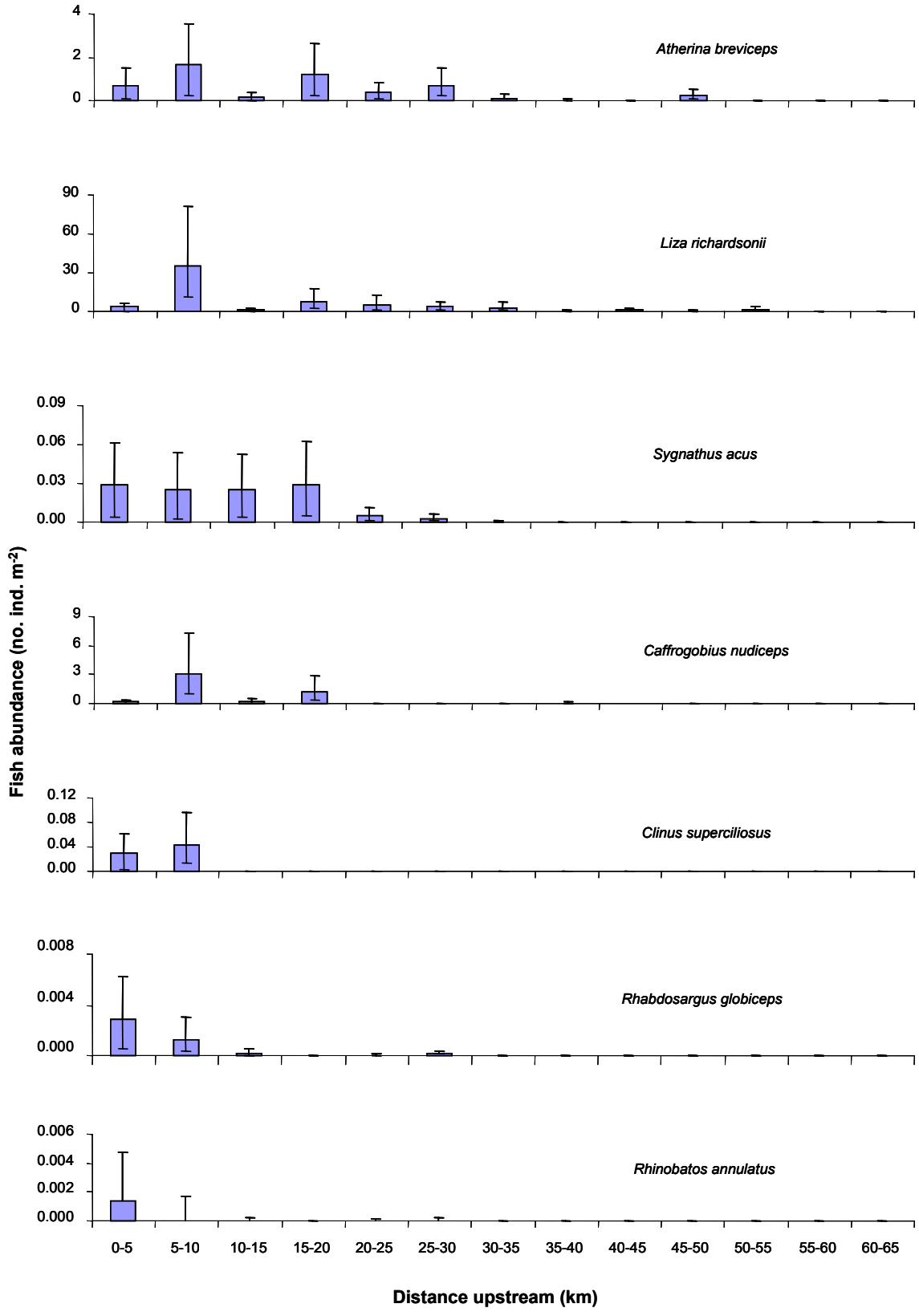


Figure 9.10 Variation in abundance of key fish species with distance upstream (II). Species favouring the lower reaches of the estuary.

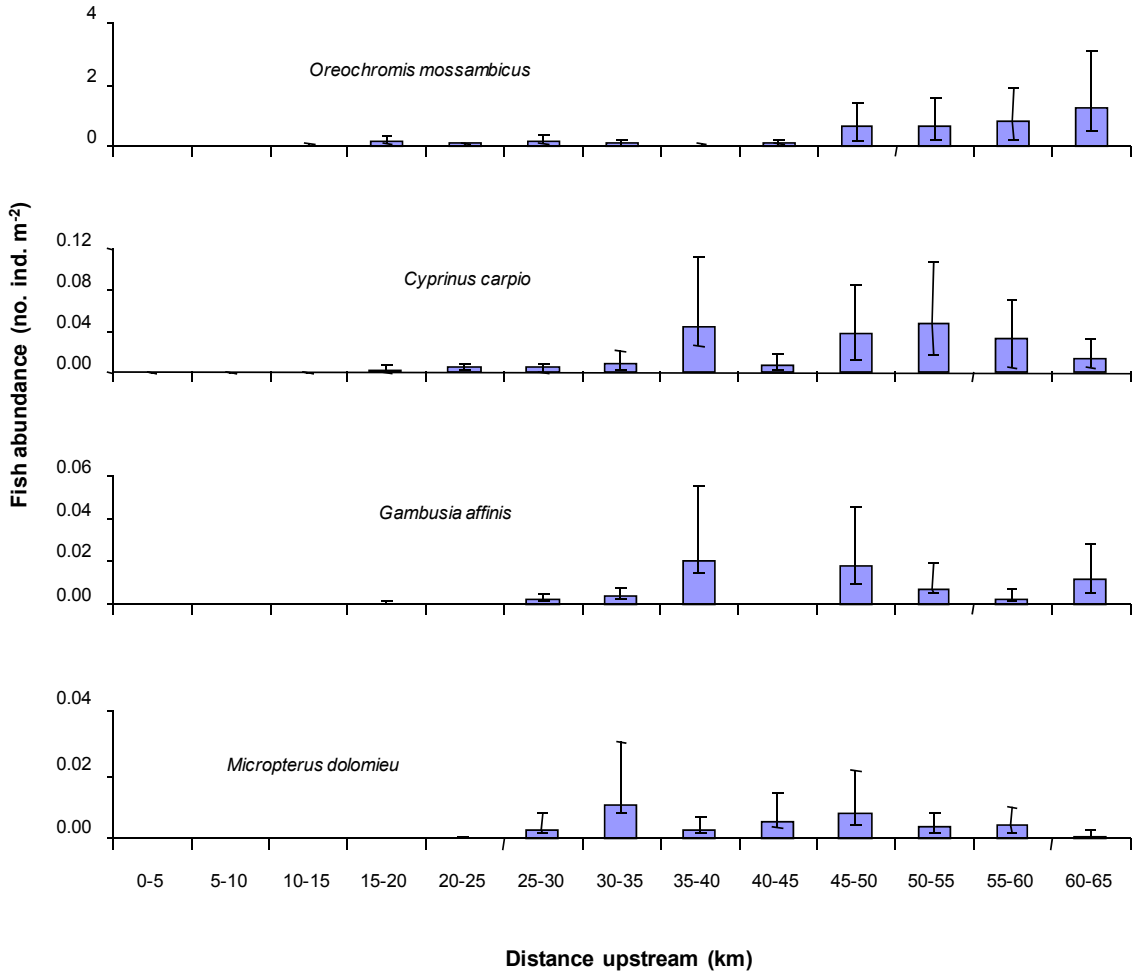


Figure 9.11 Variation in abundance of key fish species with distance upstream (III). Species favouring the upper reaches of the estuary.

9.3.5 Length frequency distributions of dominant species

Size frequency distributions of the dominant species in catches from the Berg estuary are presented in Figure 9.12 (estuarine resident species), Figure 9.13 (marine migrant species), and Figure 9.14 (freshwater species). The estuarine round herring *G. aestuaria* Figure 9.12 was comprised predominantly of adult fish up to 126 mm TL. Juveniles were more abundant in catches in the winter than summer. The silverside *A. breviceps* was represented by high numbers of both adults and juveniles, with adult individuals predominating (Figure 9.12). The maximum size of this species sampled was 108 mm TL but the majority of individuals were < 90 mm TL. Juveniles < 30 mm TL were most abundant during the summer sampling excursions. Knysna sand goby *P. knysnaensis* from the Berg estuary ranged in size from 15 to 81 mm TL, juveniles (30 mm TL) being more abundant in summer than winter (Figure 9.12). Similar size frequency distributions were recorded for *C. nudiceps* (nude goby) and C. multifasciatus with both adults and juveniles being abundant in the estuary through all sampling events (Figure 9.12). Juvenile *C. nudiceps* (<50 mm TL) made up a greater portion of the catches in winter and spring than summer or autumn, while the reverse was true for *C. multifaciatus*, with juveniles being more abundant in catches during summer and autumn than in winter or spring. The largest *C. nudiceps* and *C. multifaciatus* captured measured 142 and 291 mm TL, respectively. Pipefish *Sygnathus acus* ranged in size from 30-250 mm TL (Figure 9.12). Juveniles (<130 mm TL) were present through all sampling events but made up a greater portion of the winter catches relative to the summer catches.

Super klipfish *Clinus superciliosus* was comprised of a mix of adults and juveniles, with juveniles being more abundant than the adults.

Dominant marine migrant species for which frequency histograms were prepared included *L. richardsonii* (southern mullet), *P. saltatrix* (elf), flathead mullet (*Mugil cephalus*), *Lithognathus lithognathus* (White steenbras), and *Solea bleekeri* (blackhand sole). Most of the species were represented by juveniles only. *L. richardsonii* were present in the catches at all time of the year and include only a small number of adult individuals (>200 mm TL, Figure 9.13. The largest individual of this species, measuring 337 cm, was captured in the gill nets. *P. saltatrix* was represented almost exclusively by juveniles with a few larger, adult fish recorded in the gill net catches (up to 409 mm TL) (Figure 9.13). Smallest fish (to 30 mm TL) were all recorded during the summer field excursions. *M. cephalus* was represented almost exclusively by juveniles (<370 mm TL, Figure 9.13) with a small number of adult fish (up to 337 mm TL) appearing in the gill nets catches. *L. lithognathus* was recorded in the seine net catches only and included only juveniles in the range 30-220 mm TL (Figure 9.13). Smallest individuals (<120 mm TL) were recorded in summer only. *S. bleekeri* appeared in the catches at sizes from 45-120 mm TL, and as such included both juvenile and adult individuals. Smallest individuals (<60 mm TL) appeared sporadically in the catches and showed no clear seasonality.

Dominant freshwater species for which length frequency histograms were prepared included Mozambique tilapia *O. mossambicus*, carp *C. carpio*, mosquito fish *Gambusia affinis* and small mouth bass *Micropterus salmoides* (Figure 9.14). Tilapia, carp and bass were all mostly represented by juveniles accompanied by a handful of adult individuals. These three species all seem to breed in spring/summer with juveniles predominating in the catches taken at these times. Mosquito fish comprised a range of adult and juvenile individuals. No clear seasonal pattern was evident in the catches of either adults or juveniles of this species.

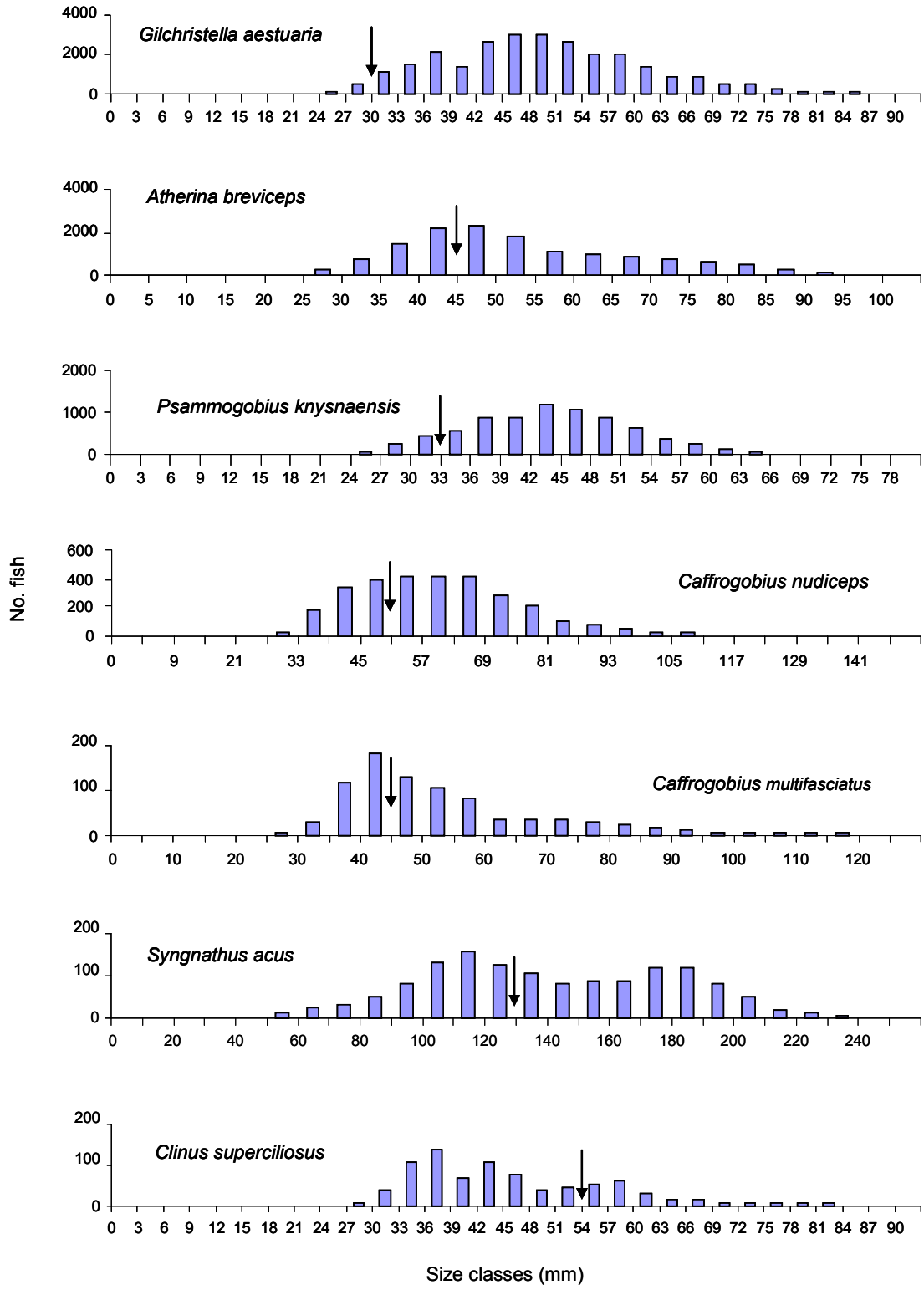


Figure 9.12 Length frequency distribution of dominant estuarine resident species in seine net catches from the Berg River Estuary, 1992-2006. Arrows indicate approximate size at 50% maturity (after Whitfield 1998).

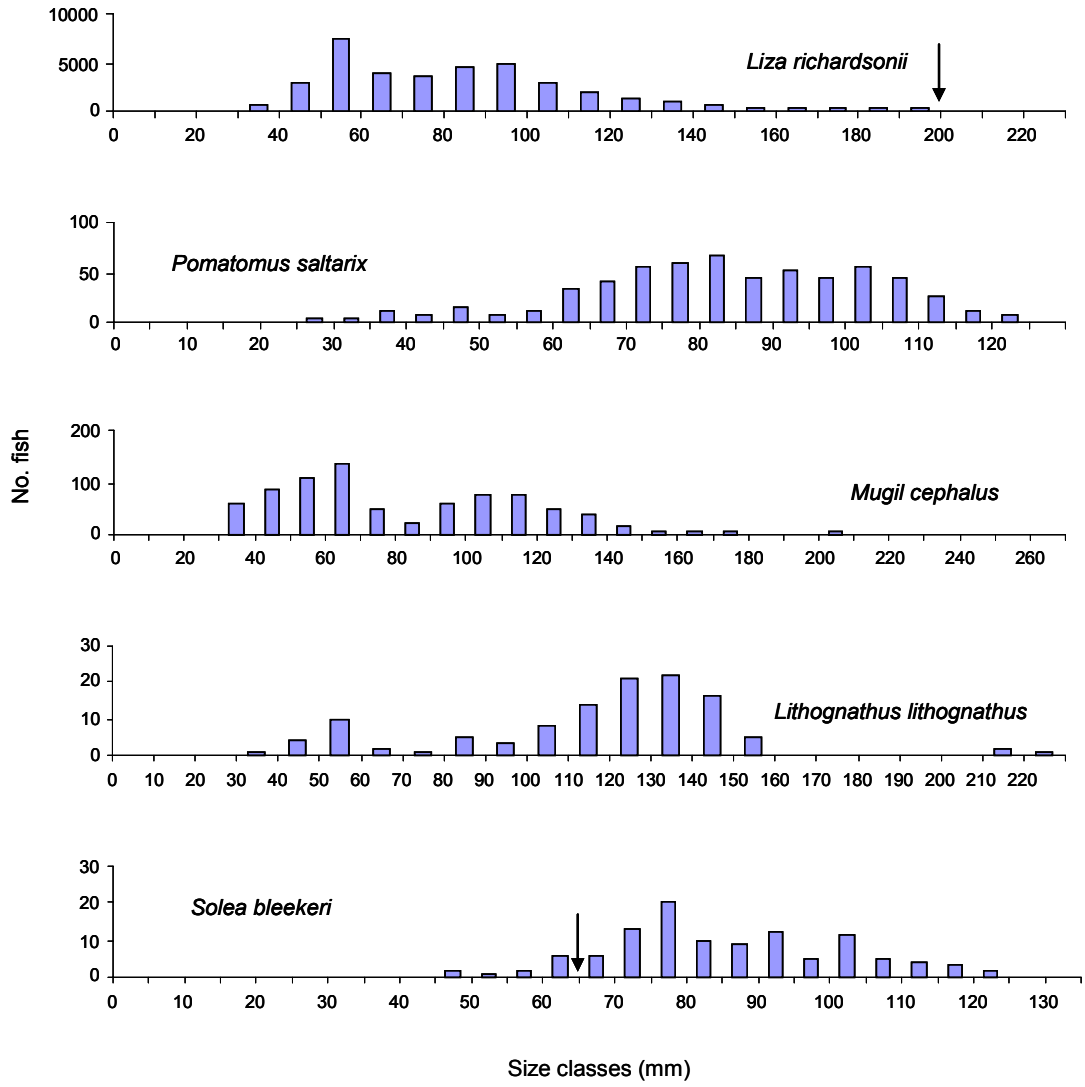


Figure 9.13 Length frequency distribution of dominant marine migrant species in seine net catches from the Berg River Estuary, 1992-2006. Arrows indicate approximate size at 50% maturity (after Whitfield 1998).

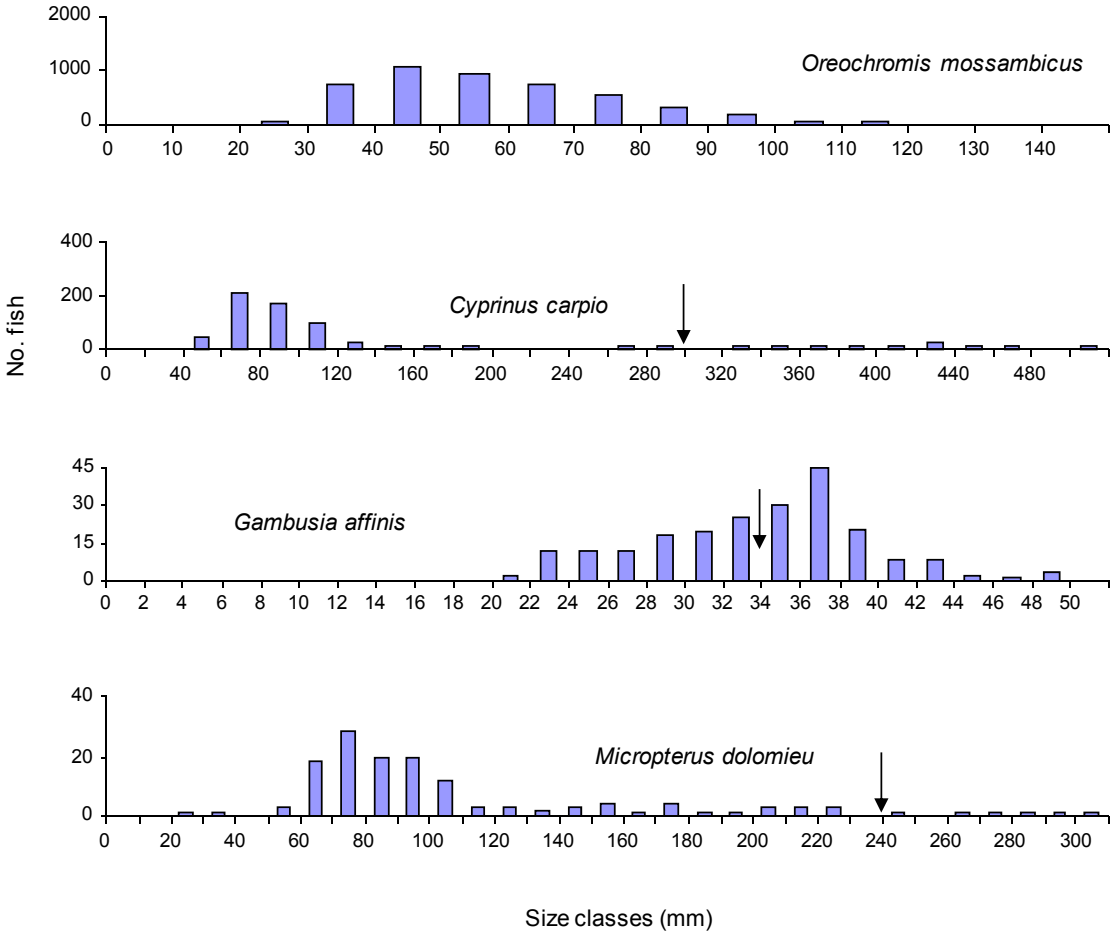


Figure 9.14 Length frequency distribution of dominant freshwater species in seine net catches from the Berg River Estuary, 1992-2006. Arrows indicate approximate size at 50% maturity (after Whitfield 1998).

9.3.6 Multivariate analysis of current and historic sampling

Multi-Dimensional Scaling (MDS) ordination plots, representing the similarity between sites based on the composition and abundance of fish contained therein, show a gradient of decreasing similarity between sites sampled in the upper reaches of the estuary with those nearer the mouth (Figure 9.15). Many of the ordination plots exhibit an arch effect which, rather than reflecting the true distribution of sites relative to one another, simply reflects the fact that the forces repelling dissimilar sites (and those causing similar sites to cluster together) decays exponentially with distance (Clarke 1993). This effect allows the distribution to form an arch, rather than forcing the sites to cluster along a linear axis. This gradient of similarity between sites is indicative of the changing physico-chemical characteristics occurring in the estuary relating to the portion of the estuary in which different fish species choose to occupy. During the winter months the gradient appears more severe than the summer months with the lower sites clustering more closely and the upper sites being more disbursed (Figure 9.15).

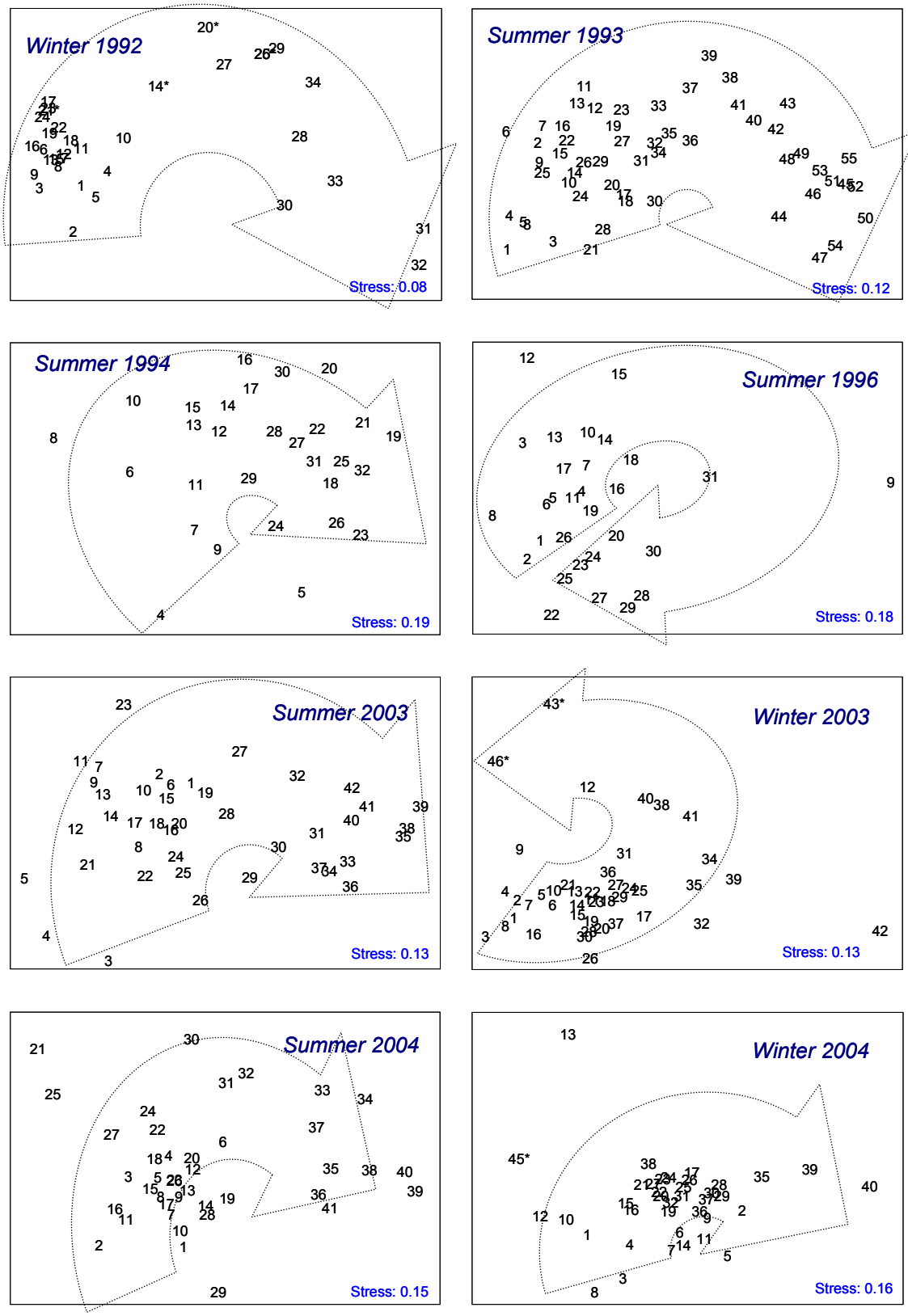


Figure 9.15 Ordination plots of seine net fish samples taken from the Berg River estuary between 1992 and 2006.

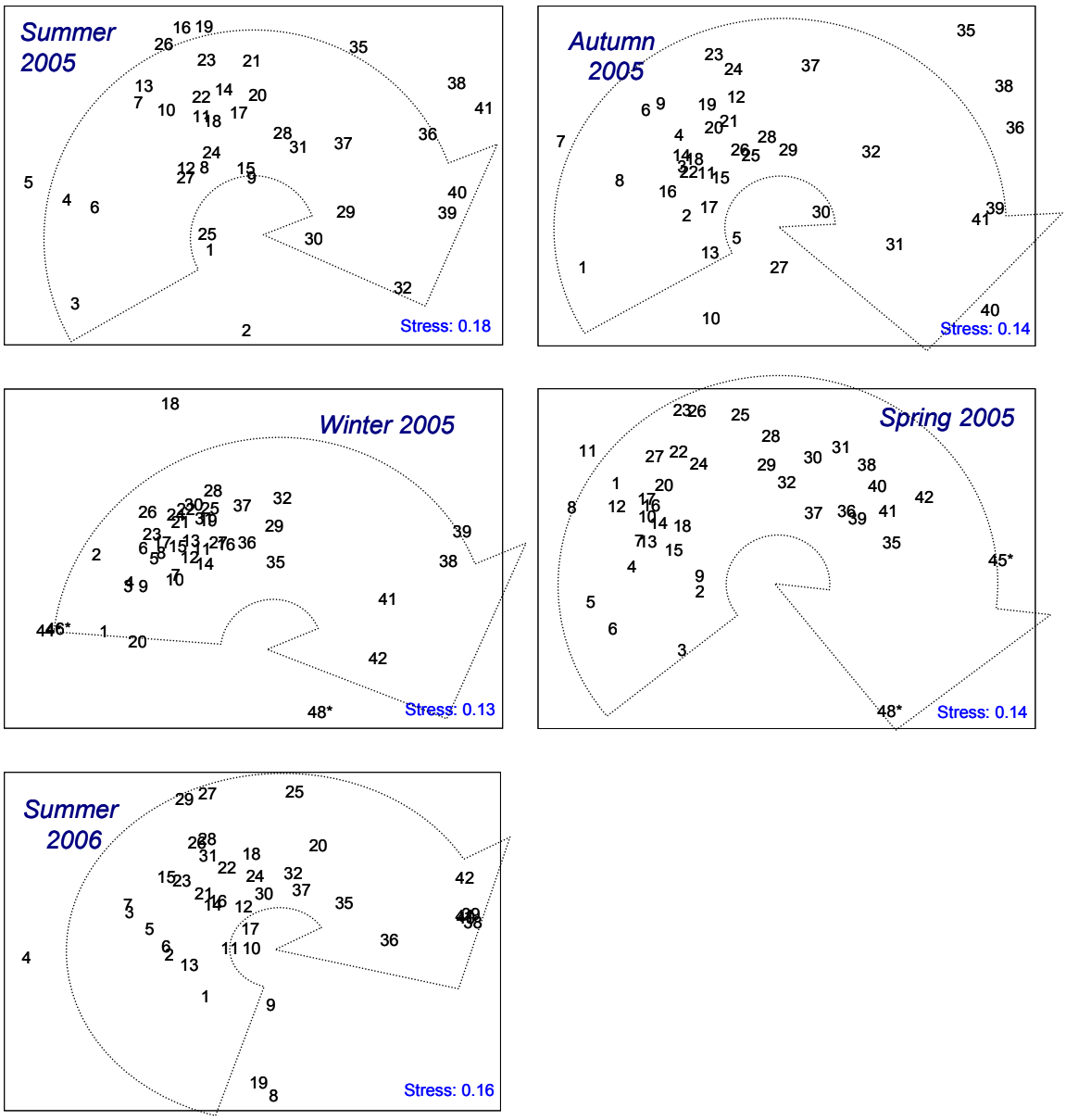


Figure 9.16 Continued. Ordination plots of seine net fish samples taken from the Berg River estuary between 1992 and 2006.

9.4 DISCUSSION

9.4.1 Importance of the Berg River estuary to estuarine fish communities

Compared to marine coastal waters, estuaries are considered to be highly productive, with calm, shallow, warm waters, low densities of piscivorous predators and lowered salinities (Bennett 1994). These attributes promote rapid growth and/or reduced mortality for fish species, hence making them ideal environments for colonisation by juveniles of marine species. For these reasons, many species of fish choose to occupy estuaries for either their entire life cycle, or part of it, becoming entirely dependent on estuaries for breeding success. Fish species that are classified as estuarine residents, only breeding in estuaries, (e.g. *Gilchristella aestuaria*) and species that are predominantly marine when adult, but are dependant, either partially or entirely, on estuaries as juveniles, (e.g. *Mugil cephalus*) are often the species of greatest concern when changes occur within an estuary. However, it is important not to loose sight of the fact that fish, irrespective of the group to which they belong, occupy an important position in the food chain within an estuary, and that changes in their composition or abundance will affect other groups, both higher up and lower down in the system. Species of greatest interest, therefore, include those of high abundance: *L. richardsonii*, *G. aestuaria, A. breviceps, C. nudiceps, P. knysnaensis* and *O. mossambicus* (some of which are partially dependent on estuaries) and those that are less abundant, but remain important due to their being largely or wholly dependent on estuaries for their continued existence (*C. superciliosus, C. multifasciatus, S. bleekeri, P. saltatrix*, *M. cephalus, S. bleekeri, Galeichthyes feliceps*, *Lichia amia,* and *Lithognathus lithognathus*). Many of the latter species are also endemic to southern Africa and some are considered threatened (Mann 2000).

On the West Coast of South Africa, only three river systems, namely, Orange, Olifants and Berg Rivers, have large enough catchments and sufficient flow to maintain a permanent connection with the sea (Harrison 1997). These systems are considered to be comparatively poor in fish species abundance when compared to estuaries on the south-east and east coasts of South Africa (Harrison 1997). Only 25 species of fish are commonly associated with west coast estuaries as compared to 100 species from the south-eastern coast and 242 from the east coast (Bennett 1994). This trend reflects the well-established eastward increase in species diversity observed for fish, and a number of other taxa, with a change from temperate to subtropical and tropical conditions (Bennett 1994). However, although the numbers of species present in west coast estuaries is low, they do represent a relatively high proportion (79%) of the total west coast inshore fish community (Bennett 1994).

The composition of the fish fauna in west coast estuaries is also strongly skewed towards resident rather than marine migrant species. The contribution by marine migrants in the Berg, both in terms of the number of species (39%) and individuals (51%) present is low relative to most other permanently open estuaries in South Africa. Estuaries of this type are typically more heavily dominated by marine migrant species, owing to the fact that they are open to the sea all year round (Bennett 1989, Whitfield 1998). Marine migrants normally account for 60-65 % of species and an even greater proportion of individuals in permanently open estuaries, while seasonally closed estuaries have a lower proportion of marine species (ca. 50-60 %) and normally closed estuaries the lowest. Most (if not all) species found in west coast estuaries also occur in estuaries further east. This implies that although estuaries on the west coast are regionally important from a conservation perspective, they are probably less important from a national conservation perspective.

Indeed, if one looks at the importance scores allocated to estuaries around the country based on botanical importance (Colloty *et al*. 2000), birds (Turpie 1995) and fish (Maree *et al*. 2003), one can see that the Berg and Olifants estuaries are rated highly in respect of the former components (Botanical: Berg = 4, Olifants =6, and Avifauna: Berg = 3, Olifants = 7) but lower (29 and 28, respectively), in respect of their fish fauna.

9.4.2 Variations in the composition and abundance of fish in the Berg River estuary

The composition and abundance of fish in the Berg River estuary has clearly varied considerably over the last 14 years with some clear long-term changes apparent. Total number of species and abundance have both increased over this period, with changes in abundance being more marked than species richness. Seasonal variations in species richness and biomass were also evident, with summer and spring catches being higher than those taken in autumn or winter. Hutchings *et al*. (2007) noticed a similar increase in catch-per-unit-effort by shore and boat anglers in the Berg River estuary over the latter portion of the survey period (2003-2005) which he attributed to a ban imposed on gill net fishing in the estuary imposed at the end of 2003. Considering that *L. richardsonii* were the primary target of this fishery it is quite likely that the increase in fish abundance evident in data collected in this study (mostly a function of an increase in abundance of this species) is also a function of the ban imposed on the gill net fishery.

Marked variations were also evident in the species composition of the catches between sampling events, both within (i.e. from one season to another) and between sampling years. These changes were mostly a function of variations in the abundance of the 5-6 dominant species in the estuary, which in turn affected the contribution by the different categories of estuary associated fish species. No clear seasonal or longer term patterns were evident in these variations.

An issue of potential relevance to variations observed in both the abundance and composition of fish in the Berg River estuary is the somewhat anomalous 'black tide' event which occurred in the adjacent St Helena Bay during the summer of 1994, and even penetrated the lower reaches of the estuary (up to 2 km from the mouth). Pitcher and Calder (2000) report that a dense accumulation of phytoplankton developed within St. Helena Bay at this time, and the gradual decay of this matter used up available oxygen in the water, while emitting hydrogen sulphide (Pitcher and Calder 2000). This resulted in the water in the bay and lower estuary becoming highly anoxic (low oxygen), causing a large-scale mortality of many marine species including fish. It has been proposed (Lamberth in prep) that large numbers of marine fish may have moved into the estuary from the sea in an attempt to escape from the noxious 'black tide' waters. This may explain the higher than expected abundance of larger fish in the estuary at this time (note that abundance of large *L. richardsonii* in 1994 is elevated somewhat relative to 1993 and 1996 on Figure 9.17) and the disproportionately large contribution by this species to overall fish numbers at this time (Figure 9.8) (similar though to their contribution in 2006).

Estuarine resident species, able to breed in both estuarine and marine waters, displayed size frequency distributions typical of species in this category. Juveniles of most of these species are very small (<50 mm TL) and were probably not effectively sampled by the meshes of net used during this study (mesh size = 12 mm stretched). This effect was most marked for the smallest of these species, *G. aestuaria* and *P. knysnaensis*, where catches appeared to be strongly skewed toward adult individuals, but less severe for the larger species (e.g. *Caffrogobius* spp. and *Syngnathus acus*). *G. aestuaria* is reported to spawn during spring and summer (Melville-Smith & Baird 1980, Whitfield 1989), and is only likely to start recruiting into the catches in winter or even the following summer when it reaches a large enough size not to pass through the meshes of the net.

Something of particular interest was the fact that individuals of the species up to 126 mm TL were recorded in the samples, which is considerably larger than the maximum size of 80 mm TL recorded for populations in other estuaries around the country (Whitfield 1998). Recruitment by the remaining resident species (*A. breviceps, C. nudiceps, P. knysnaensis* and *S. acus)* was noted to be strongest during the summer sampling events, which correspond to the peak recruitment times recorded elsewhere (Whitfield 1989, 1998). Some of these species (e.g. *C. nudiceps, P. knysnaensis*) are thought to deliberately spawn near the mouth of estuaries thus allowing the tide to disperse the larvae into the marine environment (Whitfield 1998).

Juveniles then recruit back into estuaries some months later (normally in late summer), which would correlate with the peaks in recruitment observed in this study.

Marine migrant species in the Berg estuary were represented mostly by juveniles, with peak recruitment also occurring during the summer sampling events. These species mostly grow to a large size (>>300 mm TL) and although individuals larger than this were probably not common in the estuary, they would not necessarily have been adequately sampled by the gear used in this study. Larger individuals of some of these species (e.g. *L. richardsonii, M. cephalus, P. saltatrix,* and *L. amia*) were indeed recorded in gill net surveys completed in 2005/2006. It is also likely that individuals of this size and larger would have been decimated by the commercial gill net fishers that have until 2003 were permitted to operate in the estuary. Mesh sizes used by these fishermen are mostly in the range of 44-64 mm, and while they ostensibly target mullet (*L. richardsonii* and *M. cephalus*) other bycatch species (particularly *P. saltatrix*) make an important contribution to their catches (Hutchings & Lamberth 2002a & b). Indeed, Hutchings *et al.* (2007) noted a significant increase in the size range of fish targeted by shore and boat anglers in the estuary following the imposition of the ban on this fishery. A corresponding statistically significant (r^2 = 0.76, P >0.05) increase was observed in the proportion of *L. richardsonii* larger than 200 mm TL in the catches taken during summer in this study, but not in the other seasons or for any of the other species. The lack of a corresponding increase in other species was not particularly surprising considering their low abundance in the catches and the fact that the net used in this study does not sample fish larger than 200 mm TL very effectively due to its small size (30 m in length).

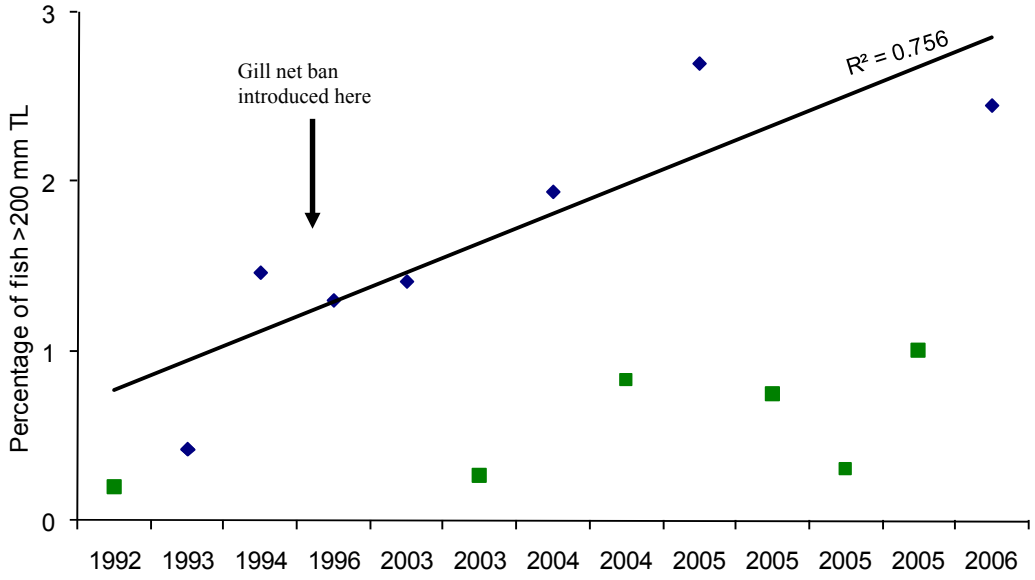


Figure 9.17 *Proportion (%) of L. richardsonii >200 mm TL in seine net catches from the Berg River estuary taken in summer (blue diamonds) and other seasons (green squares). The regression line was prepared using the summer catches only (i.e. the blue diamonds).*

Some illegal fishing still takes place in the estuary (pers. obs.) and may still be sufficient to eliminate many of the larger fish in the estuary. The body depth to total length ratio of many of the other marine migrant species frequenting the Berg estuary is much higher than that for *L. richardsonii* which would make them susceptible to capture by gill nets at a much smaller size than do for mullet. The low numbers of individuals >100 mm TL of these species (particularly *P. saltartix, L. lithognathus, L. amia*) in the Berg, which are common in estuaries on the south coast where gill netting is banned, may well be a reflection of high levels of historic gill net fishing effort.

A number of freshwater species were present in modest numbers in catches in the estuary, represented mostly by juveniles. These were all euryhaline freshwater species that occur throughout the main stem of the Berg River (Clark 2007 – BRBMP Vol. 2 Chapter 8).

The distribution of different estuary associated fish species in the estuary was also interesting. Most of the estuary dependent marine migrants (Whitfield's 1994 Category IIa and IIb species – e.g. *P. saltatrix, L. amia, L. lithognathus, S. bleekeri*) displayed a preference for the middle reaches of the system, while the facultative marine migrants (Category IIc species – e.g. *L. richardsonii* and *Rhabdosargus globiceps*) and marine vagrants (e.g. *Rhinobatos annulatus*) were more abundant near the mouth. Some estuarine residents were widely distributed throughout the estuary (e.g. G. *aestuaria*), some were most abundant in the middle reaches of the system (e.g. *C. multifasciatus, P. knysnaensis*) while others were most abundant near the mouth (*C. nudiceps, C. superciliosus,* and *S. acus*). Freshwater species (e.g. *O. mossambicus, C. carpio, M. dolomieu,* and *G. affinis*) were all concentrated in the upper reaches of the estuary. Differences in the longitudinal habitat preferences displayed by these species contributed to clear gradients in species composition up the length of the estuary as was evident in the results of multivariate analyses of community structure.

9.4.3 Importance of the lower Berg River floodplain for estuarine fish species

The floodplain surrounding the upper parts of the Berg estuary was sampled during the four of the sampling excursions - Winter 1992, 2003, 2004, 2005, and Spring 2005 – being the only times when significant parts of the floodplain were covered with water. Number of species captured in these floodplain samples was low (1-6 per survey) and included mostly freshwater species (*Lepomis macrochirus, O. mossambicus, C. carpio* and *Galaxias zebratus*) but also some estuarine residents (*P. knysnaensis* and *C. nudiceps*) and a marine migrant species (*L. richardsonii*). Densities of fish at the floodplain sites were also very low (generally <0.3 fish.m^{-2} except for two large catches of small *L. richardsonii.* All of the pans on the floodplain are known to dry out completely in summer and are located high up in the estuary (mostly >30 km from the mouth). For these reasons, they are probably of little direct value as a habitat for estuarine species, particularly as they are seldom connected to the main part of the estuary for more than a few days at a time (pers. obs.). *G. zebratus* is the only species considered to show a strong association with the floodplain areas, as it was not recorded in the main part of the estuary at all. *G. zebratus* is an indigenous species of freshwater fish that used to be abundant in the Berg River but has largely been eliminated from the system due to the introduction of alien fish species and other anthropogenic influences (Clark 2007 – BRBMP Vol. 2 Chapter 8). It is considered to be an extremely hardy species and is known to tolerate a wide range of water and temperature conditions (Skelton 1993). It is unlikely, however, that this species is able to survive when the floodplain dries out in summer or is able to complete its life cycle in the short period during which the floodplain pans contain water, considering that it only matures at 38-40 mm TL and reaches an age of at least 10 years (Barnard 1943). It is more likely that the specimens recorded in 1992 had recently arrived in this habitat, after having been carried downstream with the floodwater during the recent floods.

For these reasons the floodplain surrounding the estuary is considered of little importance to fish. (It should be noted that the only other species found exclusively on the floodplain, *L. macrochirus*, is an alien and as such its presence on the floodplain is of no consequence).

9.4.4 Likely implications for ichthyofauna of the Skuifraam Dam (altered flow regime)

Construction of the Berg River dam on any river system is likely to alter the flow regime of the river and estuary and will precipitate a cascade of effects, the severity of which will depend on the extent to which the flow regime is modified.

Likely changes in hydrology, water chemistry, estuarine vegetation and invertebrate communities can be summarised as follows:

- The reduction in base flow reaching the estuary is expected to be significant, because of the removal of small and medium floods in the upper catchment, which translate further downstream into elevated baseflow (Howard & Racliffe 2007);
- Flood peaks (from small to large floods) are expected to decline by about 10 % with a resultant decrease in flooded area of around 4 % in the upper estuary, 3-6 % in the middle reaches, and 1 % in the lower reaches (Beck & Basson 2007);
- Decreased scouring in the estuary, with a consequent build up of silt in the middle and lower estuary basin;
- Increase in turbidity of estuarine water associated with accumulation of fine silt in the estuary basin;
- Changes in floodplain vegetation communities due to changes in flooding frequency;
- Decreased productivity in the estuary, following from reduced terrestrial inputs from the floodplain;
- Possible minor changes in benthic microalgae, phytoplankton, invertebrate communities (Bate & Snow 2007, Wooldridge 2007).

Most of these effects are relatively minor and are unlikley to have serious consequences for the estuarine fish community. Some tentative predictions are included here which will have to be confirmed once more definite hydrological data become available.

One of the most serious consequences associated with dam construction or reduced fresh water flow into an estuary and a build up of sediment in the lower estuary is a consequent increase in the frequency of mouth closure. The mouth of the Berg River estuary does not close at all at present, a result of its “stabilisation” in the 1960s and periodic dredging which maintains the lower estuary channel at a depth sufficient for large purse seine vessels to navigate through. The mouth of the estuary is unlikely to ever close completely, unless these activities cease in the future. It is assumed that this will not happen. In the absence of mouth closure, it is predicted that conditions, currently prevailing within the initial 30 km of the estuary will expand some distance upstream, perhaps to within the range of 35-40 km upstream. This would increase the amount of habitat available for species occurring within this region of the estuary.

It is believed that one of the greatest benefits estuaries offer to marine species in the cool temperate region, where marine productivity is already high, is calm water. Southern Africa is one of the most exposed coastlines in the world, with very few sheltered bays that are completely protected from wave action that can act as nursery grounds for fish and other species. Ichthyofaunal data from the Berg River estuary represented herein show the highest abundance and species diversity to occur within the initial 30 km of the estuary. With an extension of the conditions prevailing here to between 40 and 50 km upstream, a potential positive influence is predicted for the estuarine resident species as well as the marine-estuarine opportunists (classification I a & b and II a, b & c and III) due simply to an increase in available habitat. Larger estuaries are considered to have higher fish species diversity and abundance than smaller estuaries (Whitfield & Marais 1999). With an increase in potential habitat area, the increased size of the estuary might result in higher diversity and/or abundance. The loss of habitat for fresh water species is considered to be of no consequence as all but one of these (*Galaxias zebratus*) are alien invasive species.

Reduced flushing by small and medium floods in winter will, in all likelihood, allow conditions suitable for the more stenohaline marine species to persist for longer periods during the year. However, reduced freshwater flow into the estuary might also result in certain negative impacts on the fish fauna of the estuary.

Reduced freshwater flow through the estuary is predicted to result in a reduction in the plume of estuarine water that prevails at present around the mouth of the estuary. Many species of juveniles and larvae rely on these 'freshwater cues' to locate and navigate into estuaries (Whitfield 1998). Any reduction in the size of this plume would compromise their ability in this respect and could reduce the relative contribution by all species not able to complete their life cycles in this environment.

Certain estuarine fish species change their location within the estuary as their spawning seasons approach. Many of these species rely on the early, small pulses of winter rainfall and freshwater flow into the estuary as cues to relocate to the most suitable area within the estuary ahead of this time. On detection of these early warning freshwater cues, some species move higher up the estuary to prepare for release of eggs (e.g. *G. aesuaria*), others move towards the mouth of the estuary to release their eggs and then seek shelter in marginal vegetation to prevent being washed out to sea themselves (e.g. *P. knysnaensis, C. nudiceps)*, and others prepare to exit the estuary to join adult populations (e.g. *L. lithognathus, R. globiceps, L. amia)*. The initial, small pulses of freshwater flowing through the estuary are usually followed by much larger, stronger flows of freshwater associated with the onset of full winter rains. These freshwater floods are considered to be the dominant, natural driving forces within the estuarine system with many species of fish, birds and macrofauna relying on the occurrence of such floods. Although the initial pulses of freshwater are not substantially large or noticeable, they serve as extremely important cues for many species of fish to successfully complete their life cycles. Without the early warning of initial small pulses of freshwater, some of these fish could be washed out to sea instead of remaining within the estuary, while others would suddenly be inundated with lower salinities than what they are able to tolerate. The patterns of freshwater flow through an estuary are thus of great importance for biological systems and management strategies are required to take these into account when advising on freshwater release events and quantities from dams.

Input of detritus into the estuary from the floodplain is likely to change if vegetation communities in this area change, and is likely to become less important if frequency of inundation is reduced. Other changes in primary production can also be expected associated with phytoplankton communities in the estuary. Changes in benthic and planktonic invertebrate communities in response to changing sediment distribution patterns and other factors will affect the amount of food available to fish and will in turn affect both absolute abundance of the different species and relative dominance patterns.

Any increase in turbidity associated with an altered flow regime are likely to have consequential changes in the quantity and type of food available for estuarine fish species, largely affecting those species that are visual predators.

Although it is impossible to accurately predict the exact response of each fish species in terms of foraging, reproduction and distribution, to increased turbidity levels and decreased freshwater inflow, Table 9.5 represents a preliminary summary of projected changes in the estuary in terms of the different trophic groups and life history patterns exhibited by the different species. Scores were allocated according to different types of feeding methods employed and to different levels of estuarine dependence, as classified by Whitfield (1994). The effect on habitat (H), breeding (B) and feeding (F) behaviour were each allocated a score of either + or – (both positive and negative), + (positive), – (negative) or N (neutral) and an overall accumulated score allocated according to the anticipated effects on the species. The overall accumulated score can be interpreted as follows:

-	Marginally negative	+	Marginally positive
- -	Negative	+ +	Positive
- - -	Significantly negative	+ + +	Significantly positive
N	No effect		

The various species represented in each category are also indicated adjacent to the overall score anticipated to be relevant to them.

Based on this assessment, the groups predicted to be most severely affected by the anticipated changes in the estuary with construction of the Berg River Dam, include all the estuarine resident species, estuarine dependent species and marine estuarine opportunist species, almost all of which will be negatively affected.

9.4.5 Monitoring recommendations

Fish species or fish communities are considered to be sensitive indicators of the relative health of aquatic ecosystems and frequently serve as the basis for biological monitoring to assess environmental degradation (Karr *et al*. 1981, Harrison *et al*. 1994). They represent a highly visible, dominant component of estuarine fauna assemblages and because of their key position in the aquatic food web, their abundance and species diversity within a system can portray both natural and anthropogenic changes therein. Fishes are also highly mobile, enabling them to respond rapidly to both deteriorating and improving estuarine conditions (Whitfield 1996). Several other aspects of fishes make them good indicator species for biological monitoring programmes, as summarised by Whitfield (1996):

- Fish are present in all aquatic ecosystems, with the exception of highly polluted waters
- Extensive life-history information is available for most fish species
- Fish are comparatively easy to identify and samples can be processed in the field
- The species that make up fish communities represent several trophic levels, which are impacted on by both aquatic and terrestrial systems and thus reflect adverse effects of stresses on a variety of components of the ecosystem
- Fish are long-lived and can provide a long-term record of environmental impacts
- Due to the direct economic benefits of a healthy fish population in the form of fisheries, societal costs of environmental degradation are more readily attached to fishes.

There are however also disadvantages of using fishes as biological indicators, which includes;

- Sampling gear being selective for certain sizes and species of fish
- Some fishes may be highly tolerant to toxic levels which are harmful to other species
- The natural seasonal movement of fishes within a system may lead to sampling bias.

These disadvantages can however also be encountered when using other components as health indicators and are far outweighed by the advantages of using fishes as biological health indicators (Whitfield 1996). As such, monitoring of fish communities of the Berg estuary is considered a very important element of any future monitoring programme.

Specific monitoring recommendations in respect of fish communities in the Berg River estuary are as follows:

1. Fish assemblages in the Berg River estuary should be monitored using both seine and gill nets in a manner corresponding as closely as possible to that done for this and preceding studies of the estuary.
2. Surveys should be conducted preferably on a annual basis in mid summer (February) of each year for at least first five years after the Berg River dam comes on line, following which time monitoring frequency can be reduced to a bi-annual frequency (every second year) for the next 10 years.

Given that monitoring of fish in the Berg estuary is the longest standing monitoring programme of its kind in the country, it is recommended that monitoring frequency be maintained at this level in perpetuity. However, provided no significant changes in fish populations are detected that can be attributed to dam construction and operation, monitoring frequency can be dropped still further at this point to once every 5 years or dropped entirely if sustained funding is not available for this purpose.

3. Seine net hauls should form an integral part of these surveys, to be conducted at at least 40 stations up the length of the estuary, corresponding as closely as possible to those sites sampled during this study. Survey equipment and methods employed should also correspond as closely as possible to those used in this study (30 m by 2 m,10 mm stretched-mesh beach seine net, to be laid by boat, and hauled by at least 4 persons).

4. Gill net hauls should form an integral part of these surveys, to be conducted at at least 9 stations up the length of the estuary, corresponding as closely as possible to those sites sampled during this study. Survey equipment and methods employed should also correspond as closely as possible to those used in this study (multi-panel gill net(s) comprising 44, 48, 51, 54, 75, 100 and 145 mm mesh panels of at least 20 m in length).

5. Corresponding surveys of physico-chemical characteristics should be undertaken in the estuary at the same time or as close as possible to the fish survey, comprising as a minimum measurements of temperature, salinity, oxygen taken a multiple intervals through the water column. Ideally, corresponding surveys of nutrient parameters, micro-algae, submerged and emergent vegetation, and invertebrates should be undertaken at the same time to facilitate interpretation of the results of the fish surveys.

Table 9.5 Preliminary predictions of the influence of changes in flow on fish communities of the Berg River estuary. See text for explanation of sysbols used in the table.

		Estuarine Resident estuaries & sea I a & I b			**Estuarine Dependent** marine species II a			**Marine Estuarine Opportunist** II b & II c			**Marine species** occasionally in estuaries III			**Freshwater species** IV		
		Score	Overall score	Species	Score	Overall score	Species	Score	Overall score	Species	Score	Overall score	Species	Score	Overall score	Species
Filter feeder		H + / - B - F -	– –	*A. breviceps*	H + / - B - F -	– –	*M. cephalus*	H + / - B - F -	– –	*L. richardsonii*	H + B N F -	N	*E. capensis*			
Piscivore	Hunter				H + / - B - F -	– –	*L. amia*	H + / - B - F -	– –	*P. saltatrix*				H + / - B + / - F + / -	N	*M. dolomieu* *L. macrchirus*
	Ambush							H + B + / - F + / -	+	*G. feliceps*	H + B N F + / -	+	*A. coronus*	H + / - B + / - F + / -	N	*M. dolomieu* *L. macrchirus*
Active capture		H + / - B + / - F -	–	*G. aestuaria* *S. acus*	H + / - B - F -	– –	*M. cephalus*							H - B + F + / -	N	*G. affinis* *G. zebratus*
Benthic forager		H + / - B - F -	– –	*C. superciliosus* *C. nudiceps* *P. knysnaensis*	H + / - B - F -	– –	*R. holubi* *L. lithognathus*	H + B N F -	N	*R. globiceps* *C. capensis* *S. bleekeri*	H + B N F -	N	*C. marleyi* *A. honkenii* *C. capensis* *D. pastinaca* *M. aquila* *R. annulatus*	H + / - B + F + / -	+	*T. mossambicus* *C. carpio* *L. macrchirus*
Herbivore								H + / - B - F -	– –	*L. richardsonii*	H + / - B N F -	–	*S. salpa*	H + / - B + / - F + / -	N	*T. mossambicus*
Detritus feeder		H + / - B - F +	N		H + / - B - F +	N	*M. cephalus*									

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CHAPTER 10 - BIRDS

Jane K. Turpie

10.1 INTRODUCTION

10.1.1 Importance of the Berg River estuary and floodplain for birds

The Berg River is one of only three permanently-open estuaries on the west coast of South Africa. It is also in the top ten percent of South African estuaries in terms of its size. Cooper *et al*. (1976) and Ryan *et al*. (1988) recognised the Berg River estuary as being of international importance for waterbirds. The estuary, with its associated floodplain wetlands, has been recognised as being the most important estuary in South Africa in terms of its waterbird populations (Turpie 1995), and is a top priority in terms of its overall biodiversity conservation importance (Turpie *et al*. 2002). It supports the highest recorded density of shorebirds on the East Atlantic Seaboard (Velasquez *et al*. 1991, Hockey *et al*. 1992). The Berg River wetlands support significant populations of several threatened bird species (Murison & Hockey 2002):

- *Nationally threatened/vulnerable*: African Marsh Harrier, Caspian Tern;
- *Globally near-threatened*: Lesser Flamingo, Black Harrier, African Black Oystercatcher;
- *Nationally near-threatened*: Eastern White Pelican, Cape Cormorant, Greater Flamingo, Greater Painted Snipe, Chestnut-banded Plover.

In a recent update of the importance rating of South African estuaries, taking into account estuary type, size, biogeographic zone, habitat areas, invertebrates, fish and birds, the Berg River was rated as third in the country in terms of conservation importance (Turpie & Clark 2007).

Nevertheless, increasing demands on water for domestic, industrial and agricultural use in the Western Cape have necessitated approval of the construction of the Berg River Dam (previously the Skuifraam Dam). The consequence of this will be reduced freshwater input into the lower floodplain wetlands and estuary, which may alter habitat and food resources for waterbirds.

10.1.2 Aim of this study

This study was commissioned as part of a baseline study against which impacts on the Berg River and estuary will be monitored following the construction of the Berg River Dam. The aims of this study were to compile a report on the avifauna of the lower floodplain wetlands and estuary on the basis of existing and new count data and personal experience of the estuary, including:

- A description of the avifauna, and its natural variability;
- A description of the way in which birds use the estuary;
- A description of key factors which influence avifauna in the estuary; and
- Recommendations for monitoring

10.1.3 Structure of the report

After a brief description of the approach, the report begins with an overview of the bird species that have been recorded in the estuary over the past 20 years, their taxonomic affiliations and migratory status, and their relative abundance. Because understanding the distribution of birds requires an understanding of their feeding and breeding habits and use of habitats, the report then presents a description of feeding and breeding. This is followed by a description of the distribution of habitats and birds throughout the estuary and floodplain. The seasonal and interannual variation in abundance of birds is then described.

These variations are interpreted in the light of seasonal and interannual variations in flow as well as other influencing factors. Finally, the relationship between flow and the estuary's avifauna is summed up, and some comments are made regarding the way in which the effects of future changes in flow on birds should be monitored.

10.2 STUDY APPROACH

10.2.1 Data sources

This study is based on a desktop review of the literature and analysis of bird counts made under the Co-ordinated Waterbird Counts (CWAC) volunteer programme and earlier counts conducted by researchers on the estuary, recent monthly count data, and field visits and counts conducted during this study.

The earliest published count of the Berg estuary is from January 1976 (Summers *et al*. 1976), though this count was restricted to wader species in the lower estuary up to the railway bridge, some 5.5 km from the mouth. Later on, a series of monthly waterbird counts were made in the lower estuary up to the railway bridge between September 1987 and April 1989 (Velasquez *et al*. 1991), spanning two austral summers and one winter. This is the part of the estuary where intertidal areas, and hence waders, are most abundant.

The first really comprehensive count of the estuary was carried out in December 1992 which included the full length of the estuary and its associated floodplain wetlands (Hockey 1993). The CWAC counts have been conducted twice per year (mid-summer and mid-winter) since 1994, using the same counting areas as Hockey (1993). These are partially summarised in Taylor *et al*. (1997), but raw data for all mid-summer and mid-winter counts were purchased from the Avian Demography Unit for this study.

In addition to this, Murison and Hockey (2002) conducted twice-monthly counts (at high tide and low tide each month) of the whole estuary and floodplain from March 2000 to February 2001. The raw count data were obtained from Giselle Murison.

10.2.2 Additional counts carried out during this study

Three comprehensive counts were undertaken during September, October and November 2005 with the assistance of the usual volunteer counters of the CWAC counts. The monthly 2001 and Spring 2005 data were obtained in order to fill a notable gap in seasonal data other than the long term monitoring of mid-winter and mid-summer bird numbers.

10.2.3 Division of the estuary and floodplain into counting sections

For the CWAC counts, the estuary has been divided into a total of 13 counting sections ranging in size from 83 to 930 ha (Figure 10.1; Table 10.1).

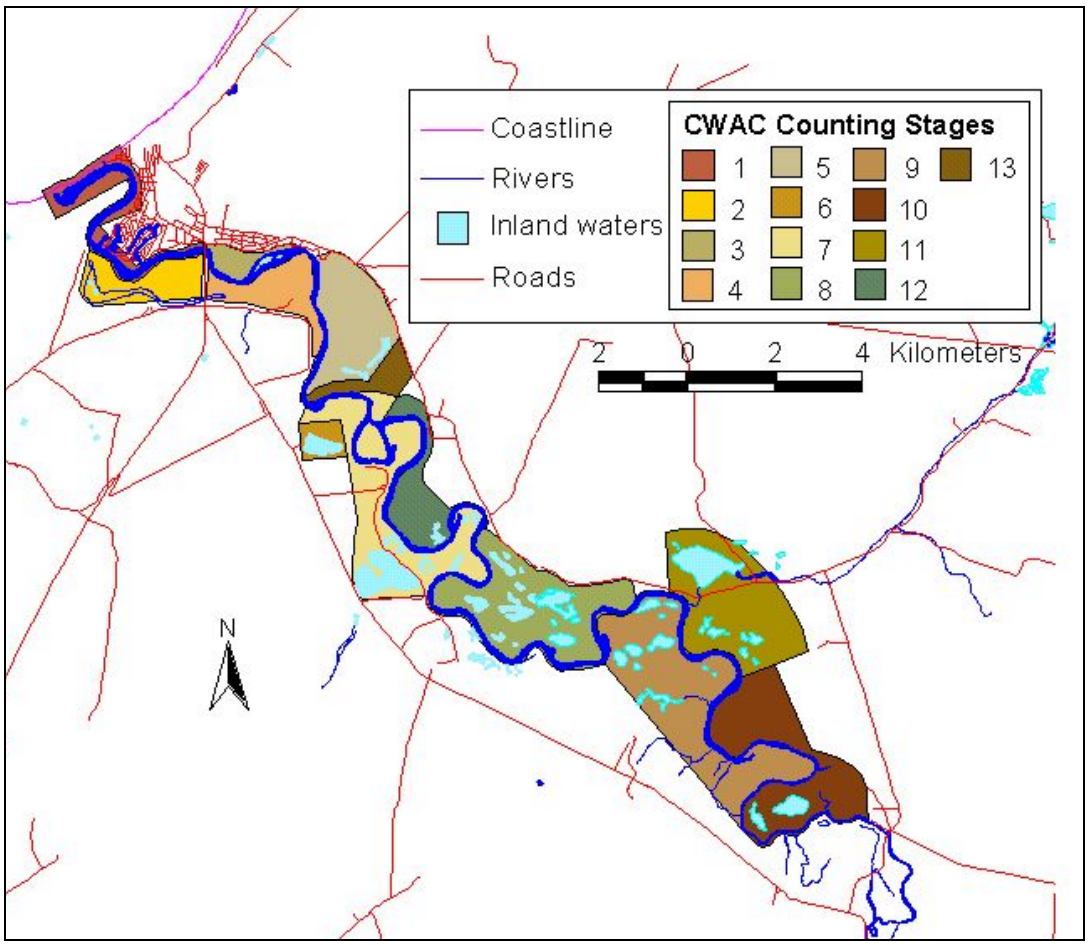


Figure 10.1 Counting sections for the bi-annual CWAC counts

Table 10.1 Areas of the different counting sections

Count area	Area (ha)	Count area	Area (ha)
1	301	8	762
2	227	9	930
3	115	10	646
4	222	11	672
5	446	12	256
6	83	13	116
7	815	TOTAL	5 589

10.3 OVERVIEW OF AVIFAUNA OF THE ESTUARY AND FLOODPLAIN

10.3.1 Species richness

About 250 bird species, both water-associated and terrestrial, have been recorded on and adjacent to the Berg River estuary (Hockey 1991, Hockey 1993), representing half of the species recorded in the southwestern Cape (Hockey *et al*. 1989). This high diversity is attributed to the diversity of aquatic and terrestrial habitats in the area (Hockey 1991).

Since 1975, some 127 water-associated species (passerine and non-passerine), have been recorded on the estuary and floodplain (Hockey 1993). This study concentrates on water-associated species, particularly the non-passerine species for which count data are available. Passerine water-associated species can loosely be described as 'hopping birds' or 'songbirds' and include warblers, cisticolas, and the like. These are generally not counted because of the difficulty involved, at least partly because they generally occupy a more 3-dimensional habitat. Nevertheless, water-associated passerines tend to be common, and are not generally a major concern in impact studies or flow assessment studies.

About 93 non-passerine waterbird species have been regularly recorded over the past 10 years (Table 10.3), excluding many exotic species (e.g. Mallard Duck) and vagrants (e.g. Rednecked Phalarope). Velasquez *et al*. (1991) recorded 84 waterbird species in series of 21 monthly counts, with 28 of these occurring in 25% or less of all counts. Hockey (1993) recorded 79 species in a single December count. Most, but not all, of the species occurring on the estuary and floodplain feed there, and many of the resident species use the area for breeding, as described below.

10.3.2 Taxonomic composition

Charadriiformes (waders, gulls and terns) account for 41% of the species on the estuary (Table 10.2), with most of these being wader species. More than half of the 27 wader species are Palaearctic migrants. Apart from these and two migratory tern species, the remaining species are species that breed in South Africa, some making local or regional movements in response to rainfall. Among the resident species, the Ciconiiformes (herons, egrets, ibises, spoonbill) and Anseriformes (ducks) form the most diverse groups on the estuary, but most waterbird orders are well represented.

Table 10.2 Taxonomic composition of non-passerine waterbirds on the Berg River estuary

Order	SA Resident	Palearctic migrant	Total
Podicipediformes (Grebes)	3		3
Pelecaniformes (Cormorants, darters, pelicans)	7		7
Ciconiiformes (Herons, egrets, ibises, spoonbill)	17		17
Phoenicopteriformes (Flamingos)	2		2
Anseriformes (Ducks)	12		12
Falconiformes (Birds of prey)	4		4
Gruiformes (Rails, crakes, gallinules, coots)	6		6
Charadriiformes (Waders, gulls, terns): Waders	11	16	27
Gulls	3		3
Terns	6	2	8
Strigiformes (Owls)	1		1
Alcediniformes (Kingfishers)	3		2
Total	**74**	**17**	**93**

10.3.3 Abundance

Average numbers of each of these species are given in Table 10.3. Using maximum counts of each species over a 21-month period, it was estimated that a minimum of 37 141 birds visited the *lower* estuary during the period Sep 87 to Jan 88 (Velasquez *et al*. 1991). Based on maximum counts of each species over 12 monthly counts, Murison & Hockey (2002) estimated that at least 55 612 birds used the whole estuary and floodplain in 2001.

Table 10.3 Non-passerine waterbird species recorded regularly on the Berg River estuary Dec 1992 – Feb 2006, giving common and scientific names (Hockey et al. 2005), and the average and maximum numbers recorded. Exotic and vagrant species are excluded.

Common name	Scientific name	Mean		Max	
		Summer	Winter	Summer	Winter
Great Crested Grebe	*Podiceps cristatus*	13.2	4.2	31	8
Black-Necked Grebe	*Podiceps nigricollis*	46.5	446.5	218	1230
Little Grebe	*Tachybaptus ruficollis*	8.4	27.6	25	67
Great White Pelican	*Pelecanus onocrotalus*	121.3	96.4	227	298
White-breasted Cormorant	*Phalacrocorax lucidus*	276.5	127.9	643	270
Cape Cormorant	*Phalacrocorax capensis*	1046.0	841.7	3 082	2949
Bank Cormorant	*Phalacrocorax neglectus*	3.0	1.1	30	11
Reed Cormorant	*Phalacrocorax africanus*	128.7	89.2	273	198
Crowned Cormorant	*Phalacrocorax coronatus*	1.3	7.6	5	73
African Darter	*Anhinga rufa*	37.4	59.4	82	107
Grey Heron	*Ardea cinerea*	64.1	37.2	104	88
Black-headed Heron	*Ardea melanocephala*	5.9	5.6	20	13
Goliath Heron	*Ardea goliath*	0.4	0.3	2	2
Purple Heron	*Ardea purpurea*	11.7	5.3	21	12
Great Egret	*Egretta alba*	1.0	1.9	6	7
Little Egret	*Egretta garzetta*	72.9	50.7	131	72
Yellow-billed Egret	*Egretta intermedia*	4.0	2.4	28	7
Cattle Egret	*Bubulcus ibis*	9.6	15.0	52	36
Squacco Heron	*Ardeola ralloides*	0.2	0.0	2	0
Black-crowned Night-Heron	*Nycticorax nycticorax*	2.6	5.8	12	20
Little Bittern	*Ixobrychus minutus*	0.4	0.2	1	1
Hamerkop	*Scopus umbretta*	0.0	0.1	0	1
White Stork	*Ciconia ciconia*	7.5	0.0	75	0
African Sacred Ibis	*Threskiornis aethiopicus*	175.8	101.8	373	164
Glossy Ibis	*Plegadis falcinellus*	7.9	86.4	40	229
Hadeda Ibis	*Bostrychia hagedash*	0.3	3.2	2	14
African Spoonbill	*Platalea alba*	109.4	83.0	294	126
Greater Flamingo	*Phoenicopterus ruber*	1435.8	1631.1	3 932	3071
Lesser Flamingo	*Phoenicopterus minor*	422.1	1040.2	1 890	1888
Fulvous Duck	*Dendrocygna bicolor*	0.2		2	0
Egyptian Goose	*Alopochen aegyptiaca*	283.7	271.2	764	585
South African Shelduck	*Tadorna cana*	235.9	160.3	599	405
Yellow-billed Duck	*Anas undulata*	329.0	187.1	1 059	307
African Black Duck	*Anas sparsa*	0.2	0.8	2	4
Cape Teal	*Anas capensis*	344.9	164.4	1 272	459
Hottentot Teal	*Anas hottentota*	0.3	0.0	3	0
Red-billed Teal	*Anas erythrorhyncha*	145.5	50.1	1 182	127
Cape Shoveler	*Anas smithii*	98.7	131.3	603	303
Southern Pochard	*Netta erythrophthalma*	2.5	13.3	16	62
Spur-winged Goose	*Plectropterus gambensis*	290.3	80.1	1 192	146

Common name	Scientific name	Mean		Max	
		Summer	Winter	Summer	Winter
Maccoa Duck	*Oxyura maccoa*	0.6	17.1	5	119
African Fish-Eagle	*Haliaeetus vocifer*	2.4	2.0	8	6
African Marsh-Harrier	*Circus ranivorus*	4.7	9.5	14	14
Black Harrier	*Circus maurus*	0.1	0.1	1	1
Osprey	*Pandion haliaetus*	1.0	0.3	4	1
African Rail	*Rallus caerulescens*	0.7	1.6	4	3
Black Crake	*Amaurornis flavirostris*	0.0	0.1	0	1
African Purple Swamphen	*Porphyrio madagascariensis*	2.4	3.6	10	18
Common Moorhen	*Gallinula chloropus*	3.3	6.3	5	15
Red-knobbed Coot	*Fulica cristata*	484.5	2544.9	2 577	6614
Greater Painted-snipe	*Rostratula benghalensis*	0.1	0.0	1	0
African Black Oystercatcher	*Haematopus moquini*	3.0	7.9	13	46
Common Ringed Plover	*Charadrius hiaticula*	163.9	2.2	475	4
White-fronted Plover	*Charadrius marginatus*	9.7	41.5	22	182
Chestnut-banded Plover	*Charadrius pallidus*	53.6	134.7	90	254
Kittlitz's Plover	*Charadrius pecuarius*	357.5	209.1	1 187	297
Three-banded Plover	*Charadrius tricollaris*	15.9	37.2	32	77
Grey Plover	*Pluvialis squatarola*	193.6	26.2	471	73
Blacksmith Lapwing	*Vanellus armatus*	174.9	168.2	232	306
Ruddy Turnstone	*Arenaria interpres*	0.7	3.8	3	19
Terek Sandpiper	*Xenus cinereus*	0.1	0.1	1	1
Common Sandpiper	*Actitis hypoleucos*	16.7	27.4	50	204
Wood Sandpiper	*Tringa glareola*	10.2	1.2	39	6
Marsh Sandpiper	*Tringa stagnatilis*	79.6	12.9	195	66
Common Greenshank	*Tringa nebularia*	331.0	79.3	566	217
Red Knot	*Calidris canutus*	4.0	0.2	19	1
Curlew Sandpiper	*Calidris ferruginea*	5 295.8	410.4	16 881	769
Little Stint	*Calidris minuta*	1 608.8	68.6	6 428	410
Sanderling	*Calidris alba*	1.0	0.4	4	4
Ruff	*Philomachus pugnax*	214.2	1.4	1 087	9
Bar-tailed Godwit	*Limosa lapponica*	14.7	4.5	41	19
Eurasian Curlew	*Numenius arquata*	20.7	7.1	42	18
Common Whimbrel	*Numenius phaeopus*	45.2	4.7	73	11
Red-necked Phalarope	*Phalaropus lobatus*	0.3	0.0	2	0
African Snipe	*Gallinago nigripennis*	2.7	0.3	12	1
Pied Avocet	*Recurvirostra avosetta*	285.8	228.8	2 273	318
Black-winged Stilt	*Himantopus himantopus*	278.3	475.1	518	751
Water Thick-knee	*Burhinus vermiculatus*	2.6	2.8	21	8
Kelp Gull	*Larus dominicanus*	303.6	560.2	459	850
Grey-headed Gull	*Larus cirrocephalus*	49.5	2.2	443	8
Hartlaub's Gull	*Larus hartlaubii*	422.8	490.9	829	937
Caspian Tern	*Sterna caspia*	40.8	16.4	72	49
Swift Tern	*Sterna bergii*	49.6	54.8	186	199
Sandwich Tern	*Sterna sandvicensis*	122.3	0.6	365	3
Common Tern	*Sterna hirundo*	382.2	1.5	1 561	8
Arctic Tern	*Sterna paradisaea*	2.0	0.2	20	2
Little Tern	*Sterna albifrons*	10.8	0.1	67	1
Whiskered Tern	*Chlidonias hybrida*	7.2	0.4	37	2
White-winged Tern	*Chlidonias leucopterus*	28.9	1.0	131	7
Marsh Owl	*Asio capensis*	0.3	0.1	2	1
Pied Kingfisher	*Ceryle rudis*	48.4	41.7	67	68
Giant Kingfisher	*Megaceryle maximus*	0.1	0.1	1	1
Malachite Kingfisher	*Alcedo cristata*	1.0	1.4	5	5

10.4 FEEDING AND FEEDING HABITATS

10.4.1 Feeding guilds

Estuarine avifauna fall into a variety of dietary guilds, although most species are fairly generalist within these guilds, as aquatic birds are opportunistic by nature. The way in which the taxonomic groups given above fit into broad dietary guilds is described in Figure 10.2. Herbivores, invertebrate feeders and piscivores are estimated to account for 25%, 55% and 20% of total energy consumption by birds on the estuary, respectively. An estimated total of 7 343 kJ per ha per day is consumed during summer (based on total intertidal plus subtidal area; Hockey & Turpie 1999).

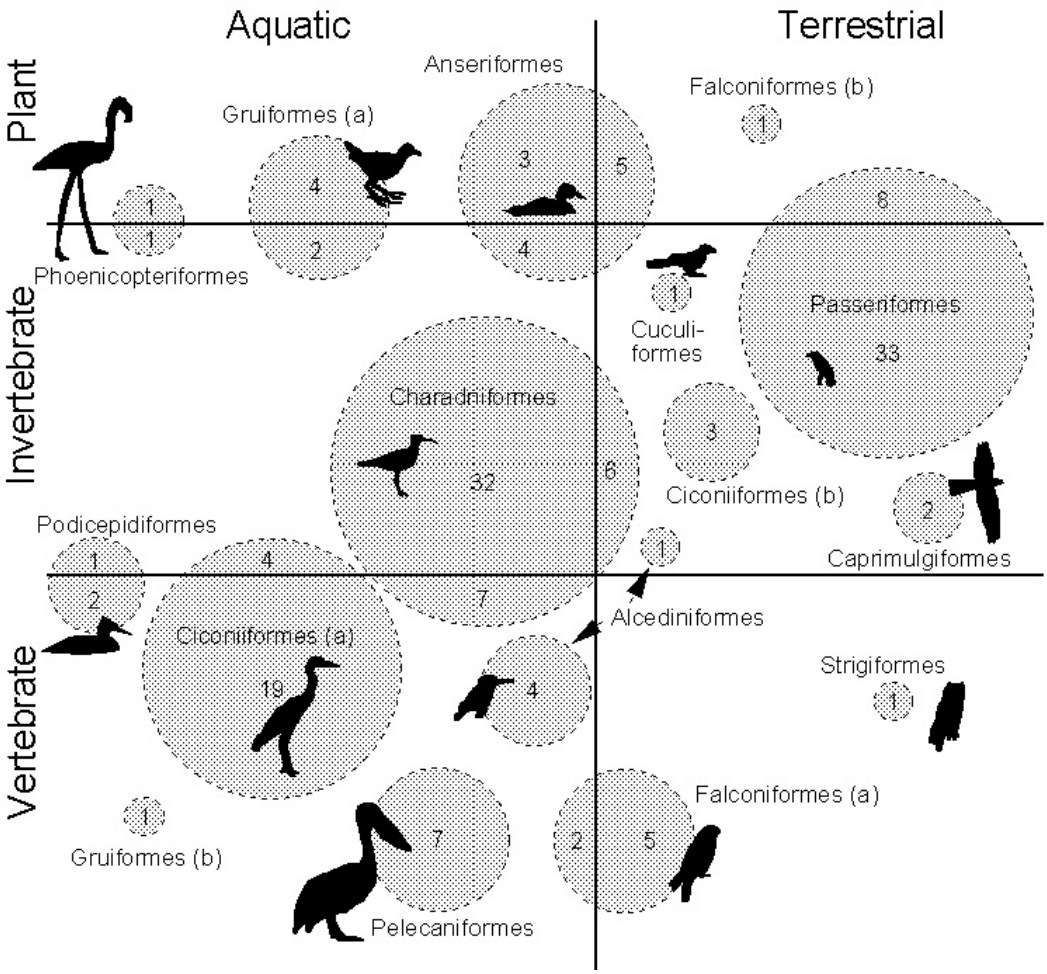


Figure 10.2 Dietary and broad habitat preferences of different orders of estuarine birds in South Africa, giving numbers of species in each category (after Hockey & Turpie 1999).

10.4.2 Invertebrate feeding birds

The majority of species on the estuary and floodplain are invertebrate feeders.

The majority of waterfowl species are invertebrate feeders, this being the principle diet of Blacknecked Grebe, Cape Teal, Hottentot Teal, Redbilled Teal and Cape Shoveller. These species forage in the river channel, but also make extensive use of the floodplain pans when they are inundated.

African Rail and Black Crake are skulking rails that feed in or close to dense reed marsh, and Painted Snipe feeds on invertebrates usually in the cover of sedge marsh.

A few of the larger wading birds are invertebrate feeders. These include the Ibises, which feed on intertidal mudflats and in floodplain pans, and Greater Flamingos, which feed on benthic or epibenthic invertebrates which they disturb and filter from the water. Blackheaded Heron and Cattle Egret forage on terrestrial invertebrates and do not depend on the estuary or floodplain wetlands for feeding.

Waders are the most abundant birds on the estuary, and are all invertebrate feeders. Thus the estuarine fauna is highly dependent on the productivity of invertebrates in the estuary.

Waders feed predominantly on intertidal mudflats and shallow water during the low tide period, by night and day, moving to saltmarshes and saltpans at high tide. Waders can be divided into obligate visual foragers and facultative tactile/visual foragers. The latter tend to forage in flocks, and include the most common bird on the estuary – Curlew Sandpiper *Calidris ferruginea*. Obligate visual foragers – the plovers, tend to be spaced out across the mudflats and sometimes defend feeding territories (Turpie 1994).

Waders are generally highly opportunistic in their diet and feeding methods, with larger species concentrating on larger prey (Turpie & Hockey 1997). Kalejta (1993) investigated the diets of three common migrant and three resident waders on the estuary, and Turpie (1994) investigated the diet and foraging behaviour of Grey Plover and Whimbrel. The Nereid worms *Ceratonereis erythraeensis* and *C. keiskama* were the principal food of five species (Curlew Sandpiper, Grey Plover, Blacksmith Plover, Kittlitz's Sandplover and Whitefronted Plover). Greenshank and Whimbrel, on the other hand, fed mainly on the crown crab *Hymenosoma orbiculare.* Most waders forage by day and by night (Turpie 1994, 1995). For the majority of waders on the Berg estuary, diurnal foraging was not always sufficient to meet the required daily energy intake (Kalejta 1992). Although nocturnal foraging was not important during the winter months and the immediate post-arrival period (migrants return in September to November), nocturnal foraging increased markedly during the pre-migration period. In addition to building up energy reserves, it is possible that the availability of some invertebrates may increase at night (Kalejta 1992). Nevertheless, visual foragers spent proportionally more time foraging at night compared to daylight hours; the reverse was true for those species that were tactile feeders.

Most bird species feeding on the two nereid worms were selective in their choice, with Kittlitz's and Whitefronted Plovers only taking the largest worms. Curlew Sandpipers are tactile feeders and their foraging density was positively and linearly correlated with the density and biomass of their preferred prey *C. keiskama* (Kalejta & Hockey 1994). The favoured prey of Grey Plovers was the larger nereid *C. erythraeensis,* although the positive correlation was with biomass only. Predation pressure by waders at the Berg River estuary is described as among the highest on the East Atlantic seaboard, and represents approximately 26% of the annual invertebrate production (Kalejta 1992, 1993).

Intertidal mudflats (and the adjacent shallow-water habitats) support a high diversity and biomass of invertebrates. Not surprisingly, they support an average of 75% of birds in the lower estuary (sites 1 – 5) during low tide, with densities averaging 74 (± 14) birds per ha in summer (November – March) and 31 (± 14) birds per ha in winter (May – Aug) (based on data in Velasquez *et al*. 1991). Summer densities can exceed 100 birds per ha (Hockey 1993).

Saltmarsh areas vary in the biomass of invertebrates that they support, depending on the degree of inundation. Most of the saltmarshes on the Berg estuary have a relatively low biomass of invertebrates compared with intertidal mudflats (pers. obs.). However, they are particularly important for their detrital input into the estuarine food chain, which affects the overall productivity of the estuary.

Saltmarshes support a relatively low density of birds, averaging 11 (± 2) birds per ha during low tide in summer and 4 (± 2.5) in winter (Velasquez *et al*. 1991). However, they are important as roost sites and feeding areas during high tide. They are mainly used by waders.

Waders are also attracted to the floodplain pans and artificial salt pans as their water levels drop, feeding on the newly exposed shorelines and in shallow water. Densities of birds can reach extremely high levels in these pans (Hockey *et al.* 1998).

10.4.3 Vertebrate feeders

There is a high diversity of vertebrate feeders, including the gulls and terns of the Charadriiformes, as well as grebes, cormorants, darters, pelicans, herons, egrets, ibises, kingfishers and fish eagles. Most of these birds eat fish, and are loosely referred to as piscivores, but amphibians and the young of other birds may also constitute an important part of the diet in floodplain habitats. Osprey are exclusively fish eaters.

Piscivorous birds mainly forage in the river channel, but also frequent floodplain pans when they are inundated. Species such as Eastern White Pelican, Reed Cormorant and Darter swim in the channel while foraging. Kingfishers perch in marginal vegetation such as reedbeds, or hover over the water, while terns fly over or hover while foraging. Great Crested Grebes forage for fish by diving in large deep water areas, and Little Grebe prefer deep water areas that are close to emergent reedmarsh which affords them some cover for safety.

Wading birds such as herons and egrets forage by wading, usually using a sit and wait strategy. These species perch in reedbeds, particularly Purple Heron, but more often frequent vegetated and unvegetated pans in the floodplain as well as intertidal mudflats.

Marsh Owl and Marsh Harrier are non-piscivorous vertebrate feeders which hunt for prey such as rodents in low to medium-height marshes.

10.4.4 Herbivores

The Lesser Flamingo is an unusual herbivore in that it feeds on phytoplankton in saline habitats, and hence is particularly common in the artificial salt pans.

Most of the remaining herbivores are found predominantly in fresher or slightly brackish habitats. In the upper estuary, low salinities allow the development of aquatic plants such as *Potamogeton* that are consumed by the herbivorous Yellowbilled Duck and Redknobbed Coot. Note that the algae found in the lower estuary is not consumed by birds.

Most of the rail species are skulking herbivores which forage in dense marshes. Preferences differ slightly, with species such as Ethiopian snipe being common in short sedge marsh, and African Purple Swamphen being more common in tall reedmarsh.

Other herbivorous waterfowl such as Egyptian Goose, Spurwinged Goose and South African Shelduck feed mainly in terrestrial areas away from the estuary and floodplain.

10.5 ROOSTING AND ROOSTING HABITATS

Some species of birds roost in different habitats to their feeding habitats. These include most of the herons, egrets and ibises, which tend to roost in fringing trees or tall marsh. Indeed the alien trees lining the upper estuary have probably played an important role in attracting many species through the provision of suitable roosting sites.

Many waterfowl species require bare or grassy banks or short marsh areas for roosting or ‘loafing’. This includes terrestrially-feeding waterfowl such as Egyptian Goose, Spurwinged Goose and South African Shelduck. For the latter species, the provision of suitable safe roosting areas is the main reason for their presence.

Waders feed intertidally and hence also require roosting areas away from their feeding areas at high tide. Bare or grassy islands and supratidal saltmarshes are the preferred roosting habitat for these species, but pans in the floodplain are also used. Indeed, high tide counts on saltmarsh and sedgemarsh areas and the floodplain in general are consistently higher than at low tide due to the influx of birds that forage on intertidal areas (Murison & Hockey 2002).

There is no evidence that they move into salt pans on the floodplain, but certain species do make significant use of saltpans in the lower estuary.

Thousands of Cape Cormorants roost on the artifical islands in the commercial saltpans, as well as on sandy shores near the mouth, together with gulls and terns. Terns and flamingos also make extensive use of the saltpans in the floodplain for roosting.

10.6 BREEDING AND BREEDING HABITATS

Most of the non-migratory species recorded on the estuary are likely to breed there, though records of breeding are incomplete. Resident species that do *not* breed on the estuary include colonial nesters such as Great White Pelican and Cape Cormorants, which breed on nearby offshore islands, and flamingos.

Breeding activity is highly seasonal and closely linked to flooding, with most birds breeding during spring, coinciding with the drawdown of water levels (when food availability peaks) on the floodplain (Figure 10.3).

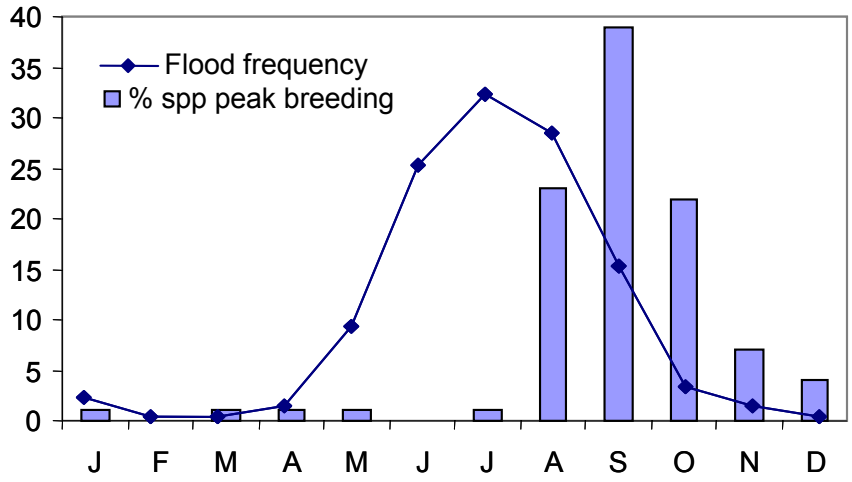


Figure 10.3 Seasonal distribution of peaks in waterbird breeding activity relative to the average seasonal frequency of flood events. Redrawn from Hockey (1993).

Waterfowl and waders favour pans (both natural and man-made) and marshes for breeding. Many waterfowl, such as ducks and Blackwinged Stilts, breed in sedges or grassy areas around the edges of pans as water levels recede. Resident waders such as Kittlitz's Plover breed in open dry pans. At least 50 pairs of Chestnutbanded Plovers breed on the saltpans. Shelducks breed in burrows near open pans. These breeding activities are inconspicuous and often pass unobserved or unrecorded.

Gulls and terns are colonial nesters which breed on bare ground in the lower estuary. Near the estuary mouth, there is a mixed breeding colony of about 350 pairs of Hartlaub's Gulls together with Swift Terns and Gelp Gulls. At least 15 pairs of Caspian Terns breed with Kelp Gulls at the Veldrif Salt works. The Berg River Estuary is an important breeding area for Caspian Terns (*Sterna caspia*), listed as "rare" in the national Red Data Book (Velasquez *et al.* 1990).

Egrets, ibises, cormorants and spoonbills breed in mixed species colonies, usually in reedbeds or flooded trees in the upper estuary. At least 13 species breed in the Kersefontein heronry (Hockey 1993), which has been known for more than 80 years. This heronry is one of the most important in the Western Cape, especially since the demise of major heronries on the Cape Flats and at Blouvlei (Century City). The Kersefontein heronry supports thousands of pairs of breeding birds (Table 10.4). Note that these include terrestrially-foraging species such as Blackheaded Heron and Cattle Egret. Goliath Heron has also been recorded breeding at Kersefontein, a first record for the Western Cape (Murison & Hockey 2002). Other heronries have also existed on the estuary, but the current number of heronries is unknown, and thought to be only one.

Table 10.4 Estimated number of breeding pairs in the heronry at Kersefontein (Murison & Hockey 2002)

Species	Breeding pairs
Reed Cormorant	200-300
Darter	25-40
Cattle Egret	800 – 1000
Little Egret	30 – 40
Yellow-billed Egret	50 – 60
Black-crowned Night Heron	20 – 30
Sacred Ibis	300 – 400
Glossy Ibis	30 – 40
African Spoonbill	150 - 180

Flamingos have been recorded building nests at the salt pans, but have never bred at this estuary. Reedbeds also provide breeding habitat for several rails (e.g. Purple Gallinule) and other passerines (e.g. Cape Reed Warbler) and support colonies of Red Bishops, Cape and Masked Weavers.

10.7 PATTERNS OF DISTRIBUTION AND COMMUNITY COMPOSITION

10.7.1 Bird habitats and their distribution in the study area

Overview

The lower floodplain wetlands and estuary of the Berg River are described in detail in the previous chapters, and are generally referred to together as the estuary, in that the wetlands are adjacent to the estuarine part of the river. The wetlands are inundated by fresh floodwaters, and not reached by the salt water that occasionally penetrates to near the top of the estuary. Nevertheless some of the wetlands are relatively saline. The rest of the estuary has a salinity gradient and fluctuates in salinity from a predominantly freshwater state in winter to a predominantly saline state during the summer low flow period.

The detailed vegetation map developed by Boucher & Jones (2007, Chapter 6) was simplified by grouping detailed elements to depict the estuary in terms of the main habitats for waterbirds (Figure 10.4). These comprise the main river channel, intertidal mudflats[3], intertidal and floodplain saltmarsh, reed and sedge marshes, ephemeral pans and artificial salt works. Exotic trees along the river banks provide additional habitat for waterbirds.

[3] Note that some of the intertidal mudflats are represented as river, possibly due to tidal conditions.

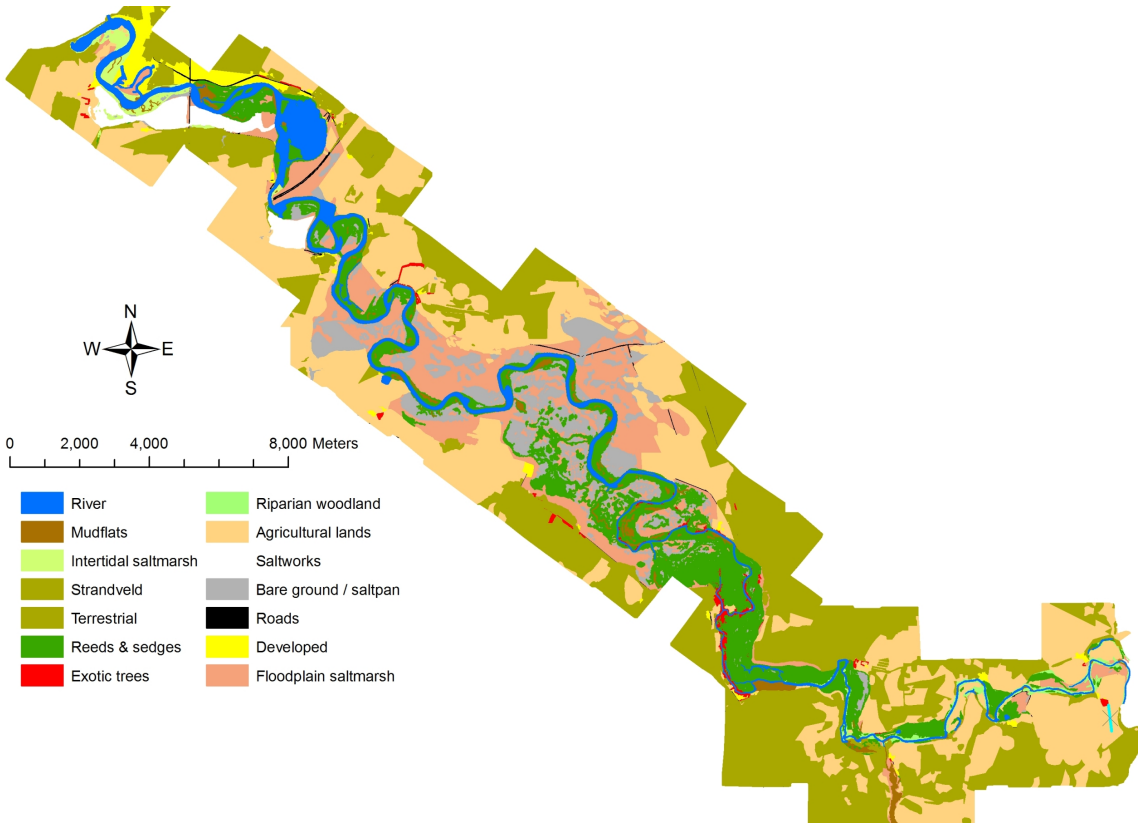


Figure 10.4 Main vegetation types of the Berg River estuary. The mouth of the estuary is at the top left.

Various studies have attempted to estimate the areas of different natural and man-made habitats. Much of the earlier work on the estuary was only on the lower estuary below the railway bridge, which is characterised by intertidal habitats and artificial saltpans.

According to Velasquez *et al*. (1991), the lower estuary contained 144 ha of intertidal mudflats, 242 ha of saltmarshes, 222 ha of commercial Cerebos saltpans and 232 ha of subtidal area, but the area of emergent marshes was not reported or counted in their study (Table 10.5).

Above the railway bridge, the system is characterised by marshes and ephemeral pans, and also includes the artificial Swartjiesbaai pans (80.7ha) and Doornfontein Pan (72.1ha). Hockey (1993) estimated that the natural wetland habitats comprise a total inundated area of up to 1 356 ha after winter flooding, shrinking to less than 1000 ha by late summer. Including man-made habitats, Hockey (1993) estimated that the inundated wetland area reaches a maximum of over 1 700 ha Table 10.5). The total area estimated in this study was far greater than the inundated areas estimated by Hockey (1993).

Table 10.5 Inundated areas of different wetland habitats in spring and summer (Hockey 1993) and areas estimated based on detailed GIS mapping in this study.

Habitat	Habitat area (ha) (Velasquez et al. 1991)	Inundated area (ha) (Hockey 1993)		Total area (this study)
		Spring	Mid-summer	
River channel	232	(no data)	(no data)	857.6
Mudflats	144	144	144	151.9
Saltmarshes	242	242	242	123.5 + 2615.1[1]
Marshes	(no data)	622	622	2215.8
Ephemeral pans	0	348	231	1147.8[2]
Artificial saltpans	222	375	375	597.9
Total		1731	1614	7709.6

[1] Intertidal + floodplain, [2] Bare ground and salt pans

River channel

The estuary channel is approximately 65 km long and varies in width from about 20 m at the head of the estuary to the widest point of 300 m in the lower estuary. The lower estuary is about 6 metres deep at its maximum. The water volume decreases upstream, as does salinity. The channel bottom is dominated by eelgrass *Zostera capensis* in the lower half of the estuary, and is replaced by fonteingras *Potamogeton pectinatus* in the upper estuary. Water hyacinth *Eichhornia crassipes* is a problem in the upper reaches.

Intertidal mudflats

Because of its permanently open status, the estuary supports a relatively large area of intertidal habitat which is important foraging area for waders and roosting area for a number of species. The intertidal habitat and shallow subtidal habitat has a variable cover of eelgrass *Zostera capensis* and the filamentous alga *Enteromorpha* sp. which is particularly abundant in spring and dies back during summer. The mudflats are also periodically covered by alien Water Hyacinth *Eichhornia crassipes* which is deposited after flooding (see Clark *et al*. 2007 – Chapter 7 for details on this). This cover affects the abundance and accessibility of invertebrates, and thus affects avian foraging.

At least 25 species of benthic macroinvertebrates have been recorded from the intertidal mudflats of the Berg River estuary (Kalejta & Hockey 1991, Wooldridge 2007 – Chapter 8).

Saltmarsh

The estuary also contains a large area of saltmarsh which is significant at a national scale. Saltmarshes occur both intertidally and supratidally and these are characterised by different species with different tolerances. Intertidal saltmarshes are mostly found in the area below the railway bridge. The intertidal saltmarshes are dominated by *Sarcocomia perennis* (brakbos), *Bassia diffusa* (formerly *Chenolea diffusa)* (soutbos), *Spartina maritima* (cord grass) (Boucher & Jones 2007 – Chapter 6) and mainly supports gastropods, isopods and amphipods (Murison & Hockey 2002). In addition, the floodplain contains extensive areas of supratidal saltmarsh, characterised by *Sarcocornia pillansii* (brakbos) and Scattered *Salicornia meyeriana* (glasswort) shrublets (Boucher & Jones 2007 – Chapter 6).

Reed and sedge marshes

Marshes are the most abundant habitat type on the estuary and floodplain, and are dominated by tall stands of reeds *Phragmites australis* (about 2 – 4 m). Reed marsh is typically found on saturated silty soils, particularly on the inner bends of the river.

Shorter sedge marshes (usually about 0.5 – 1m high), are characterised by biesie *Juncus krausii*, *Scirpus* spp but also include a variety of other species such as *Sarcocomia perennis* (brakbos) *Samolus porosus* (samolus), *Nidorella foetida* (nidorella) and *Sporobolus virginicus* (brakgras) Boucher & Jones 2007 – Chapter 6). . The marshes are typically adjacent to the river channel, with all of them lying under 0.5m (Hockey 1993, Boucher & Jones 2007 – Chapter 6).

Ephemeral pans

These natural pans generally occur in the floodplains associated with the upper estuary. They are largely freshwater habitats and inundated during winter floods. The pans are usually flooded in June to August, and dry out by mid summer. The pans are distributed between flooding levels of 0.5 and 4m, with the majority being above the 1.5m contour (Hockey 1993). Most pans are bare, but some contain sedges, typically *Juncus maritimus,* and waterblommetjies *Aponogeton distachyos* after rains. Scattered *Salicornia meyeriana* (glasswort) shrublets (to about 0.25 metres) are generally the only noticeable groundcover during the dry season (Boucher & Jones 2007 – Chapter 6). The pans contain very little in the way of invertebrate or fish biomass (Wooldridge 2007 - Chapter 8; Clark 2007 - Chapter 9).

Artificial pans

There are extensive areas of commercial saltpans on the Berg River estuary, most of which have replaced saltmarsh areas. All of the artificial pans are found below the 1.5m contour (Hockey 1993). Saltwater is pumped into the saltpans and they are allowed to dry by evaporation. The saltpans are all in various stages of this process, and thus offer a variety of habitats to birds, ranging from deepwater pans to exposed shorelines and hypersaline pans. Benthic invertebrates are abundant in pans of 30 – 60 ppt, particularly chironomid fly larvae, polychaetes, amphipods and mudprawns *Upogebia africana* (Murison & Hockey 2002). Brine shrimps *Artemia* sp are abundant in extremely high salinity pans (>100 ppt).

The artificial wetlands of the study area support a variety of birds, depending on their salinity and stage of evaporation. Those that fill with freshwater attract waterfowl and some terns, while those filled with pumped seawater tend to attract gulls and terns. As the saltpans dry out, waders are attracted to the newly-exposed shorelines and shallow water habitats. When conditions favour chironomid larvae, the pans can support extraordinary densities of waders, particularly small species such as Curlew Sandpiper (Hockey *et al*. 1998). Greater Flamingos appear as salinities increase, feeding on brine shrimp. Lesser Flamingos are tolerant of a higher salinity range, and feed on phytoplankton. When dry, the pans are used by resident waders, mainly Chestnut-banded Plover, Kittlitz's Plover and Whitefronted Plover.

10.7.2 Species distributions along the estuary

Individual bird species are highly consistent in their distribution along the estuary (Figure 10.5 to Figure 10.10), although some may shift their distribution seasonally. Certain birds are highly site specific. For example, the majority of Great-Crested Grebes and Dabchicks and all Maccoa Ducks are found in one particular pan in section 6 (see Figur 10.1).

Cape Cormorants and Crowned Cormorants are almost entirely confined to the mouth, and Whitebreasted Cormorants concentrate at the mouth but are found all the way up the estuary (Table 10.6). Several species are confined or largely confined to the lower estuary.

These are mostly migrant waders such as Grey Plover, but also include resident waders (e.g. African Black Oystercatcher, White-fronted Plover), Kelp Gull, Swift Tern and flamingos.

Almost all other waders are generally more common in the lower than the upper estuary. This pattern also holds for African Spoonbill and Redknobbed Coot.

Several species are fairly evenly distributed throughout the estuary (Table 10.6). These are mostly piscivorous species such as White Pelican, Reed Cormorant and Darter, but also include some waterfowl and African Marsh Harrier. Pied Kingfisher, Sacred Ibis, Little Egret and most herons are found throughout the estuary, tending to be slightly more common towards the mouth.

Table 10.6 Species typical of different parts of the estuary or common throughout

	Mouth	**Lower estuary**	**Upper estuary**
All or nearly all here	Cape Cormorants, Crowned Cormorants	Blacknecked Grebe, African Black Oystercatcher, White-fronted Plover, Grey Plover, Ruddy Turnstone, Terek Sandpiper, Knot, Bartailed Godwit, Eurasian Curlew, Common Whimbrel	Ethiopian Snipe, African Black Duck, Goliath Heron, African Black Duck, Marsh Owl
Most common here	Whitebreasted Cormorant	African Spoonbill, Redknobbed Coot, Kelp Gull, Swift Tern, Greater Flamingo Lesser Flamingo Ringed Plover, Chestnutbanded Plover, Kittlitz's Plover, Threebanded Plover Blacksmith Plover, Common Sandpiper, Marsh Sandpiper, Greenshank, Curlew Sandpiper, Little Stint, Sanderling, Ruff, Avocet, Blackwinged Stilt.	Egyptian Goose, Redbilled Teal, Spurwinged Goose, African Fish Eagle, Moorhen, Wood Sandpiper
Common throughout	White Pelican, Reed Cormorant and Darter, Glossy Ibis, South African Shelduck, Yellowbilled Duck, African Marsh Harrier, Pied Kingfisher, Sacred Ibis, Little Egret, herons		

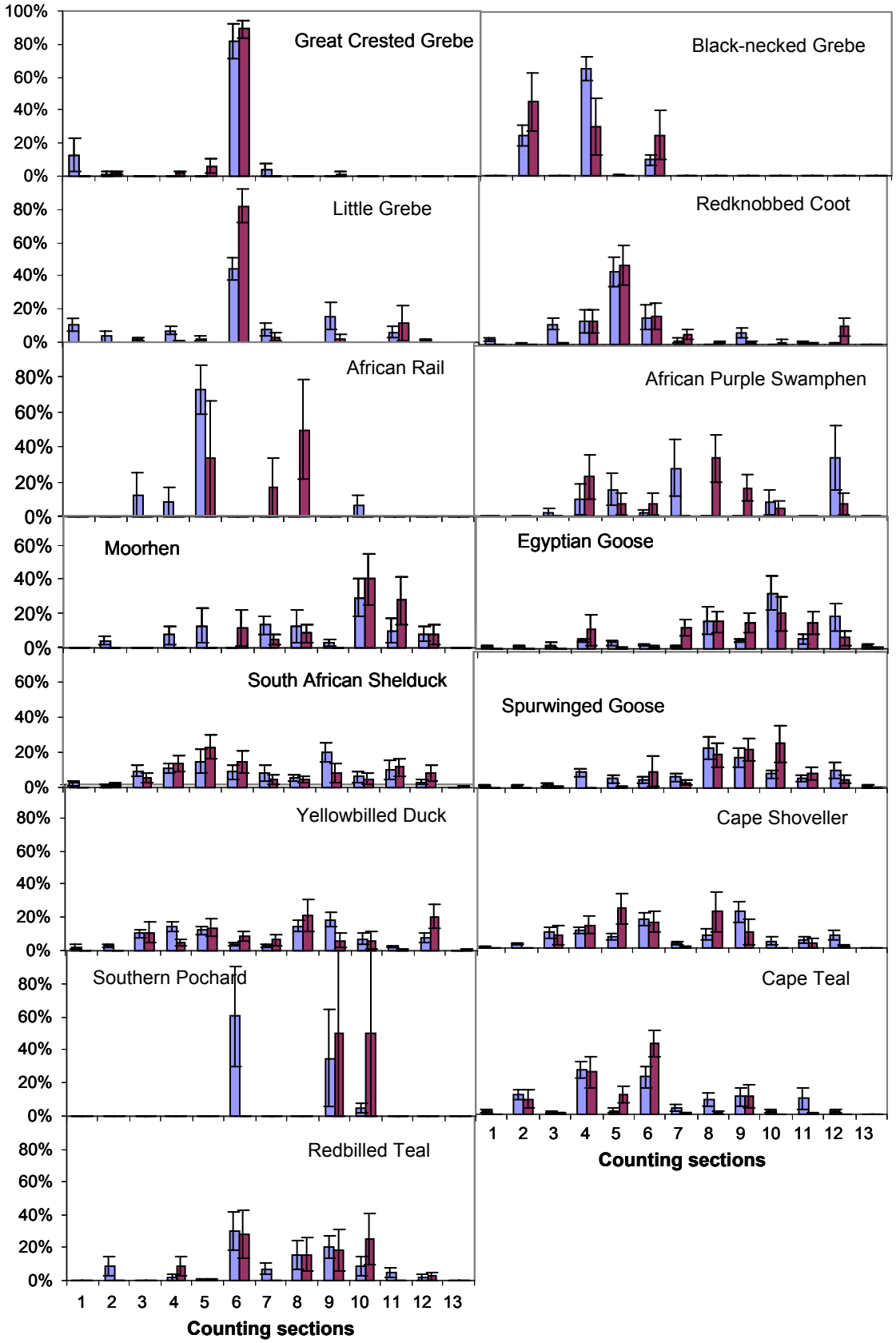


Figure 10.5 Distribution of waterfowl along the estuary during winter (blue bars) and summer (red bars). Locations of the bird counting sections are shown in Figue10.1

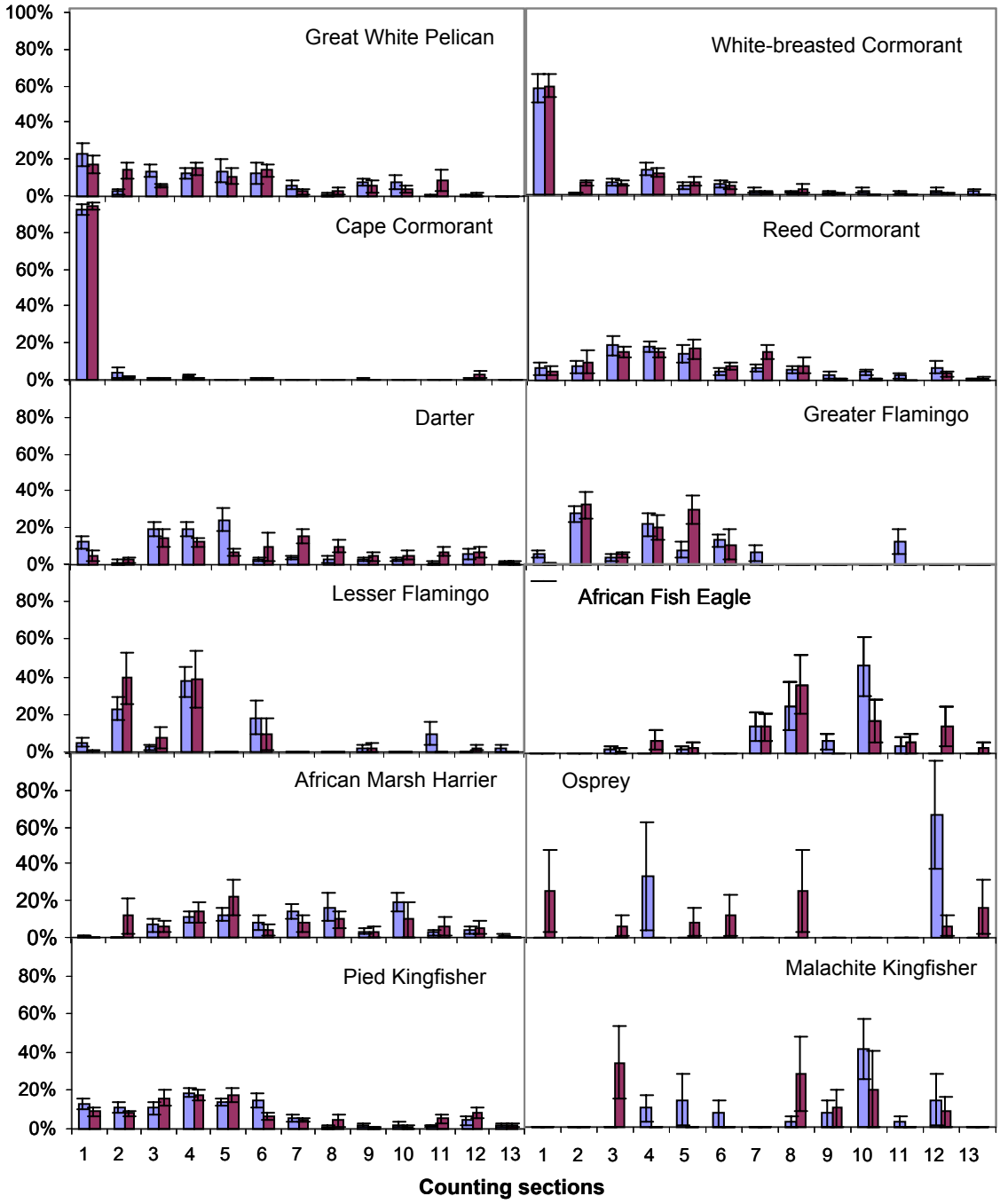


Figure 10.6 Distribution of pelicans, cormorants, darters, flamingos, birds of prey and kingfishers along the estuary during winter (blue bars) and summer (red bars). Locations of the bird counting sections are shown in Figure 10.1

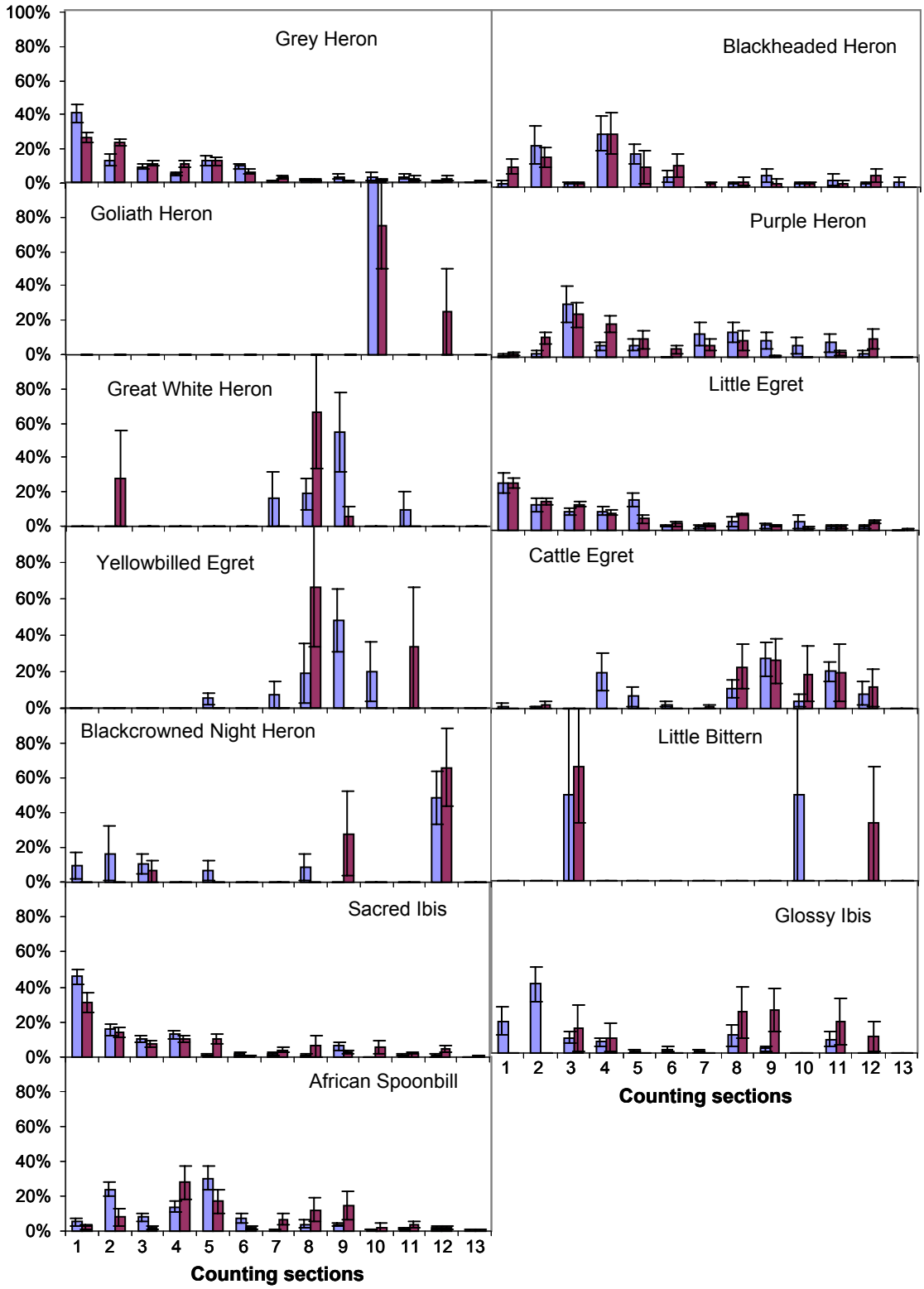


Figure 10.7 Distribution of herons, egrets, ibises and spoonbills along the estuary during winter (blue bars) and summer (red bars). Locations of the bird counting sections are shown in Figure 10.1

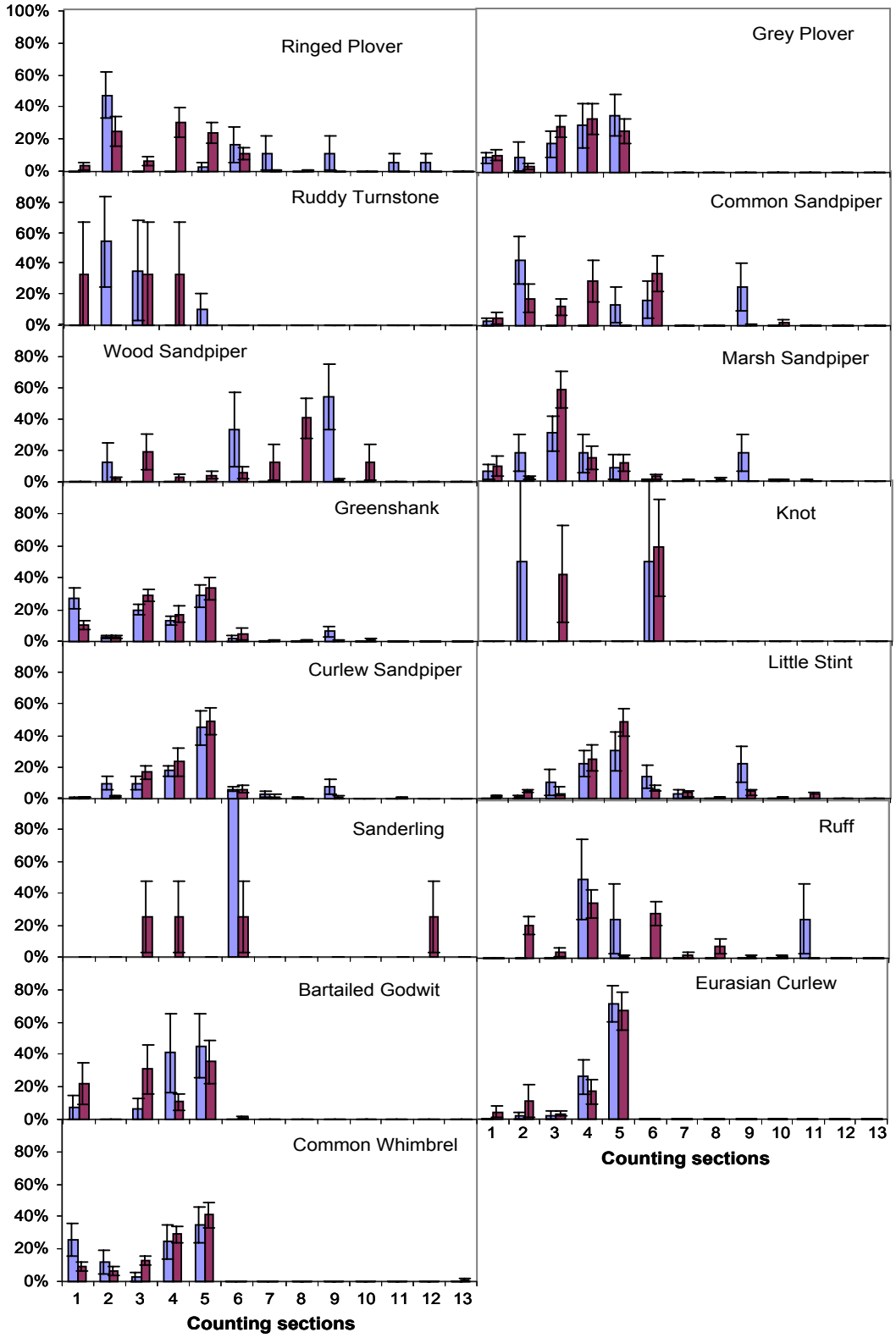


Figure 10.8 Percentage distribution of migratory waders along the estuary during winter (blue bars) and summer (red bars). Locations of the bird counting sections are shown in Figure 10.1

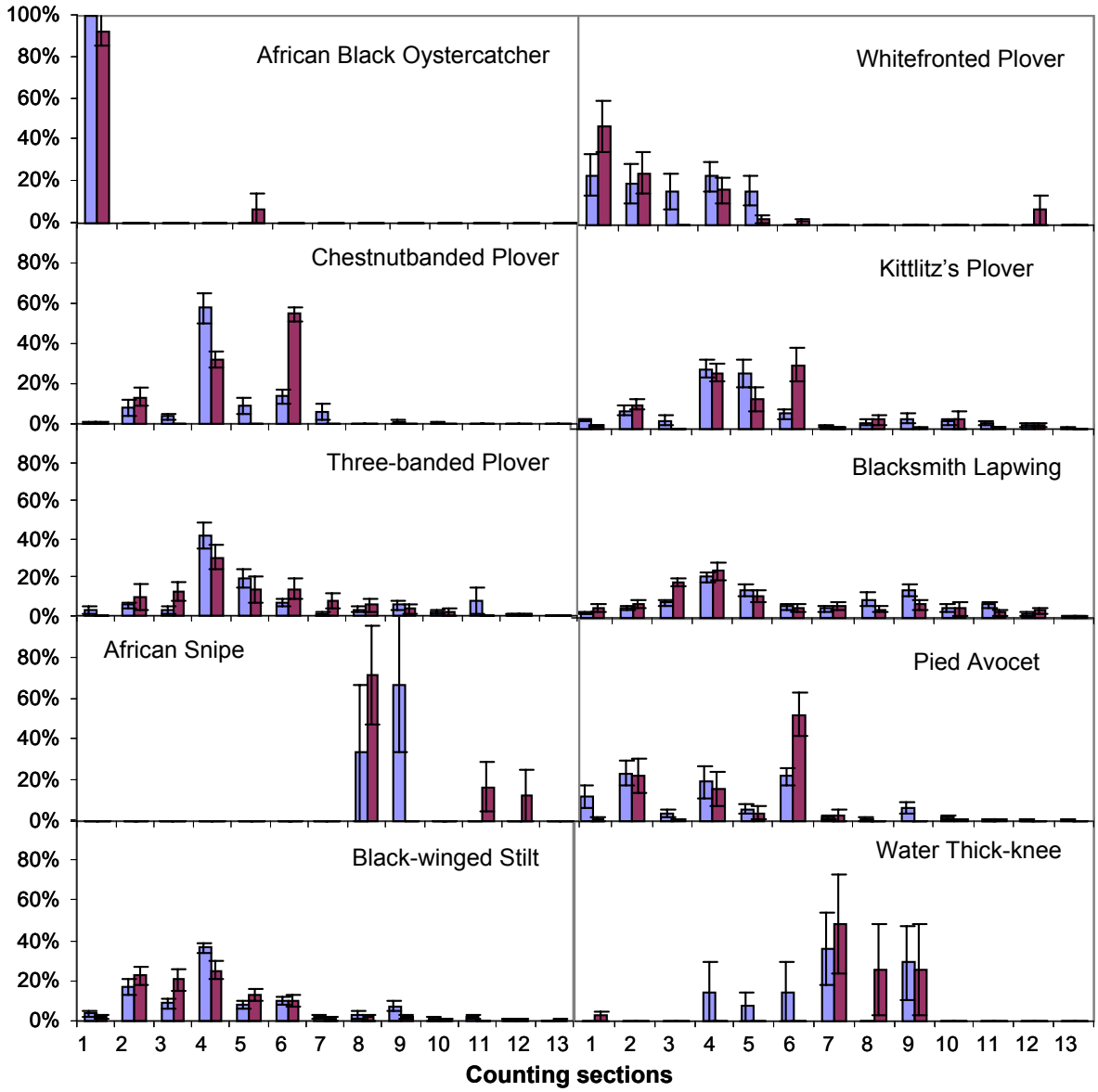


Figure10.9 Distribution of resident waders along the estuary during winter (blue bars) and summer (red bars). Locations of the bird counting sections are shown in Figure 10.1.

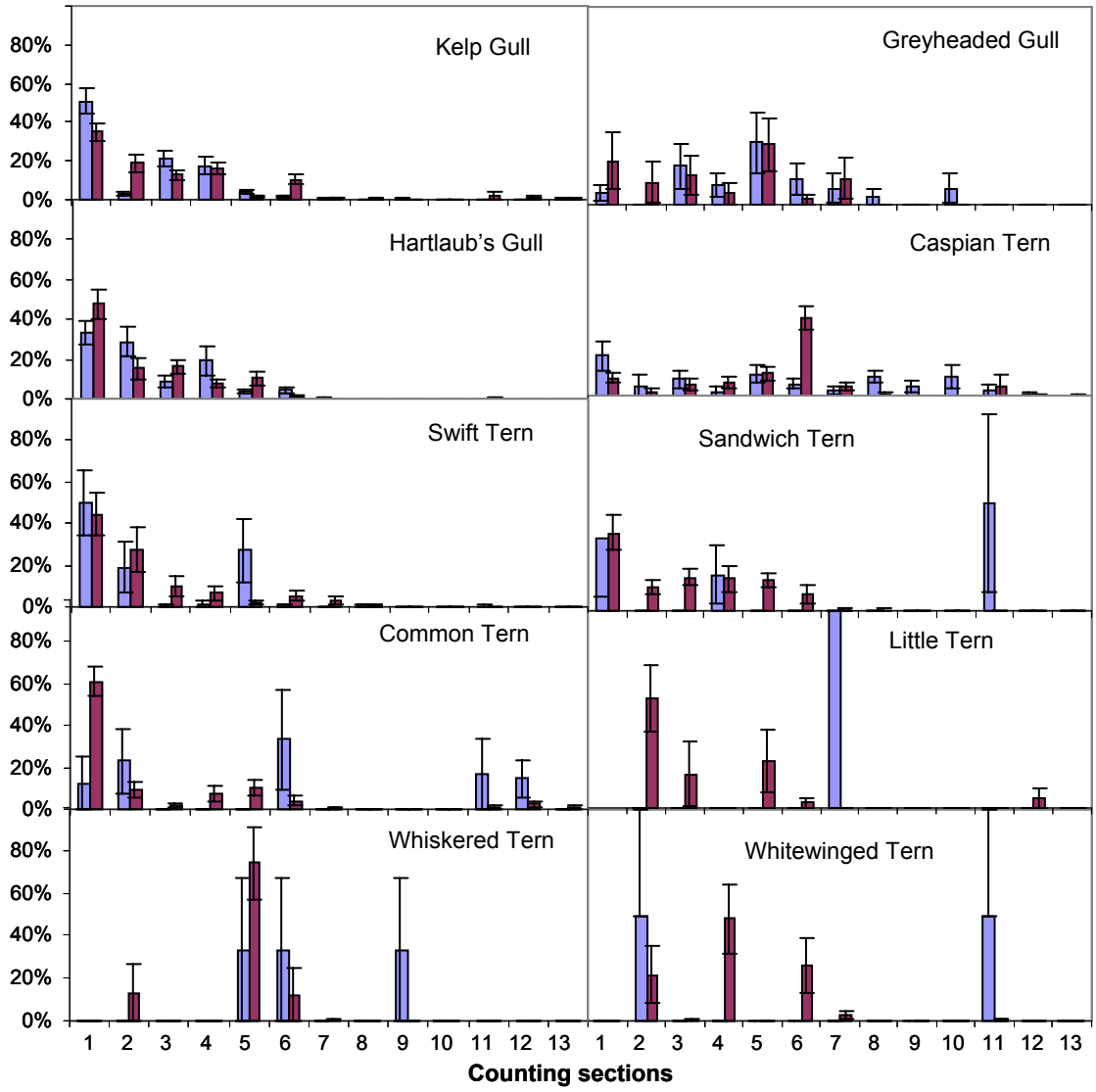


Figure 10.10 Distribution of gulls and terns along the estuary during winter (blue bars) and summer (red bars). Locations of the bird counting sections are shown in Figure 10.1

Some species distributed throughout the estuary tend to be more common in the upper estuary. These are mostly waterfowl, but also include African Fish Eagle, Moorhen and Wood Sandpiper (Table 10.6).

Very few species are confined to the upper estuary. These include Ethiopian Snipe, plus several species that are only occasionally recorded on the estuary, such as African Black Duck, Goliath heron, and Marsh Owl.

10.7.3 Community composition

Waders dominate the estuarine avifauna during summer, making up about 53 – 64% of bird numbers (Figure 10.11). Based on the December 1992 count, 89% of waders occurring in summer are Palearctic migrants and 57% of all birds on the estuary are migrants. Other numerically important groups during summer are the flamingos and ducks, and to a variable extent, pelecaniformes (cormorants, darters and pelicans).

Avifaunal composition is completely different in winter (Figure 10.11), with a far more even representation of taxonomic groups. The most dominant groups are flamingos, gruiformes, the latter numbers being dominated by Redknobbed Coots (99.4%), and waders (mostly resident species, but also the subadults of some migratory species), while ducks and pelecaniformes are also numerous.

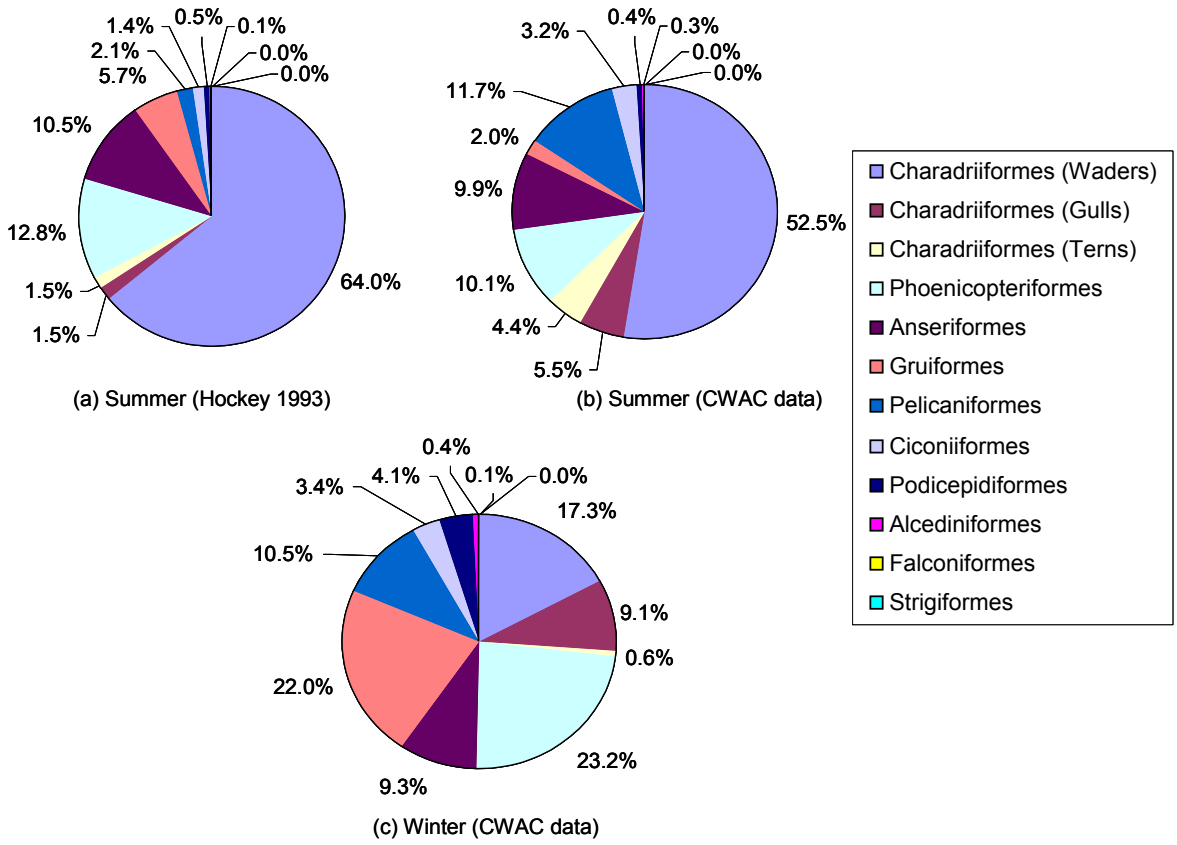


Figure 10.11 Percentage contribution of different orders of non-passerine waterbirds on the Berg River estuary during mid-summer (a) according to a more comprehensive count in 1992 and (b) according to CWAC counts, and (c) during mid winter (CWAC counts)

At a broad scale, there is marked spatial variation in bird community composition along the estuary. Multidimensional scaling analysis revealed four clear groups in terms of community structure (Figure 10.12). These corresponded to the mouth, lower estuary and upper estuary, and a fourth area adjacent to the railway line (site 13). The latter site contained less than 1% of the birds on the estuary, however. The mouth, lower and upper estuary contained 16%, 71% and 12% of the estuaries birds in summer and 17%, 66% and 16% in winter, respectively (based on CWAC count data).

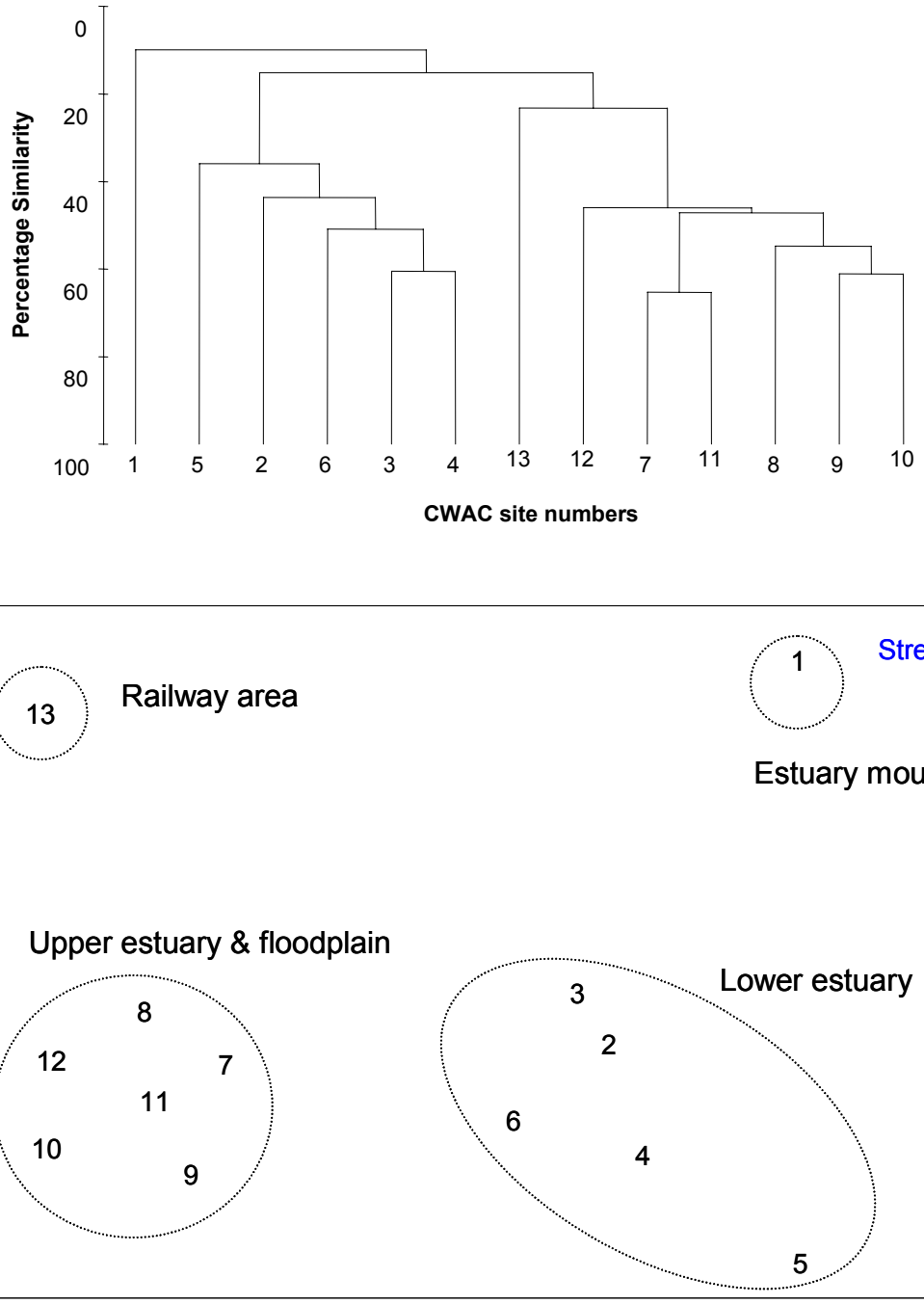


Figure 10.12 Similarity dendrogram and MDS plot showing grouping of counting sites based on community composition, using untransformed data.

The differences in community structure in the mouth, lower and upper estuary areas is shown in Figure 10.13.

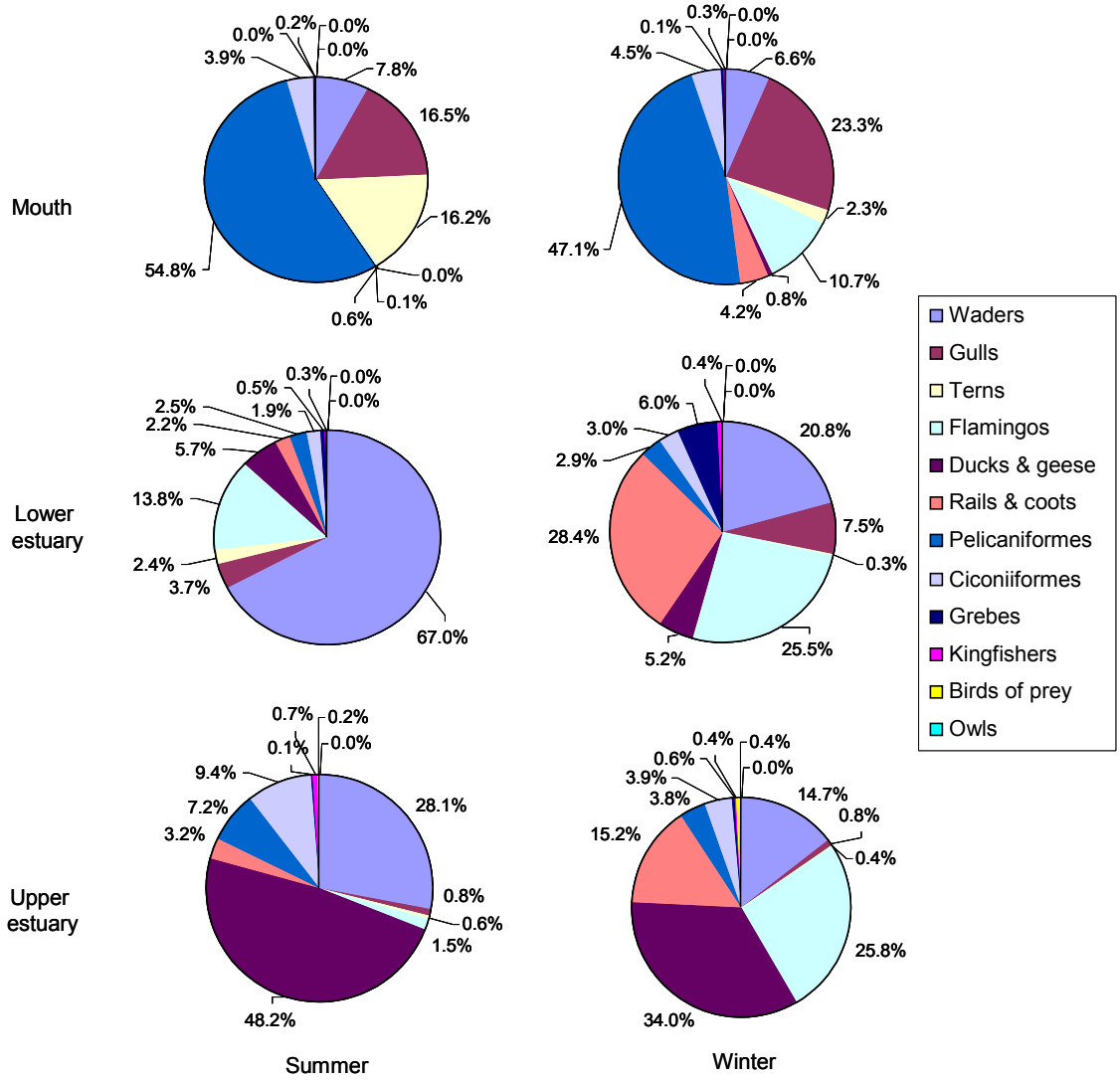


Figure 10.13 Percentage contribution of different orders of non-passerine waterbirds on different sections of the Berg River estuary during mid-summer and mid-winter, based on CWAC data (1994-2003).

In summer, the mouth area is dominated by cormorants (Pelicaniformes), terns and gulls (totalling 88%), plus a few egrets, ibises and waders. Terns are replaced by flamingos and coots in winter (Figure 10.13).

The lower estuary is dominated by waders during summer, with flamingos making up about 14% of birds. There is a high diversity of other groups but in relatively small numbers. Less than a quarter of the waders remain in winter (resident species plus immature migrants), while flamingos increase in number and large numbers of coots appear in the lower estuary. These three groups make up about three-quarters of birds (Figure 10.13).

While relatively few ducks and geese occur in the lower estuary, they make up nearly half of the birds counted in CWAC counts in the upper estuary during summer. Waders are also a dominant group, probably more so than indicated in Figure 10.13.

The pelicaniformes (cormorants, pelicans) and ciconiformes (herons, egrets, ibises, spoonbills) are far more prevalent in the upper estuary than lower sites. Both of these groups are found breeding in heronries in the upper estuary during summer, and their numbers drop dramatically in winter.

Numbers of ducks also drop slightly in winter, while flamingos and coots increase in abundance.

10.8 SEASONAL VARIATION IN ABUNDANCE AND RELATIONSHIP TO RIVER FLOW

10.8.1 Overall numbers

Detailed counts of the whole lower floodplain and estuary for the 12 months from March 2000 to February 2001 showed that there are marked seasonal changes in the abundance of many species. These patterns were largely echoed in the 2005-6 seasonal counts. However, comparison of the two sets of counts also shows some interesting variation.

In interpreting these figures it is first important to note the seasonal changes in rainfall and flow, and the fact that the two sets of counts were made during years of different levels of rainfall and flow. At least some of the seasonal variation, and the differences in these patterns between the two years, are thus likely to be flow related. The 2001-2 counts took place during a particularly dry year, whereas the 2005-6 counts took place in an average rainfall year (Figure 10.14). It must also be noted that local farmers reported that the extent of flooding in 2005, which covered the entire floodplain, was the highest they had seen in many years.

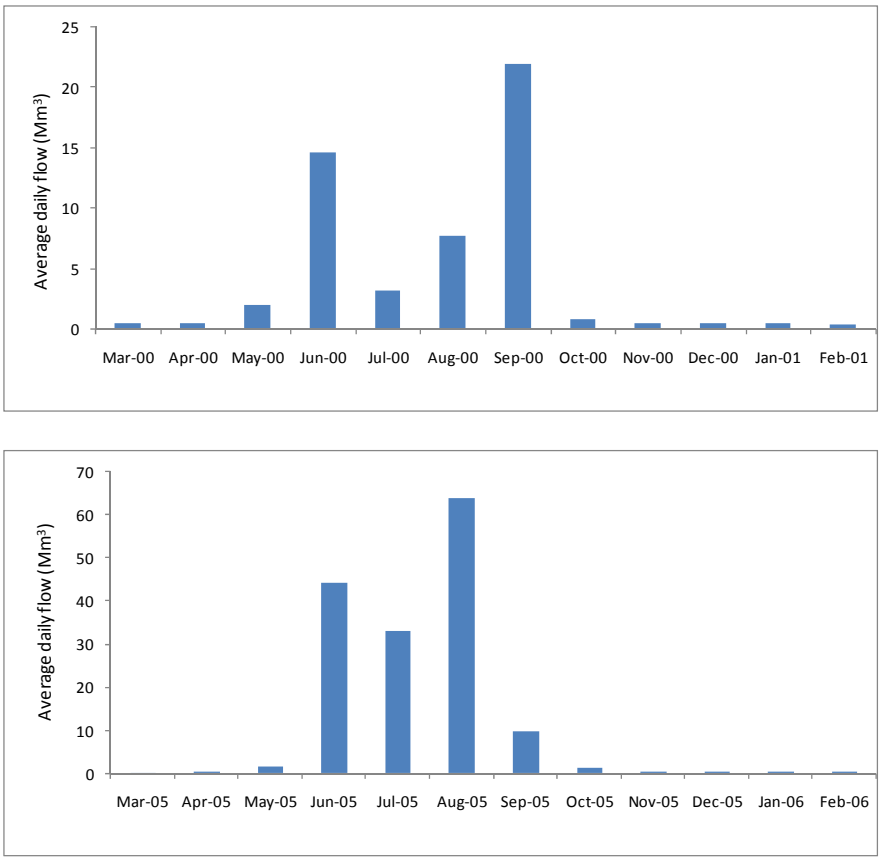


Figure 10.14 Measured monthly flow at Misverstand during the two years for which seasonal data were obtained (data from DWAF).

The seasonal variation in overall counts, counts of different groups and counts of individual species are compared between the two years in Figure 10.15, Figure 10.16 and in Figure 10.17 to Figure 10.20 respectively.

The 2001-2002 counts showed that total waterbird numbers on the estuary were highest during October-December and in March (Figure 10.15).

Numbers in spring peaked at over 25 000 birds, compared with about 15 – 20 000 birds in mid-summer. Similar results were found in this study, in which three additional counts were made during the spring months of 2005. Both counts showed that bird numbers tended to be higher in spring than in July or February counts when CWAC counts are normally carried out.

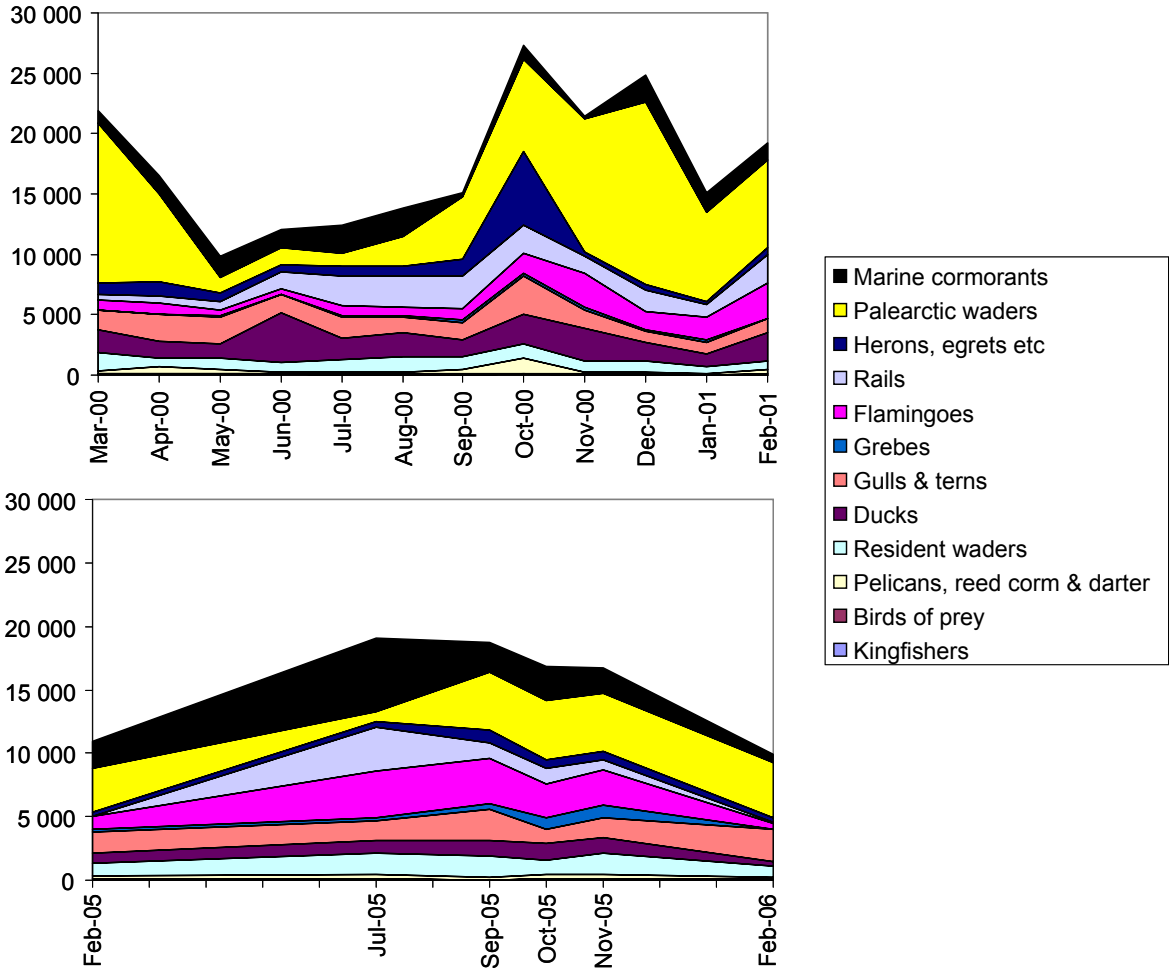


Figure10.15 Seasonal variation in numbers of waterbirds on the lower Berg River floodplain and estuary from Mar 2000 to Feb 2001 (raw data from G. Murison), and from Feb 2005 to Feb 2006 (this study). Only months for which count data were available are labelled.

In the 2001-2002 counts, total waterbird numbers were maximal in October, with high numbers persisting until December. The October peak was largely due to a massive influx of herons, egrets etc., to breed at the heronry. The December high was due to the arrival of large numbers of migratory waders. Their numbers were also high in March, just prior to northward migration in April. Minimum overall bird numbers were recorded in June to August, though numbers of rails (mainly Redknobbed Coot) were maximal during this period, and there was also an increase in the number of marine cormorants (mainly Cape Cormorant) during this period.

In the 2005-6 counts, overall numbers were highest in July, but this was mainly due to the very high numbers of marine cormorants. These have begun to move into the estuary (mainly around the mouth and salt works) as a roosting area, for unknown reasons. Apart from marine cormorants, numbers of birds peaked in September. Overall numbers in spring were far lower in 2005 than in 2000. This is probably at least partly due to the fact that the heronry may have been undercounted in 2005.

Overall bird numbers were also considerably lower in November 2005 than 2000, mainly due to much lower numbers of migratory waders. Numbers of migratory waders were also much lower in February 2005than 2001, though comparable in February 2006.

It is also interesting to note that the bird groups that peaked in October 2000 also peaked in September in 2005. The monthly flows in the two different years peaked one month earlier than the peak bird numbers, in September and August, respectively. While higher numbers of heronry birds could not really be compared, the numbers of some other groups, such as resident waders, were higher in 2005. This was probably linked to the greater extent of flooding in that year.

The majority of groups (Figure 10.16) and species (Figure 10.17 to Figure 10.20) showed consistency in their basic seasonal pattern between the two counting years. In many cases, similar seasonal patterns were observed, but the numbers of individual species differed by up to an order of magnitude (e.g. Black-necked Grebe, Eastern White Pelican, as well as heronry species such as Cattle Egret, for reasons described above).

The biggest seasonal changes are in the numbers of Palearctic migrant species. Their main influx is in September and October, although the first migrants arrive in August. Numbers of migrants peaked in December, and in 2001-2002 there was another peak in their numbers prior to northward migration in March. The majority of migrants departed in March and April, but immatures of certain species remained over the winter. There were far fewer migrants in 2005-6, with numbers no longer climbing after the early spring influx.

Resident wader numbers tended to peak in the winter months when most of the migrants are absent.

Waterfowl were more abundant during winter. Murison & Hockey (2002) reported that hundreds of waterfowl moved into the floodplain wetlands during 2000 at the usual time for the first winter flood, despite the lack of rainfall and flooding.

Resident gulls and terns tended to be more abundant in summer. The influx of juvenile Kelp Gulls during autumn suggested that the area is important as a post breeding habitat for this species (Murison & Hockey 2002). Swift terns are more abundant in winter, arriving to breed with Hartlaub's Gulls in colonies near the estuary mouth.

Heronry species fluctuated through the year but with a tendency for increased numbers in spring.

Numbers of flamingos, which do not breed at the estuary, did not show a consistent seasonal pattern and were far higher in the second period than the first. It is possible that the higher number of Greater Flamingos in the second period was linked to the greater degree of flooding of the floodplain.

Figure 10.17 to Figure 10.20 also show in which species the seasonal maxima are completely missed by the mid-summer and mid-winter counts because their numbers peak during spring. This appears to be the case for grebes, most ciconiiformes (herons, egrets etc), Egyptian Goose, South African Shelduck and most of the less abundant duck species, Avocet, and most migratory wader species.

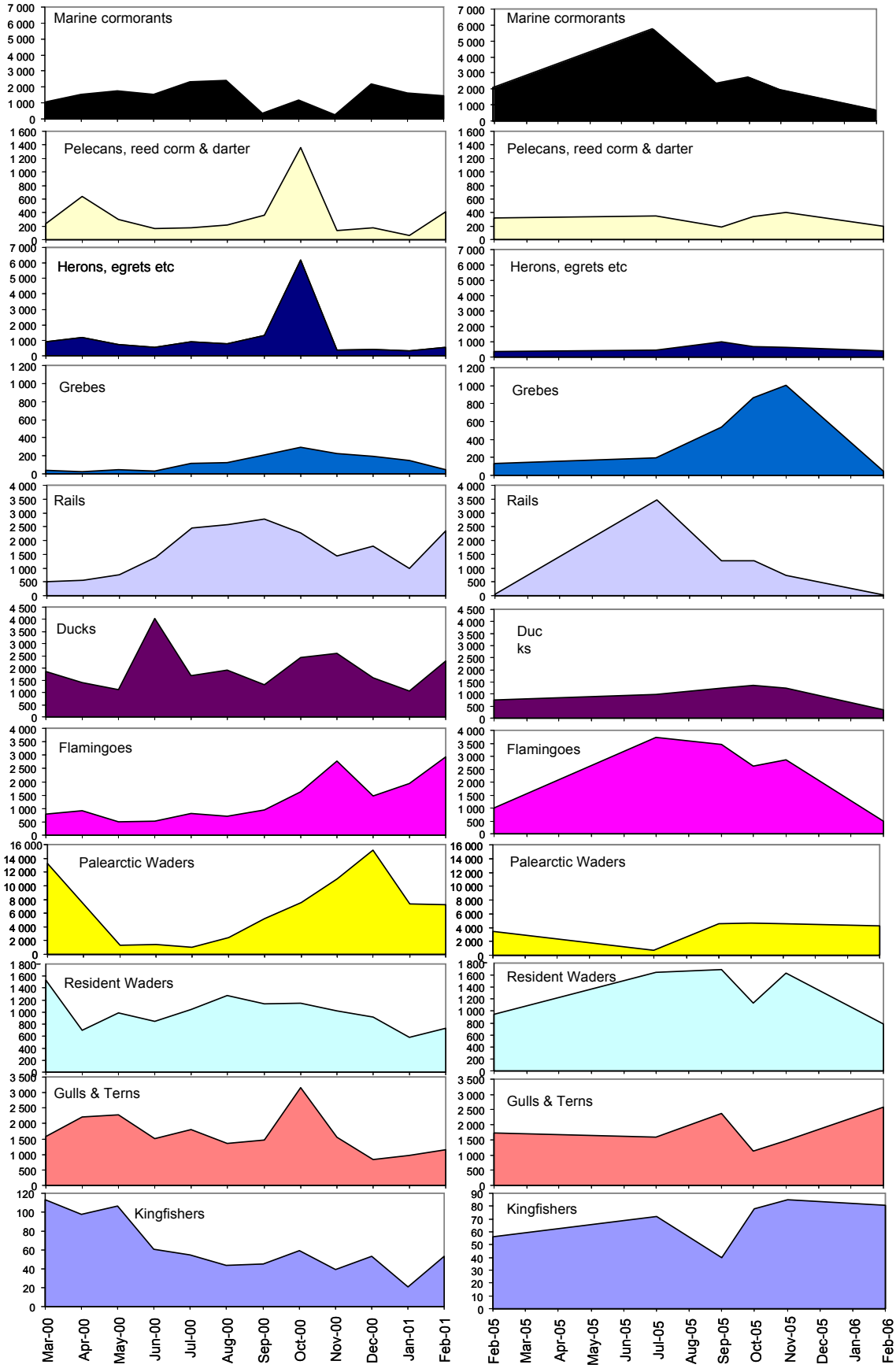


Figure 10.16 Seasonal variation in numbers of waterbirds by group. Data as above.

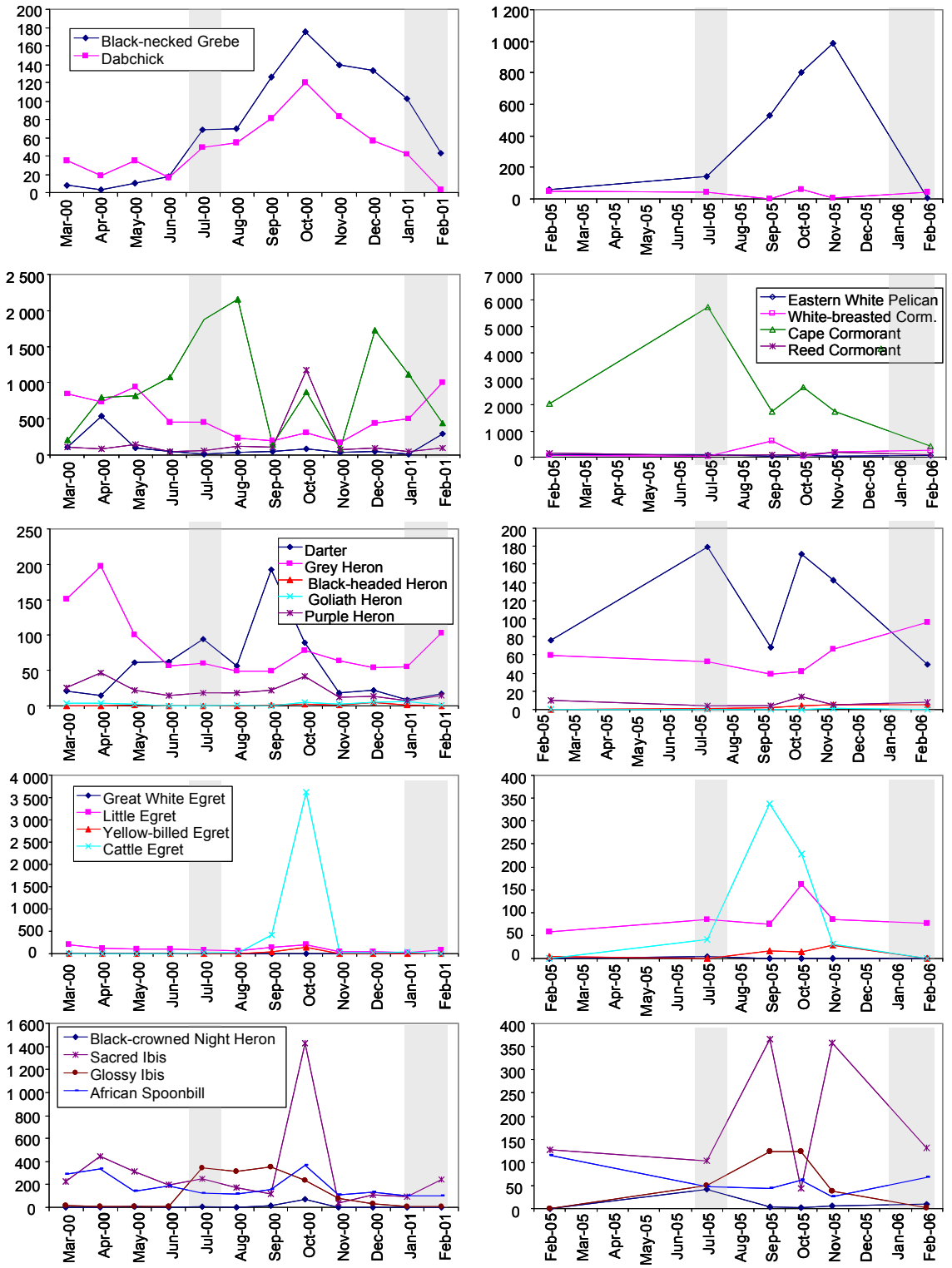


Figure10.17 Monthly count data showing seasonal changes in bird numbers during 2000/1 and 2005/6: Podicipediformes, Pelecaniformes and Ciconiiformes Source: G. Murison and this study.

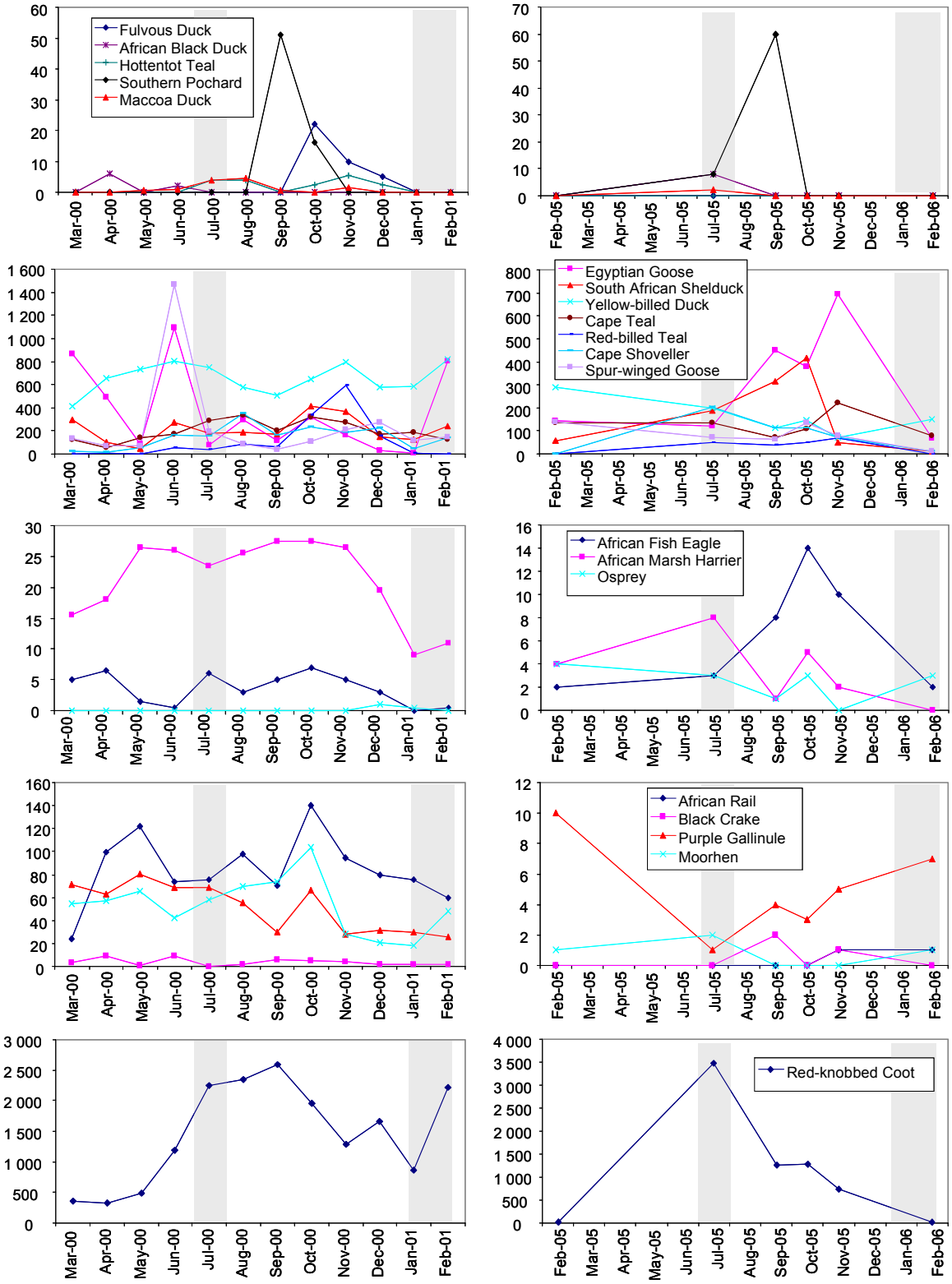


Figure 10.18 Monthly count data showing seasonal changes in bird numbers during 2000/1 and 2005/6: Anseriformes, Falconiformes and Gruiformes Source: G. Murison and this study.

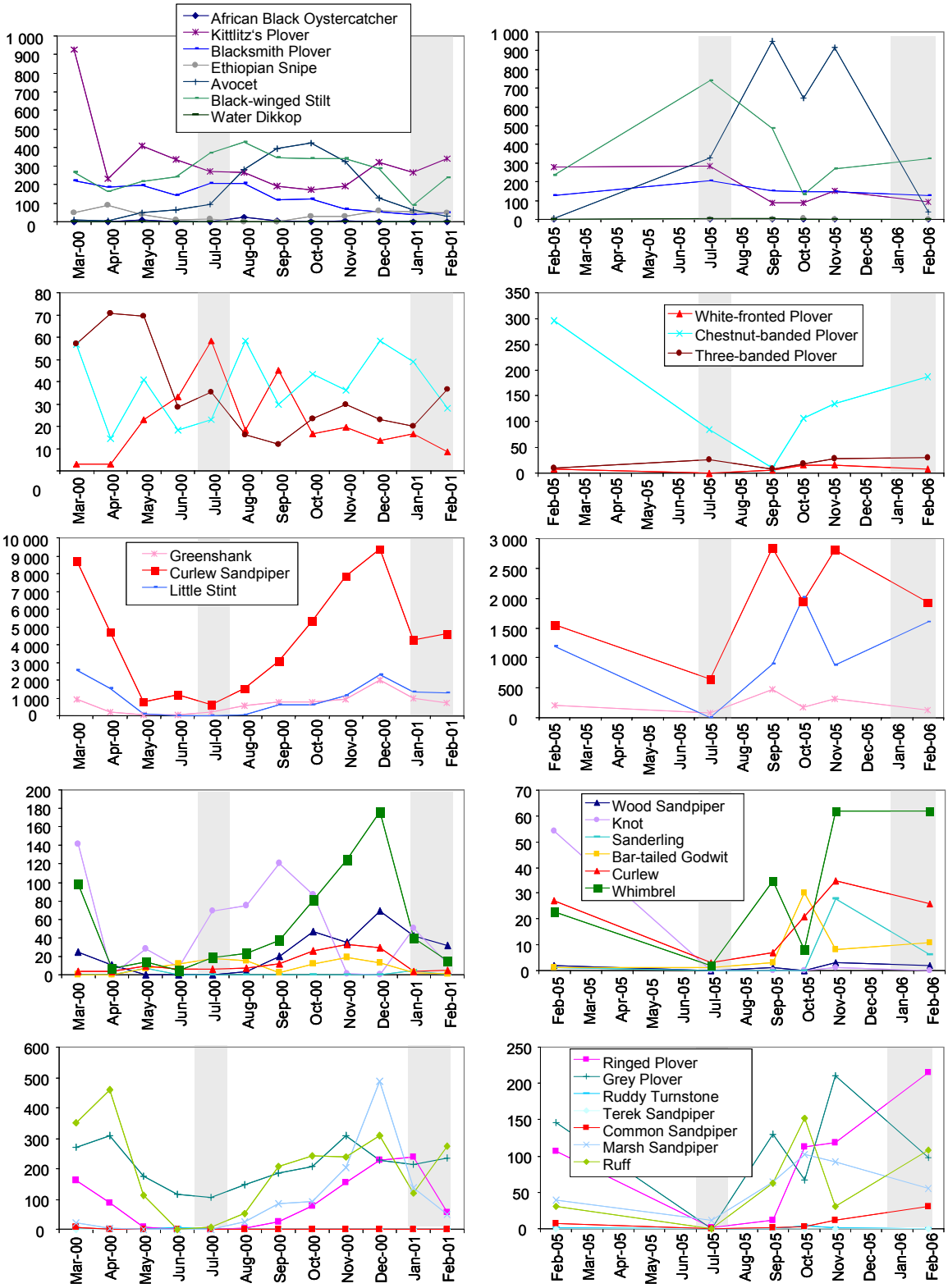


Figure 10.19 Monthly count data showing seasonal changes in bird numbers during 2000/1 and 2005/6: Waders (Charadriiformes). Source: G. Murison, JK Turpie

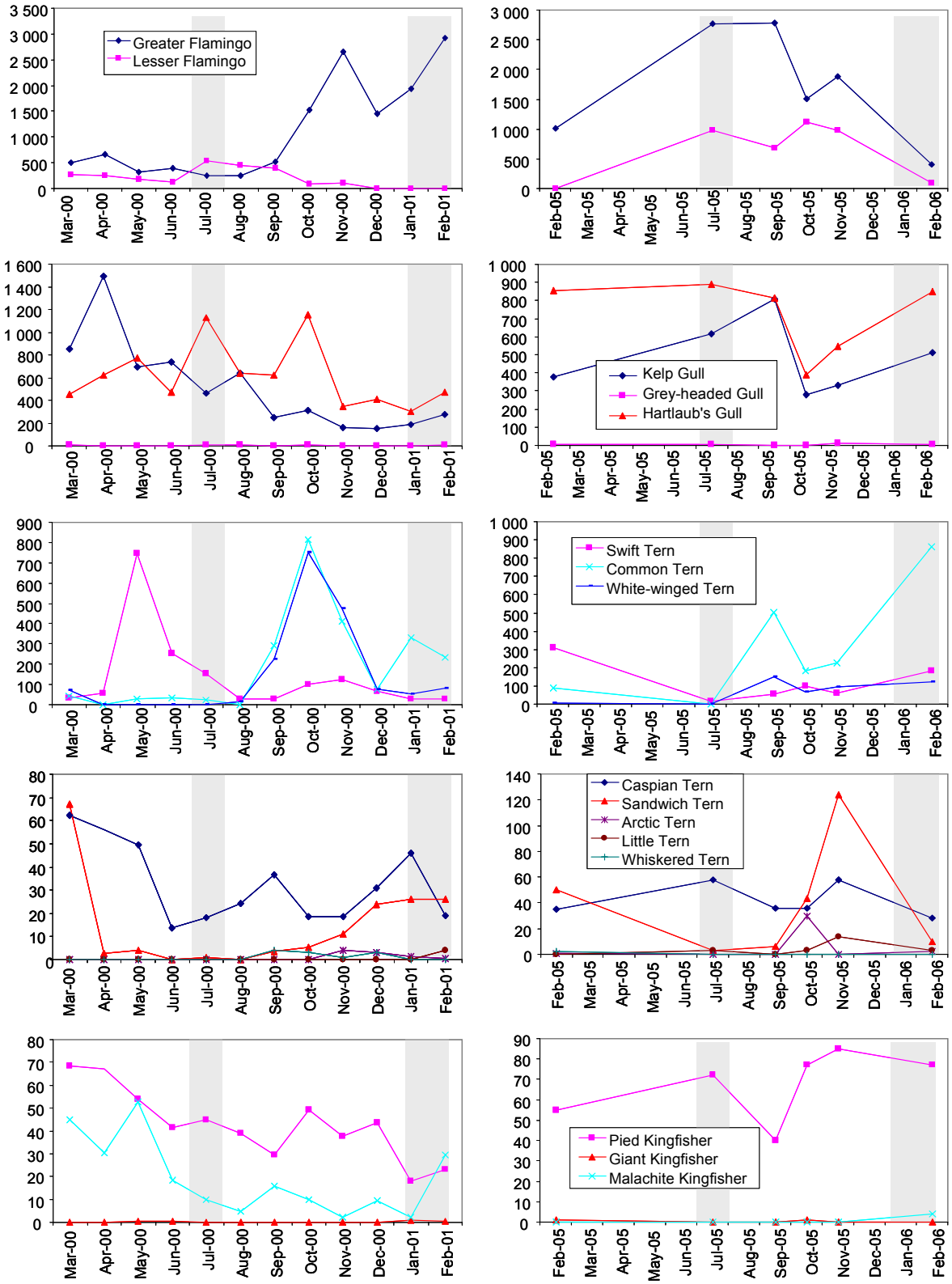


Figure 10.20 Monthly count data showing seasonal changes in bird numbers during 2000/1 and 2005/6: Flamingos (Phoenicopteriformes), gulls and terns (Charadriiformes) and kingfishers (Alcediniformes). Source: G. Murison and this study.

10.8.2 Comparison between estuary and floodplain wetlands

When broken down further, seasonal patterns differ substantially between the estuary and floodplain wetlands. Two studies have provided detailed seasonal counts for these areas (Velasquez *et al.* 1991, and Murison & Hockey 2002).

Their divisions are not strictly the division between estuary and the freshwater dominated floodplain, since the river and intertidal habitats above the road bridge are excluded from the estuary counts in both studies, and the river (which is strictly estuarine) is also included in Murison & Hockey's floodplain estimates (effectively the upper estuary and floodplain). This is not a major issue, however, and the separated analyses provide a very good picture of what happens seasonally in the estuary *versus* the floodplain.

Velasquez *et al*. (1991) described the seasonal variation in waterbird numbers in the *lower* part of the estuary, which is dominated by waders (Figure 10.21).

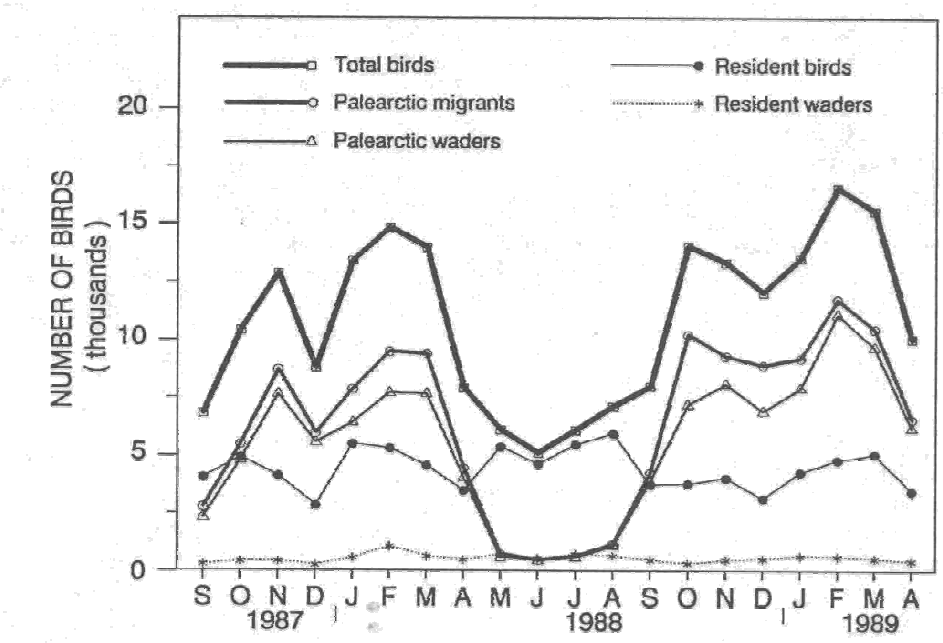


Figure 10.21 Seasonal variation in the numbers of resident and migrant waterbirds on the lower Berg River estuary, from Velasquez et al. (1991).

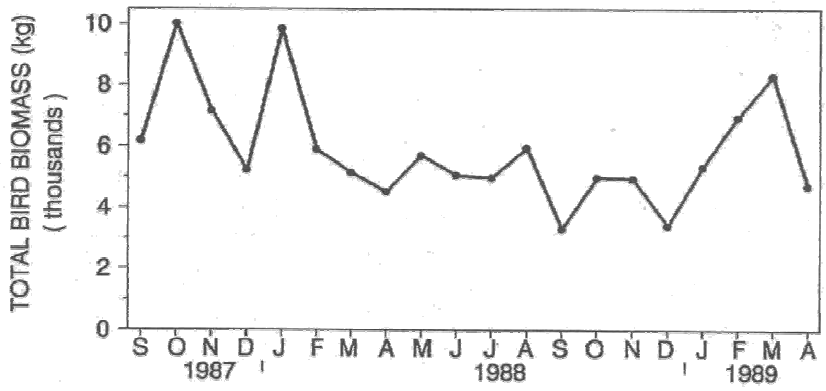


Figure 10.22 Seasonal variation in the biomass of waterbirds on the lower Berg River estuary, from Velasquez et al. (1991).

There were marked seasonal changes in overall bird numbers, mainly due to the influx of migrants in summer.

Most migratory birds arrived during September and October and departed in early April. Resident species tended to be more common in winter. Amongst the resident wader species, all but Avocets were most abundant in mid-winter.

Apart from Redknobbed Coots and Egyptian Geese which were more common in winter, waterfowl tended to be most numerous in summer. Most resident gulls and terns were also most abundant during summer, except for Kelp Gulls, some of which leave to breed elsewhere (Velasquez *et al*. 1991). Pelicans, egrets and herons tended to be more common in summer, but their numbers fluctuated greatly during the year (Velasquez *et al*. 1991). Interestingly, the variation in biomass did not correspond closely to the seasonal variation in numbers, although it also tended to be highest in the spring/summer months (Figure 10.22).

An analysis of the count data presented in Murison & Hockey (2002) clearly shows the difference in seasonal patterns observed on the lower estuary (taken as representative of the whole estuary) *versus* the upper estuary and floodplain (taken as representative of the floodplain) (Figure 10.23, Figure 10.24). Again, numbers on the estuary were strongly seasonal with a summer peak, mostly driven by the influx of migratory waders in spring and summer.

As with Velasquez *et al. (*1991), Murison & Hockey (2002) also recorded a mid-summer dip in migratory wader numbers. This could be due to birds moving on to other sites such as Langebaan Lagoon. This study shows that the movement is not onto the floodplain. Numbers of migratory waders pick up again as birds gather before the northward migration.

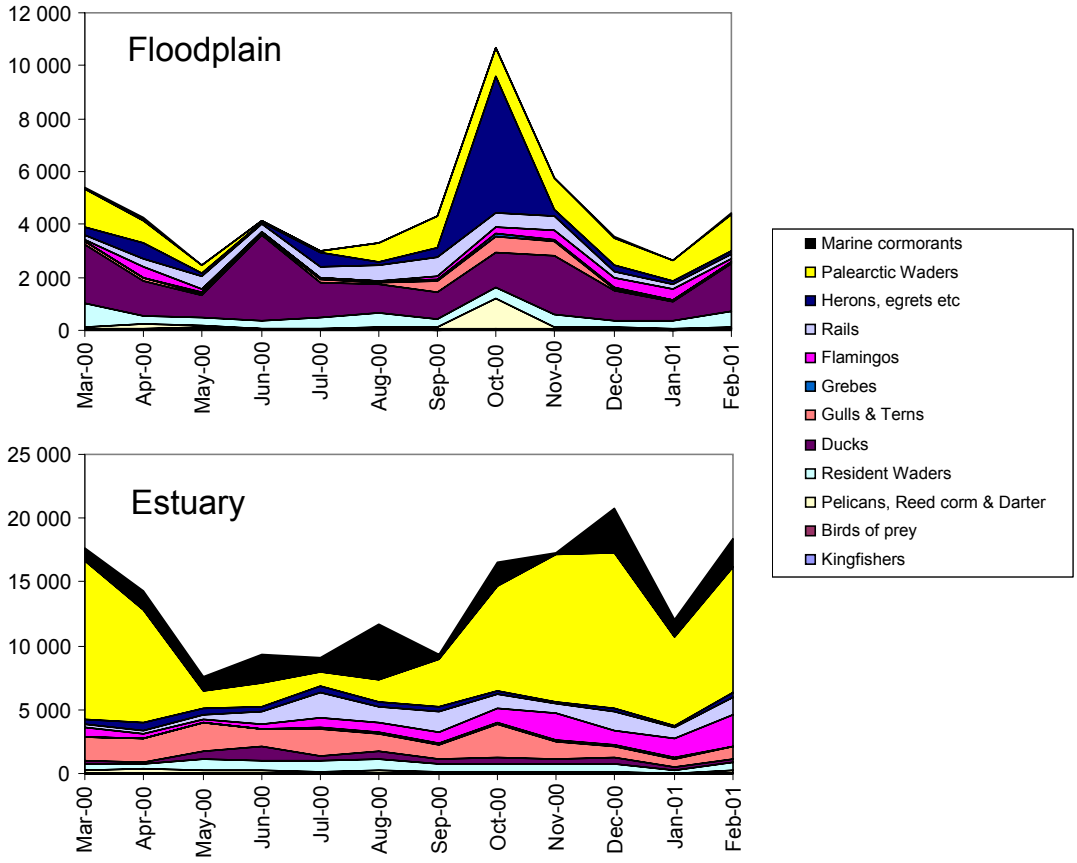


Figure 10.23 Numbers of birds counted on the lower estuary and on the upper estuary and floodplain over a one year period (Source: Murison & Hockey 2002).

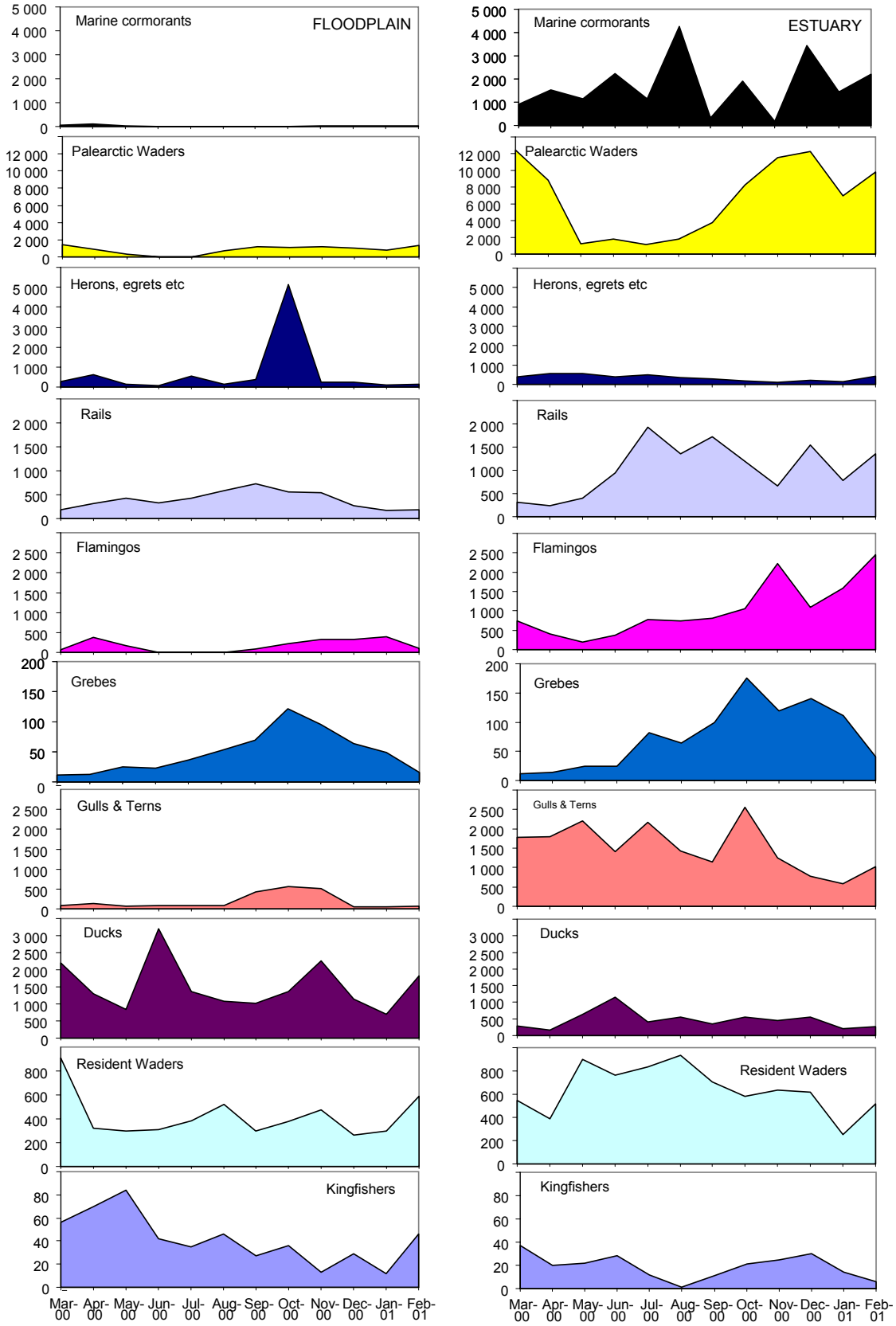


Figure 10.24 Seasonal changes in the numbers of different groups of birds on the lower estuary (including mouth) and the upper estuary and floodplain.

Marine cormorants remain on the lower estuary, mostly near the mouth, and their numbers peak during winter and mid-summer. Herons, egrets, ibises, spoonbills and the remaining pelicaniformes (the pelicans, reed cormorants and darters), are most abundant on the floodplain during spring. Although some birds clearly move away from the estuary at this time, presumably to breed, the vast majority of breeding birds apparently arrive from other areas. For the rest of the year, the population of these birds is relatively constant.

The migratory waders are very strongly seasonal on the estuary, with very low numbers occurring in winter and very high numbers in summer. In contrast, their abundance on the floodplain shows very little seasonal variation, apart from a virtually complete absence in early winter. This suggests an upper limit to the suitability of floodplain habitat for these birds. Indeed the floodplain only provides favoured feeding conditions for a few of these species. The resident waders show an apparently inverse seasonal pattern between the floodplain and estuary. Numbers are highest in the estuary during winter, and lowest during summer, while apparently moving onto the floodplain during summer. Kittlitz's plovers arrived on the floodplain before the estuary, demonstrating a preference for the floodplain.

Rail numbers (mainly Redknobbed Coot) are seasonal in both the floodplain and estuary, peaking in winter, though numbers are considerably higher on the estuary. All the rails on the estuary are Redknobbed Coots, whereas the other rail species are predominantly found in the floodplain (Figure 10.25). The latter species are not seasonal in their abundance.

Kingfishers do not follow strongly seasonal trends, but were counted in higher numbers on the floodplain in April-May. Other resident piscivores such as Fish Eagles are largely constant, though only sporadically counted.

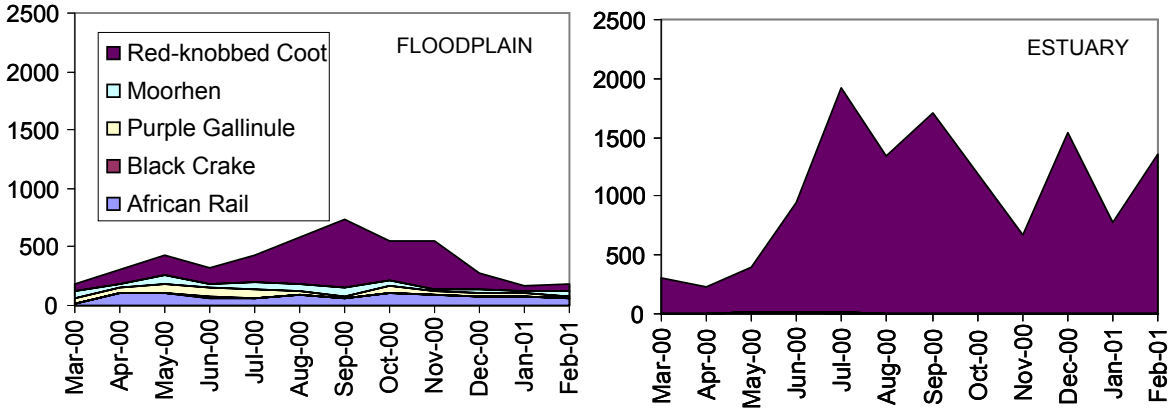


Figure 10.25 Composition of rail species on the floodplain and estuary over a 12-month period.

Flamingos are predominantly found in the lower estuary, but this is mainly in the artificial salt pans. There were no flamingos in the floodplain during winter, but they moved into the floodplain after the pans were flooded. The relative numbers in the two areas suggests that the floodplain was not particularly important for flamingos in 2001-2, but this was a dry year (see above). Also note that overall seasonality was not repeated in 2005-6.

Grebes followed a similar seasonal trend both in the estuary and floodplain.

Gull and tern numbers were erratic in the estuary, and only showed a clear seasonal pattern in the floodplain, in that small numbers of gulls are found in the floodplain only during spring. Numbers of ducks increase generally during autumn. The seasonal pattern is similar in the estuary and floodplain, but much more pronounced on the floodplain.

10.9 INTER-ANNUAL VARIATION IN ABUNDANCE AND RELATIONSHIP TO FLOW

10.9.1 Trends in flow

Counts of birds have been made over the past 20 years. Since this study is particularly concerned with the possible links between bird abundance and flow, it is useful to examine how flow has varied over this time. Measured flow data for the period 1992 to 2006 are shown in Figure 10.26. Peak flow years were in 1996 and 2001, corresponding with peak rainfall years (2523 and 2091 mm at Franschoek, respectively). 2002 and 2005 were also years of relatively high flow over this period.

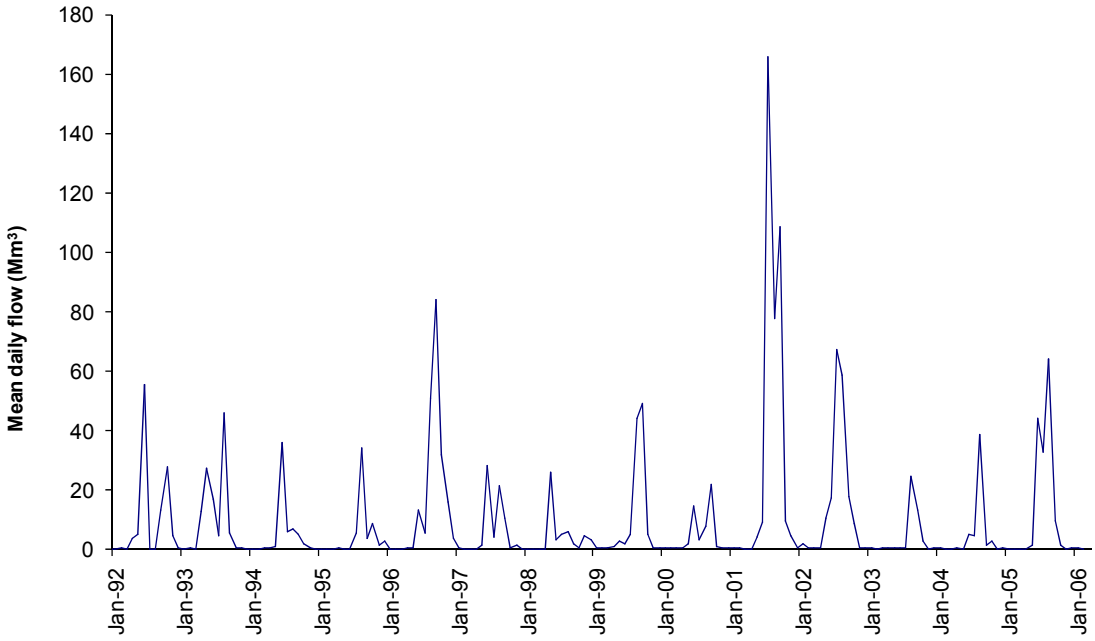


Figure 10.26 Pattern of monthly flows into the Berg River estuary from 1992 to 2006, measured at Misverstand (Data from DWAF).

10.9.2 Trends in overall bird numbers

There is substantial inter-annual variation in the number of birds recorded on the estuary, some of which is natural and some of which is an artefact of counting methods. There is roughly equal variation in the summer and in the winter counts (Figure 10.27). Counts may be affected to some extent by their timing, e.g. January vs. February. In general, the count data suggest that there is no increasing or decreasing trend in overall bird numbers on the estuary.

Apart from an anomalous count of over 45 000 birds by Hockey (1993; see discussion below), a maximum of about 19 500 non-passerine waterbirds[4] has been recorded during mid-summer and mid-winter counts on the Berg River estuary over the period from September 1987 to February 2006 (Figure 10.27).

Summer and winter counts average 13 540 and 12 300, respectively, or 12 320 and 10 715, respectively if marine cormorants are excluded.

These counts are much lower than the maximum of 27 470 birds (or 26 295 without marine cormorants) recorded by Murison & Hockey (2002) during spring 2001, though closer to the maximum of 19 060 recorded in spring during this study.

[4] This excludes exotic species and vagrants as well as passerines.

All of the CWAC summer counts took place between 16 January and 8 February. By this time the floodplain wetlands are usually quite dry. Thus it is reasonable to conclude that the CWAC counts consistently underestimate the total numbers of birds that use the estuary and floodplain.

It is noteworthy that they also provide a different picture of community structure which reflects a drier floodplain. Nevertheless, as long as the CWAC counts are carried out in a consistent manner, they can be useful in detecting trends in composition and abundance.

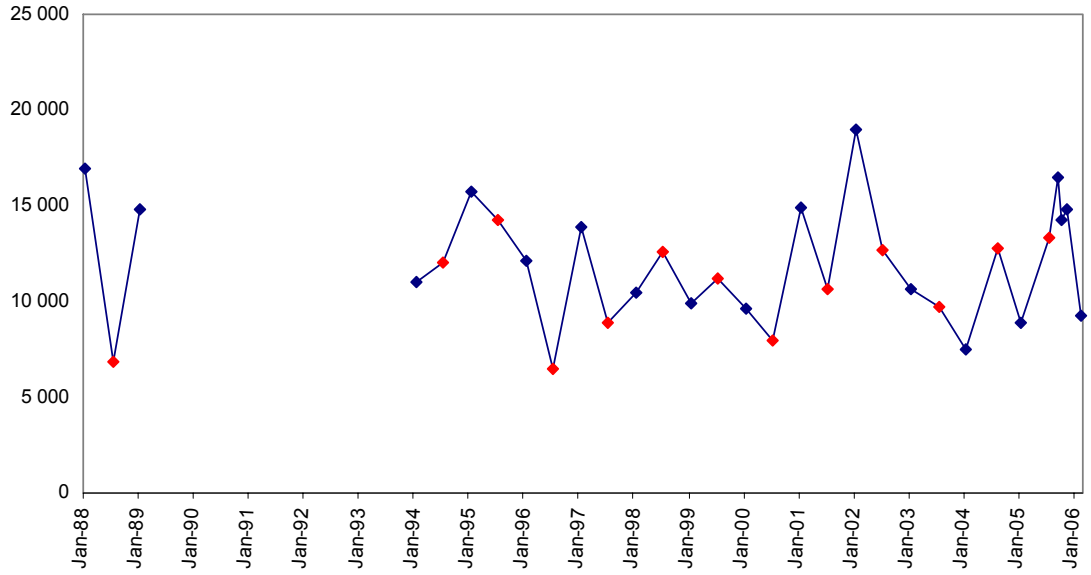


Figure 10.27 Total numbers of waterbirds (excluding marine cormorants) counted on the Berg River estuary during mid-summer and mid-winter counts. CWAC counts begin in Summer 93/94. Preceding counts are from Velasquez et al. (1991). Mid-winter counts are marked red.

10.9.3 Was the 1992 count an anomaly?

Hockey (1993) recorded over 45 000 birds in a December 1992 count, far higher than other counts of the estuary. The very high discrepancy between this and other counts required some investigation. It is also noteworthy that there is no significant difference between the counts of 1987-9 and the CWAC counts, in spite of the fact that the former only counted the lower estuary (sections 1-5). A comparison of CWAC data and the Hockey (1993) count data reveals that there is little or no discrepancy in numbers of species that are largely restricted to mudflats, saltmarshes and saltpans in the lower estuary, while there are large discrepancies in the numbers of birds that occur predominantly in the floodplains, or in both areas (Table 10.7). Numbers of Redbilled Teal and Avocet were more than 25 times the average for other counts, while numbers of Cape Shoveller and Southern Pochard were more than 10 times the average. All of these are species typical of freshwater wetlands and floodplain environments. Ruff, a wader typical of open and low sedge pans was also far more common in the 1992 count. Counts of some fairly cryptic floodplain species that needed to be flushed from the floodplain marshes, such as Marsh Owl, Ethiopian Snipe and African Rail were 5 to 10 times the average.

Among species that are common in both floodplain and intertidal habitats, the largest discrepancies occurred for Curlew Sandpiper and Little stint, which were over 4 times as numerous. However, part of this was due to very much larger than usual counts on the mudflat areas, which indicates that it might have been a particularly good breeding year for arctic breeders.

There were much smaller discrepancies in the numbers of species that are typically confined to habitats of the lower estuary, such as Whimbrels, Greenshank, gulls and terns, or of species that occur conspicuously in the upper parts of the estuary, congregating in known breeding colonies along the riparian marshes, such as herons, egrets and ibises.

Table 10.7 A comparison of the December 1992 count with the mean of all other summer counts of waterbird species on the Berg River estuary, for species with a mean count > 20.

Species	Mean	Dec 92	Ratio	Species	Mean	Dec 92	Ratio
Black-Necked Grebe	29	218	7.4	Kittlitz's Plover	372	213	0.6
White Pelican	124	92	0.7	Grey Plover	166	471	2.8
Whitbreasted Cormorant	298	59	0.2	Blacksmith Plover	170	225	1.3
Cape Cormorant	1 089	618	0.6	Marsh Sandpiper	75	127	1.7
Reed Cormorant	128	135	1.1	Greenshank	316	482	1.5
Darter	37	43	1.2	Curlew Sandpiper	4 137	16 881	4.1
Grey Heron	67	38	0.6	Little Stint	1 127	6 428	5.7
Little Egret	69	112	1.6	Ruff	127	1 087	8.6
Sacred Ibis	185	88	0.5	Curlew	22	6	0.3
African Spoonbill	91	294	3.2	Whimbrel	43	72	1.7
Greater Flamingo	1 186	3932	3.3	Avocet	87	2 273	26.1
Lesser Flamingo	275	1890	6.9	Blackwinged Stilt	254	518	2.0
Egyptian Goose	236	764	3.2	Kelp Gull	320	141	0.4
S African Shelduck	240	192	0.8	Greyheaded Gull	54	1	0.0
Yellowbilled Duck	334	281	0.8	Hartlaub's Gull	412	532	1.3
Cape Teal	252	1272	5.0	Caspian Tern	41	36	0.9
Redbilled Teal	42	1182	28.3	Swift Tern	46	90	2.0
Cape Shoveller	48	603	12.5	Sandwich Tern	98	365	3.7
Spurwinged Goose	272	473	1.7	Common Tern	406	144	0.4
Redknobbed Coot	275	2577	9.4	Whitewinged Tern	28	39	1.4
Ringed Plover	159	211	1.3	Pied Kingfisher	47	67	1.4
Chestnutbanded Plover	55	45	0.8				

Apart from the Curlew Sandpipers and Little Stints, the discrepancies lie mainly in the floodplain counts. It is possible that the CWAC counts underestimate the total number of birds on the estuary, mainly due to undercounting of the floodplain, that the Dec 1992 count was an overestimate, that conditions on the floodplain in Dec 1992 were extraordinary. It is probable that the discrepancy is due to a combination of these factors.

The December 1992 count involved a team of counters (including JKT) working with large aerial photographs of each section of the estuary and floodplain, making sure that no pans were missed on floodplain.

Many of the pans would probably not have been located on foot if it were not for the use of these photographs. Counting effort in the CWAC counts is similar in terms of manpower (using amateurs instead of professionals is probably not a major factor), but detailed maps are not used.

In the December 1992 count, tall marshes were counted using a transect method, from which numbers were extrapolated, but it was considered that the technique provided a conservative estimate of marsh populations (Hockey 1993).

A third possibility is that the conditions on the floodplain were far more favourable to waterbirds in December 1992 than they normally are during CWAC counts. Indeed, an analysis of rainfall and flooding data suggest that this could be the case.

The rainfall in the catchment (Franschoek) in 1992 was the second highest since 1980, being 2478 mm compared with an average of 1918 mm.

Furthermore, the floods came particularly late in 1992 (Hockey 1993), which meant that the floodplain still had plenty of water by the time they were counted in early December (pers. obs.). The December 1992 count thus could have resembled a spring count for the upper estuary, when bird numbers on the floodplain are likely to be at their peak. However, even this was high relative to subsequent spring counts. Thus it is probable that the discrepancy is partly due to the unusual flood conditions of 1992, coupled with the earlier timing of the count, but counting methods are likely to have played some role.

10.9.4 Variation in abundance of individual species

Although there are no discernable trends in overall abundance, certain species appear to show some pattern. Trends in the winter and summer counts of each species are shown in Figure 10.28 to Figure 10.31.

Certain species have shown a steady or recent increase in numbers since 1988. These include: Cape Cormorant, Darter, Grey Heron and Hadeda Ibis, as well as Pied Avocet, Knot and Black-crowned Night Heron. Others have decreased steadily or in recent years. This is apparent for Egyptian Goose, Yellowbilled Egret, Southern Pochard, African Rail and possibly Common Moorhen. Numbers of some wader species also appear to have decreased, including Ruddy Turnstone, Ruff, Bartailed Godwit and the resident White-fronted Plover.

It appears that some birds may have been affected by the “black tide” event of 1994 which resulted in large fish kills. Numbers of piscivores such as Reed Cormorant and Darter were particularly low the following summer, African Fish Eagle disappeared altogether, and numbers of Little Egret and Purple heron were also depressed. However, this pattern can also be observed for species such as Egyptian Goose and Spurwinged Goose, and may have been influenced by the relatively low rainfall in the preceding season.

Wader numbers are highly variable. In the case of migrants, this is at least partly due to variability of success on their distant breeding grounds.

In general, the numbers of waterbirds are influenced not only be local conditions but by conditions in surrounding wetlands and coastal areas. The numbers of birds on the Berg River depend not only on the source pool of birds but on the relative attractiveness of the Berg in relation to other available habitats. It is believed that there is considerable movement between the Berg and Langebaan Lagoon, for example, although this has not been proven.

Several floodplain species such as Egyptian Goose, South African Shelduck, Yellowbilled Duck and Spurwinged Goose showed marked increases in numbers in the high flow years, probably because some of the lower pans remained inundated by the time of the summer CWAC counts in those years. Another noticeable trend is that the numbers of several piscivorous species such as White Pelican, Reed Cormorant and even Cape Cormorant are particularly high in high-rainfall years.

Other birds that followed this trend include African Spoonbill, Sacred Ibis, and Glossy Ibis. The only wader to show this trend was the Knot, possibly because of their use of open pans.

In addition, large numbers of Greyheaded Gull were recorded after the 1996 floods, whereas they are usually not recorded on the Berg River estuary. Whitewinged terns were numerous after the 1996 floods, and Whiskered Terns were more numerous after the 2001 floods. The remaining species appear to be little affected by flow levels *per se*.

While a number of positive correlations were found with flow, most of these relationships were weak, due to the high level of variability. It is likely that there would be a greater correlation with extent of flooding each year (which is not necessarily strongly related to the size of the flow peak – see Beck & Basson 2007 – Chapter 2 for details on this), but these data are not available for the corresponding time series.

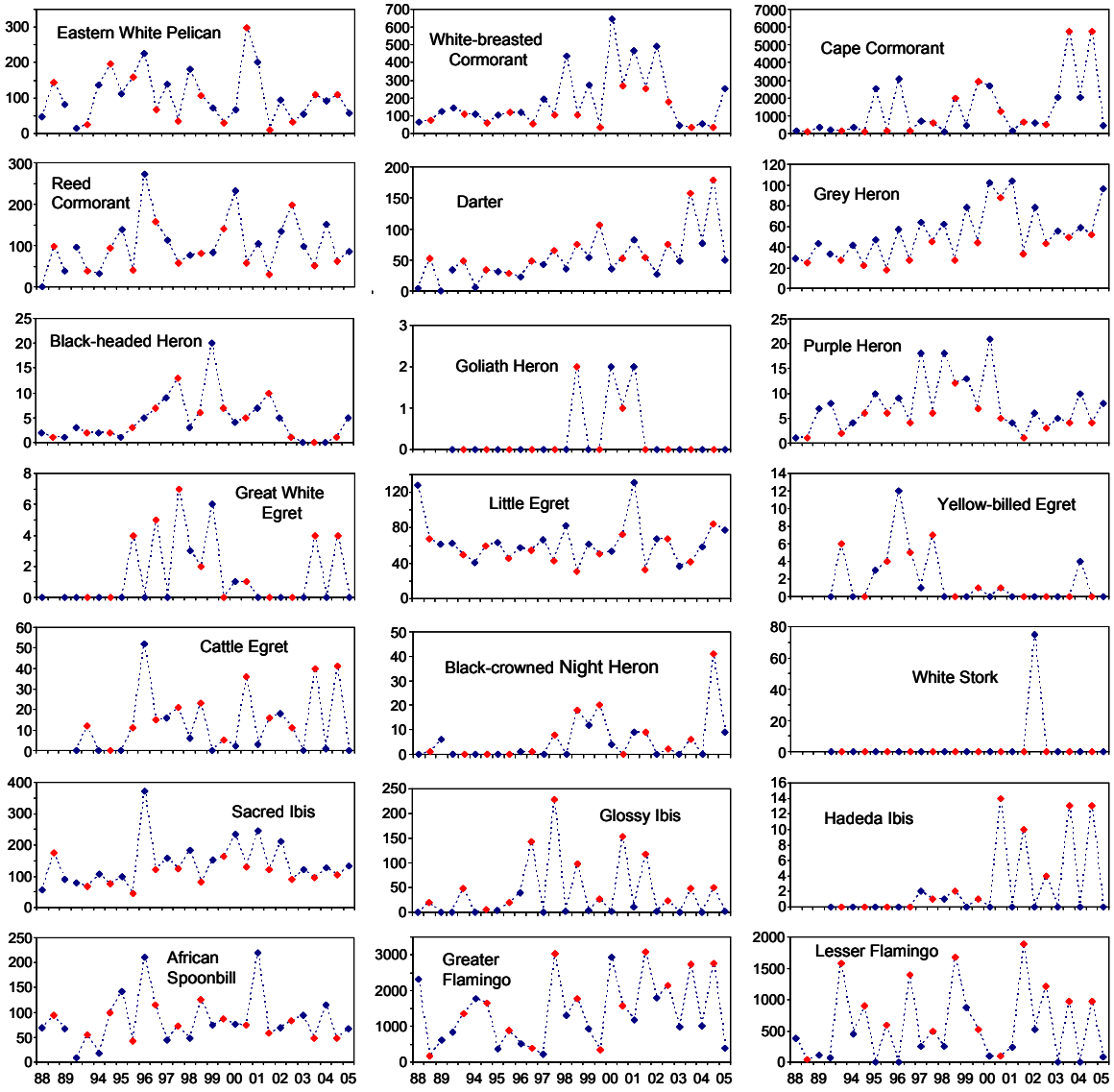


Figure 10.28 Interannual variation in the summer (blue) and winter (red) numbers of pelicans, cormorants, darters, herons, egrets, ibis, spoonbills and flamingos.

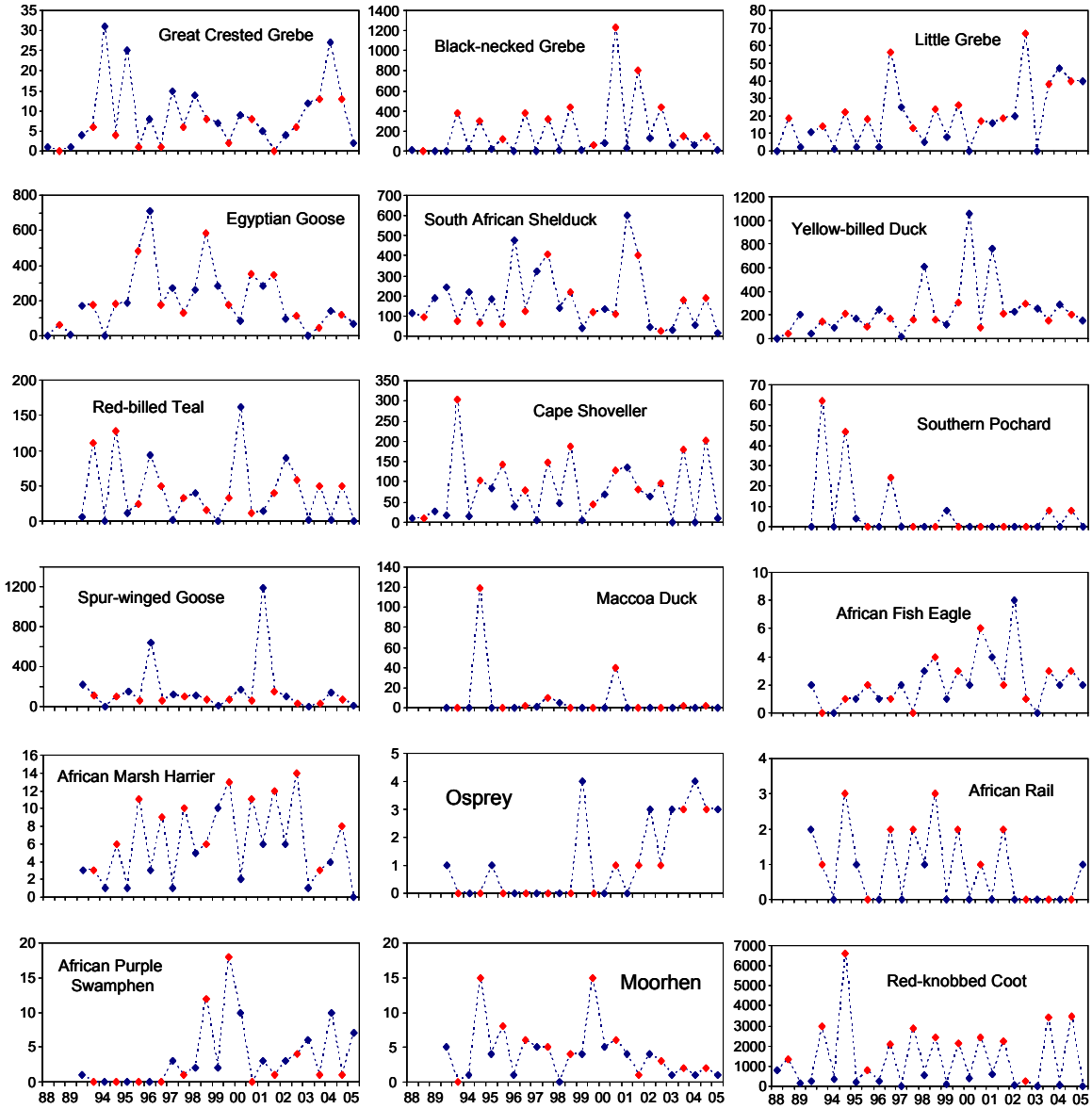


Figure 10.29 Interannual variation in the summer (blue) and winter (red) numbers of waterfowl.

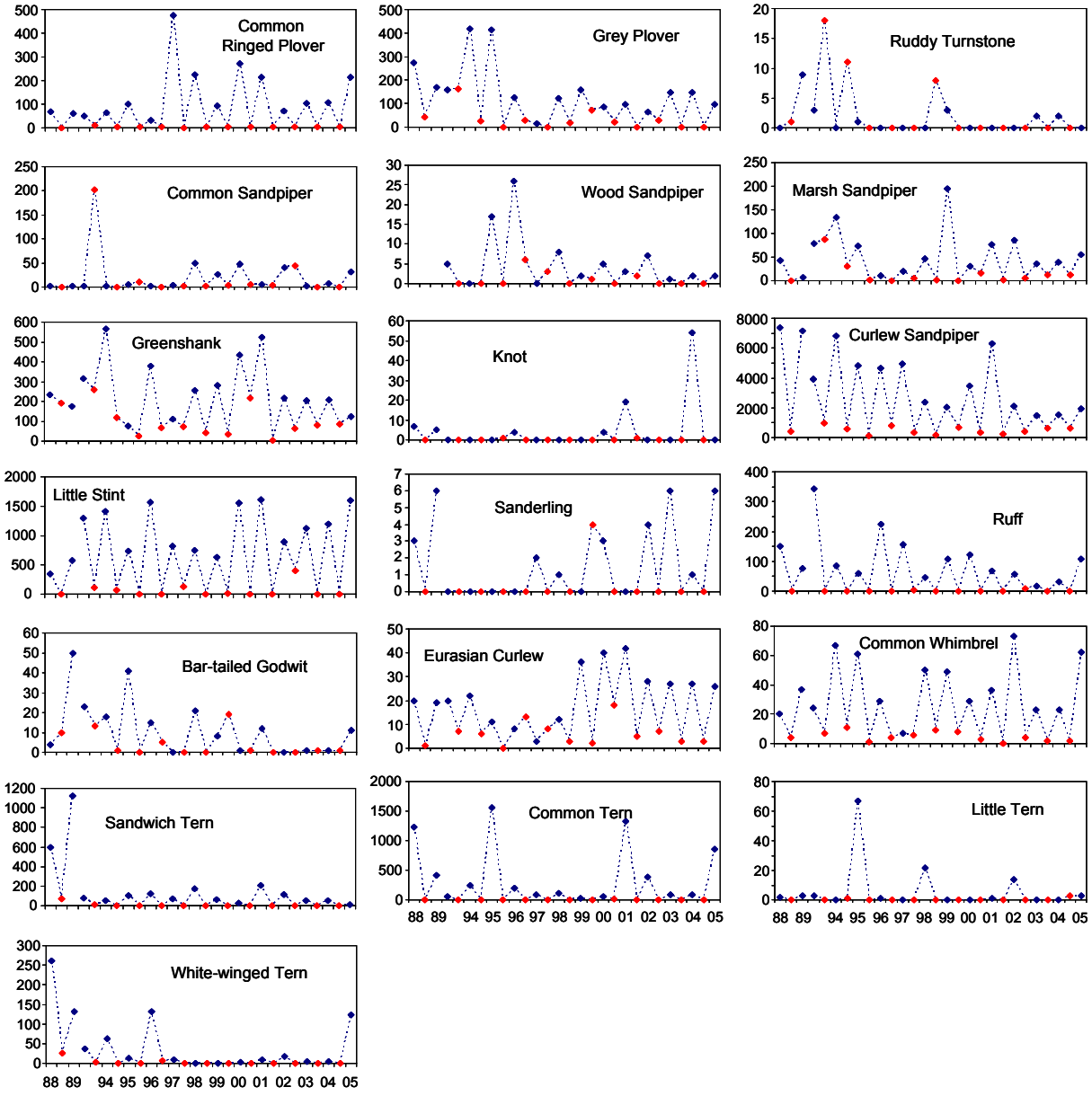


Figure 10.30 Interannual variation in the summer (blue) and winter (red) numbers of long-distance migrant waders and terns.

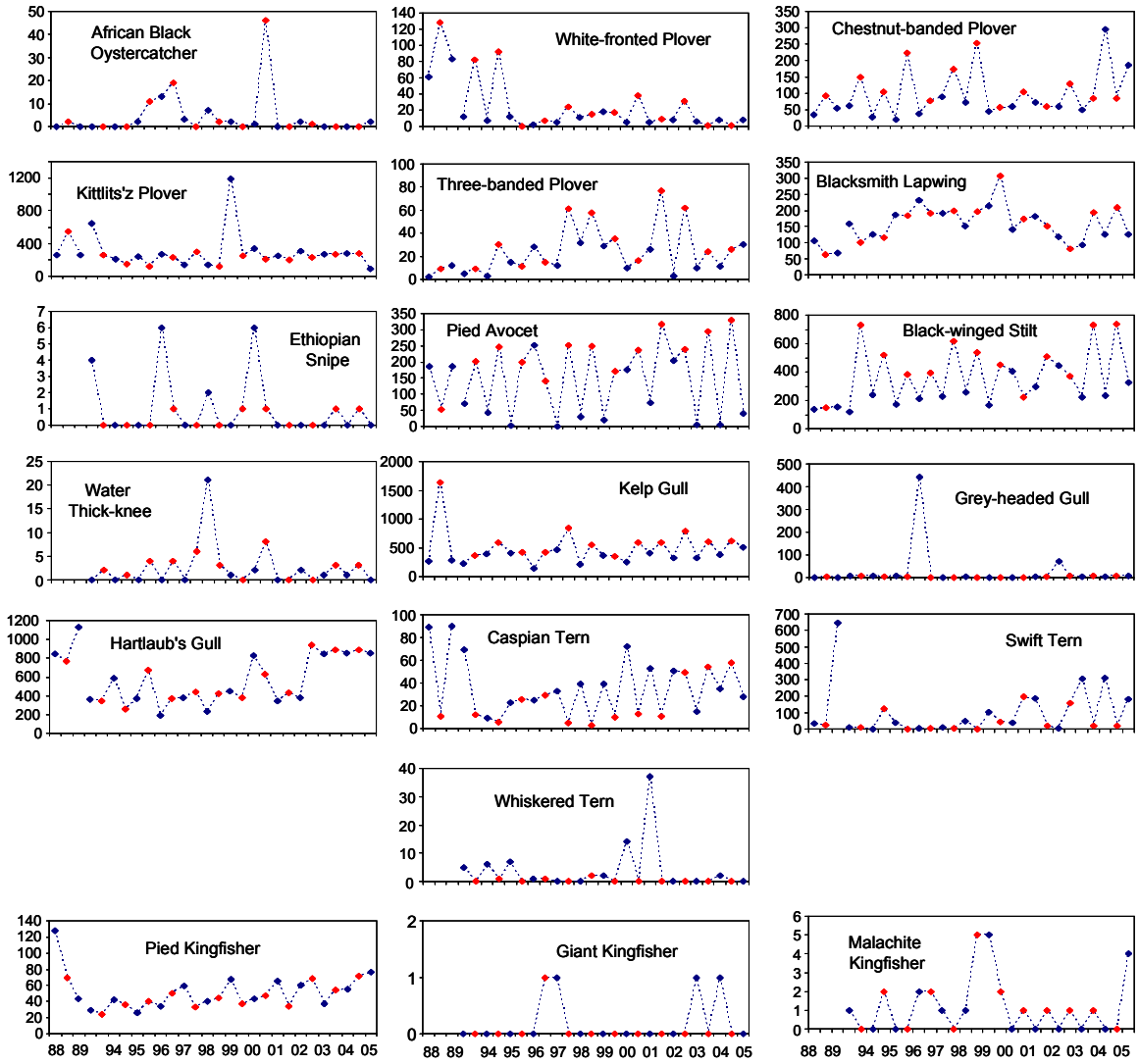


Figure 10.31 Interannual variation in the summer (blue) and winter (red) numbers of resident (or short distance migrant) waders, terns and gulls.

10.10 DISCUSSION AND CONCLUSIONS

10.10.1 Factors affecting the distribution and abundance of birds

A number of factors affect the composition of bird communities along the estuary, through their influence on the distribution and abundance of individual species.

The primary factors are the availability of *food* and *habitat* for feeding, roosting and breeding. While some species are fairly catholic in their choice of habitats or food, most are restricted to certain food and habitat types. These preferences align to a broad extent with taxonomic grouping, and are discussed in detail above.

In turn, these primary factors are affected by secondary factors. For example, abundance of certain food or habitat types may be linked to *salinity*, with the result that certain bird species are only found in more or less saline conditions. The latter links are often easier to ascertain than the primary links. Another example is the link between food availability or habitat type and aspects of *flow or flooding*. This is explored in more detail below.

In addition to these natural factors, anthropogenic factors also influence bird communities on the estuary. These factors include:

- Increase in *primary productivity* or eutrophication, e.g. through fertiliser runoff from the catchment. This may result in the increase of species which are attracted by weed, such as certain waterfowl, and the decrease of species that require deep, clear water for feeding, e.g. diving piscivores.
- Creation of *new habitats*, e.g. by construction of artificial salt pans. This attracts species such as flamingos and resident waders that prefer dry or saline pans, e.g. Chestnut-banded Plovers.
- *Human disturbance*, e.g. through recreational activities, which flush birds from feeding, roosting and breeding areas. This has been shown to be a major issue in some estuaries, resulting in significant decreases in numbers of birds. Although not significant at present, this could become a major problem if development of the area continues unchecked.
- *Degradation of habitats*, e.g. through trampling. This is not a major issue for birds on the Berg River.
- *Loss of habitats*, e.g. through reclamation of wetland and estuary areas for developments. This usually has a direct impact on bird numbers. In general, it has been found that reduction in habitat results in a proportional loss of birds, rather than an increased concentration of bird, suggesting that these areas are used at their full carrying capacity.
- *Reduction in food*, e.g. through fishing activities. Fishing activities can have a significant effect on the average size and density of fish or invertebrates. This would affect the number of birds that the estuary could support.

10.10.2 Influence of flow on different groups of birds

While no statistically strong correlations were found to explain interannual variability in bird numbers, both seasonal and interannual patterns of abundance of different groups of birds can be directly or indirectly linked to flow to different extents.

In the case of the heronry species (egrets, herons, darters, cormorants, ibises, spoonbills), which dominate waterbird numbers during spring, breeding activity could be related to flow inasmuch as the suitability of the breeding area is influenced by the extent to which the bases of the reed beds and trees that are used for nesting are flooded. These areas would not be safe for breeding if they are high and dry. Breeding success may also be flow-related (via food abundance), and current breeding numbers will reflect past breeding success to a certain extent.

The rail species, which are all resident, have fairly stable numbers year-round, apart from Redknobbed Coot, the most abundant rail species, which is more abundant in winter. However, their abundance is not linked to flow, and may be more directly related to the availability of *Potamageton*, the abundance of which is quite dynamic and influenced by multiple factors.

Numbers of other waterfowl species fluctuate enormously, but are probably fairly strongly linked to flow, mainly in terms of the degree to which the floodplain is flooded. The timing of flooding is also important for breeding.

Flamingo numbers fluctuate widely from year to year, and these fluctuations are at least partly linked to conditions on breeding and feeding grounds elsewhere. At the Berg River, artificial salt pans constitute one of the most important habitats for flamingos. Nevertheless, the extent of flooding appears to play an important role in attracting flamingos to the area, probably especially when some of the larger bare pans are flooded.

Migratory wader species that make use of freshwater wetlands are influenced by the availability of habitat in the floodplain. These include some of the most abundant species such as Little Stint and Greenshank. Those that tend to be restricted to coastal intertidal habitats, such as Eurasian Curlew, are less likely to be directly affected by flow conditions, since there would be little immediate change in habitat availability, but may ultimately be affected by more gradual changes in habitat or indirectly by changes in food availability.

Many resident wader species are highly dependent on the freshwater wetlands of the floodplain, and their numbers are directly influenced by the availability of habitat due to extent of flooding. The timing of flooding is also important for breeding. There are some resident wader species, however, that would be little affected by flow, since they are more numerous on the estuary (e.g. African Black Oystercatcher) or on the artificial saltpans (e.g. Chestnutbanded Plover).

Numbers of those species of gulls and terns that make extensive use of freshwater habitats (e.g. Greyheaded Gull, Whitewinged Tern) are clearly influenced by the degree of flooding in the floodplain. The more marine species, e.g. Kelp Gull, Common Tern, are unlikely to be affected by flow changes, except ultimately due to gradual changes in food supply, as for all other foraging species.

Most of the more direct flow related changes described above are due to changes in the degree of flooding of the floodplain wetlands, rather than flow *per se*. Species that use the floodplain pans, in particular, for feeding and breeding, are most likely to be particularly responsive to changes in the degree of flooding, as this affects the availability of suitable or productive habitat. Other changes may occur more gradually, if longer term changes in flow affect the productivity of the estuary or the configuration of habitats.

10.10.3 The Functional Role Of The Floodplain Wetlands

The Berg River estuary is fairly unique in that it is functionally linked to a major floodplain area with freshwater wetlands, as well as major artificial saltpans.

Both the natural and man-made pans add considerable diversity to the estuary as well as the area as a whole. In other words these habitats probably allow the estuary to support more birds than it would be able to support in isolation. Both the floodplain wetlands and saltworks provide high-tide roosting habitat for birds that forage in the estuary, with different species being prevalent in each. These supplementary habitats are thus probably a significant part of the reason for the particularly high density of birds on the estuary.

The floodplain area also offers additional habitat for waterbird species that also use intertidal foraging areas, as well as providing habitat for species that are relatively rare or absent in intertidal areas.

When inundated and during the drawdown period, the floodplain also attracts additional breeding birds that forage elsewhere during the rest of the year. Thus the floodplain plays a significant role in contributing to the overall species richness and abundance of birds on the lower Berg River, and its overall conservation importance.

Thus the floodplain area, whose productivity is highly dependent on degree of flooding, forms a critical component of the wetland area as a whole, and is a strong factor in determining the overall conservation importance of the estuary.

10.10.4 Recommendations for monitoring

Monitoring of avifauna currently comprises detailed counts of the entire estuary and floodplain twice a year, in July and January/February undertaken by the Avian Demography Unit, at the University of Cape Town. The July count corresponds to the peak numbers of some waterfowl and resident waders. However, this study has shown that the summer counts, which are intended to coincide with maximum numbers, have missed the most important periods for birds both on the estuary and floodplain. Peak numbers on the estuary usually occur in about December, and are also higher in March than mid-summer. Peak numbers on the floodplain are in September or October. The timing of the latter peak is linked to the timing of high flows.

Future monitoring should take place three times a year: in June/July, September/October, and December. The timing of the spring counts should be responsive to rainfall and flooding events, and should ideally be timed to take place in the month following the first major flood, but not later than October.

In addition, physical monitoring should include regular recording of the water level on the floodplain, as well as in the river channel, so that bird counts can be interpreted in the light of the amount of flooding that has occurred and the period over which there is water on the floodplain. Water level in the estuary channel is currently measured on an hourly basis at three localities (Laaiplek, Kliphoek and Jantjiesfontein), except that there have been numerous interruptions in these data prior to 2002 due to equipment failure and human error. If monitored properly, the latter site, in particular, will provide a better measure of flooding than information on flow. On floodplain water level needs to be recorded in such a way as to provide a picture of the extent to which the pans are inundated. This should include a selection of backwater pans alongside the river, sedge pans and the large open pans on the floodplain. It is recommended that nine stations are monitored on a weekly basis, at least from June to December. The positions of the stations are shown in Figure 10.32. These should be located at the deepest points of the pans indicated.

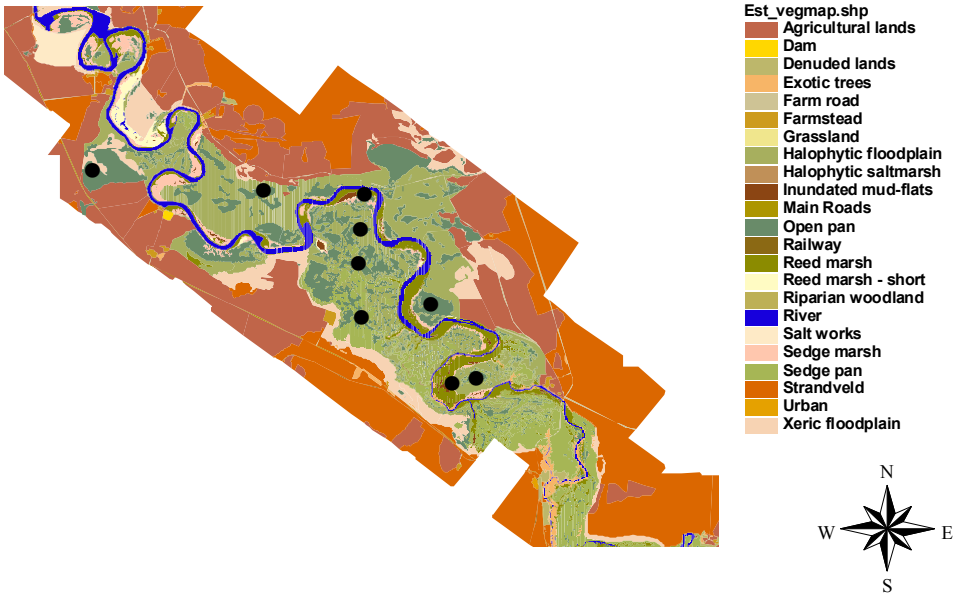


Figure 10.32 Position of proposed water level monitoring sites on the floodplain

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APPENDIX 1

APPENDIX 1.1

HYDRAULICS & FLUVIAL MORPHOLOGY:

SURVEYED ESTUARY CROSS-SECTIONS

(2003, 2004 & 2006)

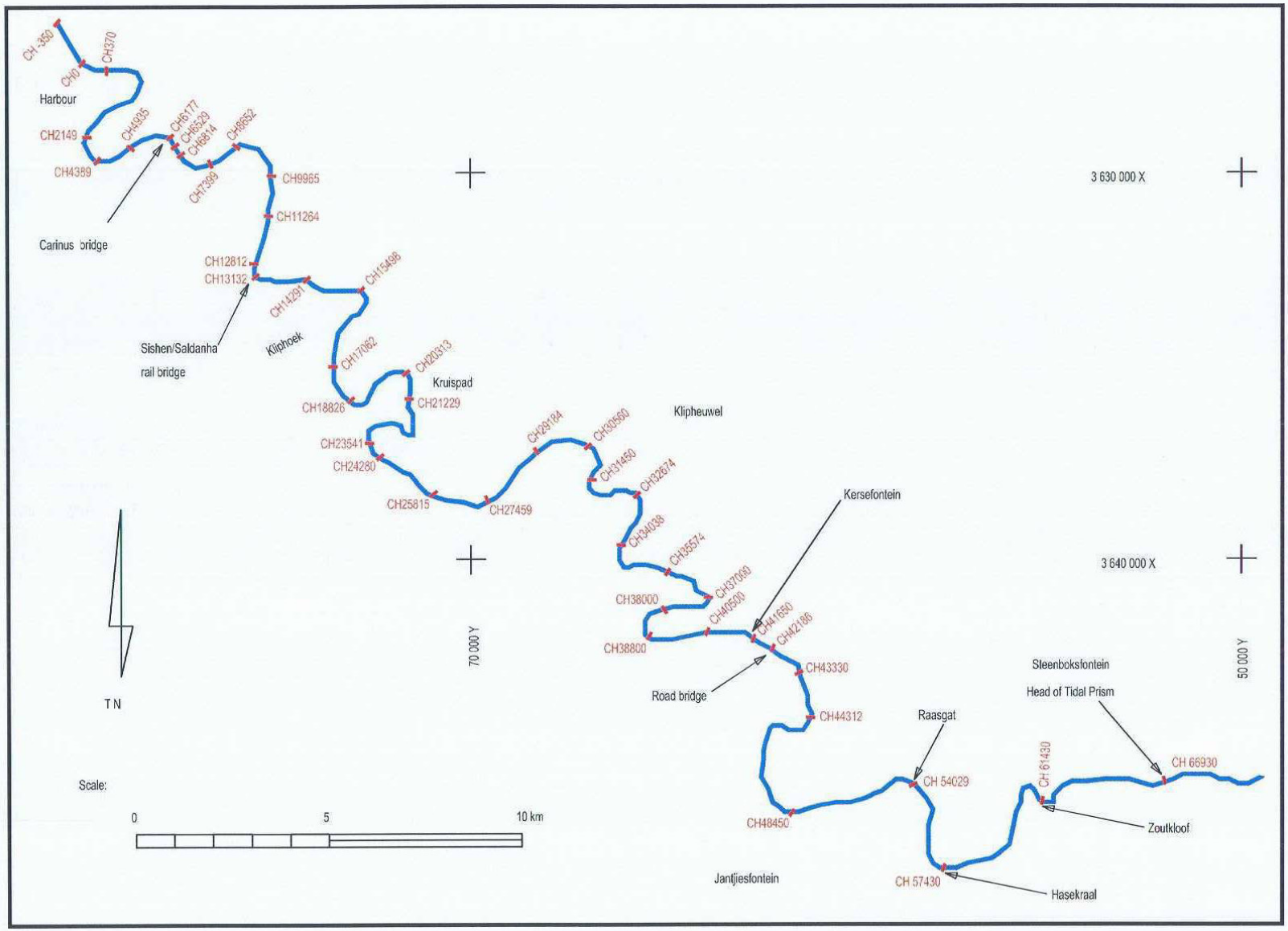


Figure A 1.1.1 Locations of the estuary cross sections

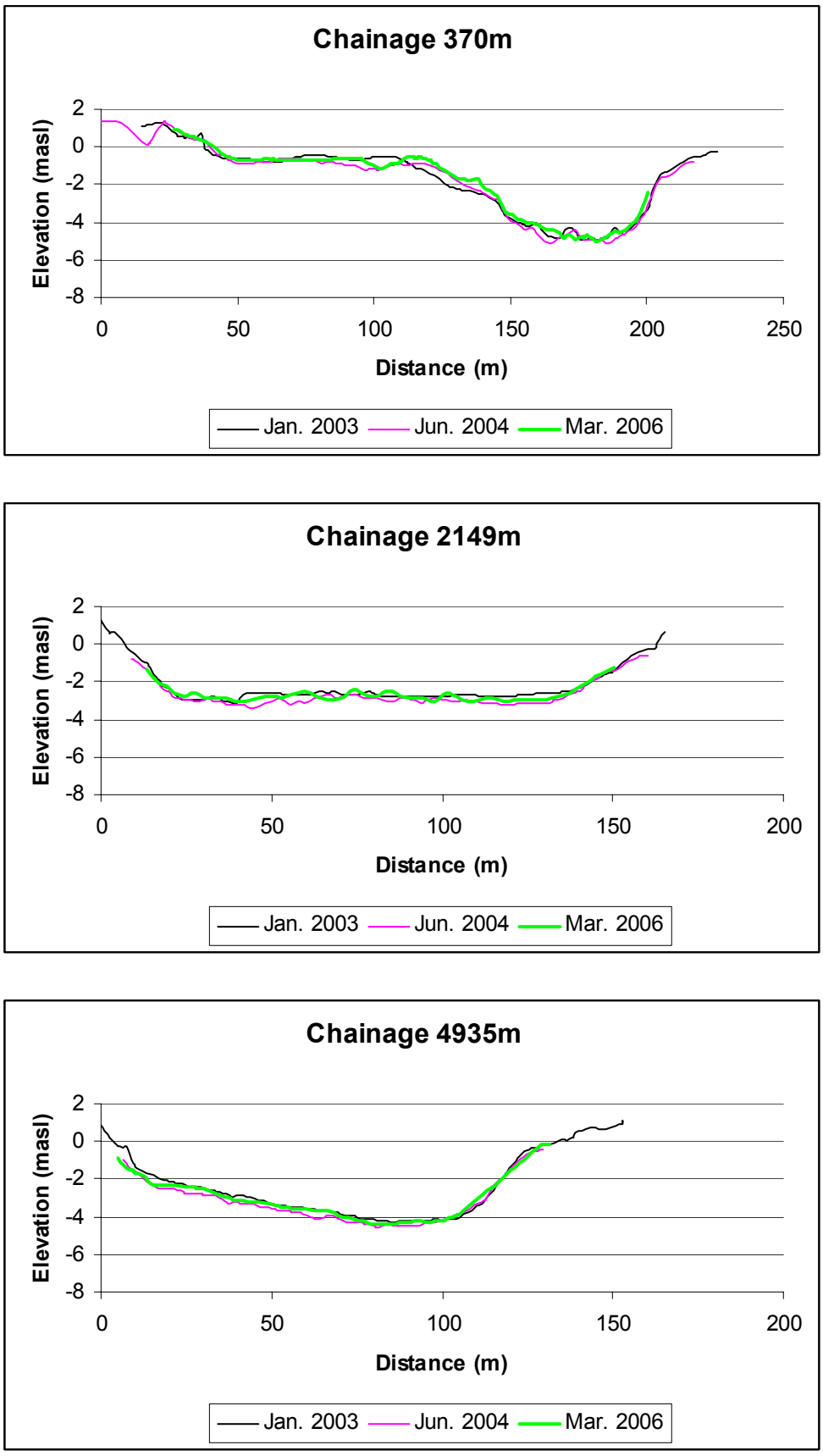
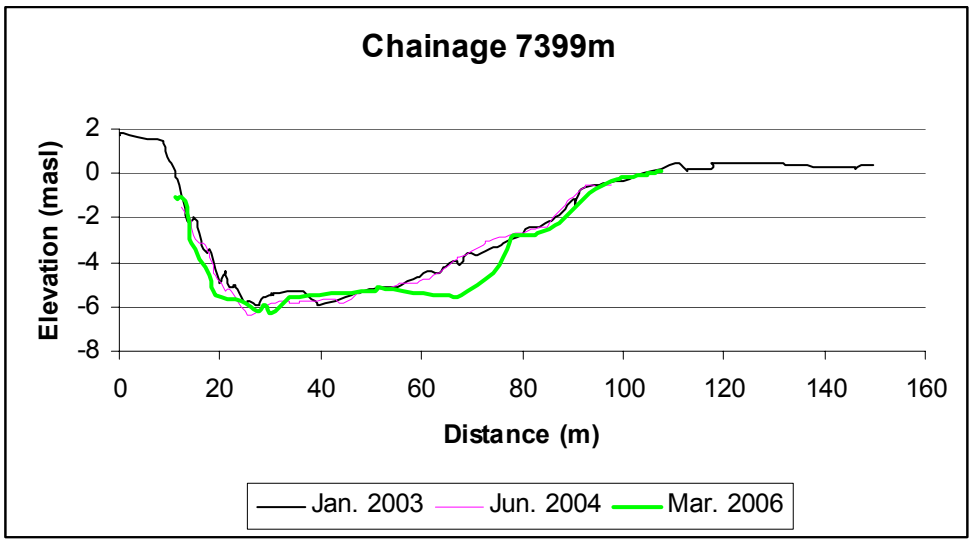
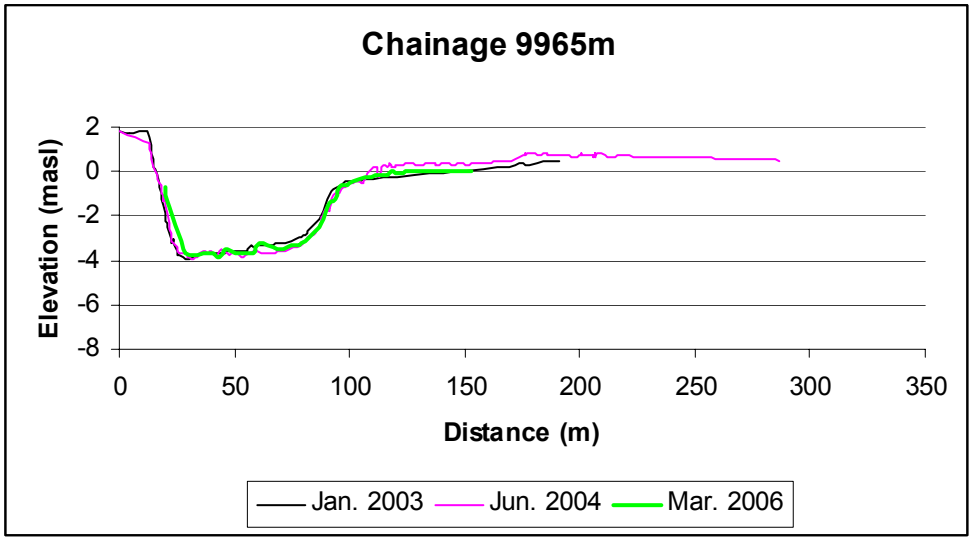


Figure A 1.1.2 Bathymetric cross sections of Berg River Estuary 2003, 2004 and 2006.





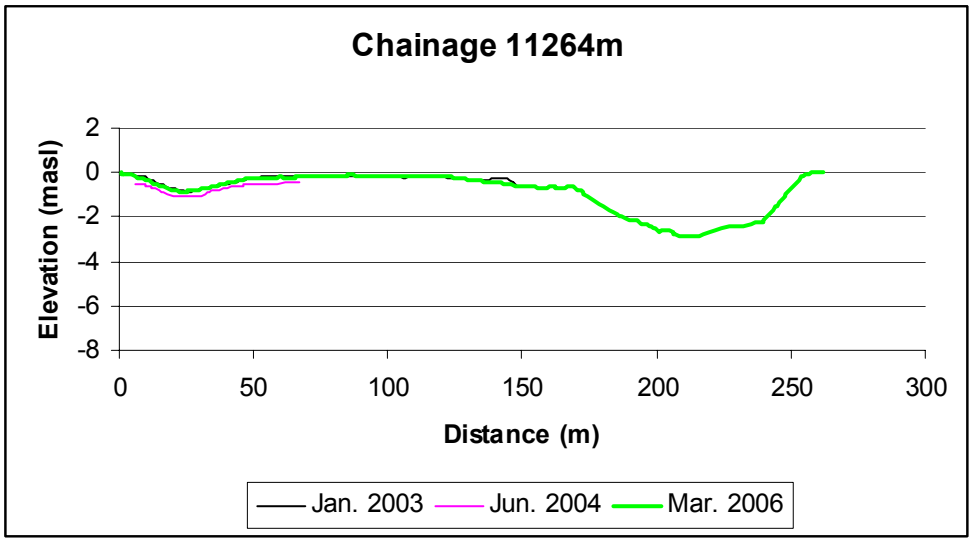
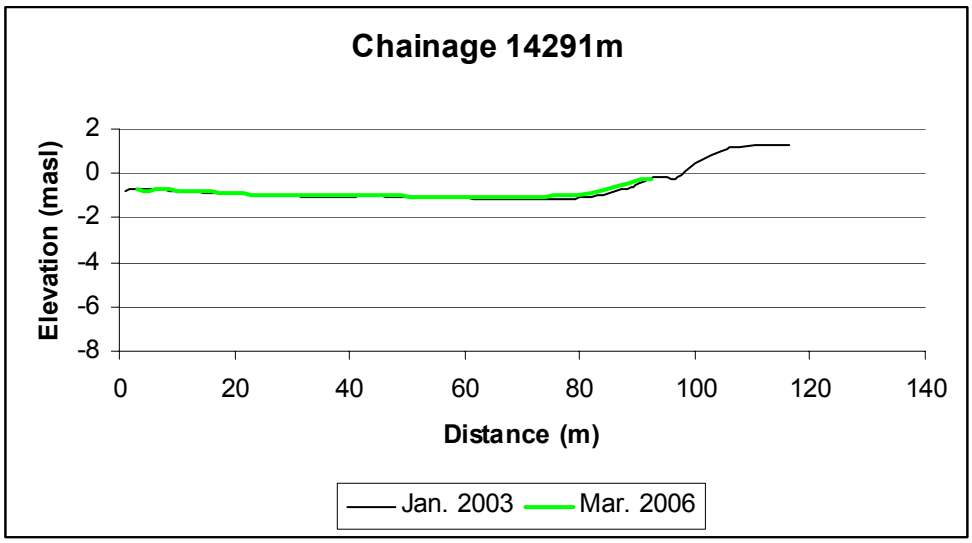
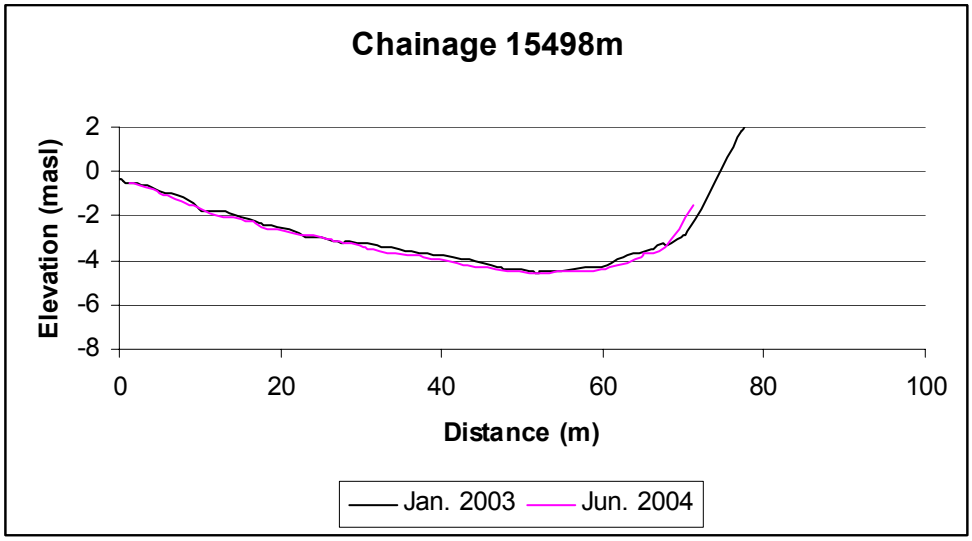


Figure A 1.1.2 Continued. Bathymetric cross sections of Berg River Estuary 2003, 2004 and 2006.





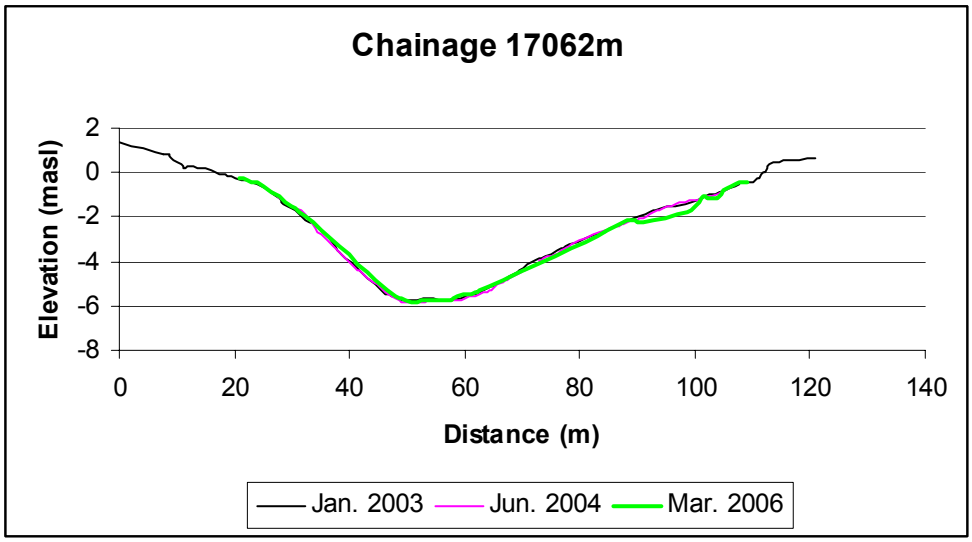
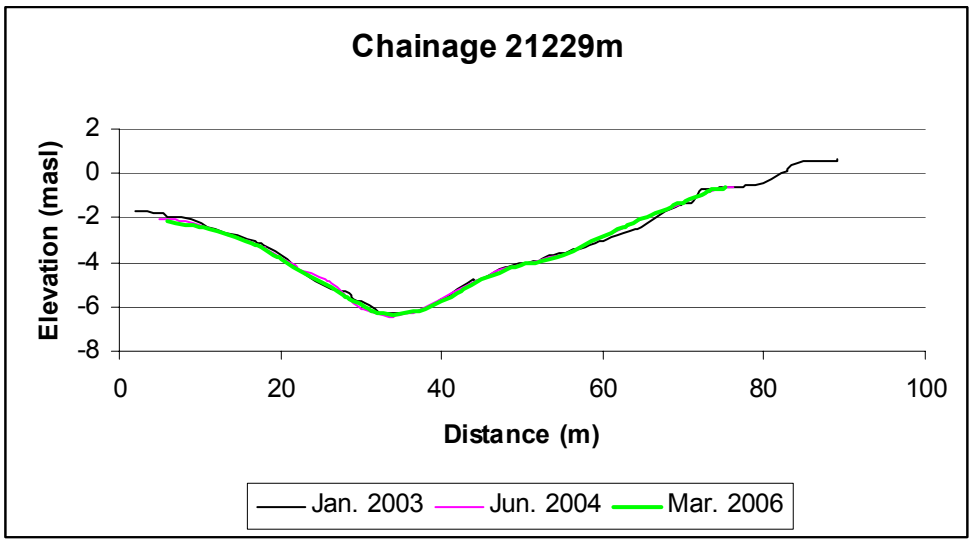
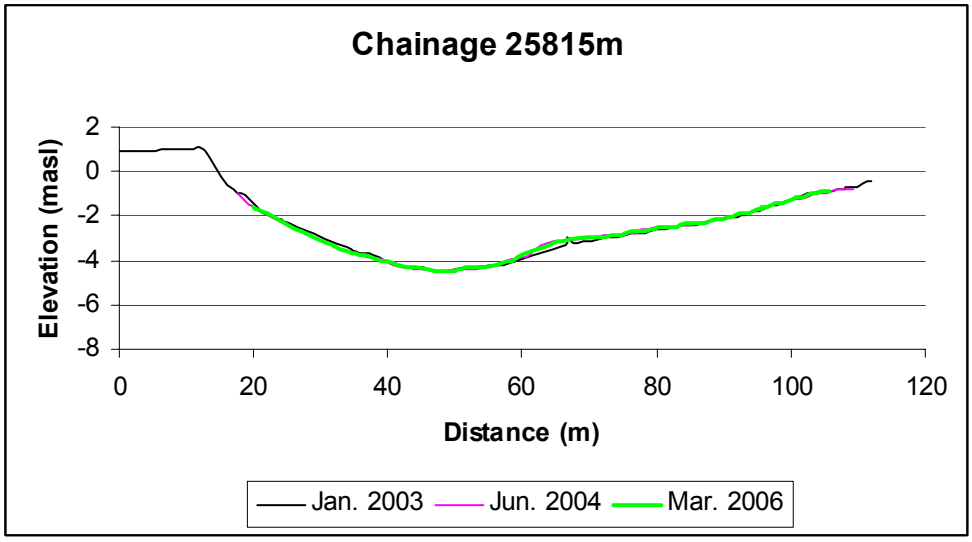


Figure A 1.1.2 Continued. Bathymetric cross sections of Berg River Estuary 2003, 2004 and 2006.





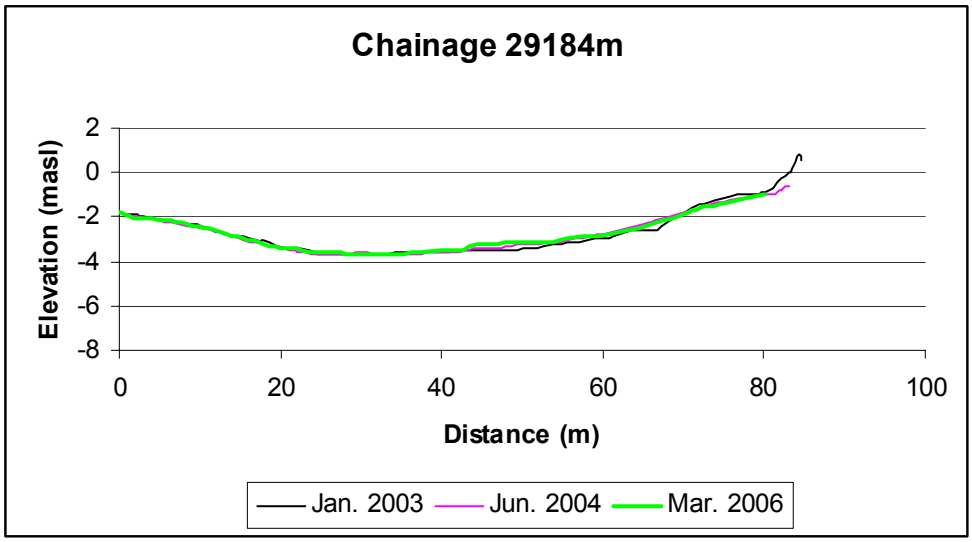
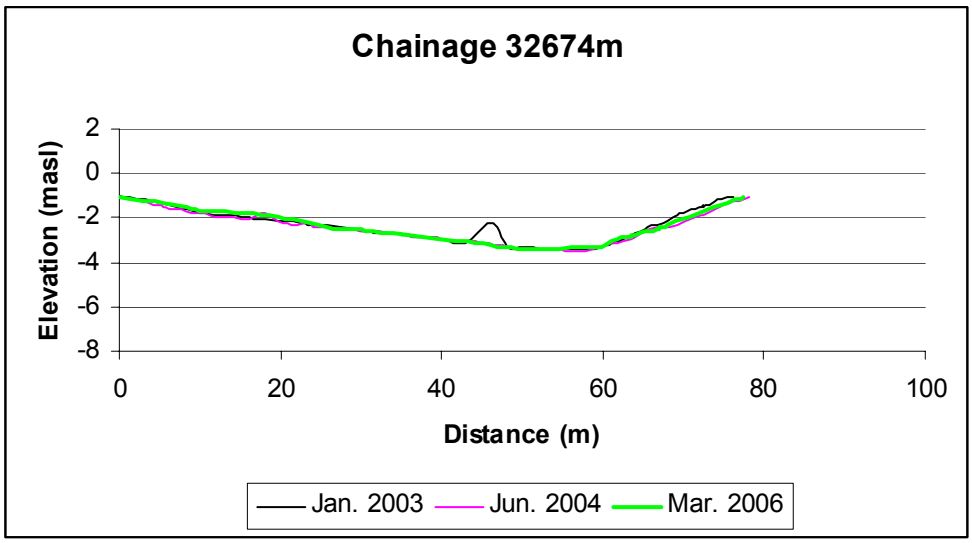
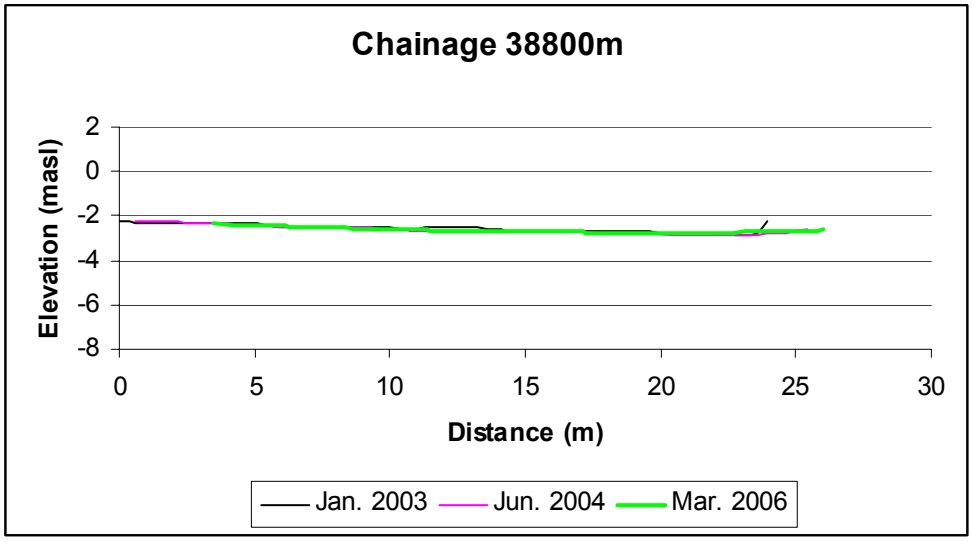


Figure A 1.1.2 Continued. Bathymetric cross sections of Berg River Estuary 2003, 2004 and 2006.





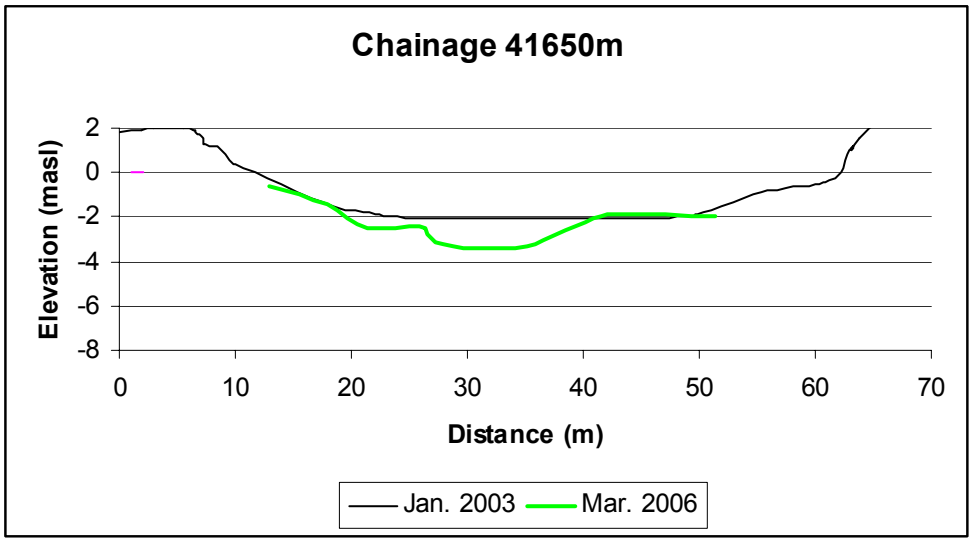


Figure A 1.1.2 Continued. Bathymetric cross sections of Berg River Estuary 2003, 2004 and 2006.

APPENDIX 1.2

HYDRAULICS & FLUVIAL MORPHOLOGY:

GRAPHS OF SIMULATED WATER DEPTH AT 100 POINTS IN THE ESTUARY FOR THE WINTERS OF 1999 AND 2003

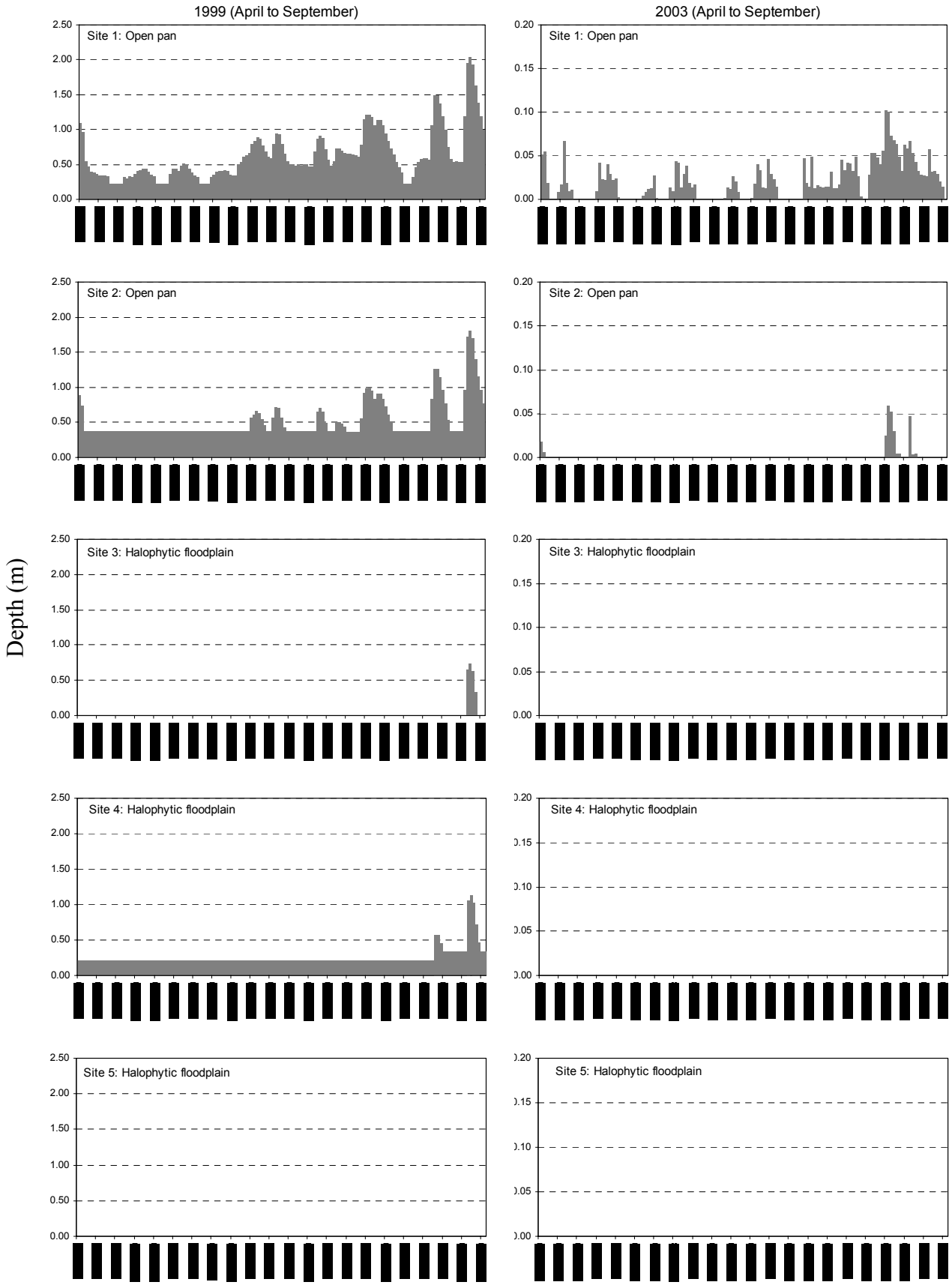


Figure A1.2.1 Simulated water depth at 100 points in the estuary for the winters of 1999 and 2003

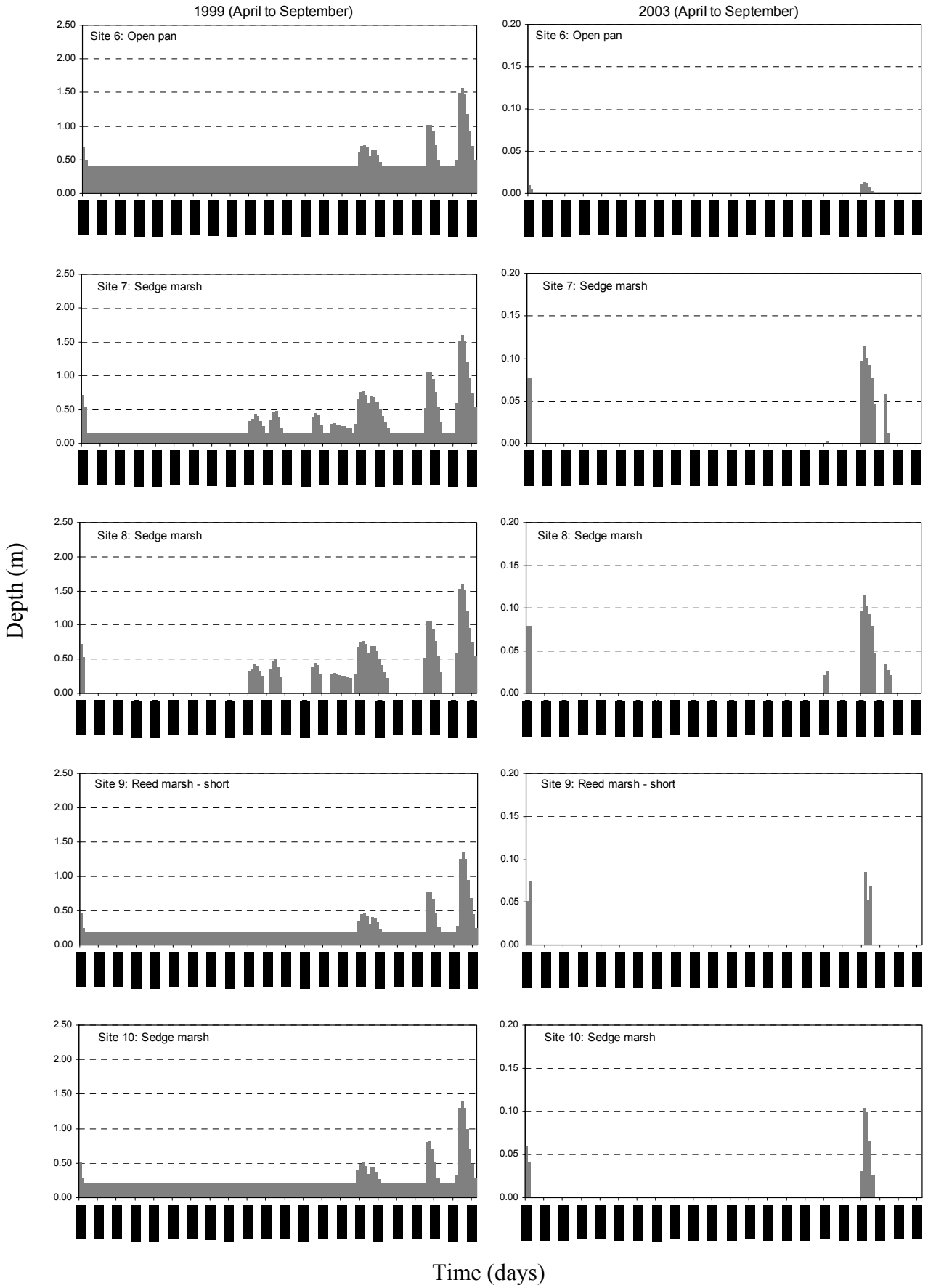


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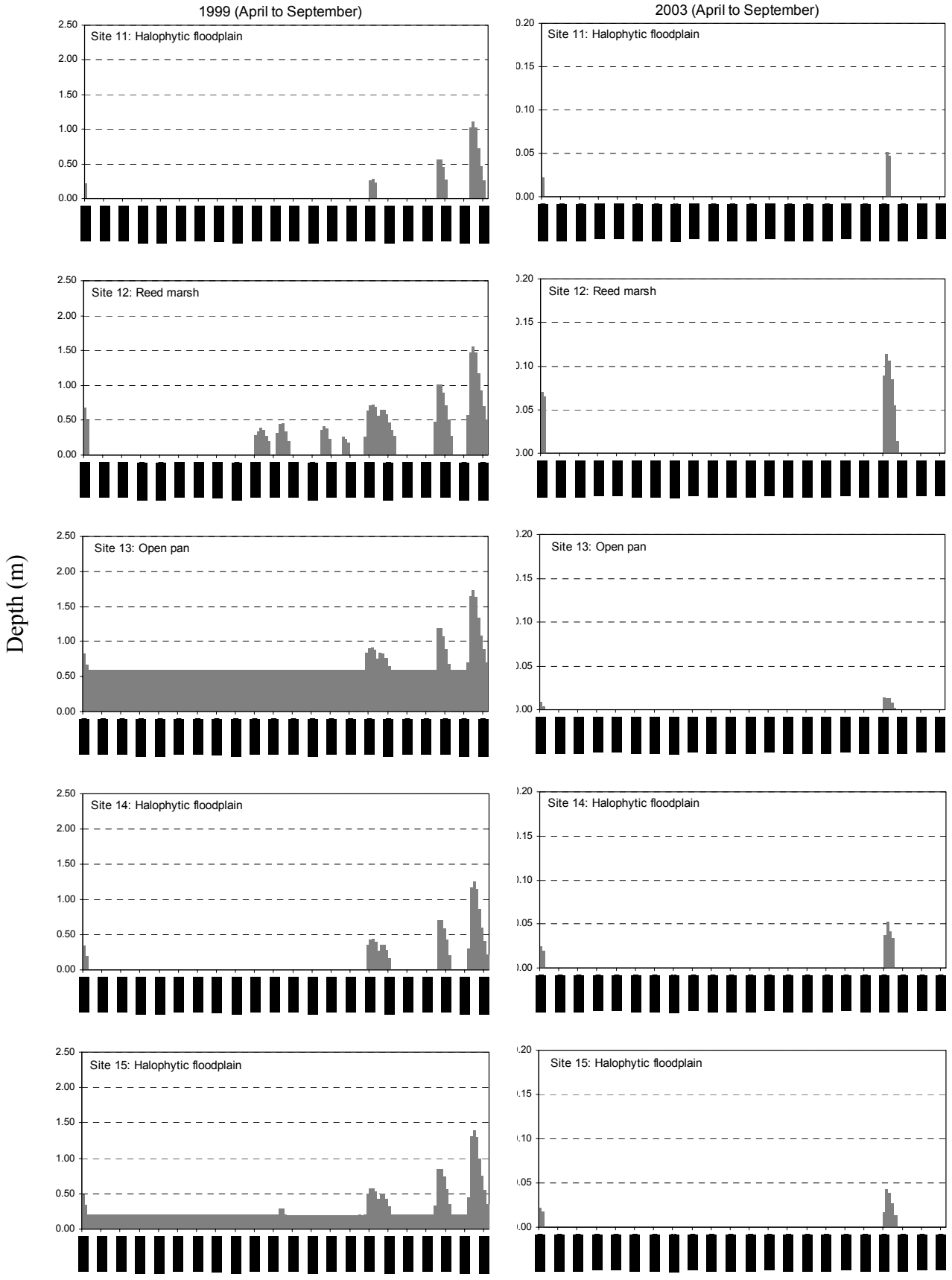


Figure A1.2.1 Continued. Simulated water depth at 100 points in the estuary for the winters of 1999 and 2003

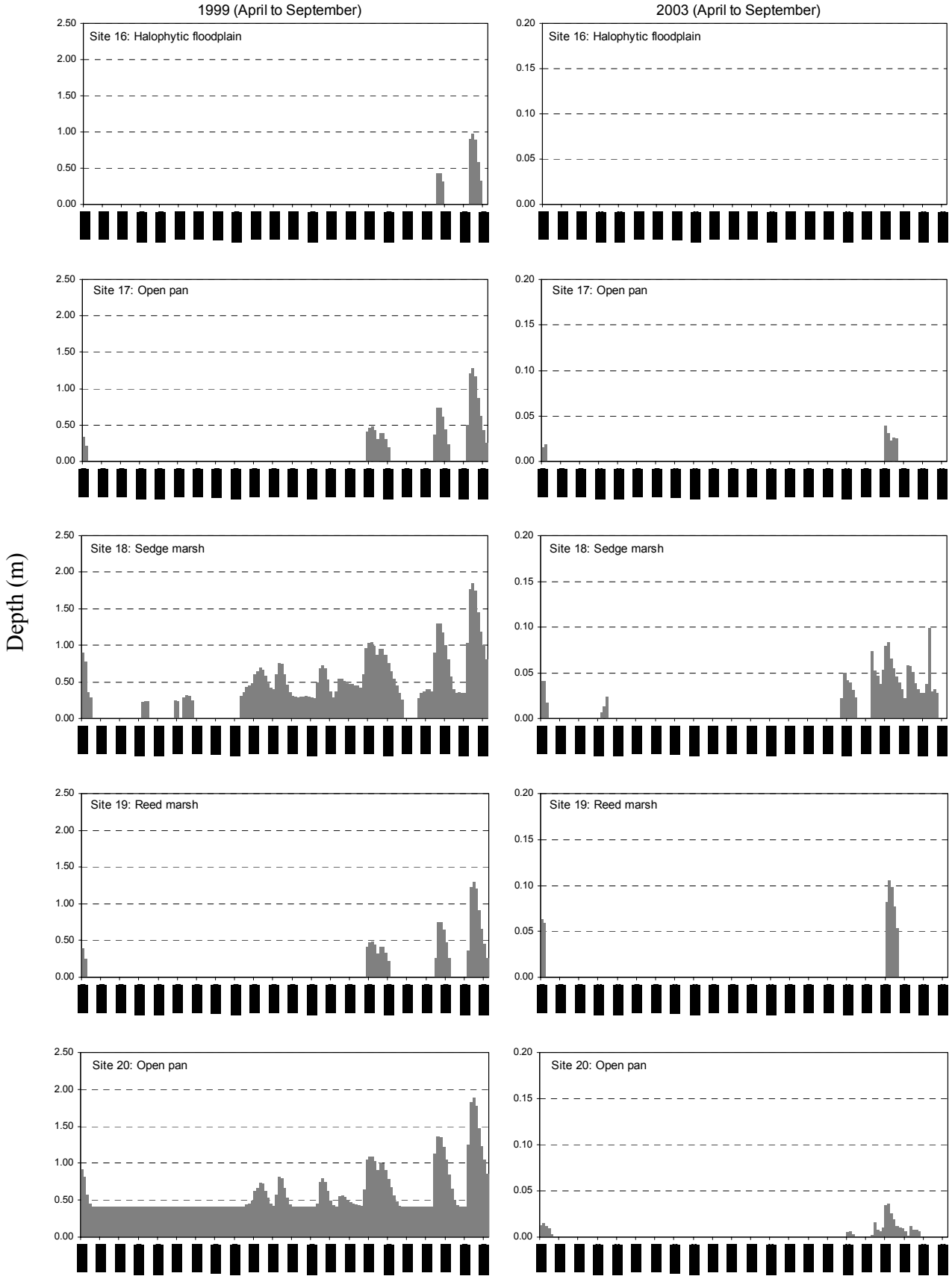


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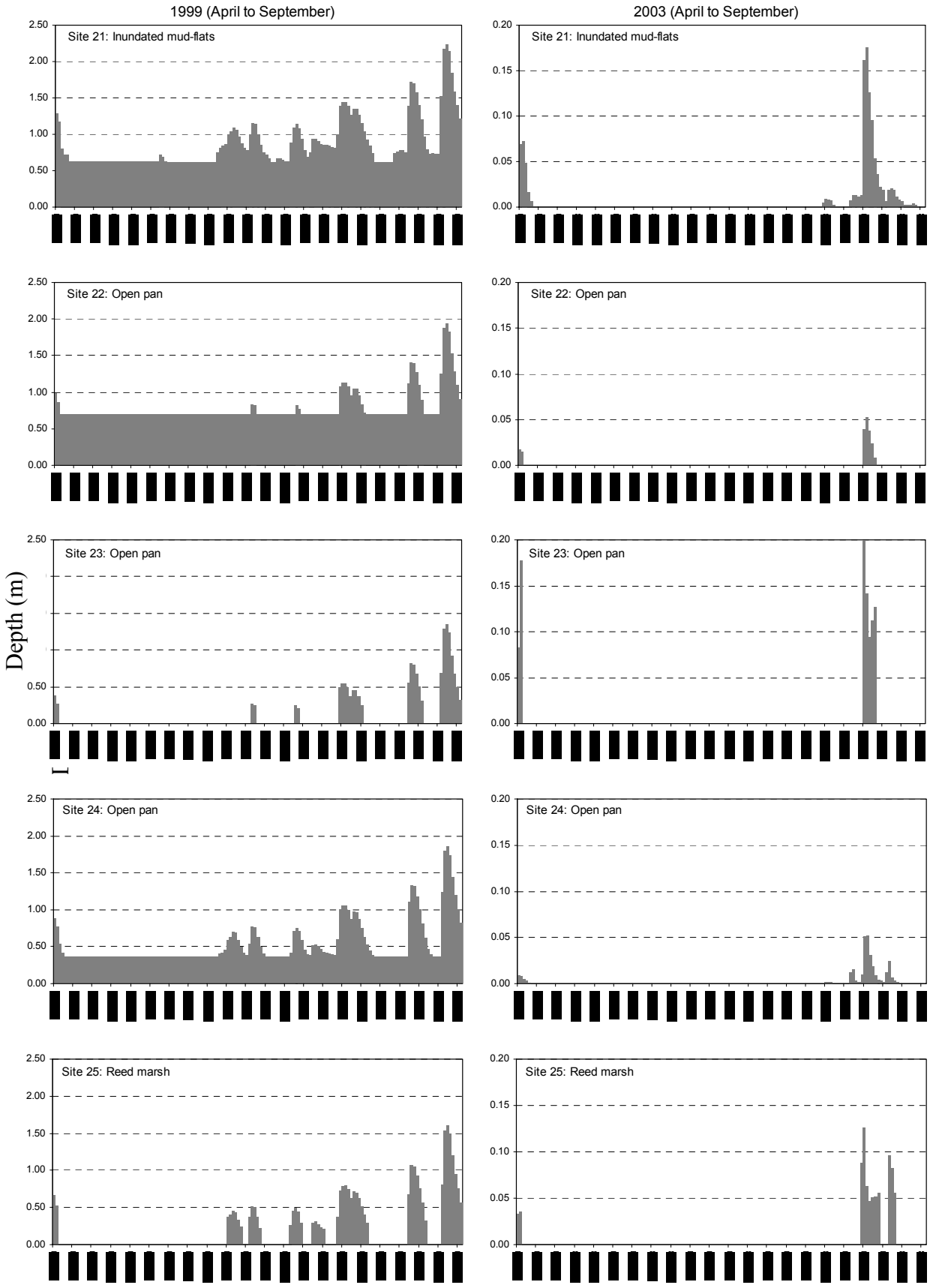


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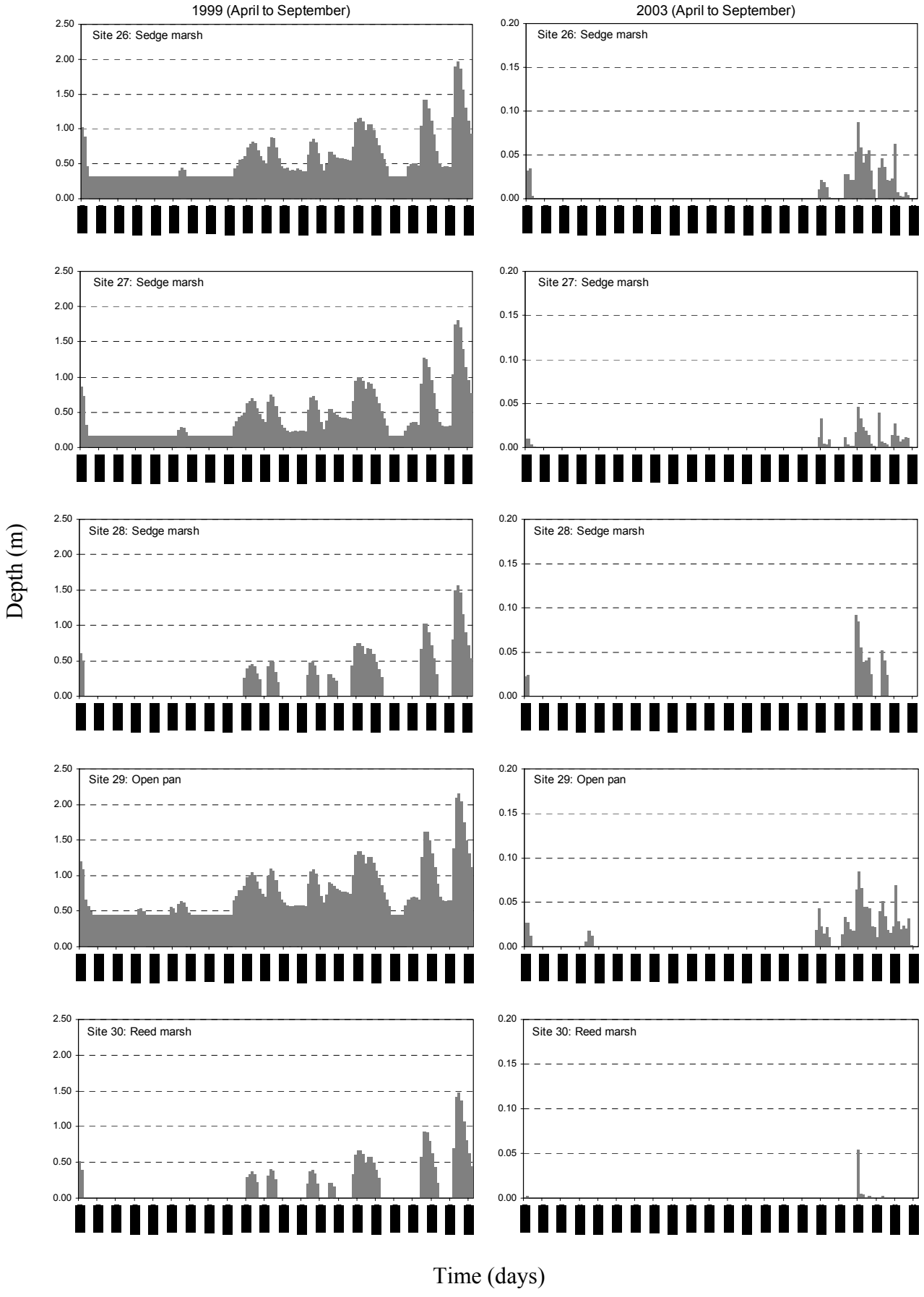


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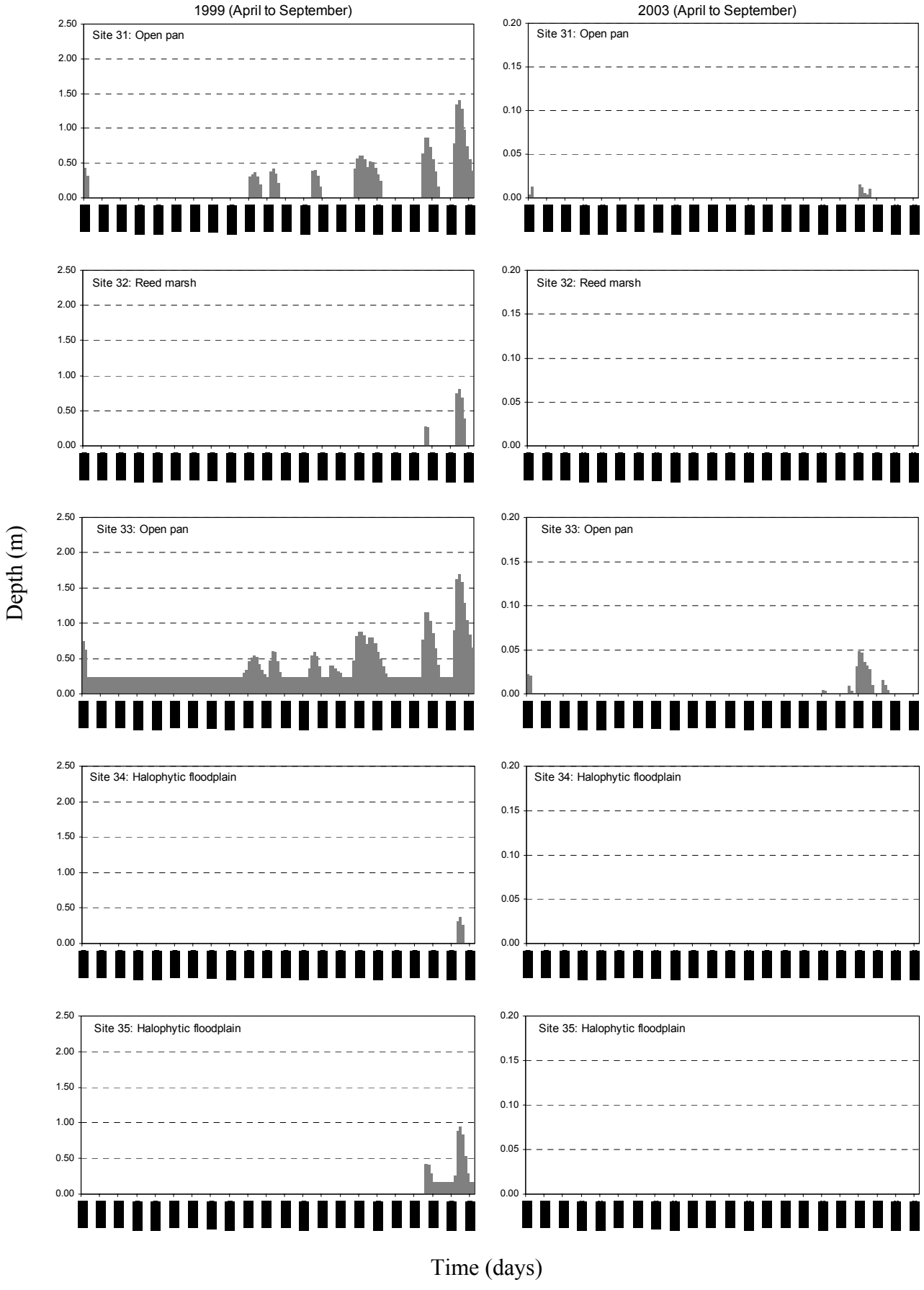


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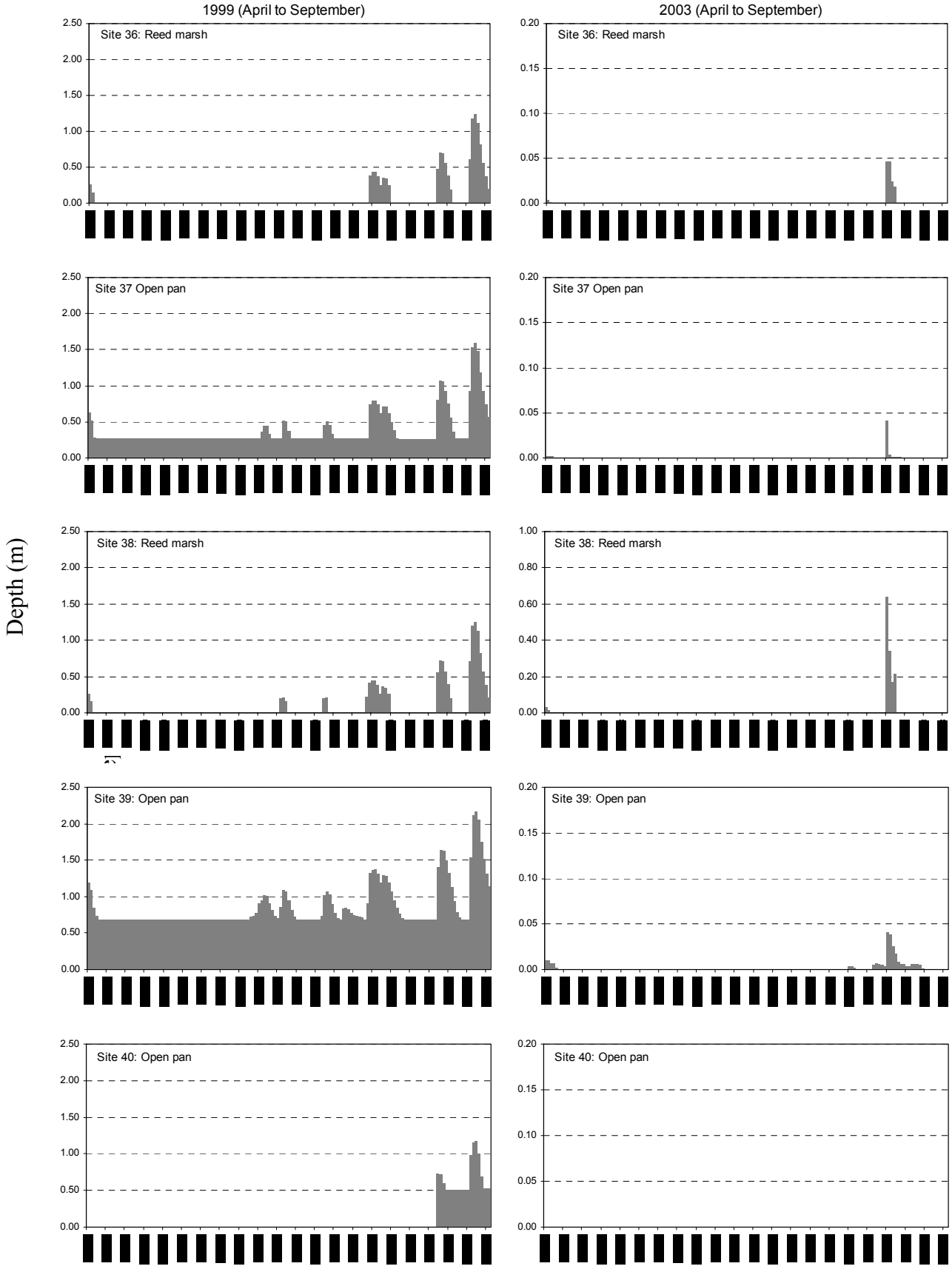


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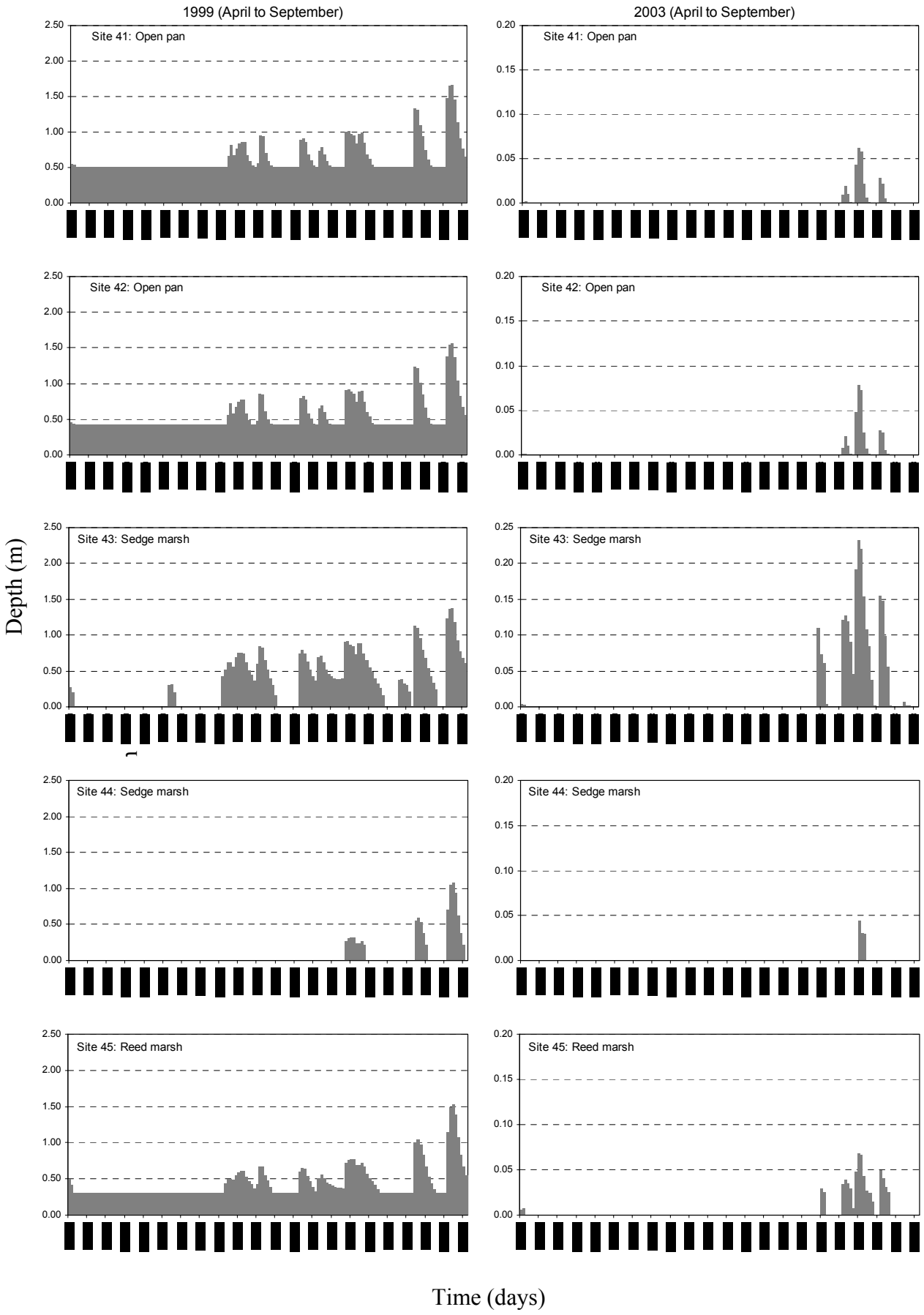


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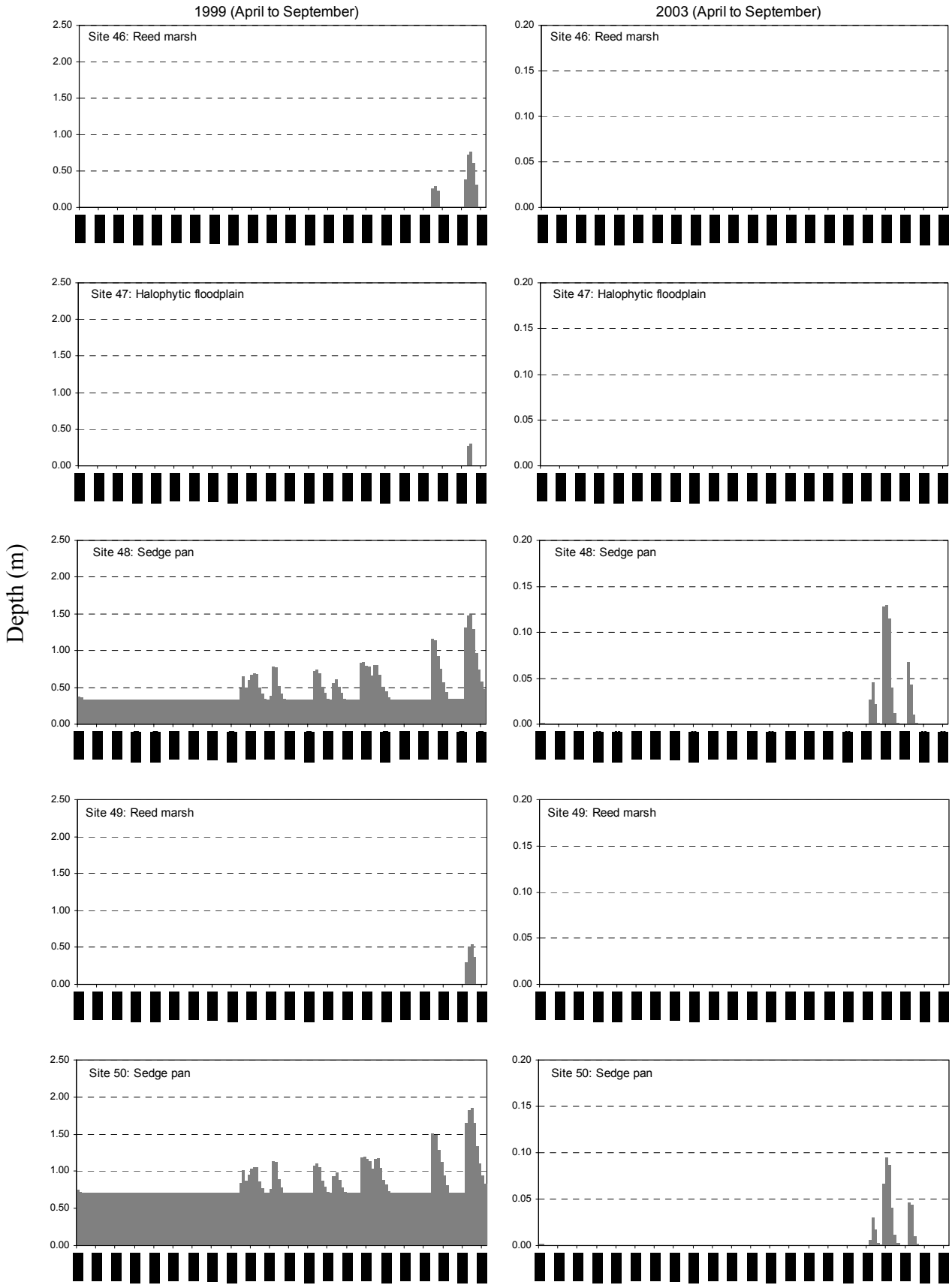


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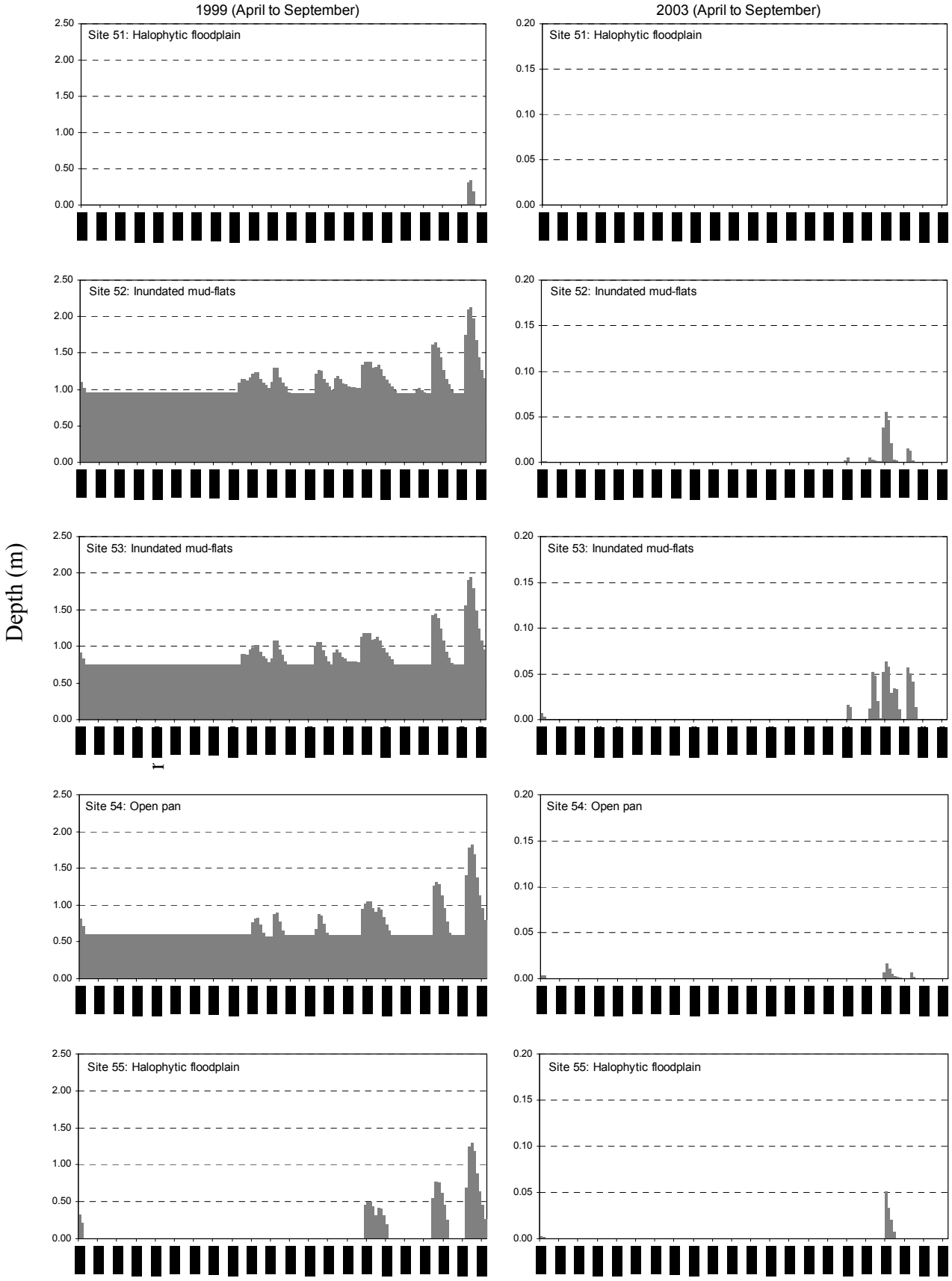


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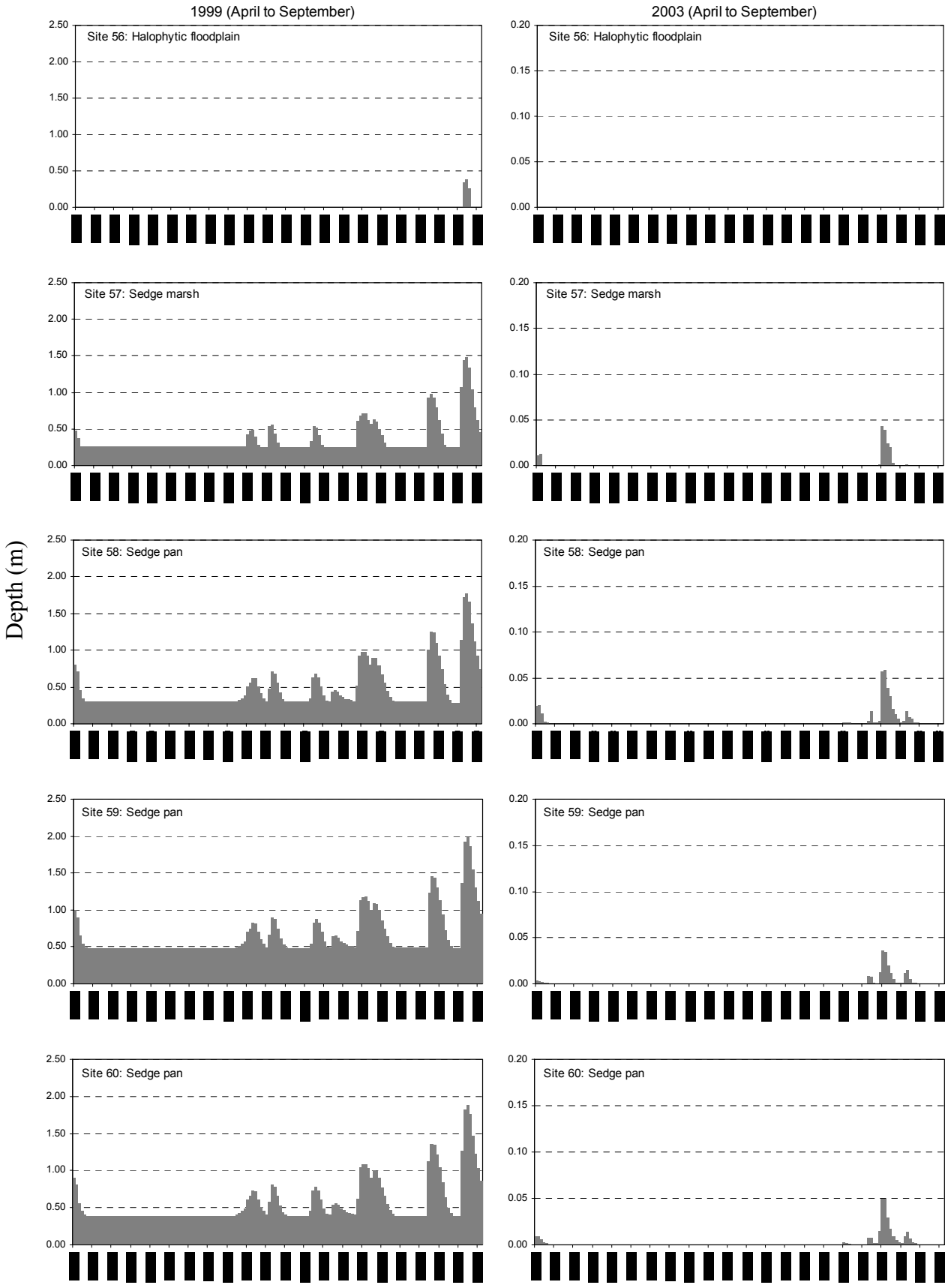


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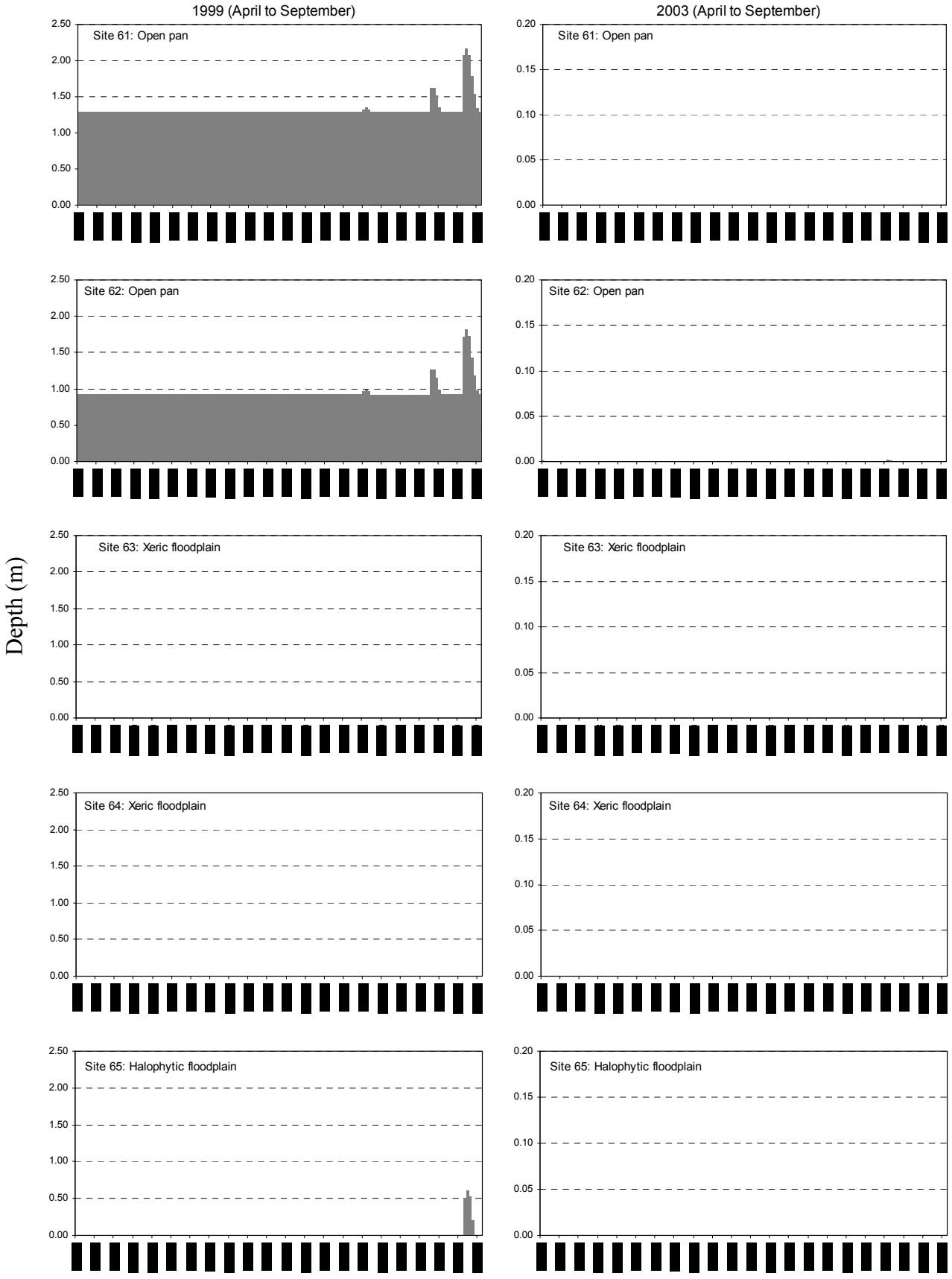


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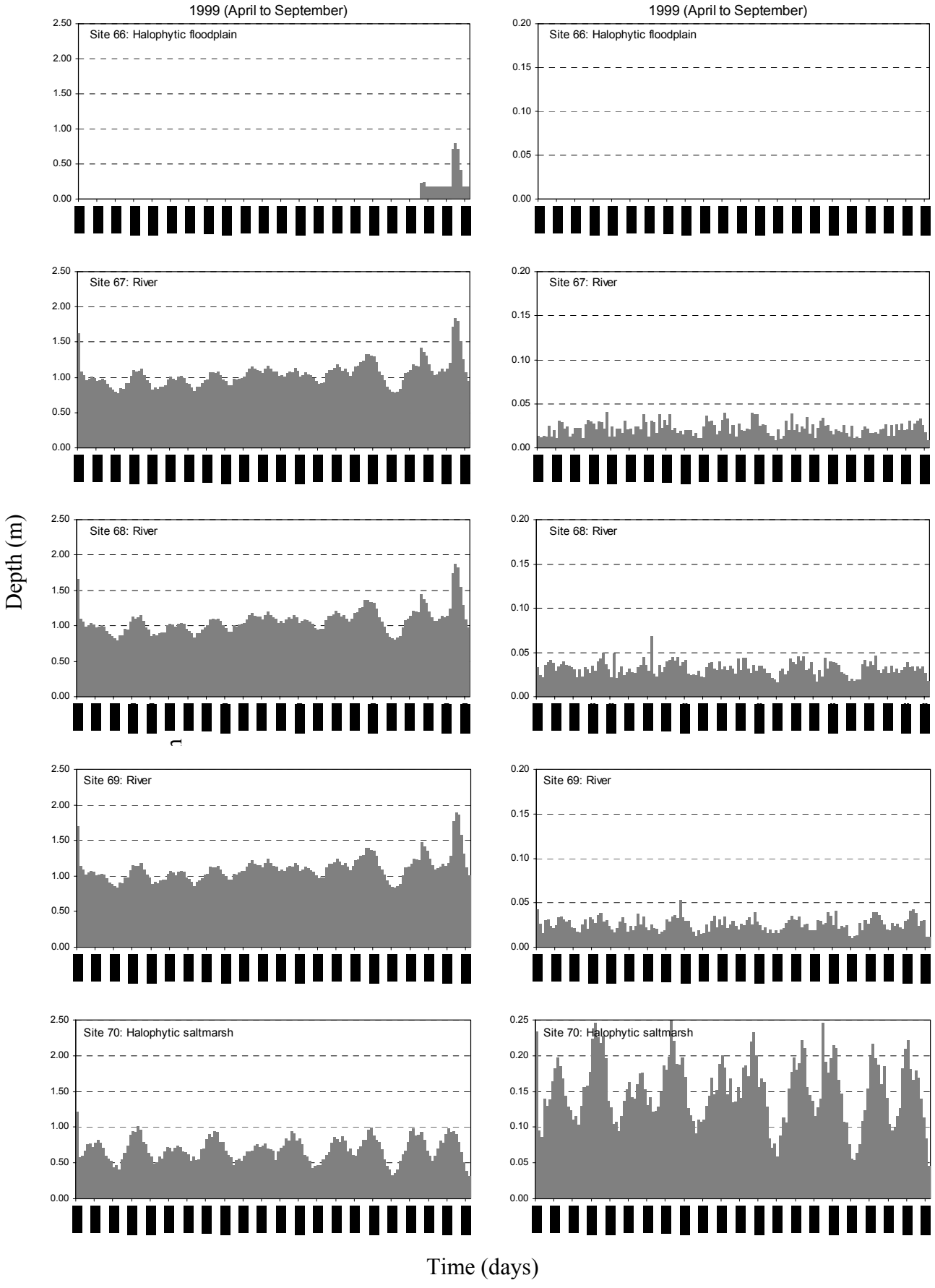


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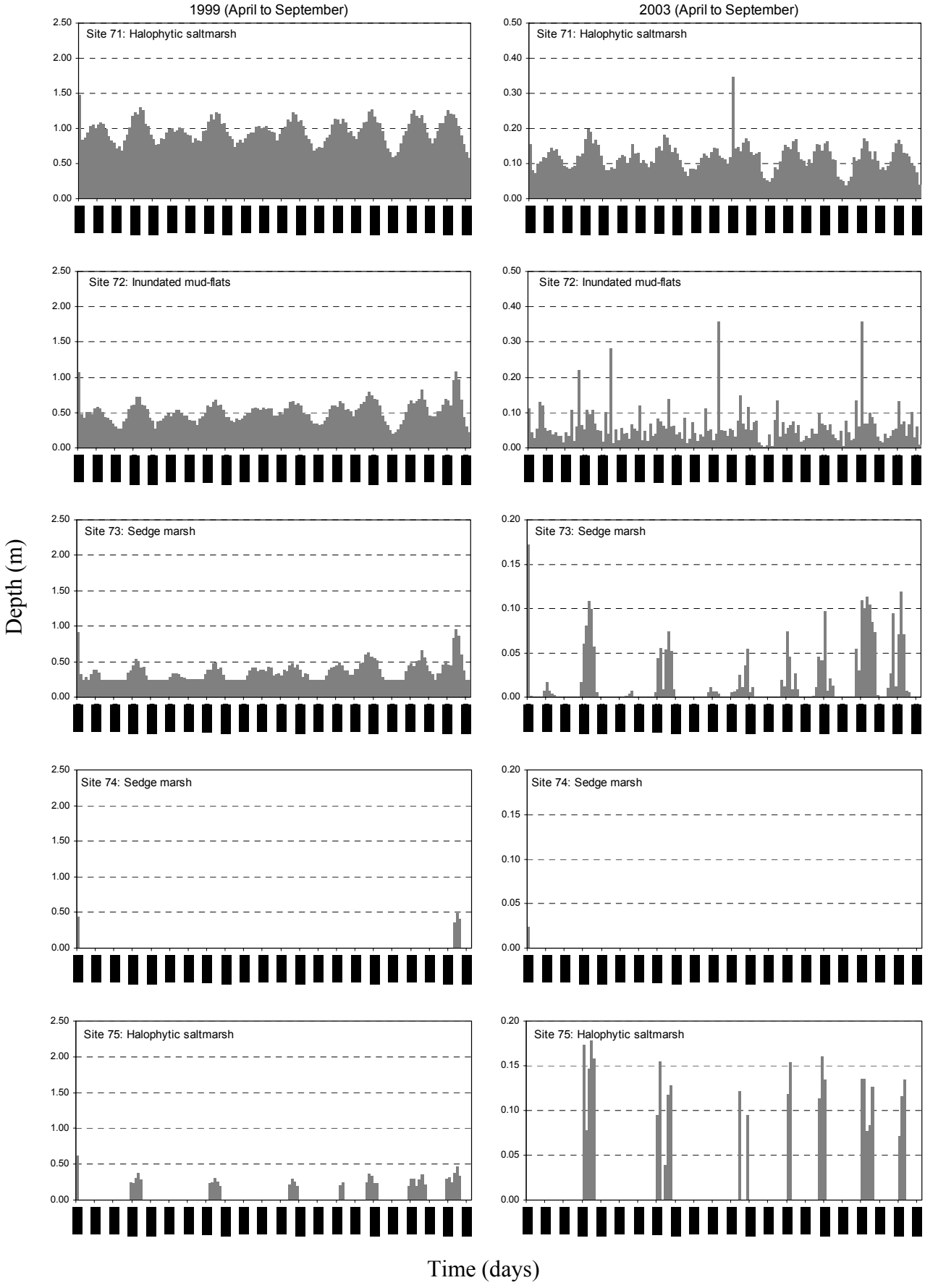


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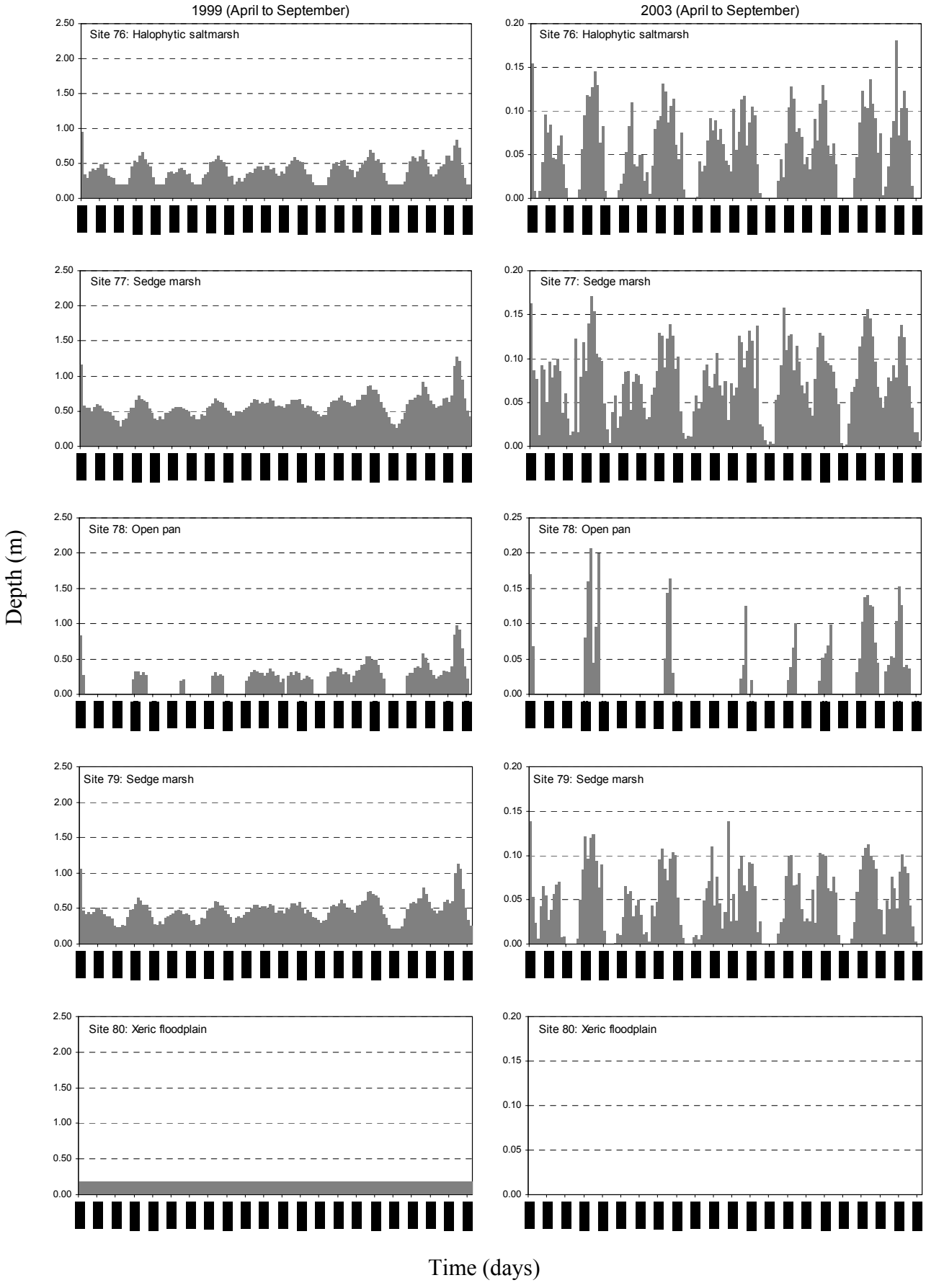


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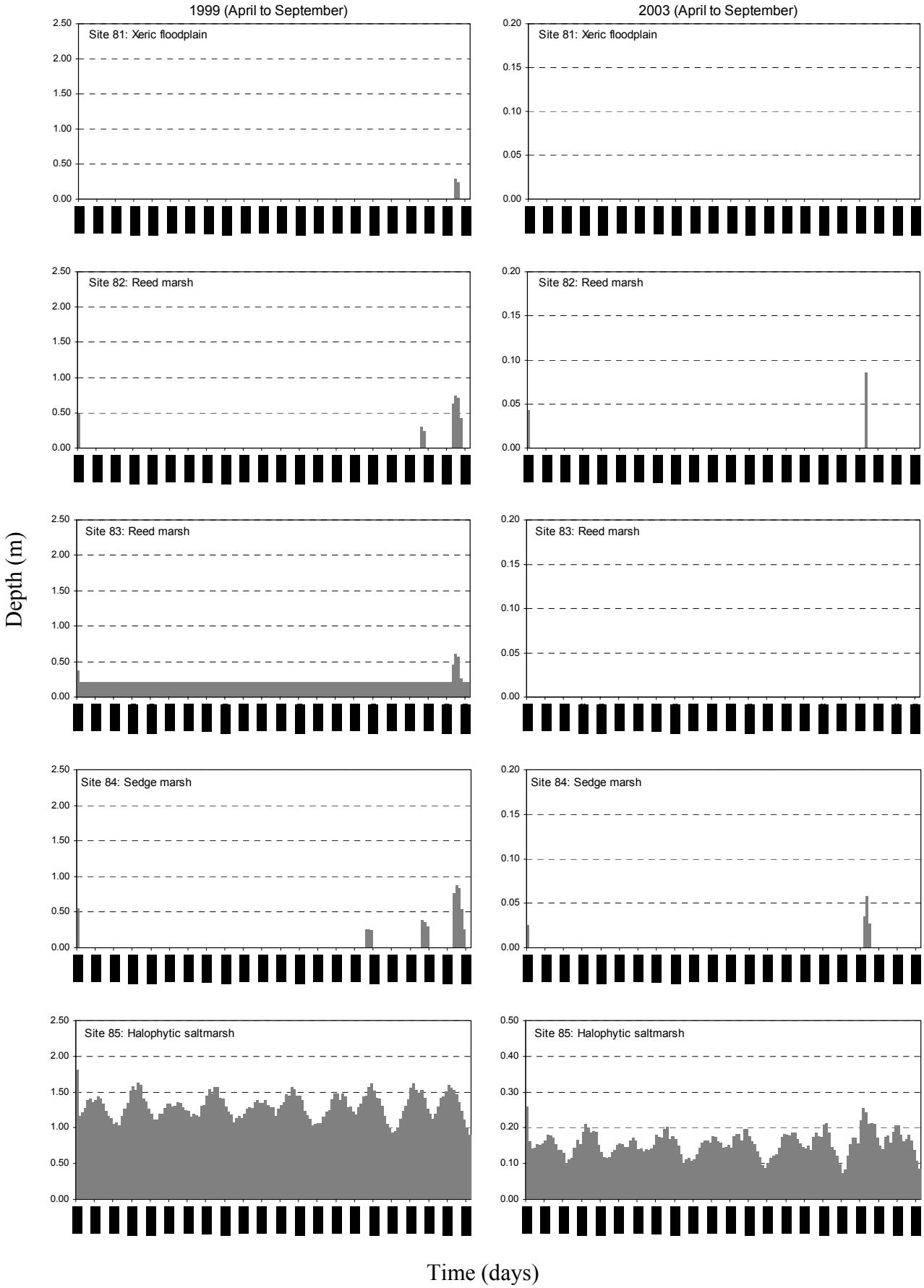


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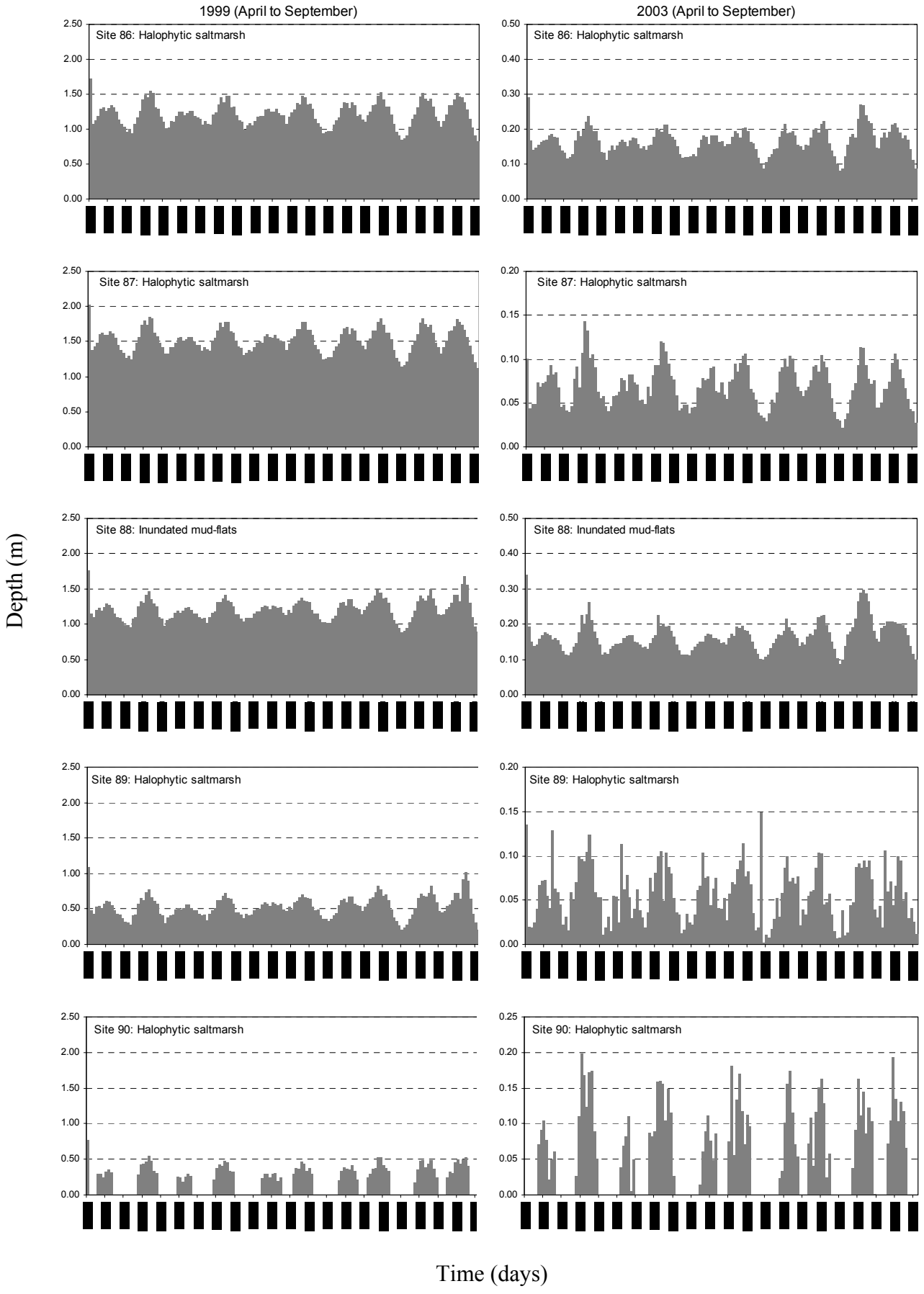


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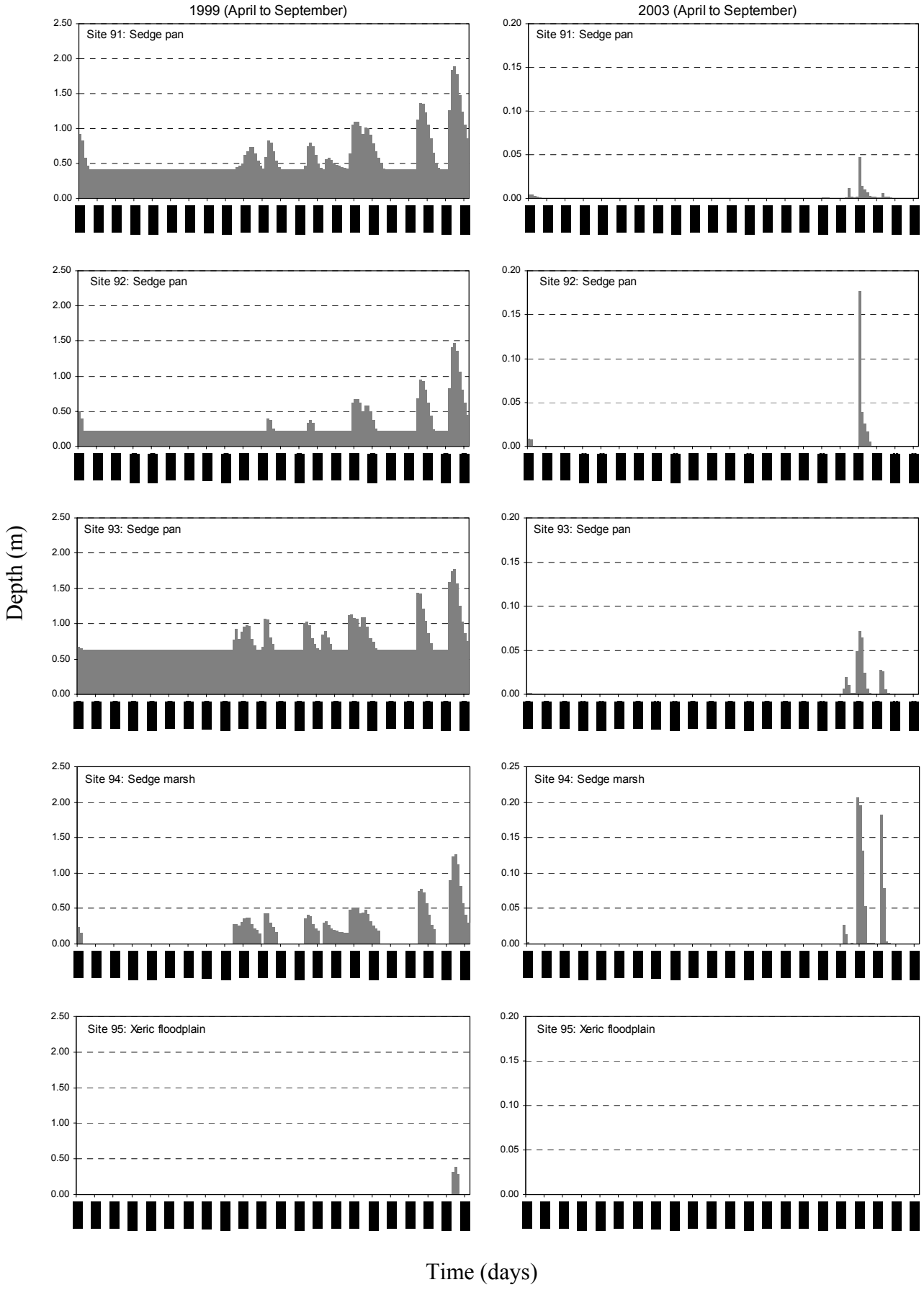


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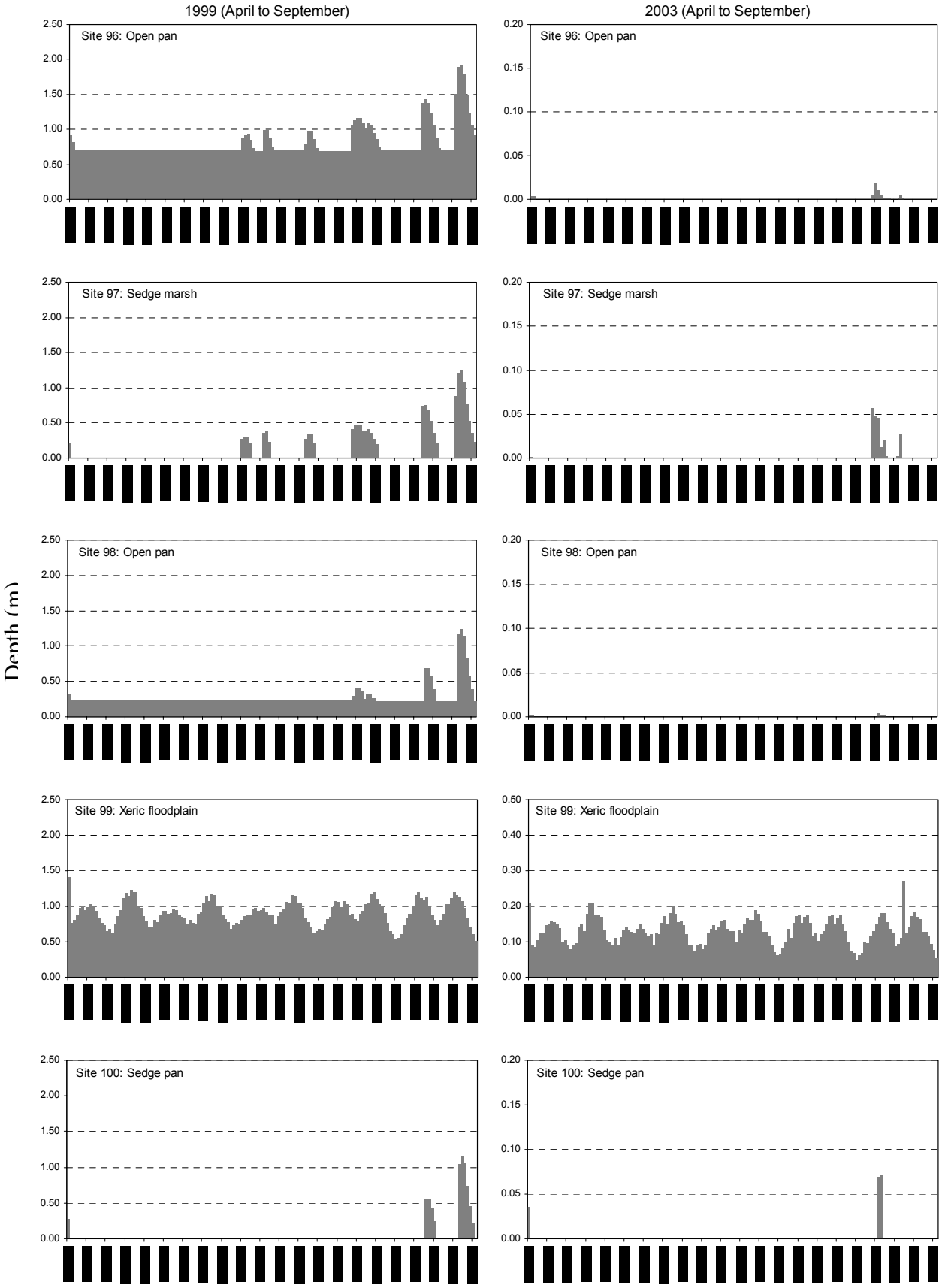


Figure A1.2.1 Continued. Simulated water depth at 100 points in the estuary for the winters of 1999 and 2003

APPENDIX 1.3

SIMULATED FLOW DEPTH AND VELOCITY DATA AT 100 POINTS IN THE ESTUARY FOR THE WINTERS OF 1999 AND 2003

Simulated flow velocity at 100 points in the estuary (m/s) for winter of 1999

	Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7	Point 8	Point 9	Point 10	Point 11	Point 12
23/04/1999 12:00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
23/04/1999 14:24	0.012	0.011	0.000	0.000	0.000	0.009	0.038	0.039	0.021	0.040	0.021	0.031
23/04/1999 16:48	0.036	0.018	0.000	0.000	0.000	0.007	0.060	0.060	0.032	0.059	0.021	0.058
23/04/1999 19:12	0.045	0.017	0.000	0.000	0.000	0.007	0.072	0.072	0.040	0.059	0.000	0.068
23/04/1999 21:36	0.052	0.012	0.000	0.000	0.000	0.006	0.078	0.079	0.051	0.052	0.000	0.070
24/04/1999 00:00	0.056	0.007	0.000	0.000	0.000	0.005	0.079	0.079	0.077	0.043	0.000	0.066
24/04/1999 02:24	0.055	0.004	0.000	0.000	0.000	0.004	0.074	0.074	0.000	0.018	0.000	0.058
24/04/1999 04:48	0.052	0.003	0.000	0.000	0.000	0.002	0.071	0.071	0.000	0.026	0.000	0.051
24/04/1999 07:12	0.053	0.005	0.000	0.000	0.000	0.001	0.070	0.070	0.000	0.000	0.000	0.044
24/04/1999 09:36	0.052	0.005	0.000	0.000	0.000	0.000	0.064	0.066	0.000	0.000	0.000	0.037
24/04/1999 12:00	0.049	0.005	0.000	0.000	0.000	0.000	0.047	0.050	0.000	0.000	0.000	0.010
24/04/1999 14:24	0.040	0.003	0.000	0.000	0.000	0.000	0.029	0.036	0.000	0.000	0.000	0.009
24/04/1999 16:48	0.039	0.003	0.000	0.000	0.000	0.000	0.010	0.039	0.000	0.000	0.000	0.000
24/04/1999 19:12	0.042	0.003	0.000	0.000	0.000	0.000	0.003	0.020	0.000	0.000	0.000	0.000
24/04/1999 21:36	0.038	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
25/04/1999 00:00	0.036	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
25/04/1999 02:24	0.023	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
25/04/1999 04:48	0.026	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
25/04/1999 07:12	0.030	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
25/04/1999 09:36	0.032	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
25/04/1999 12:00	0.032	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
25/04/1999 14:24	0.018	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
25/04/1999 16:48	0.020	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
25/04/1999 19:12	0.025	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
25/04/1999 21:36	0.028	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
26/04/1999 00:00	0.027	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
26/04/1999 02:24	0.007	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
26/04/1999 04:48	0.016	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
26/04/1999 07:12	0.021	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
26/04/1999 09:36	0.024	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
26/04/1999 12:00	0.022	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
26/04/1999 14:24	0.011	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
26/04/1999 16:48	0.019	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
26/04/1999 19:12	0.018	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
26/04/1999 21:36	0.012	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
27/04/1999 00:00	0.012	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
27/04/1999 02:24	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
27/04/1999 04:48	0.017	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
27/04/1999 07:12	0.011	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
27/04/1999 09:36	0.011	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
27/04/1999 12:00	0.011	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
27/04/1999 14:24	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
27/04/1999 16:48	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
27/04/1999 19:12	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
27/04/1999 21:36	0.014	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
28/04/1999 00:00	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
28/04/1999 02:24	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
28/04/1999 04:48	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
28/04/1999 07:12	0.008	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
28/04/1999 09:36	0.013	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
28/04/1999 12:00	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
28/04/1999 14:24	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
28/04/1999 16:48	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
28/04/1999 19:12	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
28/04/1999 21:36	0.013	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
29/04/1999 00:00	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
29/04/1999 02:24	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
29/04/1999 04:48	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
29/04/1999 07:12	0.016	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
29/04/1999 09:36	0.013	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
29/04/1999 12:00	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
29/04/1999 14:24	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
29/04/1999 16:48	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
29/04/1999 19:12	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
29/04/1999 21:36	0.012	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
30/04/1999 00:00	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
30/04/1999 02:24	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
30/04/1999 04:48	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
30/04/1999 07:12	0.025	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
30/04/1999 09:36	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
30/04/1999 12:00	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
30/04/1999 14:24	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Figure A1.3.1 Simulated Flow Depth And Velocity Data At 100 Points In The Estuary For The Winters Of 1999 And 2003

Simulated flow depth at 100 points in the estuary (m) for winter of 1999

Point	1	2	3	4	5	6	7	8	9	10	11	12
23/04/1999 12:00	1.099	0.875	0.000	0.200	0.000	0.679	0.718	0.716	0.474	0.513	0.226	0.671
23/04/1999 14:24	1.096	0.872	0.000	0.200	0.000	0.665	0.703	0.701	0.449	0.489	0.213	0.658
23/04/1999 16:48	1.071	0.847	0.000	0.200	0.000	0.627	0.667	0.664	0.401	0.440	0.178	0.623
23/04/1999 19:12	1.040	0.816	0.000	0.200	0.000	0.581	0.624	0.621	0.349	0.387	0.000	0.582
23/04/1999 21:36	1.003	0.780	0.000	0.200	0.000	0.535	0.578	0.576	0.296	0.335	0.000	0.538
24/04/1999 00:00	0.964	0.742	0.000	0.200	0.000	0.489	0.533	0.531	0.249	0.286	0.000	0.494
24/04/1999 02:24	0.924	0.701	0.000	0.200	0.000	0.451	0.495	0.492	0.220	0.249	0.000	0.455
24/04/1999 04:48	0.884	0.662	0.000	0.200	0.000	0.417	0.454	0.452	0.188	0.208	0.000	0.415
24/04/1999 07:12	0.838	0.616	0.000	0.200	0.000	0.410	0.402	0.400	0.188	0.198	0.000	0.365
24/04/1999 09:36	0.784	0.562	0.000	0.200	0.000	0.410	0.343	0.340	0.188	0.198	0.000	0.307
24/04/1999 12:00	0.729	0.507	0.000	0.200	0.000	0.410	0.287	0.285	0.188	0.198	0.000	0.253
24/04/1999 14:24	0.688	0.465	0.000	0.200	0.000	0.410	0.266	0.263	0.188	0.198	0.000	0.226
24/04/1999 16:48	0.657	0.435	0.000	0.200	0.000	0.410	0.230	0.229	0.188	0.198	0.000	0.193
24/04/1999 19:12	0.620	0.402	0.000	0.200	0.000	0.410	0.185	0.183	0.188	0.198	0.000	0.000
24/04/1999 21:36	0.577	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000
25/04/1999 00:00	0.533	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000
25/04/1999 02:24	0.528	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000
25/04/1999 04:48	0.544	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000
25/04/1999 07:12	0.526	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000
25/04/1999 09:36	0.490	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000
25/04/1999 12:00	0.445	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000
25/04/1999 14:24	0.436	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000
25/04/1999 16:48	0.469	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000
25/04/1999 19:12	0.447	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000
25/04/1999 21:36	0.403	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000
26/04/1999 00:00	0.348	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000
26/04/1999 02:24	0.364	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000
26/04/1999 04:48	0.467	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000
26/04/1999 07:12	0.438	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000
26/04/1999 09:36	0.383	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000
26/04/1999 12:00	0.319	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000
26/04/1999 14:24	0.304	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000
26/04/1999 16:48	0.396	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000
26/04/1999 19:12	0.389	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000
26/04/1999 21:36	0.330	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000
27/04/1999 00:00	0.258	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000
27/04/1999 02:24	0.256	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000
27/04/1999 04:48	0.363	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000
27/04/1999 07:12	0.395	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000
27/04/1999 09:36	0.335	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000
27/04/1999 12:00	0.258	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000
27/04/1999 14:24	0.222	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000
27/04/1999 16:48	0.222	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000
27/04/1999 19:12	0.357	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000
27/04/1999 21:36	0.300	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000
28/04/1999 00:00	0.227	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000
28/04/1999 02:24	0.222	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000
28/04/1999 04:48	0.222	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000
28/04/1999 07:12	0.379	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000
28/04/1999 09:36	0.326	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000
28/04/1999 12:00	0.250	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000
28/04/1999 14:24	0.222	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000
28/04/1999 16:48	0.222	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000
28/04/1999 19:12	0.356	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000
28/04/1999 21:36	0.304	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000
29/04/1999 00:00	0.231	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000
29/04/1999 02:24	0.222	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000
29/04/1999 04:48	0.222	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000
29/04/1999 07:12	0.363	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000
29/04/1999 09:36	0.334	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000
29/04/1999 12:00	0.260	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000
29/04/1999 14:24	0.222	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000
29/04/1999 16:48	0.222	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000
29/04/1999 19:12	0.335	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000
29/04/1999 21:36	0.314	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000
30/04/1999 00:00	0.242	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000
30/04/1999 02:24	0.222	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000
30/04/1999 04:48	0.222	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000
30/04/1999 07:12	0.337	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000
30/04/1999 09:36	0.341	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000
30/04/1999 12:00	0.271	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000
30/04/1999 14:24	0.222	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000

Figure A1.3.1 Cont. Simulated Flow Depth And Velocity Data At 100 Points In The Estuary For The Winters Of 1999 And 2003

Simulated flow velocity at 100 points in the estuary (m/s) for winter of 2003

	1	2	3	4	5	6	7	8	9	10	11	12
23/04/2003 12:00	1.29E-10	1.62E-10	1.00E-35	5.00E-10	1.00E-35	2.08E-10	1.97E-10	1.98E-10	2.99E-10	2.76E-10	6.27E-10	2.11E-10
23/04/2003 14:24	0.012	0.011	0.000	0.000	0.000	0.009	0.038	0.039	0.021	0.040	0.021	0.031
23/04/2003 16:48	0.036	0.018	0.000	0.000	0.000	0.007	0.060	0.061	0.032	0.059	0.022	0.058
23/04/2003 19:12	0.045	0.017	0.000	0.000	0.000	0.007	0.072	0.073	0.040	0.058	0.000	0.068
23/04/2003 21:36	0.051	0.012	0.000	0.000	0.000	0.006	0.078	0.078	0.051	0.052	0.000	0.070
24/04/2003 00:00	0.055	0.007	0.000	0.000	0.000	0.005	0.077	0.078	0.075	0.042	0.000	0.065
24/04/2003 02:24	0.054	0.004	0.000	0.000	0.000	0.004	0.074	0.074		0.018	0.000	0.057
24/04/2003 04:48	0.053	0.006	0.000	0.000	0.000	0.002	0.072	0.073			0.000	0.051
24/04/2003 07:12	0.053	0.004	0.000	0.000	0.000	0.001	0.070	0.070			0.000	0.043
24/04/2003 09:36	0.050	0.006	0.000	0.000	0.000	0.000	0.060	0.062			0.000	0.024
24/04/2003 12:00	0.044	0.005	0.000	0.000	0.000	0.000	0.039	0.043			0.000	0.009
24/04/2003 14:24	0.037	0.005	0.000	0.000	0.000	0.000	0.013	0.045			0.000	
24/04/2003 16:48	0.036	0.004	0.000	0.000	0.000	0.000	0.008	0.014			0.000	0.000
24/04/2003 19:12	0.029	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000
24/04/2003 21:36	0.028	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000
25/04/2003 00:00	0.019	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000
25/04/2003 02:24	0.004	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000
25/04/2003 04:48	0.016	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000
25/04/2003 07:12	0.019	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000
25/04/2003 09:36	0.012	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000
25/04/2003 12:00	0.001	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000
25/04/2003 14:24	0.001	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000
25/04/2003 16:48	0.002	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000
25/04/2003 19:12	0.001	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000
25/04/2003 21:36	0.001	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000
26/04/2003 00:00	0.000	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000
26/04/2003 02:24	0.000	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000
26/04/2003 04:48	0.000	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000
26/04/2003 07:12	0.000	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000
26/04/2003 09:36	0.000	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000
26/04/2003 12:00	0.000	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000
26/04/2003 14:24	0.000	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000
26/04/2003 16:48	0.000	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000
26/04/2003 19:12	0.000	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000
26/04/2003 21:36	0.000	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000
27/04/2003 00:00	0.000	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000
27/04/2003 02:24	0.000	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000
27/04/2003 04:48	0.000	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000
27/04/2003 07:12	0.000	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000
27/04/2003 09:36	0.000	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000
27/04/2003 12:00	0.000	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000
27/04/2003 14:24	0.000	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000
27/04/2003 16:48	0.000	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000
27/04/2003 19:12	0.000	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000
27/04/2003 21:36	0.000	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000
28/04/2003 00:00	0.000	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000
28/04/2003 02:24	0.000	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000
28/04/2003 04:48	0.000	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000
28/04/2003 07:12	0.000	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000
28/04/2003 09:36	0.000	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000
28/04/2003 12:00	0.000	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000
28/04/2003 14:24	0.000	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000
28/04/2003 16:48	0.000	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000
28/04/2003 19:12	0.000	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000
28/04/2003 21:36	0.000	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000
29/04/2003 00:00	0.000	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000
29/04/2003 02:24	0.000	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000
29/04/2003 04:48	0.000	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000
29/04/2003 07:12	0.004	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000
29/04/2003 09:36	0.009	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000
29/04/2003 12:00	0.001	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000
29/04/2003 14:24	0.001	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000
29/04/2003 16:48	0.000	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000
29/04/2003 19:12	0.005	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000
29/04/2003 21:36	0.001	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000
30/04/2003 00:00	0.001	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000
30/04/2003 02:24	0.000	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000
30/04/2003 04:48	0.000	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000
30/04/2003 07:12	0.008	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000
30/04/2003 09:36	0.012	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000
30/04/2003 12:00	0.002	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000
30/04/2003 14:24	0.000	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000

Figure A1.3.1 Cont. Simulated Flow Depth And Velocity Data At 100 Points In The Estuary For The Winters Of 1999 And 2003

Simulated flow depth at 100 points in the estuary (m) for winter of 2003

	1	2	3	4	5	6	7	8	9	10	11	12
23/04/2003 12:00	1.09899	0.875379	1.00E-35	0.2	1.00E-35	0.679336	0.717857	0.715641	0.473737	0.513131	0.225732	0.670772
23/04/2003 14:24	1.095	0.872	0.000	0.200	0.000	0.665	0.703	0.701	0.449	0.488	0.213	0.658
23/04/2003 16:48	1.070	0.847	0.000	0.200	0.000	0.625	0.666	0.663	0.400	0.439	0.177	0.622
23/04/2003 19:12	1.038	0.815	0.000	0.200	0.000	0.580	0.622	0.620	0.347	0.386	0.000	0.580
23/04/2003 21:36	1.001	0.778	0.000	0.200	0.000	0.533	0.576	0.574	0.295	0.333	0.000	0.536
24/04/2003 00:00	0.961	0.738	0.000	0.200	0.000	0.488	0.532	0.530	0.250	0.286	0.000	0.492
24/04/2003 02:24	0.921	0.698	0.000	0.200	0.000	0.449	0.491	0.489	0.214	0.245	0.000	0.452
24/04/2003 04:48	0.878	0.655	0.000	0.200	0.000	0.413	0.445	0.443	0.188	0.200	0.000	0.407
24/04/2003 07:12	0.827	0.605	0.000	0.200	0.000	0.411	0.389	0.386	0.188	0.198	0.000	0.352
24/04/2003 09:36	0.767	0.546	0.000	0.200	0.000	0.411	0.327	0.324	0.188	0.198	0.000	0.290
24/04/2003 12:00	0.706	0.485	0.000	0.200	0.000	0.411	0.274	0.272	0.188	0.198	0.000	0.238
24/04/2003 14:24	0.654	0.434	0.000	0.200	0.000	0.411	0.232	0.230	0.188	0.198	0.000	0.193
24/04/2003 16:48	0.600	0.388	0.000	0.200	0.000	0.411	0.178	0.176	0.188	0.198	0.000	0.000
24/04/2003 19:12	0.537	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000
24/04/2003 21:36	0.466	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000
25/04/2003 00:00	0.408	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000
25/04/2003 02:24	0.429	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000
25/04/2003 04:48	0.398	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000
25/04/2003 07:12	0.343	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000
25/04/2003 09:36	0.271	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000
25/04/2003 12:00	0.224	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000
25/04/2003 14:24	0.288	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000
25/04/2003 16:48	0.297	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000
25/04/2003 19:12	0.244	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000
25/04/2003 21:36	0.222	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000
26/04/2003 00:00	0.222	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000
26/04/2003 02:24	0.222	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000
26/04/2003 04:48	0.222	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000
26/04/2003 07:12	0.222	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000
26/04/2003 09:36	0.222	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000
26/04/2003 12:00	0.222	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000
26/04/2003 14:24	0.222	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000
26/04/2003 16:48	0.222	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000
26/04/2003 19:12	0.222	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000
26/04/2003 21:36	0.222	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000
27/04/2003 00:00	0.222	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000
27/04/2003 02:24	0.222	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000
27/04/2003 04:48	0.222	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000
27/04/2003 07:12	0.222	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000
27/04/2003 09:36	0.222	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000
27/04/2003 12:00	0.222	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000
27/04/2003 14:24	0.222	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000
27/04/2003 16:48	0.222	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000
27/04/2003 19:12	0.222	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000
27/04/2003 21:36	0.222	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000
28/04/2003 00:00	0.222	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000
28/04/2003 02:24	0.222	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000
28/04/2003 04:48	0.222	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000
28/04/2003 07:12	0.222	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000
28/04/2003 09:36	0.222	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000
28/04/2003 12:00	0.222	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000
28/04/2003 14:24	0.222	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000
28/04/2003 16:48	0.222	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000
28/04/2003 19:12	0.222	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000
28/04/2003 21:36	0.222	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000
29/04/2003 00:00	0.222	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000
29/04/2003 02:24	0.222	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000
29/04/2003 04:48	0.222	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000
29/04/2003 07:12	0.327	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000
29/04/2003 09:36	0.267	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000
29/04/2003 12:00	0.222	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000
29/04/2003 14:24	0.222	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000
29/04/2003 16:48	0.222	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000
29/04/2003 19:12	0.314	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000
29/04/2003 21:36	0.254	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000
30/04/2003 00:00	0.222	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000
30/04/2003 02:24	0.222	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000
30/04/2003 04:48	0.222	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000
30/04/2003 07:12	0.345	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000
30/04/2003 09:36	0.289	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000
30/04/2003 12:00	0.221	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000
30/04/2003 14:24	0.222	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000

Figure A1.3.1 Cont. Simulated Flow Depth And Velocity Data At 100 Points In The Estuary For The Winters Of 1999 And 2003

APPENDIX 1.4

MONTHLY FLOW DEPTH AND VELOCITY DURATION STATISTICS FOR 100 POINTS IN THE ESTUARY FOR THE INTERS OF 1999 AND 2003

Table: Percentiles of mean **depth** (m) and **Speed** (m/s) based on modelled data for 100 points for winter 1999

Speed Frequency

percentile	Percentile	Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7	Point 8	Point 9	Point 10	Point 11	Point 12	Point 13
May														
0.01	99	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.05	95	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.1	90	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.2	80	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.3	70	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.4	60	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.5	50	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.6	40	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.7	30	0.009	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.8	20	0.014	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.9	10	0.019	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.95	5	0.024	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.99	1	0.033	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.99999	0.001	0.117	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
June														
0.01	99	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.05	95	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.1	90	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.2	80	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.3	70	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.4	60	0.009	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.5	50	0.013	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.6	40	0.024	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.7	30	0.039	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.8	20	0.047	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.9	10	0.060	0.002	0.000	0.000	0.000	0.000	0.042	0.049	0.000	0.000	0.000	0.009	0.000
0.95	5	0.067	0.003	0.000	0.000	0.000	0.000	0.059	0.062	0.000	0.000	0.000	0.024	0.000
0.99	1	0.075	0.005	0.000	0.000	0.000	0.000	0.075	0.076	0.000	0.000	0.000	0.036	0.000
0.99999	0.001	0.078	0.016	0.000	0.000	0.000	0.000	0.080	0.081	0.000	0.000	0.000	0.039	0.000
July														
0.01	99	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.05	95	0.006	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.1	90	0.015	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.2	80	0.022	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.3	70	0.025	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.4	60	0.031	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.5	50	0.035	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.6	40	0.040	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.7	30	0.049	0.001	0.000	0.000	0.000	0.000	0.001	0.020	0.000	0.000	0.000	0.000	0.000
0.8	20	0.057	0.002	0.000	0.000	0.000	0.000	0.018	0.043	0.000	0.000	0.000	0.000	0.000
0.9	10	0.070	0.004	0.000	0.000	0.000	0.000	0.071	0.071	0.000	0.000	0.000	0.043	0.000
0.95	5	0.079	0.005	0.000	0.000	0.000	0.000	0.079	0.078	0.000	0.000	0.000	0.054	0.000
0.99	1	0.084	0.011	0.000	0.000	0.000	0.000	0.086	0.086	0.000	0.000	0.000	0.063	0.000
0.99999	0.001	0.087	0.020	0.000	0.000	0.000	0.000	0.089	0.089	0.000	0.000	0.000	0.065	0.000
August														
0.01	99	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.05	95	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.1	90	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.2	80	0.011	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.3	70	0.024	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.4	60	0.029	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.5	50	0.033	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.6	40	0.041	0.000	0.000	0.000	0.000	0.000	0.000	0.018	0.000	0.000	0.000	0.000	0.000
0.7	30	0.063	0.008	0.000	0.000	0.000	0.000	0.070	0.068	0.000	0.000	0.000	0.047	0.000
0.8	20	0.072	0.029	0.000	0.000	0.000	0.006	0.090	0.092	0.035	0.060	0.000	0.087	0.003
0.9	10	0.087	0.056	0.000	0.000	0.000	0.014	0.102	0.103	0.056	0.091	0.025	0.106	0.013
0.95	5	0.098	0.064	0.000	0.000	0.000	0.026	0.106	0.107	0.068	0.113	0.054	0.113	0.016
0.99	1	0.141	0.119	0.000	0.029	0.000	0.092	0.115	0.116	0.103	0.189	0.075	0.121	0.044
0.99999	0.001	0.158	0.126	0.000	0.046	0.000	0.097	0.130	0.132	0.120	0.197	0.080	0.142	0.046
September														
0.01	99	0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.05	95	0.012	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.1	90	0.022	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.2	80	0.028	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.3	70	0.035	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.4	60	0.063	0.004	0.000	0.000	0.000	0.000	0.069	0.070	0.000	0.000	0.000	0.043	0.000
0.5	50	0.070	0.023	0.000	0.000	0.000	0.006	0.074	0.077	0.049	0.051	0.000	0.079	0.004
0.6	40	0.073	0.054	0.000	0.000	0.000	0.040	0.080	0.083	0.065	0.106	0.050	0.084	0.016

Figure A1.4.1 Monthly Flow Depth And Velocity Duration Statistics For 100 Points In The Estuary For The Winters Of 1999 And 2003

Table: Percentiles of mean **depth** (m) and **Speed** (m/s) based on modelled data for 100 points for winter 1999

Depth Frequency

percentile	Percentile	Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7	Point 8	Point 9	Point 10	Point 11	Point 12	Point 13
May														
0.01	99	0.222	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000	0.587
0.05	95	0.222	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000	0.587
0.1	90	0.222	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000	0.587
0.2	80	0.222	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000	0.587
0.3	70	0.222	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000	0.587
0.4	60	0.222	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000	0.587
0.5	50	0.222	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000	0.587
0.6	40	0.232	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000	0.587
0.7	30	0.283	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000	0.587
0.8	20	0.333	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000	0.587
0.9	10	0.391	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000	0.587
0.95	5	0.417	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000	0.587
0.99	1	0.490	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000	0.587
0.99999	0.001	0.509	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000	0.587
June														
0.01	99	0.222	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000	0.587
0.05	95	0.222	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000	0.587
0.1	90	0.222	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000	0.587
0.2	80	0.222	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000	0.587
0.3	70	0.222	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000	0.587
0.4	60	0.278	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000	0.587
0.5	50	0.341	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000	0.587
0.6	40	0.413	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000	0.587
0.7	30	0.537	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000	0.587
0.8	20	0.622	0.373	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000	0.587
0.9	10	0.778	0.555	0.000	0.200	0.000	0.410	0.320	0.318	0.188	0.198	0.000	0.287	0.587
0.95	5	0.827	0.604	0.000	0.200	0.000	0.410	0.364	0.362	0.188	0.198	0.000	0.333	0.587
0.99	1	0.870	0.647	0.000	0.200	0.000	0.410	0.418	0.415	0.188	0.198	0.000	0.381	0.587
0.99999	0.001	0.879	0.657	0.000	0.200	0.000	0.410	0.427	0.425	0.188	0.198	0.000	0.389	0.587
July														
0.01	99	0.312	0.369	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000	0.587
0.05	95	0.339	0.369	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000	0.587
0.1	90	0.372	0.369	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000	0.587
0.2	80	0.431	0.371	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000	0.587
0.3	70	0.463	0.372	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000	0.587
0.4	60	0.493	0.372	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000	0.587
0.5	50	0.562	0.372	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000	0.587
0.6	40	0.614	0.372	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000	0.587
0.7	30	0.665	0.429	0.000	0.200	0.000	0.410	0.231	0.229	0.188	0.198	0.000	0.000	0.587
0.8	20	0.721	0.497	0.000	0.200	0.000	0.410	0.275	0.273	0.188	0.198	0.000	0.235	0.587
0.9	10	0.841	0.619	0.000	0.200	0.000	0.410	0.382	0.380	0.188	0.198	0.000	0.347	0.587
0.95	5	0.897	0.676	0.000	0.200	0.000	0.410	0.431	0.428	0.188	0.198	0.000	0.395	0.587
0.99	1	0.926	0.704	0.000	0.200	0.000	0.410	0.475	0.473	0.188	0.198	0.000	0.437	0.587
0.99999	0.001	0.937	0.715	0.000	0.200	0.000	0.410	0.487	0.485	0.188	0.198	0.000	0.448	0.587
August														
0.01	99	0.222	0.369	0.000	0.200	0.000	0.407	0.152	0.000	0.188	0.198	0.000	0.000	0.587
0.05	95	0.222	0.369	0.000	0.200	0.000	0.407	0.152	0.000	0.188	0.198	0.000	0.000	0.587
0.1	90	0.222	0.369	0.000	0.200	0.000	0.407	0.153	0.000	0.188	0.198	0.000	0.000	0.587
0.2	80	0.360	0.372	0.000	0.200	0.000	0.407	0.153	0.000	0.188	0.198	0.000	0.000	0.587
0.3	70	0.466	0.372	0.000	0.200	0.000	0.407	0.153	0.000	0.188	0.198	0.000	0.000	0.587
0.4	60	0.532	0.372	0.000	0.200	0.000	0.407	0.153	0.000	0.188	0.198	0.000	0.000	0.587
0.5	50	0.567	0.372	0.000	0.200	0.000	0.407	0.153	0.000	0.188	0.198	0.000	0.000	0.587
0.6	40	0.638	0.372	0.000	0.200	0.000	0.410	0.216	0.214	0.188	0.198	0.000	0.000	0.587
0.7	30	0.894	0.672	0.000	0.200	0.000	0.410	0.455	0.451	0.188	0.198	0.000	0.419	0.587
0.8	20	1.055	0.832	0.000	0.200	0.000	0.549	0.600	0.598	0.311	0.347	0.000	0.563	0.752
0.9	10	1.158	0.934	0.000	0.200	0.000	0.661	0.702	0.699	0.408	0.447	0.155	0.662	0.848
0.95	5	1.209	0.985	0.000	0.200	0.000	0.710	0.750	0.748	0.447	0.486	0.267	0.711	0.904
0.99	1	1.474	1.248	0.000	0.553	0.000	1.004	1.029	1.027	0.737	0.777	0.542	0.985	1.167
0.99999	0.001	1.482	1.257	0.000	0.566	0.000	1.021	1.051	1.048	0.770	0.809	0.562	1.006	1.182
September														
0.01	99	0.397	0.371	0.000	0.332	0.000	0.409	0.153	0.000	0.188	0.198	0.000	0.000	0.587
0.05	95	0.418	0.371	0.000	0.332	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000	0.587
0.1	90	0.464	0.371	0.000	0.332	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000	0.587
0.2	80	0.518	0.371	0.000	0.332	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000	0.587
0.3	70	0.559	0.371	0.000	0.332	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000	0.587
0.4	60	0.844	0.622	0.000	0.332	0.000	0.410	0.388	0.385	0.188	0.198	0.000	0.351	0.587
0.5	50	1.022	0.799	0.000	0.332	0.000	0.509	0.567	0.565	0.268	0.305	0.000	0.531	0.709
0.6	40	1.184	0.960	0.000	0.332	0.000	0.714	0.749	0.746	0.453	0.492	0.262	0.708	0.888

Figure A1.4.1 Cont. Monthly Flow Depth And Velocity Duration Statistics For 100 Points In The Estuary For The Winters Of 1999 And 2003

Table: Percentiles of mean **depth** (m) and **Speed** (m/s) based on modelled data for 100 points for winter 2003

Speed Frequency

percentile	Percentile	Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7	Point 8	Point 9	Point 10	Point 11	Point 12	Point 13
May														
0.01	**99**	0.000	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000	0.000
0.05	**95**	0.000	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000	0.000
0.1	**90**	0.000	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000	0.000
0.2	**80**	0.000	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000	0.000
0.3	**70**	0.000	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000	0.000
0.4	**60**	0.000	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000	0.000
0.5	**50**	0.000	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000	0.000
0.6	**40**	0.000	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000	0.000
0.7	**30**	0.000	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000	0.000
0.8	**20**	0.003	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000	0.000
0.9	**10**	0.011	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000	0.000
0.95	**5**	0.016	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000	0.000
0.99	**1**	0.028	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000	0.000
0.99999	**0.001**	0.066	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000	0.000
June														
0.01	**99**	0.000	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000	0.000
0.05	**95**	0.000	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000	0.000
0.1	**90**	0.000	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000	0.000
0.2	**80**	0.000	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000	0.000
0.3	**70**	0.000	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000	0.000
0.4	**60**	0.000	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000	0.000
0.5	**50**	0.000	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000	0.000
0.6	**40**	0.000	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000	0.000
0.7	**30**	0.001	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000	0.000
0.8	**20**	0.003	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000	0.000
0.9	**10**	0.010	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000	0.000
0.95	**5**	0.013	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000	0.000
0.99	**1**	0.030	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000	0.000
0.99999	**0.001**	0.044	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000	0.000
July														
0.01	**99**	0.000	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000	0.000
0.05	**95**	0.000	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000	0.000
0.1	**90**	0.000	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000	0.000
0.2	**80**	0.000	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000	0.000
0.3	**70**	0.000	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000	0.000
0.4	**60**	0.000	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000	0.000
0.5	**50**	0.000	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000	0.000
0.6	**40**	0.000	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000	0.000
0.7	**30**	0.001	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000	0.000
0.8	**20**	0.008	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000	0.000
0.9	**10**	0.012	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000	0.000
0.95	**5**	0.015	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000	0.000
0.99	**1**	0.040	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000	0.000
0.99999	**0.001**	0.049	0.000	0.000	0.000	0.000	0.000		0.000			0.000	0.000	0.000
August														
0.01	**99**	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.035	0.017	0.000	0.000	0.000
0.05	**95**	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.036	0.018	0.000	0.000	0.000
0.1	**90**	0.000	0.000	0.000	0.000	0.000	0.000	0.009	0.000	0.038	0.025	0.000	0.000	0.000
0.2	**80**	0.000	0.000	0.000	0.000	0.000	0.000	0.054	0.000	0.041	0.044	0.000	0.000	0.000
0.3	**70**	0.002	0.000	0.000	0.000	0.000	0.000	0.065	0.000	0.042	0.049	0.000	0.000	0.000
0.4	**60**	0.010	0.000	0.000	0.000	0.000	0.000	0.074	0.000	0.045	0.065	0.000	0.000	0.000
0.5	**50**	0.014	0.000	0.000	0.000	0.000	0.000	0.079	0.000	0.048	0.072	0.000	0.000	0.000
0.6	**40**	0.027	0.000	0.000	0.000	0.000	0.000	0.085	0.000	0.050	0.080	0.000	0.000	0.000
0.7	**30**	0.036	0.000	0.000	0.000	0.000	0.000	0.091	0.000	0.052	0.085	0.000	0.000	0.000
0.8	**20**	0.047	0.000	0.000	0.000	0.000	0.000	0.094	0.000	0.055	0.095	0.000	0.000	0.000
0.9	**10**	0.061	0.008	0.000	0.000	0.000	0.002	0.100	0.076	0.061	0.099	0.000	0.055	0.001
0.95	**5**	0.072	0.042	0.000	0.000	0.000	0.009	0.103	0.091	0.070	0.101	0.012	0.091	0.010
0.99	**1**	0.096	0.057	0.000	0.000	0.000	0.013	0.112	0.103	0.081	0.104	0.048	0.106	0.013
0.99999	**0.001**	0.102	0.059	0.000	0.000	0.000	0.014	0.115	0.115	0.085	0.104	0.051	0.114	0.015
September														
0.01	**99**	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000			0.000	0.000	0.000
0.05	**95**	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000			0.000	0.000	0.000
0.1	**90**	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000			0.000	0.000	0.000
0.2	**80**	0.009	0.000	0.000	0.000	0.000	0.000	0.007	0.000			0.000	0.000	0.000
0.3	**70**	0.015	0.000	0.000	0.000	0.000	0.000	0.008	0.000			0.000	0.000	0.000
0.4	**60**	0.021	0.000	0.000	0.000	0.000	0.000	0.009	0.000			0.000	0.000	0.000
0.5	**50**	0.024	0.000	0.000	0.000	0.000	0.000	0.010	0.000			0.000	0.000	0.000
0.6	**40**	0.026	0.000	0.000	0.000	0.000	0.000	0.011	0.000			0.000	0.000	0.000

Figure A1.4.1 Cont. Monthly Flow Depth And Velocity Duration Statistics For 100 Points In The Estuary For The Winters Of 1999 And 2003

Table: Percentiles of mean **depth** (m) and **Speed** (m/s) based on modelled data for 100 points for winter 2003

Depth Frequency

percentile	Percentile	Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7	Point 8	Point 9	Point 10	Point 11	Point 12	Point 13
May														
0.01	**99**	0.222	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000	0.588
0.05	**95**	0.222	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000	0.588
0.1	**90**	0.222	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000	0.588
0.2	**80**	0.222	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000	0.588
0.3	**70**	0.222	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000	0.588
0.4	**60**	0.222	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000	0.588
0.5	**50**	0.222	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000	0.588
0.6	**40**	0.222	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000	0.588
0.7	**30**	0.222	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000	0.588
0.8	**20**	0.258	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000	0.588
0.9	**10**	0.330	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000	0.588
0.95	**5**	0.370	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000	0.588
0.99	**1**	0.411	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000	0.588
0.99999	**0.001**	0.431	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000	0.588
June														
0.01	**99**	0.221	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000	0.588
0.05	**95**	0.222	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000	0.588
0.1	**90**	0.222	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000	0.588
0.2	**80**	0.222	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000	0.588
0.3	**70**	0.222	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000	0.588
0.4	**60**	0.222	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000	0.588
0.5	**50**	0.222	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000	0.588
0.6	**40**	0.222	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000	0.588
0.7	**30**	0.222	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000	0.588
0.8	**20**	0.239	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000	0.588
0.9	**10**	0.311	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000	0.588
0.95	**5**	0.350	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000	0.588
0.99	**1**	0.388	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000	0.588
0.99999	**0.001**	0.406	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000	0.588
July														
0.01	**99**	0.222	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000	0.588
0.05	**95**	0.222	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000	0.588
0.1	**90**	0.222	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000	0.588
0.2	**80**	0.222	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000	0.588
0.3	**70**	0.222	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000	0.588
0.4	**60**	0.222	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000	0.588
0.5	**50**	0.222	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000	0.588
0.6	**40**	0.222	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000	0.588
0.7	**30**	0.222	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000	0.588
0.8	**20**	0.278	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000	0.588
0.9	**10**	0.332	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000	0.588
0.95	**5**	0.353	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000	0.588
0.99	**1**	0.383	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000	0.588
0.99999	**0.001**	0.408	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000	0.588
August														
0.01	**99**	0.222	0.376	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000	0.587
0.05	**95**	0.222	0.376	0.000	0.200	0.000	0.411	0.153	0.000	0.188	0.198	0.000	0.000	0.588
0.1	**90**	0.222	0.376	0.000	0.200	0.000	0.411	0.153	0.000	0.188	0.198	0.000	0.000	0.588
0.2	**80**	0.222	0.376	0.000	0.200	0.000	0.411	0.153	0.000	0.188	0.198	0.000	0.000	0.588
0.3	**70**	0.224	0.376	0.000	0.200	0.000	0.411	0.153	0.000	0.188	0.198	0.000	0.000	0.588
0.4	**60**	0.309	0.376	0.000	0.200	0.000	0.411	0.153	0.000	0.188	0.198	0.000	0.000	0.588
0.5	**50**	0.357	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000	0.588
0.6	**40**	0.492	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000	0.588
0.7	**30**	0.570	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000	0.588
0.8	**20**	0.636	0.376	0.000	0.200	0.000	0.411	0.154	0.000	0.188	0.198	0.000	0.000	0.588
0.9	**10**	0.933	0.710	0.000	0.200	0.000	0.430	0.498	0.496	0.219	0.250	0.000	0.459	0.623
0.95	**5**	1.101	0.878	0.000	0.200	0.000	0.609	0.653	0.650	0.366	0.404	0.086	0.612	0.799
0.99	**1**	1.178	0.954	0.000	0.200	0.000	0.691	0.733	0.731	0.441	0.480	0.249	0.694	0.880
0.99999	**0.001**	1.185	0.960	0.000	0.200	0.000	0.700	0.742	0.740	0.457	0.496	0.256	0.701	0.883
September														
0.01	**99**	0.222	0.371	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000	0.587
0.05	**95**	0.222	0.371	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000	0.587
0.1	**90**	0.243	0.371	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000	0.587
0.2	**80**	0.336	0.371	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000	0.587
0.3	**70**	0.383	0.371	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000	0.587
0.4	**60**	0.421	0.371	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000	0.587
0.5	**50**	0.456	0.371	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000	0.587
0.6	**40**	0.481	0.371	0.000	0.200	0.000	0.410	0.153	0.000	0.188	0.198	0.000	0.000	0.587

Figure A1.4.1 Cont. Monthly Flow Depth And Velocity Duration Statistics For 100 Points In The Estuary For The Winters Of 1999 And 2003

APPENDIX 1.5

SIMULATED WATER DEPTHS IN REACHES DURING FLOODS

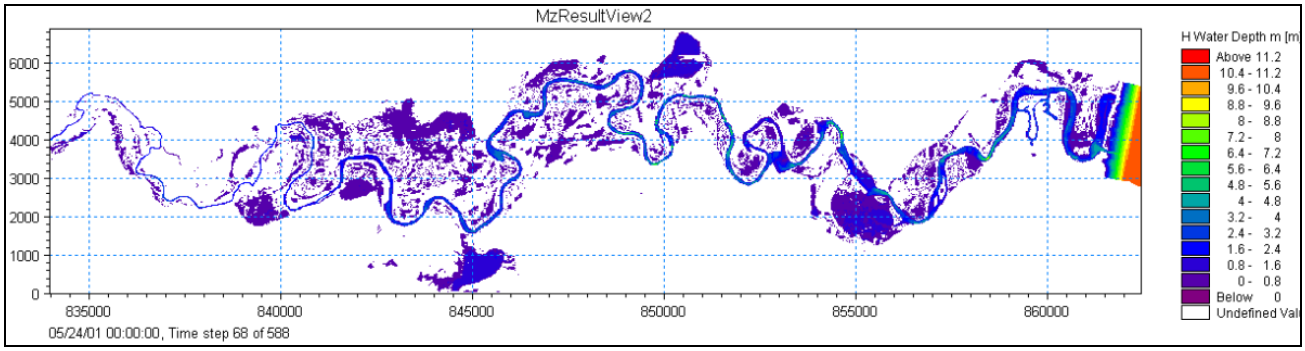


Figure A 1.5.1 Berg River estuary initial depths prior to winter

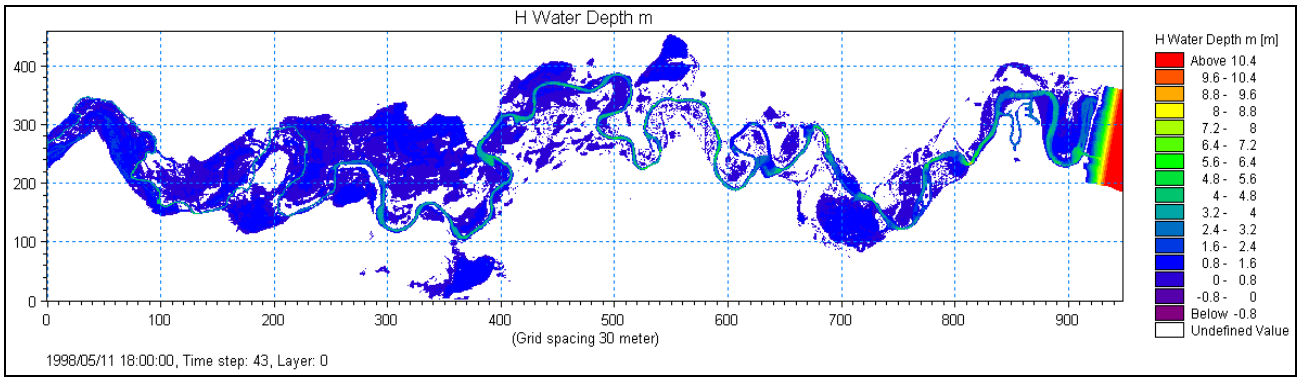


Figure A 1.5.2 Water depth in reach 1 - 1998/05/10

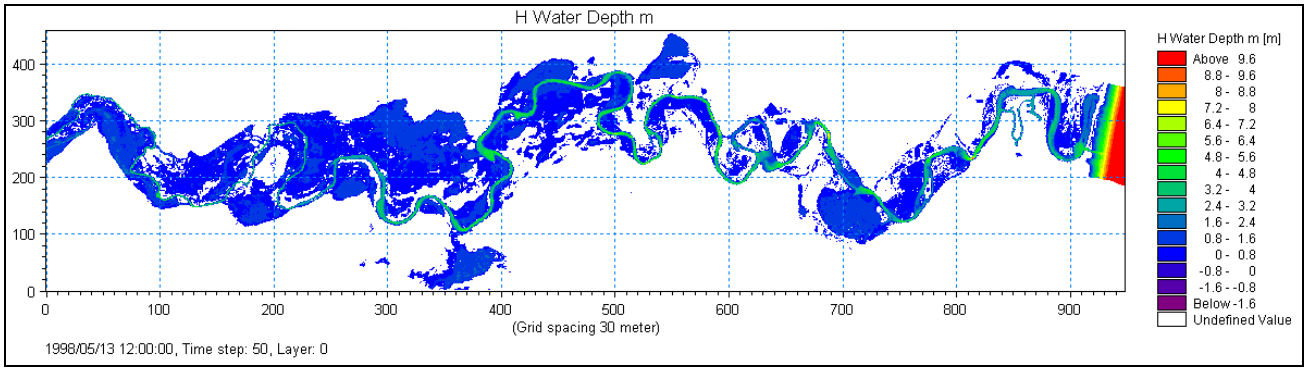


Figure A 1.5.3 Water depth in reach 2 - 1998/05/10

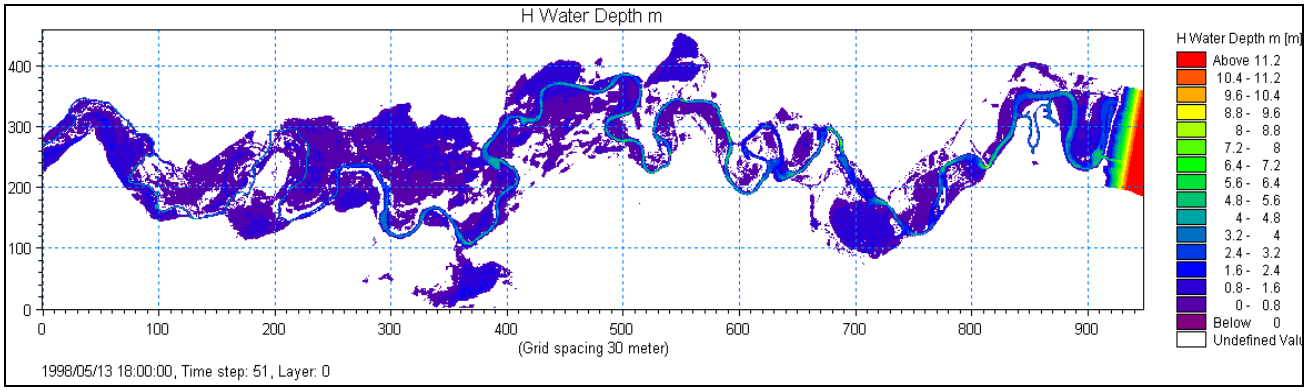


Figure A 1.5.4 Water depth in reach 3 & 4 - 1998/05/10

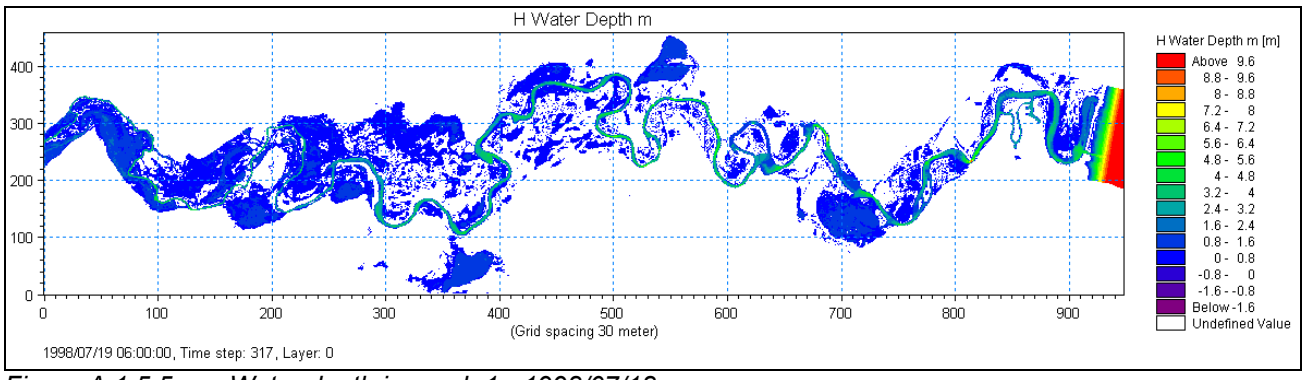


Figure A 1.5.5 Water depth in reach 1 - 1998/07/18

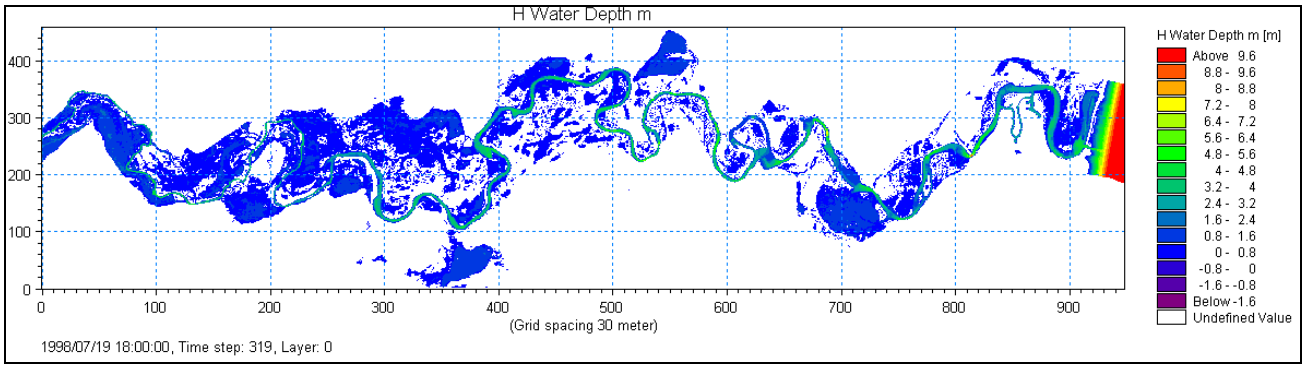


Figure A 1.5.6 Water depth in reach 2 & 3 - 1998/07/18

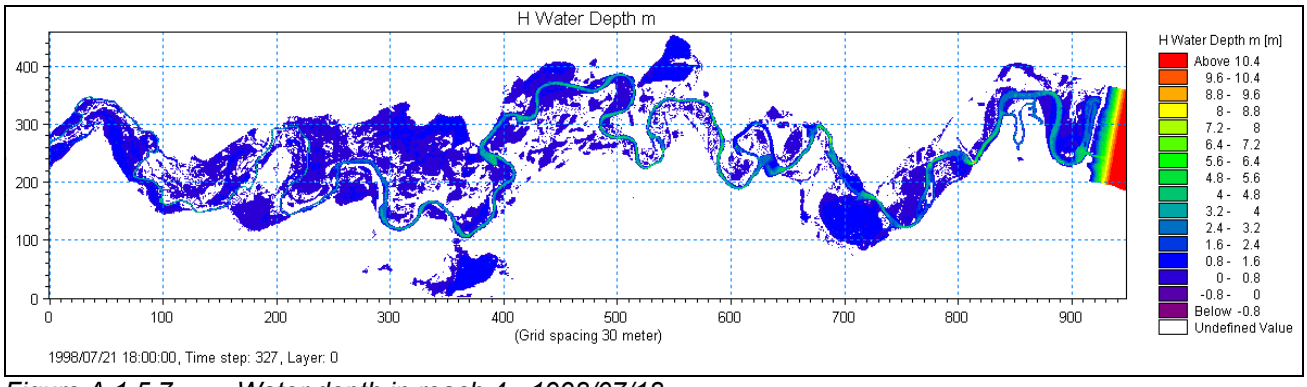


Figure A 1.5.7 Water depth in reach 4 - 1998/07/18

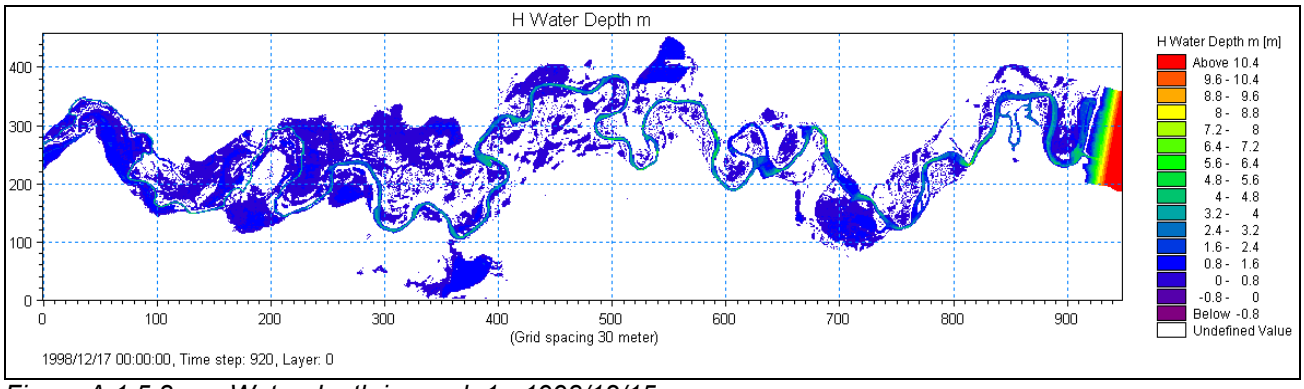


Figure A 1.5.8 Water depth in reach 1 - 1998/12/15

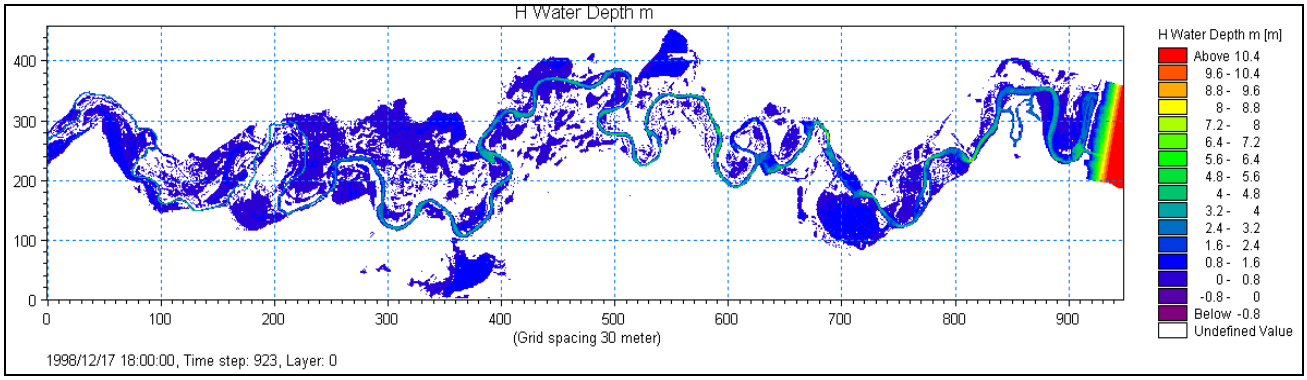


Figure A 1.5.9 Water depth in reach 2, 3 & 4 - 1998/12/15

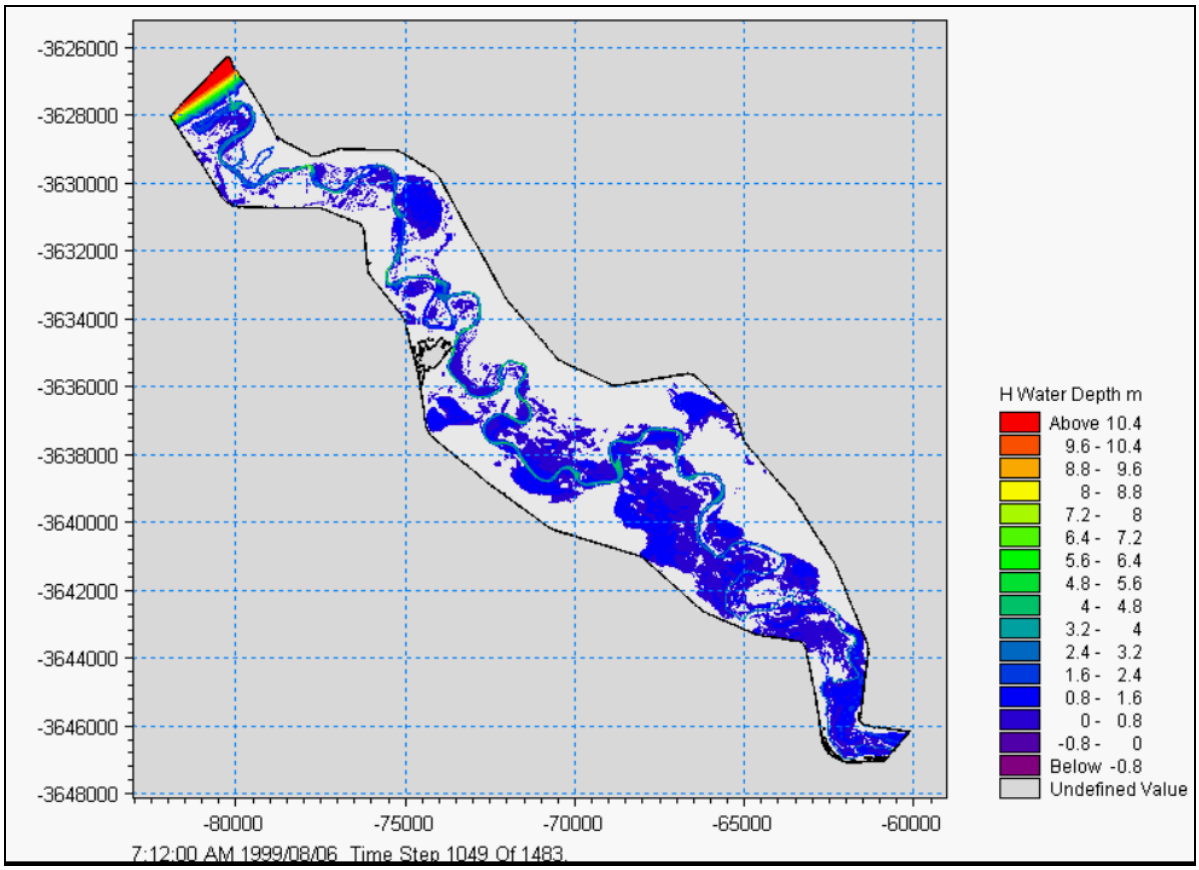


Figure A 1.5.10 Water depth in reach 1 - 1999/08/04

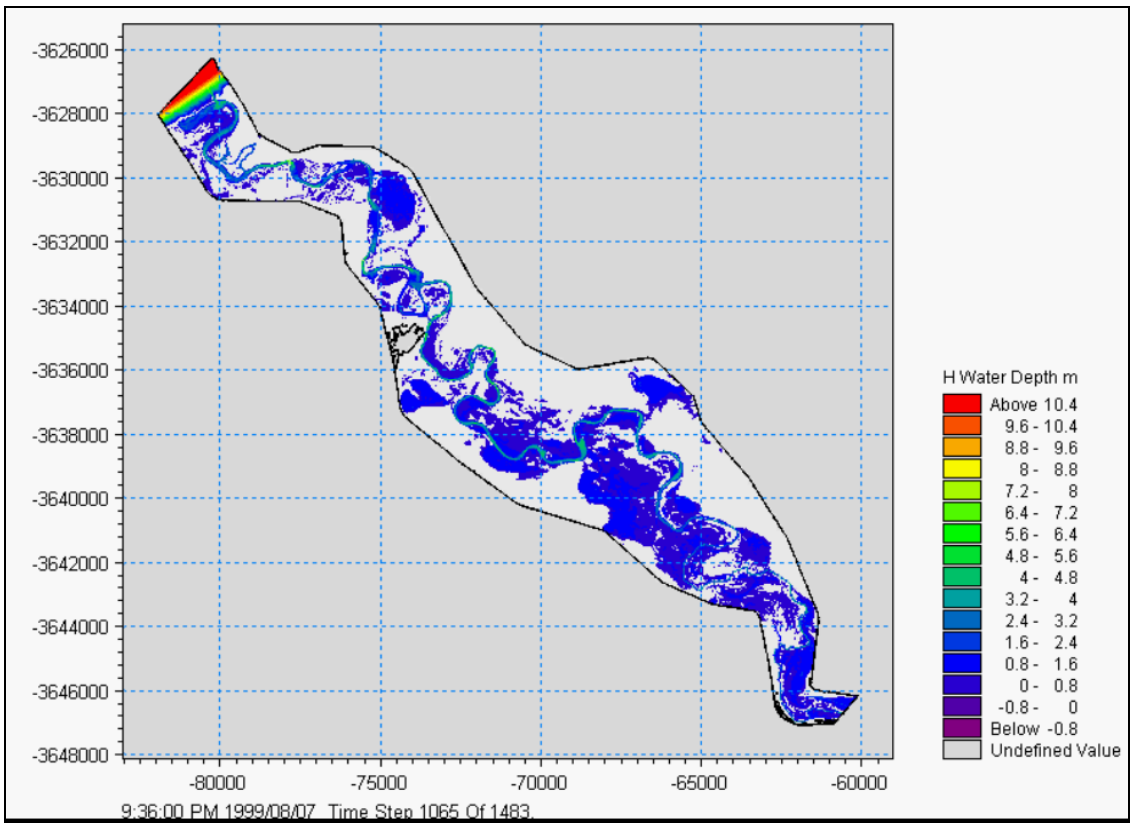


Figure A 1.5.11 Water depth in reach 2, 3 & 4 - 1999/08/04

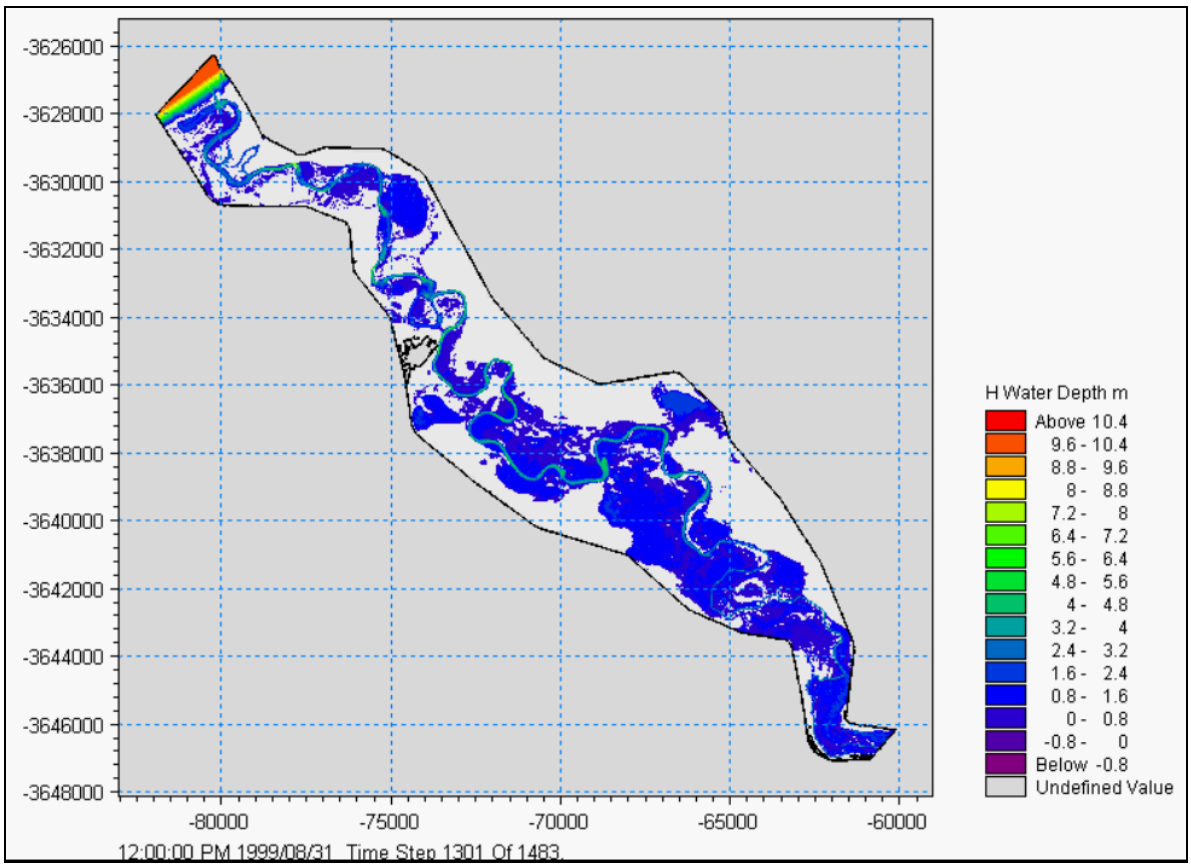


Figure A 1.5.12 Water depth in reach 1 & 2 - 1999/08/30

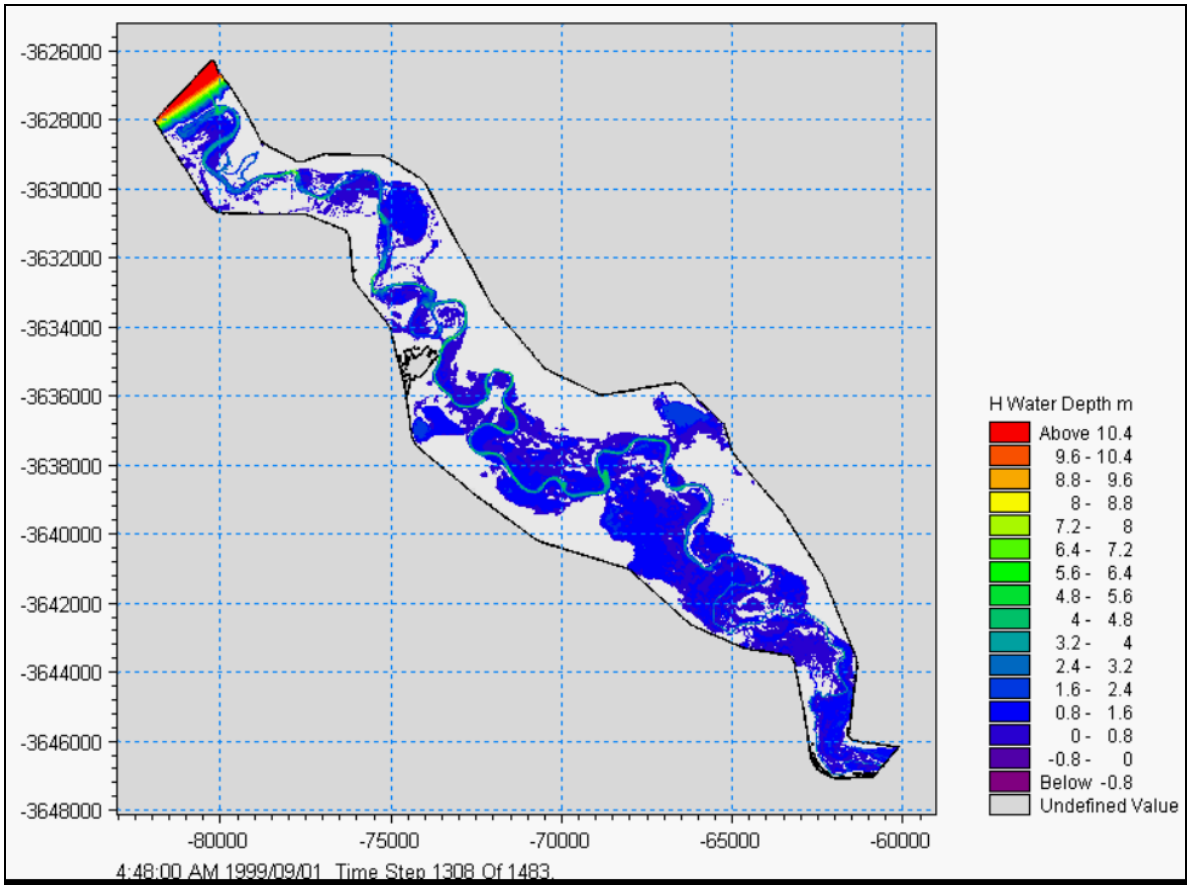


Figure A 1.5.13 Water depth in reach 3 & 4 - 1999/08/30

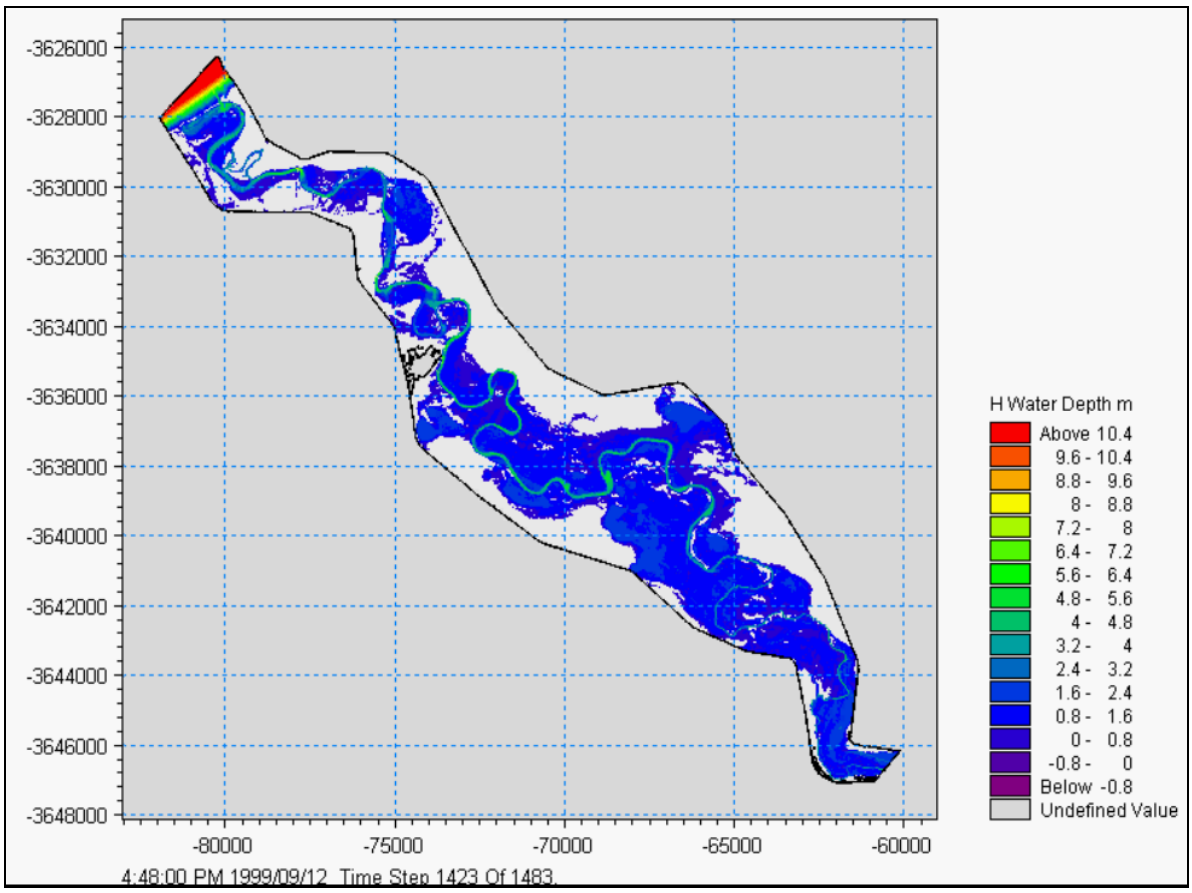


Figure A 1.5.14 Water depth in reach 1 & 2 - 1999/09/12

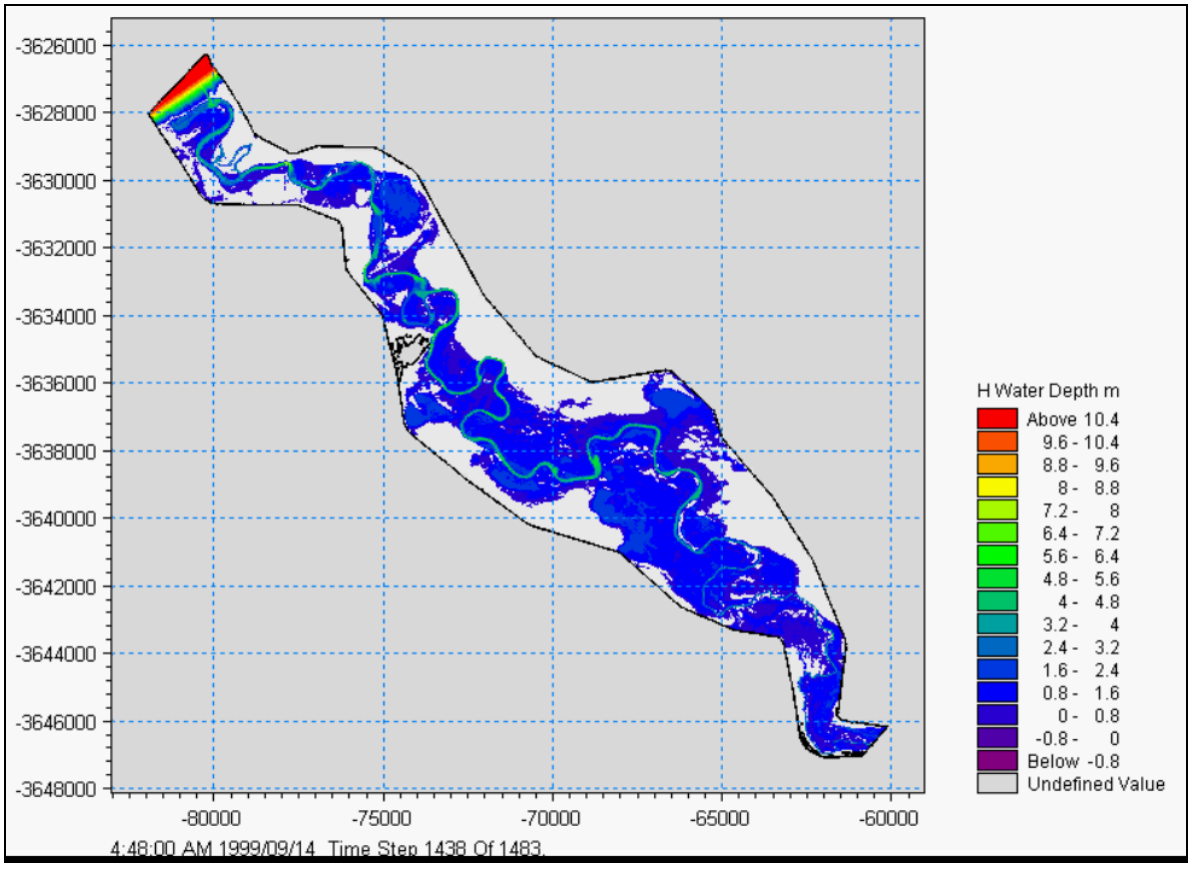


Figure A 1.5.15 Water depth in reach 3 & 4 - 1999/09/12

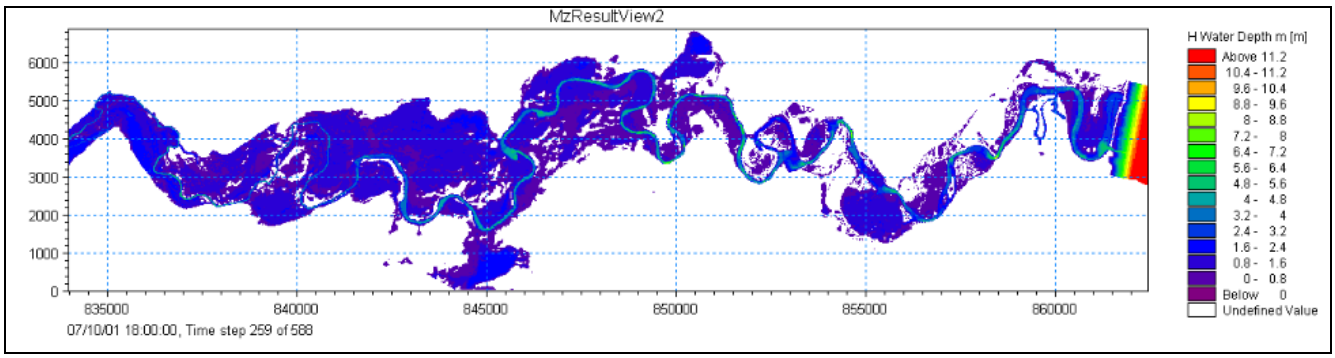


Figure A 1.5.16 Water depth in reach 1 - 2001/07/10

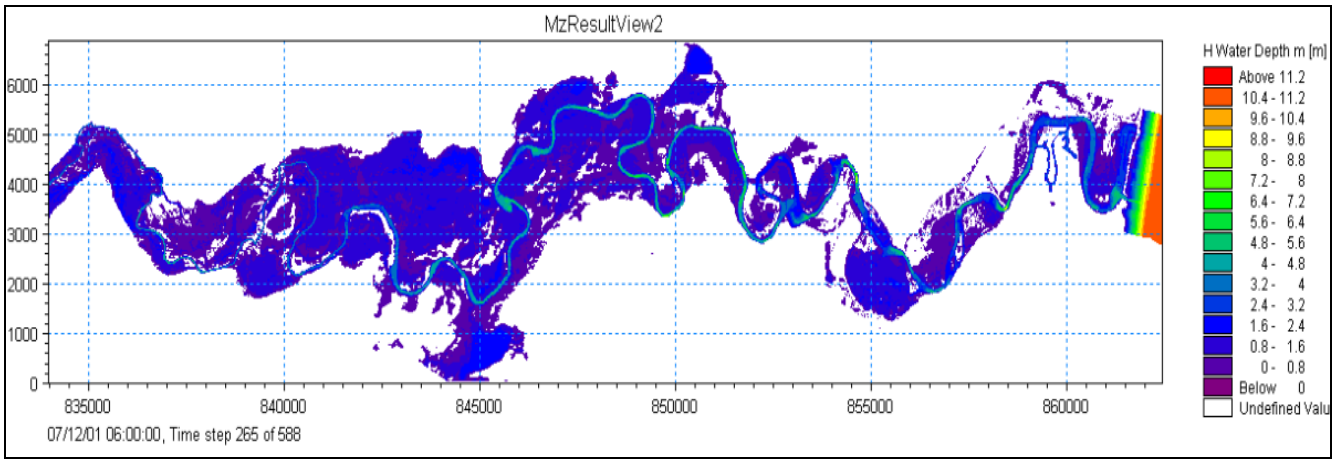


Figure A 1.5.17 Water depth in reach 2, 3 & 4 - 2001/07/10

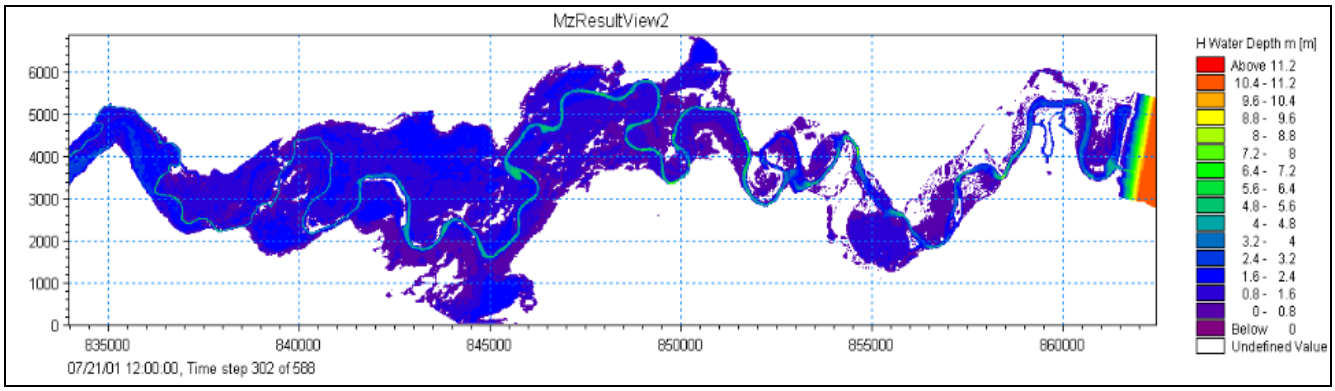


Figure A 1.5.18 Water depth in reach 1 - 2001/07/20

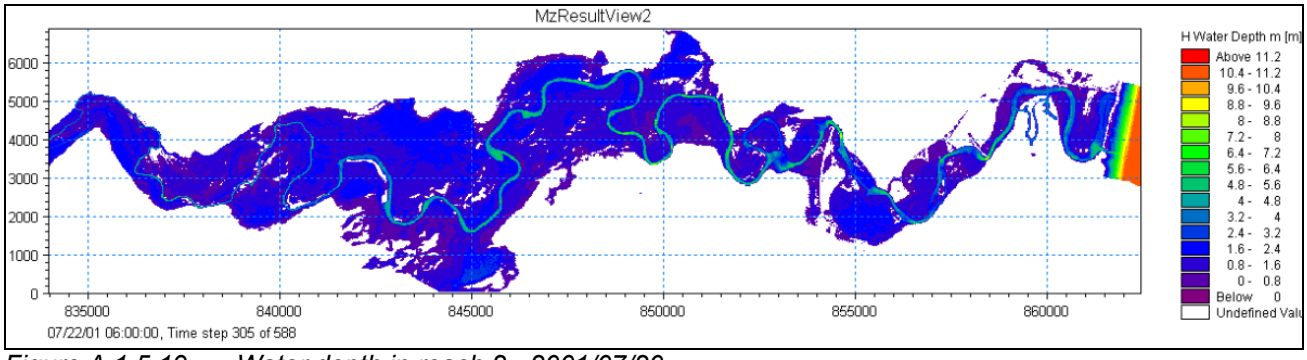


Figure A 1.5.19 Water depth in reach 2 - 2001/07/20

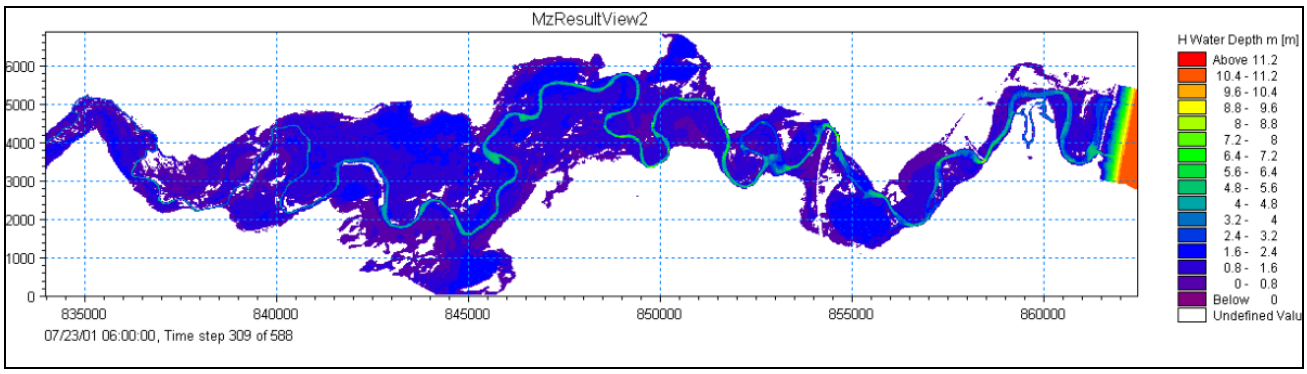


Figure A 1.5.20 Water depth in reach 3 & 4 - 2001/07/20

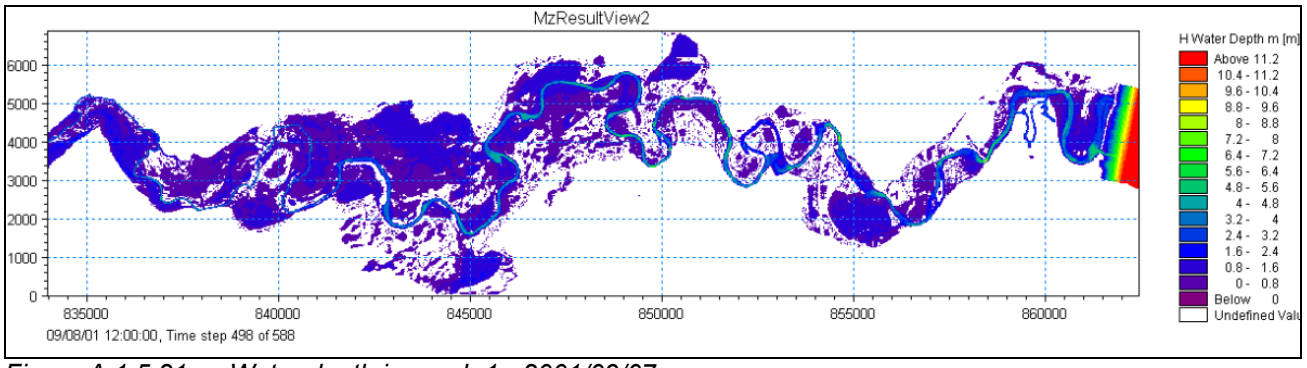


Figure A 1.5.21 Water depth in reach 1 - 2001/09/07

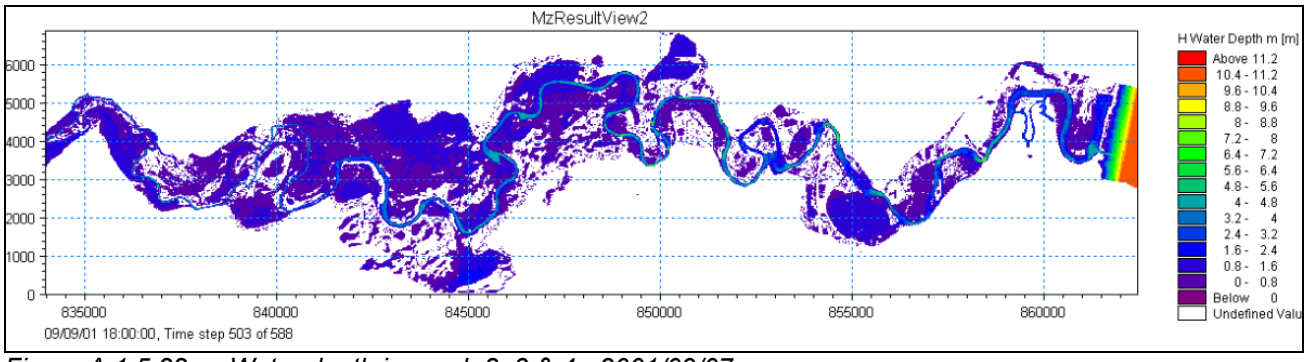


Figure A 1.5.22 Water depth in reach 2, 3 & 4 - 2001/09/07

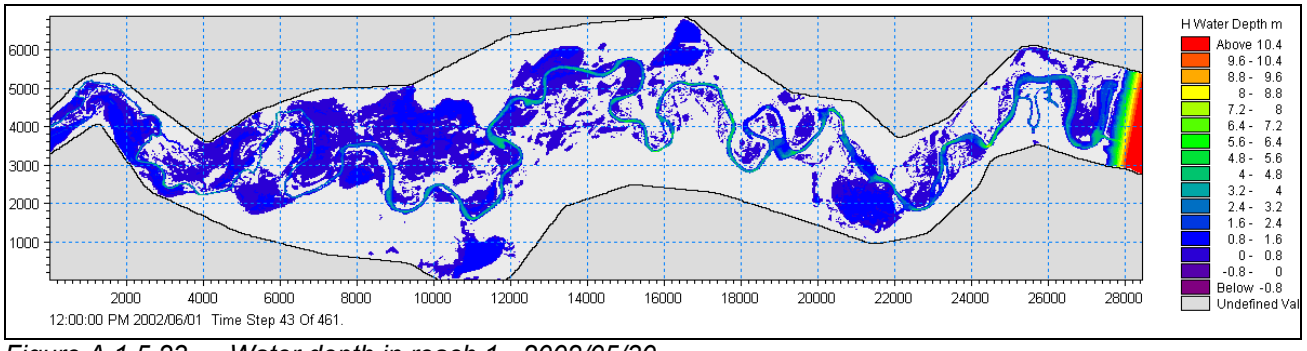


Figure A 1.5.23 Water depth in reach 1 - 2002/05/30

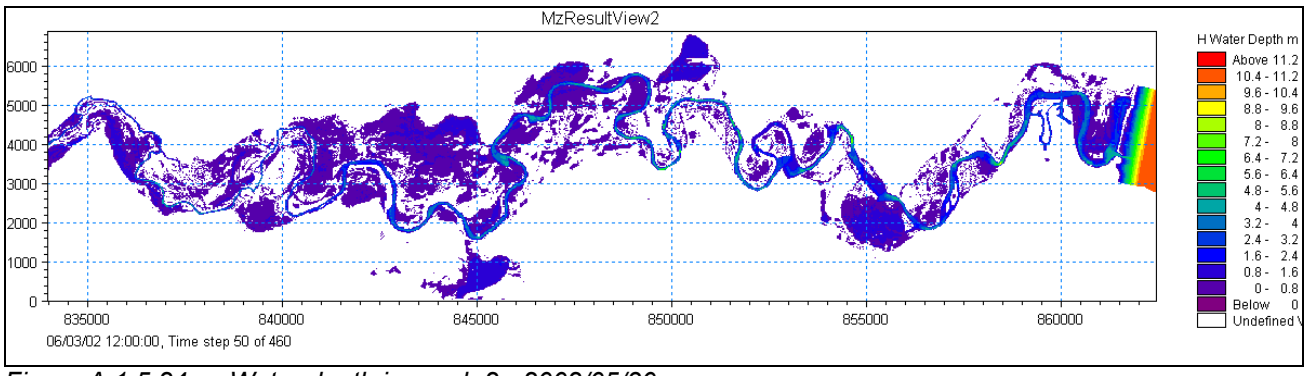


Figure A 1.5.24 Water depth in reach 2 - 2002/05/30

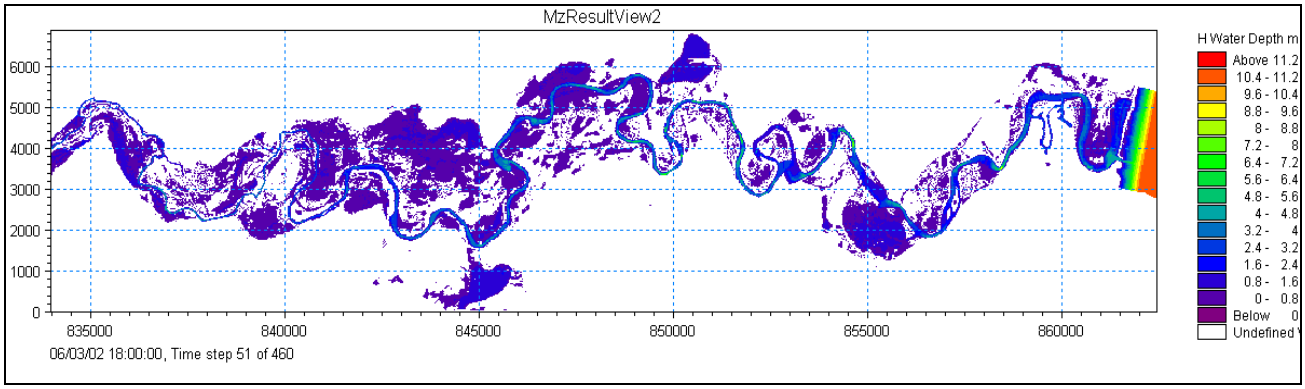


Figure A 1.5.25 Water depth in reach 3 - 2002/05/30

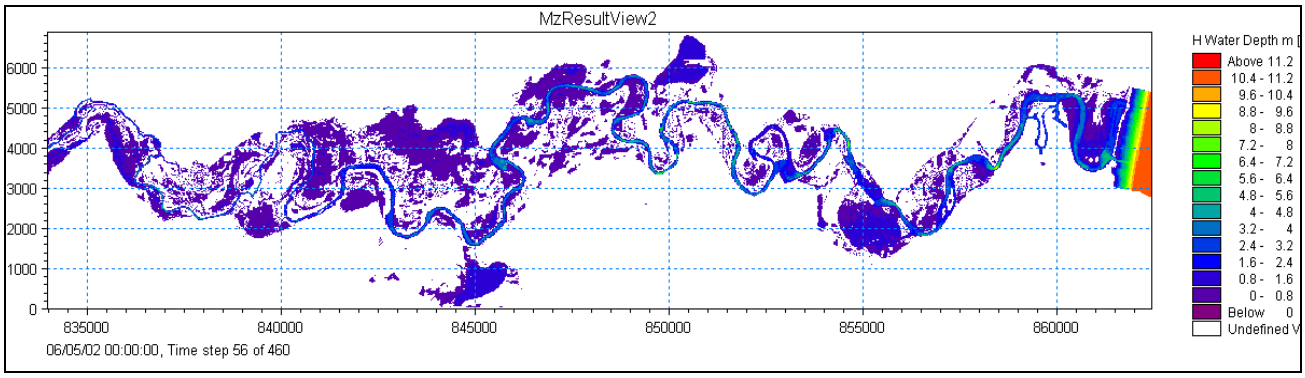


Figure A 1.5.26 Water depth in reach 4 - 2002/05/30

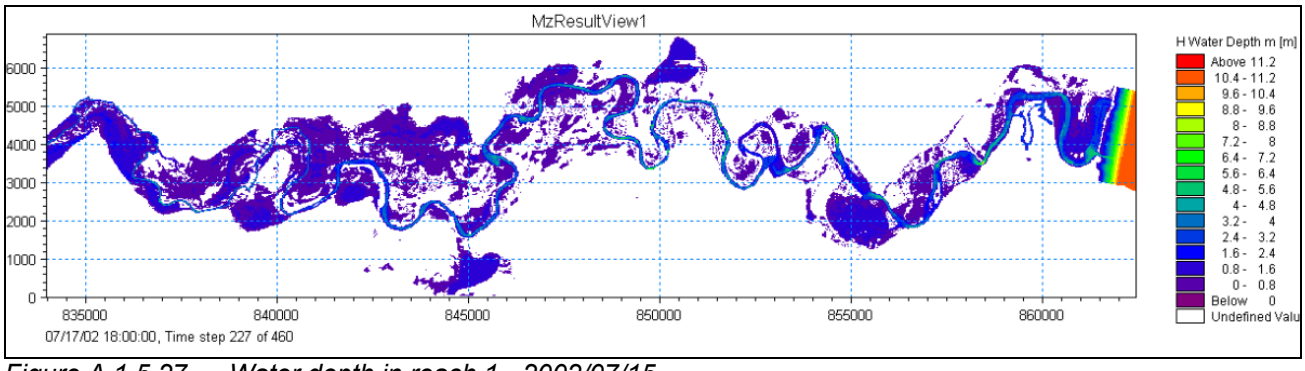


Figure A 1.5.27 Water depth in reach 1 - 2002/07/15

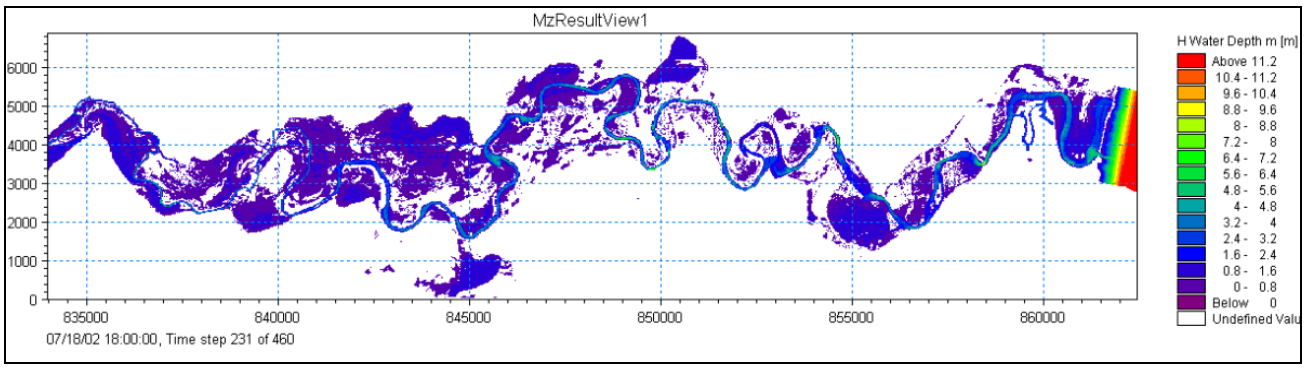


Figure A 1.5.28 Water depth in reach 2, 3 & 4 - 2002/07/15

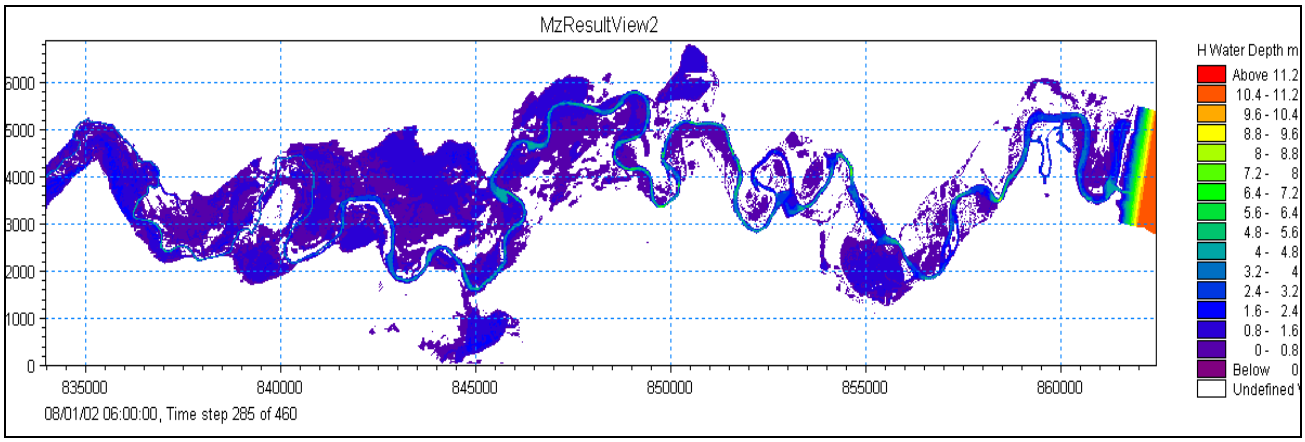


Figure A 1.5.29 Water depth in reach 1 - 2002/07/30

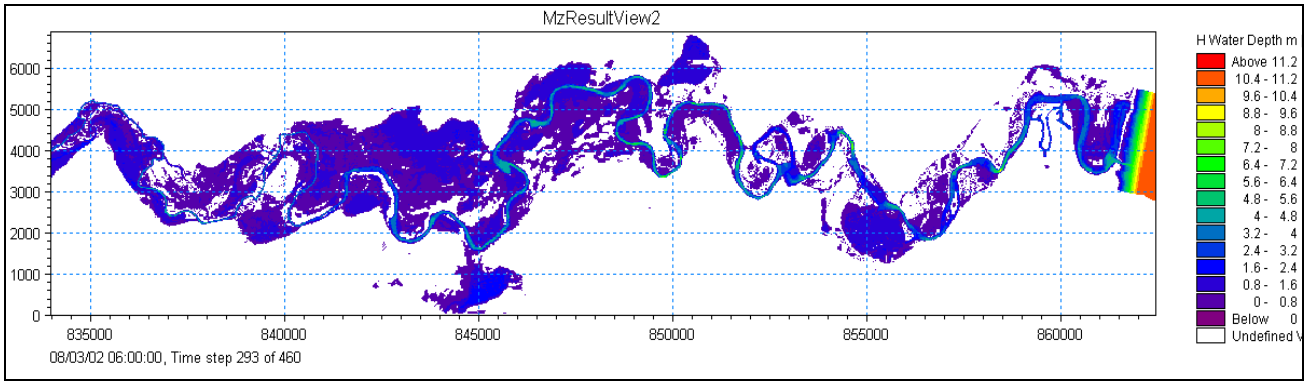


Figure A 1.5.30 Water depth in reach 2 - 2002/07/30

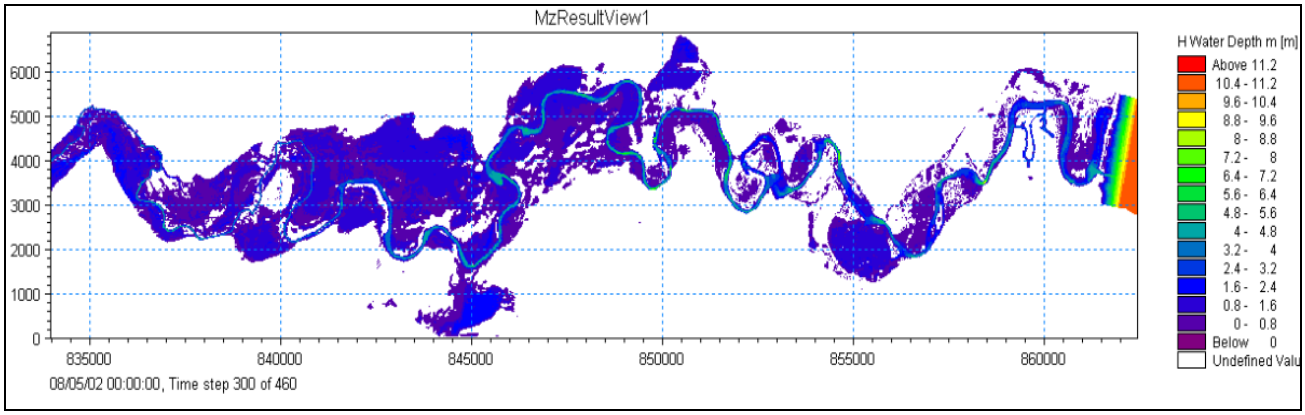


Figure A 1.5.31 Water depth in reach 3 - 2002/07/30

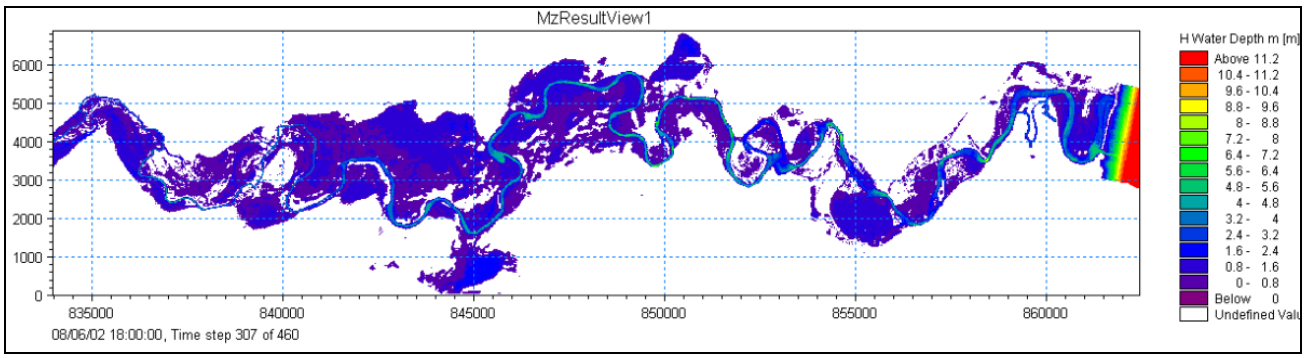


Figure A 1.5.32 Water depth in reach 4 - 2002/07/30

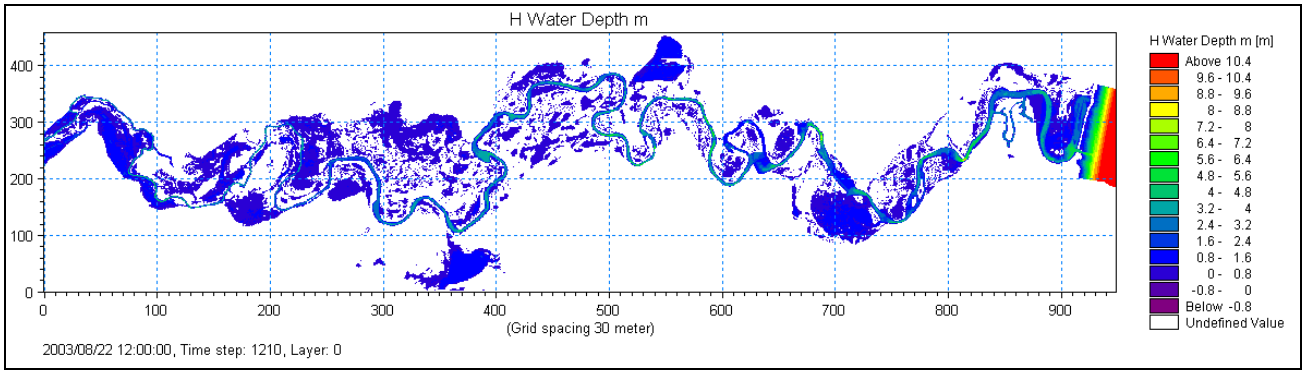


Figure A 1.5.33 Water depth in reach 1, 2, 3 & 4 - 2002/08/21

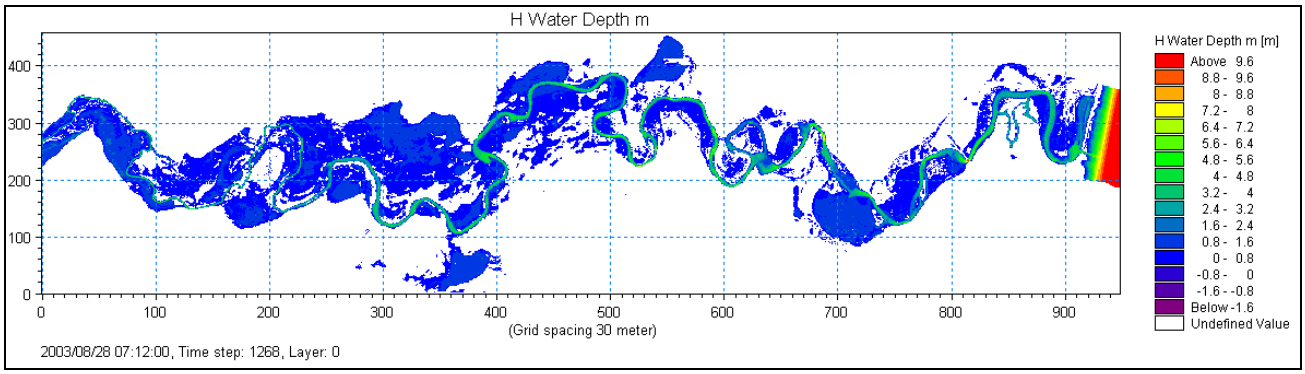


Figure A 1.5.34 Water depth in reach 1 - 2002/08/27

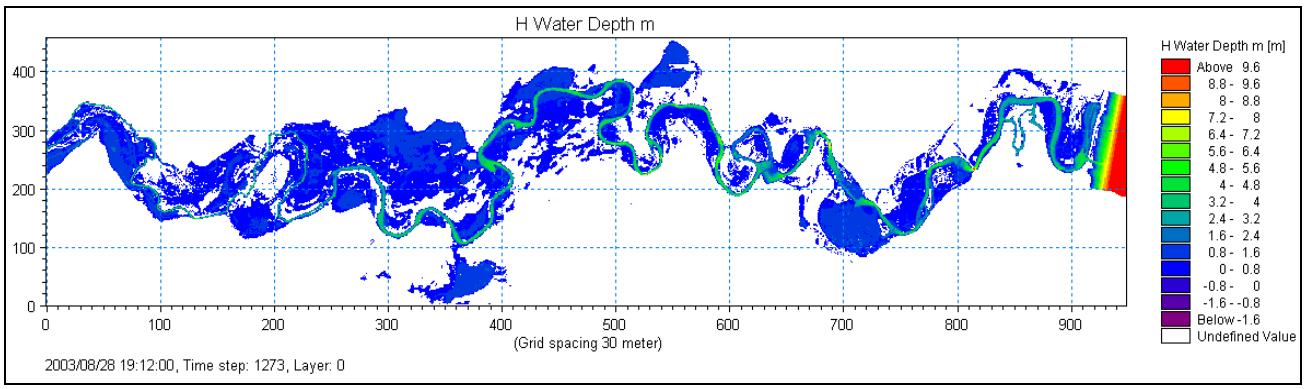


Figure A 1.5.35 Water depth in reach 2 - 2002/08/27

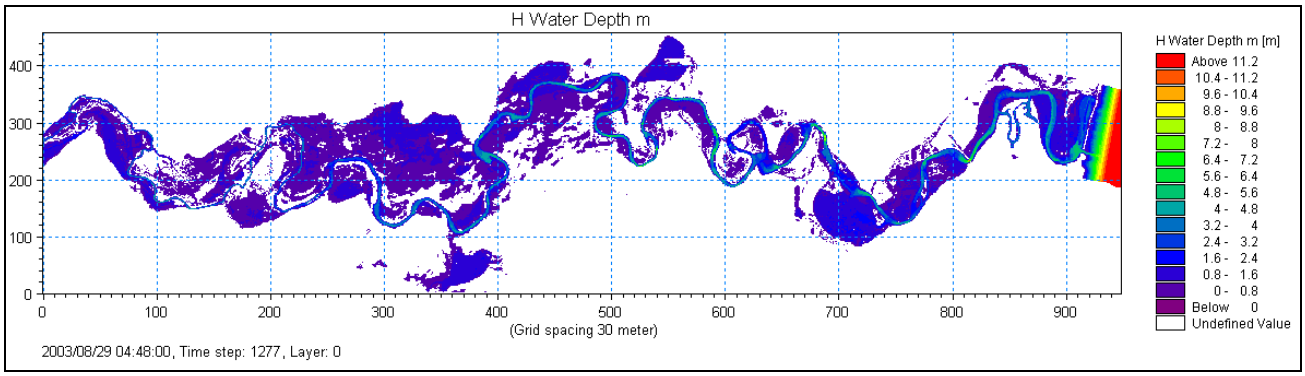


Figure A 1.5.36 Water depth in reach 3 & 4 - 2002/08/27

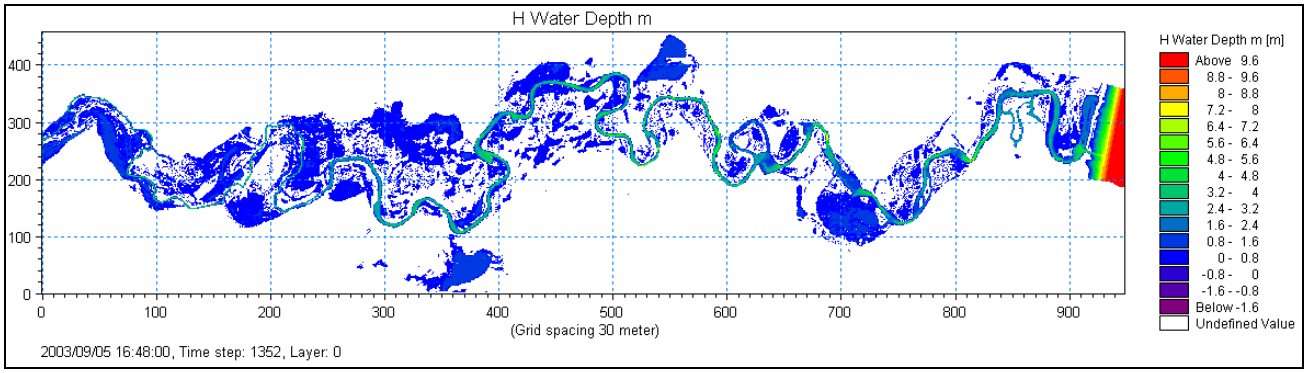


Figure A 1.5.37 Water depth in reach 1 & 2 - 2002/09/04

APPENDIX 2

APPENDIX 2.1

WATER CHEMISTRY - SALINITY, TEMPERATURE, OXYGEN AND TURBIDITY

BERG ESTUARY STATIONS and CROSS-SECTIONS

A decision was made at the start to use the same boat stations that were used in an earlier investigation by the CSIR of the Berg Estuary. In retrospect, it was not clear why these particular positions were chosen, since there seems to be no particular structure in terms of distance along the estuary, or local features. Some of the stations in the downstream section are very close together, but farther upstream it was decided to depart from the CSIR stations, and these are more evenly spaced; additional stations were added in the upper reaches to give a total of 25 stations. The station positions occupied on the first sampling trip were kept for all subsequent trips, and are referenced as B01, B02 ..... B24, 25.
Two additional stations were added in the blind appendix of the old estuary mouth. These station references are Ba1 and Ba2.
The station positions were recorded using a *Garmin 12* GPS and were plotted on a 1:50 000 survey map obtained from the Chief Directorate: Surveys and Mapping. Details of the station positions are depicted in Figure A2.1, and are given in Table A2.1. The chainage, or distance upstream from the mouth for each of the stations was found by stepping up the estuary channel on the Survey map with a pair of dividers.

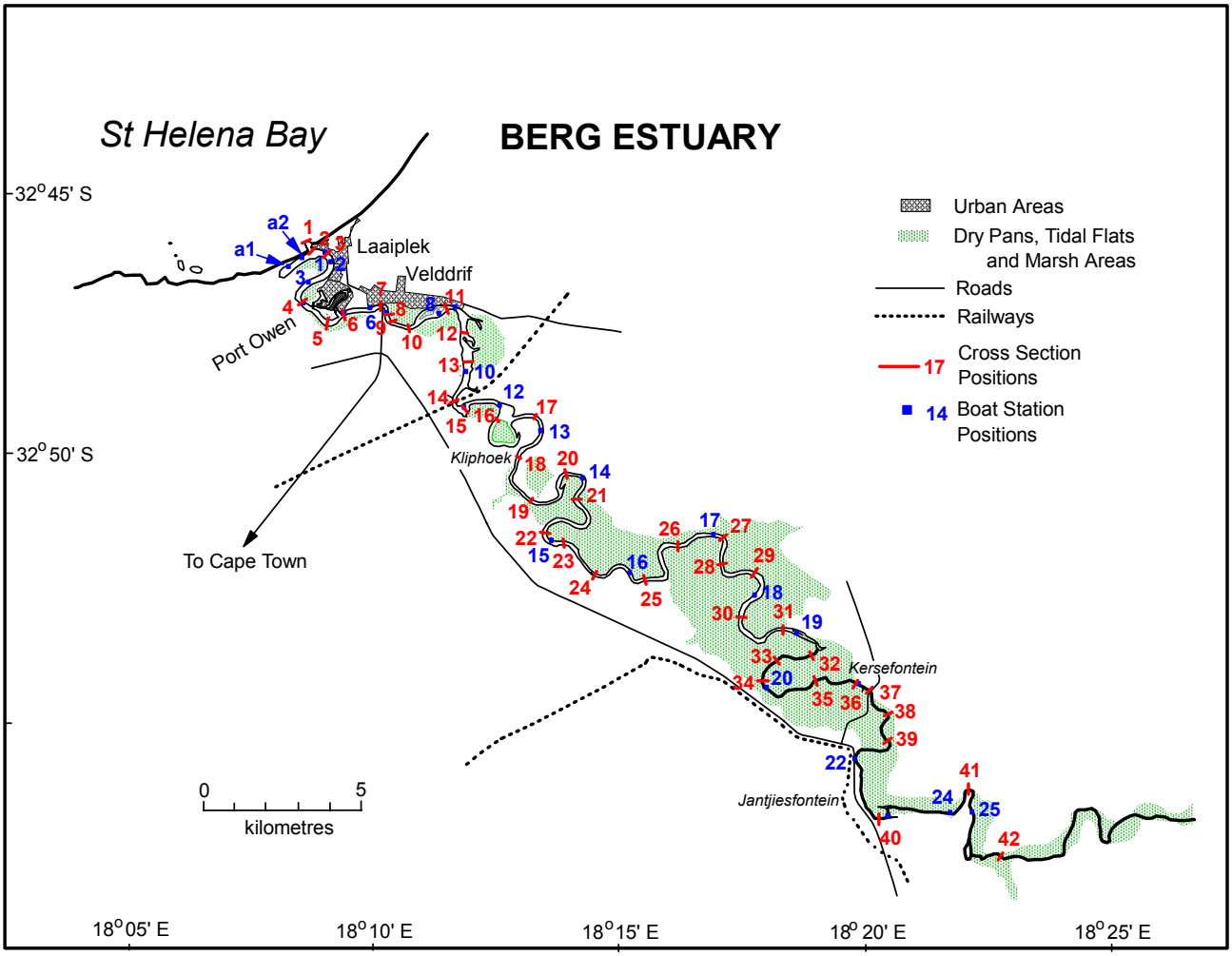


Figure A2.1.1 Details of the Berg Estuary, with the positions of the boat stations (blue) and the cross-sectional areas measured on the estuary (red).

Table A2.1.1 Latitude and longitude of the boat station positions on the Berg Estuary. The different distances given by stepping on the 1:50000 map, and that measured by the GPS are given, as well as the distance used in section figures.

StnRef	Latitude	Longitude	Chainage(km)MapGPSUsed		
B01	32°46.410'S	18°08.956'E	0.35	0.5	0.45
B02	32°46.502'S	18°09.092'E	0.60	0.9	0.75
B03	32°46.956'S	18°08.803'E	1.75	1.9	1.85
B04	32°47.416'S	18°08.591'E	2.90	3.2	3.05
B05	32°47.589'S	18°09.337'E	4.25	4.55	4.40
B06	32°47.303S	18°09.877'E	5.10	5.4	5.25
B07	32°47.320'S	18°10.228'E	5.75	6.1	5.95
B08	32°47.428'S	18°11.203'E	7.75	8.2	8.00
B09	32°47.267'S	18°11.542'E	8.50	8.8	8.65
B10	32°48.687'S	18°11.891'E	11.05	11.4	11.20
B11	32°49.158'S	18°11.740'E	12.45	13.0	12.70
B12	32°49.113'S	18°12.547'E	13.95	14.05	14.00
B13	32°49.683'S	18°13.348'E	16.20	16.4	16.30
B14	32°50.467'S	18°13.775'E	21.50	21.15	21.35
B15	32°51.325'S	18°13.535'E	25.20	25.4	25.30
B16	32°52.163'S	18°15.078'E	28.50	29.1	28.80
B17	32°51.493'S	18°16.772'E	32.95	33.5	33.25
B18	32°52.480'S	18°17.913'E	36.50	37.0	36.75
B19	32°53.355'S	18°18.495'E	39.75	40.7	40.25
B20	32°54.375'S	18°17.968'E	43.60	44.3	43.95
B21	32°54.265'S	18°19.778'E	46.85	47.6	47.25
B22	32°55.803'S	18°19.767'E	51.15	-	51.30
B23	32°56.863'S	18°20.500'E	53.95	-	54.10
B24	32°56.834'S	18°21.710'E	56.15	-	56.30
B25	32°56.860'S	18°22.249'E	58.10	-	58.20
Ba1	32°46.556'S	18°08.489'E	-	-	-
Ba2	32°46.720'S	18°08.161'E	-	-	-

Triton Survey also carried out cross-sectional surveys of the Berg Estuary at 43 positions on the estuary, with an additional position 350 m offshore of the mouth. The chainage distances of these cross-sectional sites were obtained from the CSIR, however, at the position of the bridge at the farm *Kersefontein* this distance and the chainage estimated from the map differed by approximately 4 km. The distances given in the paper by Slinger and Taljaard (1994) and in other CSIR reports correspond with the distances obtained from the survey map.

It could be that the actual estuary differs in places from the map depiction, and as a final check the *Garmin* GPS was used on a measurement trip to determine the distance travelled by the boat to each of the stations. These GPS distances agree approximately with the map estimates, and it was therefore decided that the given cross-sectional chainage distances were wrong, and would be ignored. These positional details are given in Table A2.1.

The cross-sectional surveys consisted of 44 depth profiles measured across the estuary, given in WGS84 coordinates. The positions of all of the measurements on each profile was plotted onto a 1:50 000 scale, and then superimposed on the Survey map; in this way the new chainage positions of the cross-sections could be determined. These are also given in Table A2.1 and depicted in Figure A2.1; note that the estimates incorporate the differences found with the GPS readings in the boat station positions.

The file provided by *Triton* with the positions of the cross-sectional surveys also had maximum depths listed with respect to mean sea. However, when the detailed cross-sectional profiles given by the WGS84 coordinates was plotted out, it was found that the maximum depths on the profiles differed from the first file with maximum depths. These details are given in Table A2.2 and the WGS84 coordinate depths are drawn in Figure A2.2; note that station 16 lies in an offshoot of the estuary, and is not used in the estuary sections. It is not known why some of the sections were not measured over the whole width of the estuary.

No clarity could be found on which of the two files with different maximum depths is correct. However, since the programs had been written with the original *Triton* depths, and a number of longitudinal estuarine sections had already been plotted, these depths were used in all the sections depicted in this appendix.

Table A2.1.2 Details of chainages from the map and that given by the CSIR, as well as maximum estuary depth from Triton and extracted from the cross-sections.

Stn Ref	Chainage (km)		Maximum Depth msl (m)	
	Map	CSIR	Map	CSIR
X01	-0.35	-0.35	8.349	4.801
X02	0	0	5.284	4.613
X03	0.42	0.37	5.581	4.956
X04	2.90	2.15	3.176	3.106
X05	3.60	4.39	2.562	2.497
X06	4.35	4.94	4.537	4.323
X07	5.40	6.18	8.911	8.911
X08	5.85	6.53	3.943	3.585
X09	6.10	6.81	2.873	2.764
X10	6.80	7.40	7.461	5.923
X11	8.20	8.56	2.559	2.400
X12	9.50	9.97	4.028	3.928
X13	10.85	11.26	2.858	2.739
X14	12.35	12.81	4.997	4.976
X15	12.60	13.13	3.995	3.917
X16	14.30	14.29	1.193	1.164
X17	15.40	15.50	5.109	4.539
X18	17.20	17.06	5.857	5.771
X19	18.90	18.83	6.124	5.695
X20	20.70	20.31	4.734	3.800
X21	22.15	21.23	6.544	6.332
X22	24.90	23.54	4.162	4.024
X23	25.60	24.28	3.330	3.123
X24	27.20	25.82	4.548	4.473
X25	29.20	27.46	2.768	2.712
X26	31.80	29.18	3.757	3.708
X27	33.50	30.56	4.513	4.417
X28	34.40	31.45	3.780	3.708
X29	36.40	32.67	3.596	3.420
X30	37.50	34.04	2.758	2.685
X31	39.90	35.57	2.320	2.127
X32	41.40	37.00	3.226	2.770
X33	42.50	38.00	3.177	3.072
X34	43.60	38.80	2.493	2.873
X35	45.50	40.50	3.040	2.797
X36	47.00	41.65	2.159	2.071
X37	47.60	42.19	5.510	3.610
X38	48.40	43.33	3.980	3.980
X39	49.60	44.31	3.239	3.239
X40	53.90	48.45	2.131	2.131
X41	57.10	54.03	2.823	2.823
X42	60.50	57.43	0.715	0.715

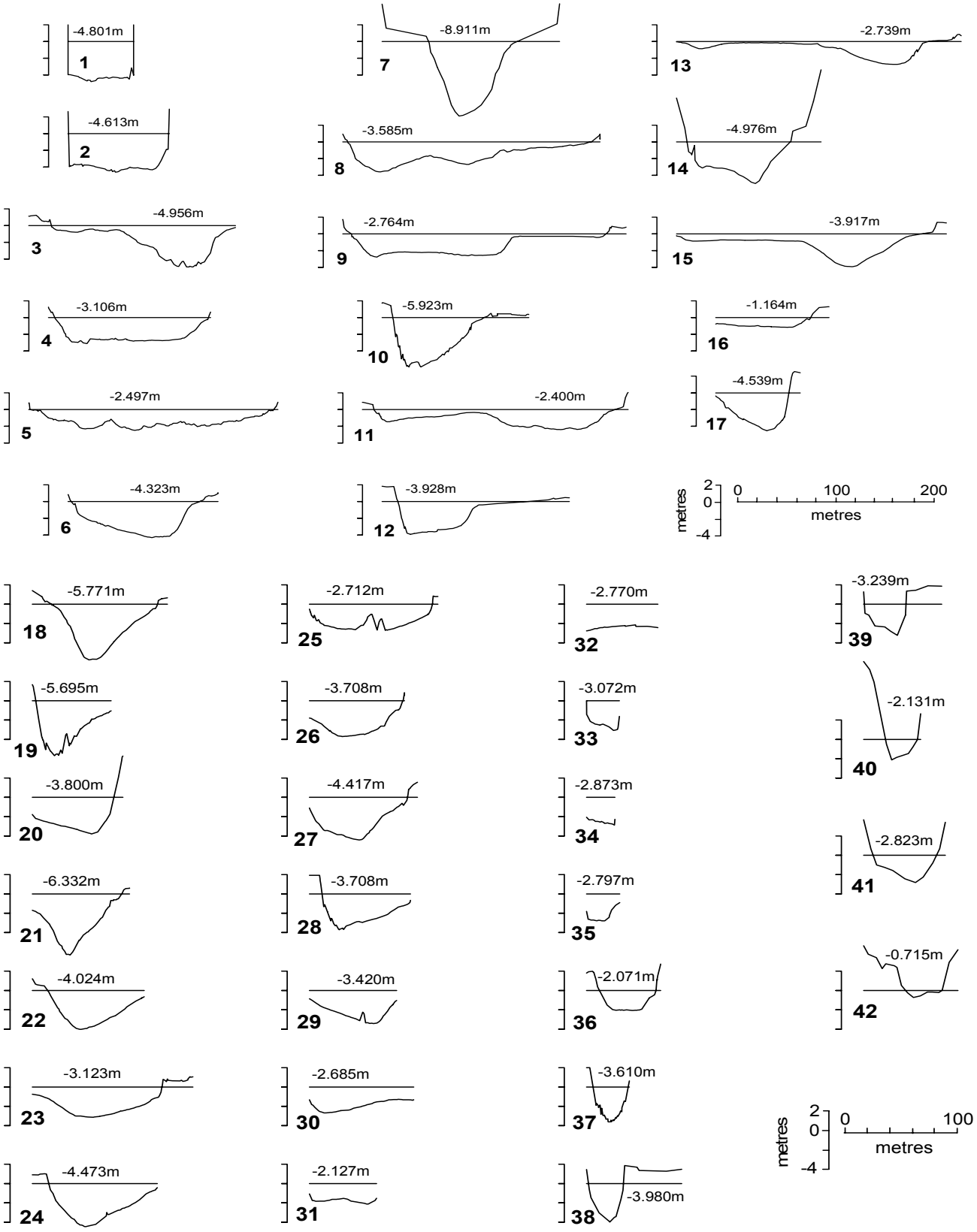


Figure A2.1.2 Cross-sectional areas (looking downstream) of the Berg Estuary from the measurements taken in 2003 (referred to as the WGS84 measurements); the number given above each section is the maximum depth relative to msl. The section area numbers are given in bold next to each profile, and correspond to the numbers given in Table A2.1.1.

APPENDIX 2.2

WATER CHEMISTRY - SALINITY, TEMPERATURE, OXYGEN AND TURBIDITY: ESTUARY SECTIONS

In this Appendix longitudinal sections of the given variables are shown in chronological order. The names, e.g. BR1a, are the same as the corresponding data files.

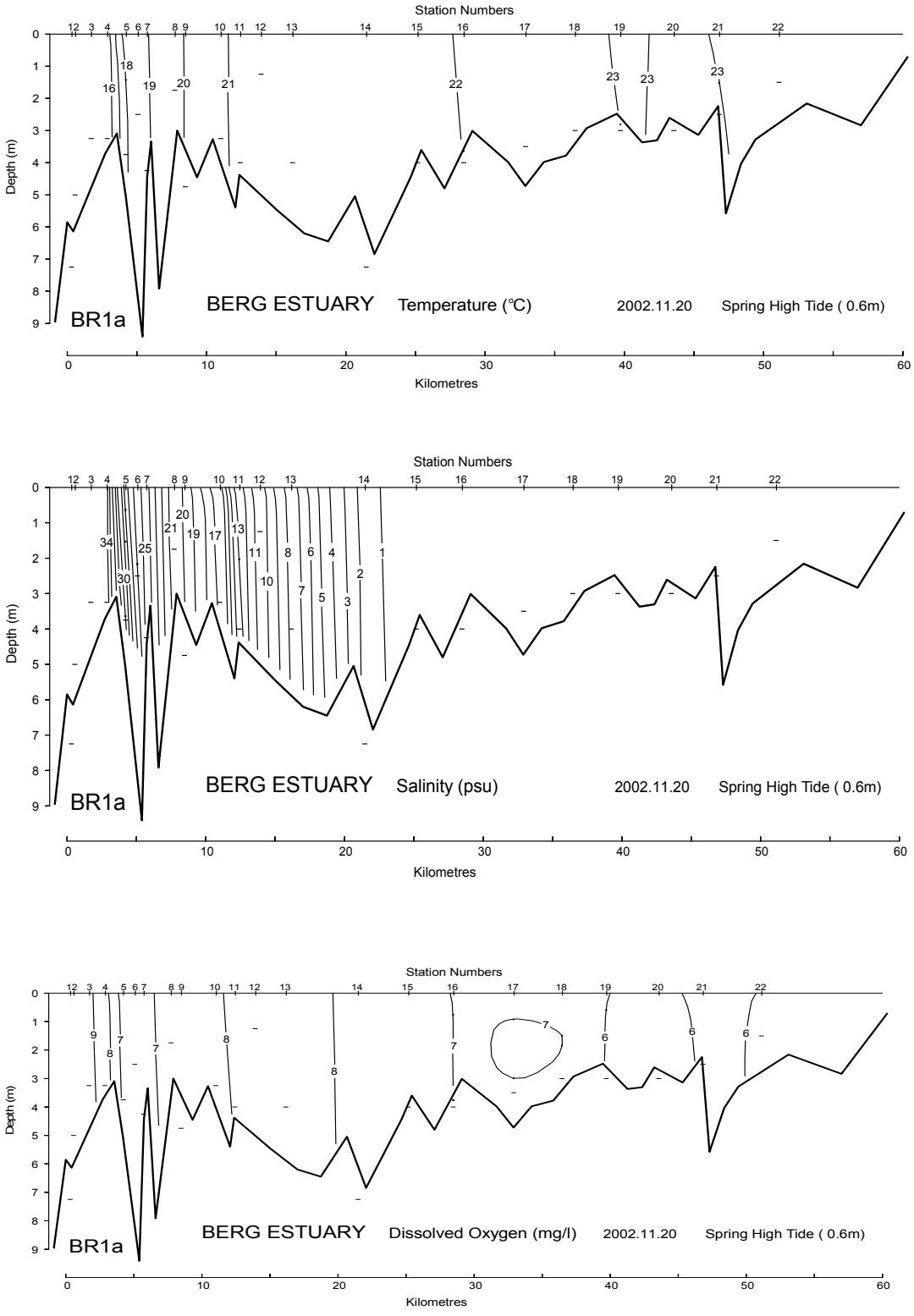


Figure A2.2.1 BR1a - SPRING HIGH – Nov 2002

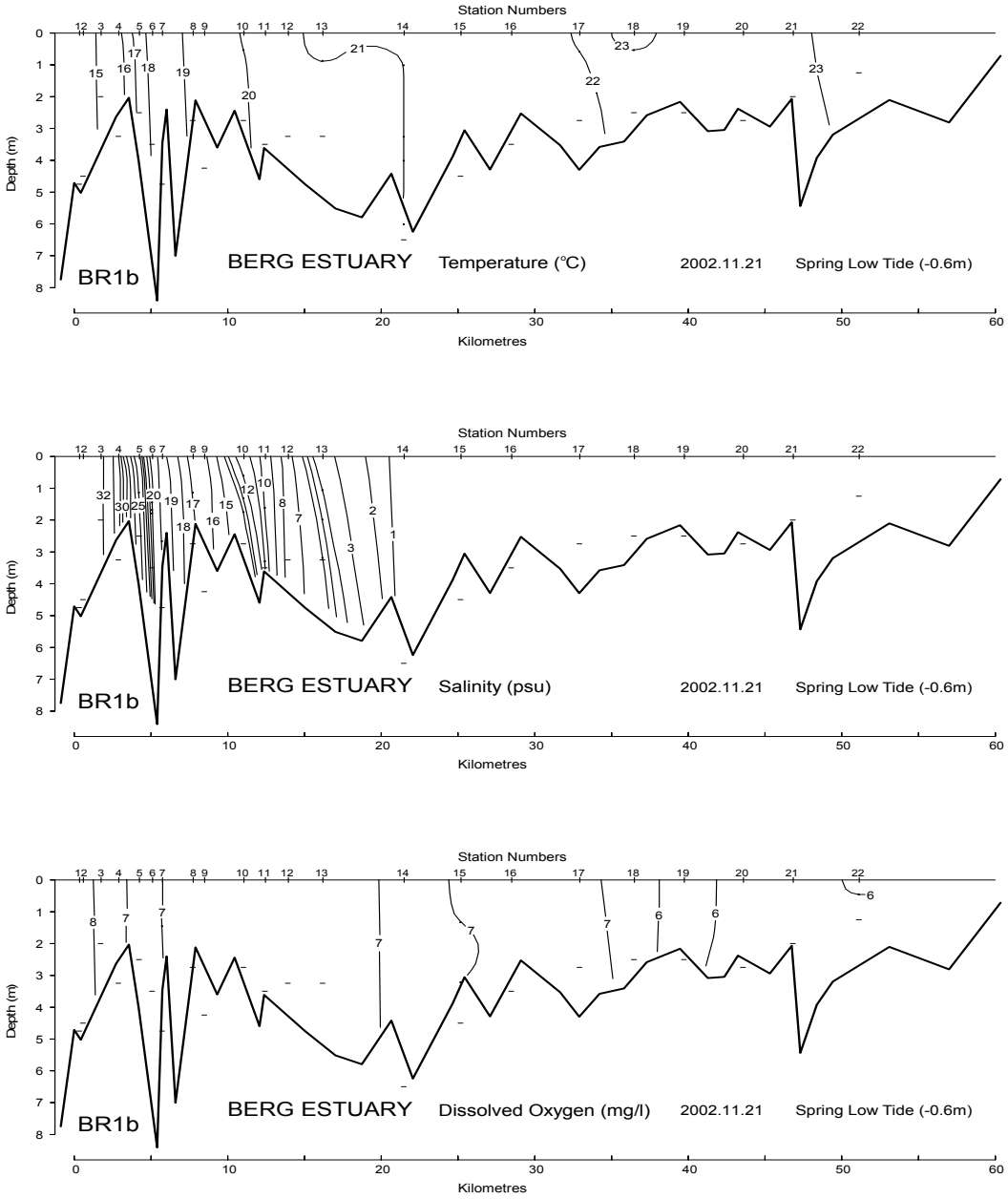


Figure A2.2.2 BR1b - SPRING LOW – Nov 2002

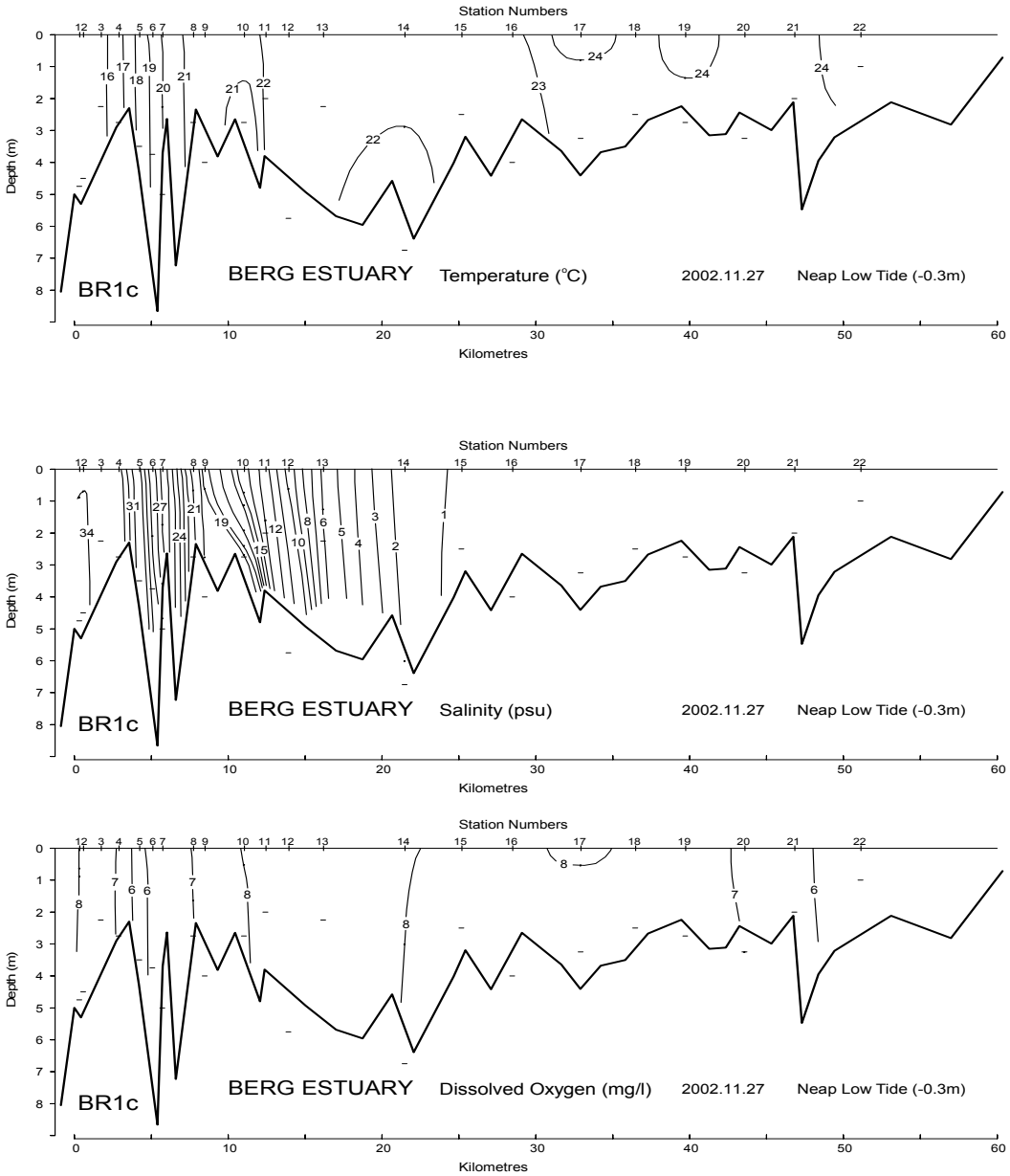


Figure A2.2.3 BR1c - NEAP LOW - Nov 2002

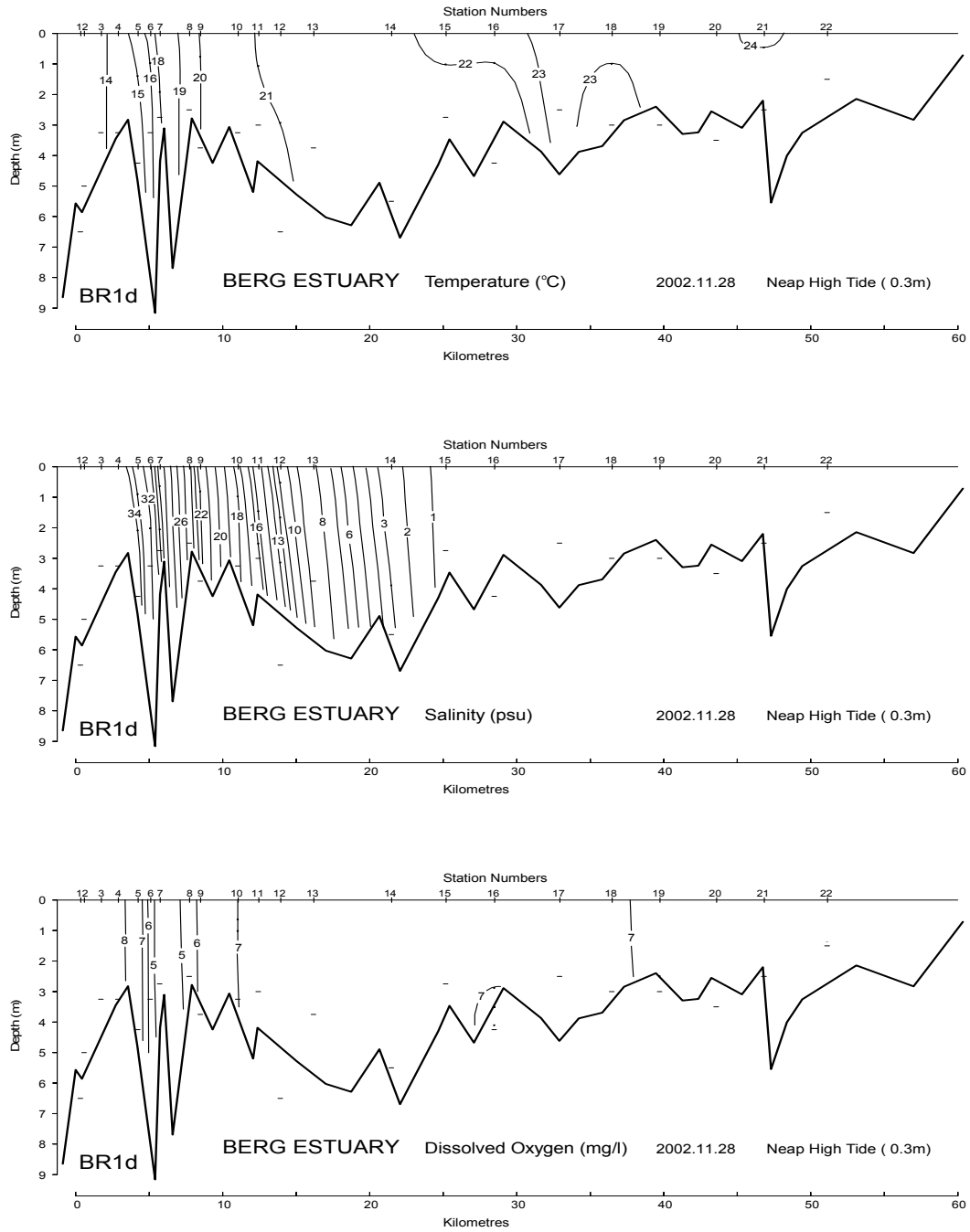


Figure A2.2.4 BR1d - NEAP HIGH - Nov 2002

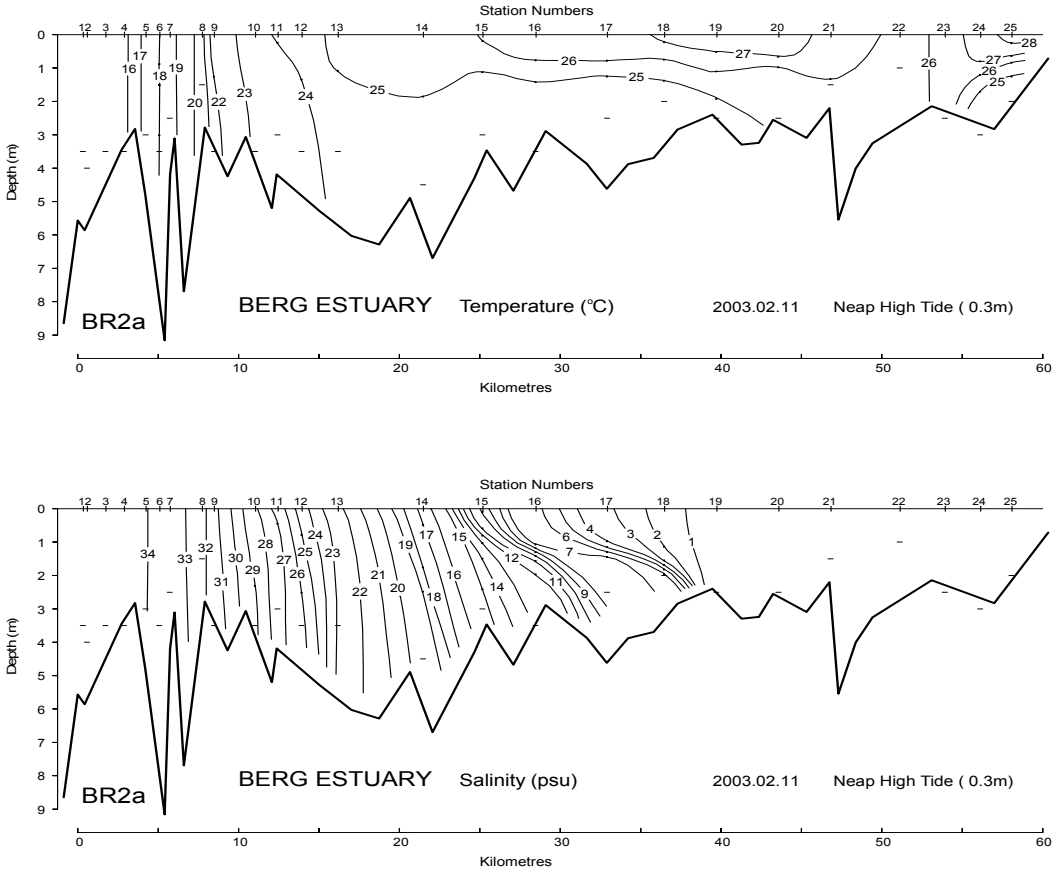


Figure A2.2.5 BR2a – NEAP HIGH - Nov 2002

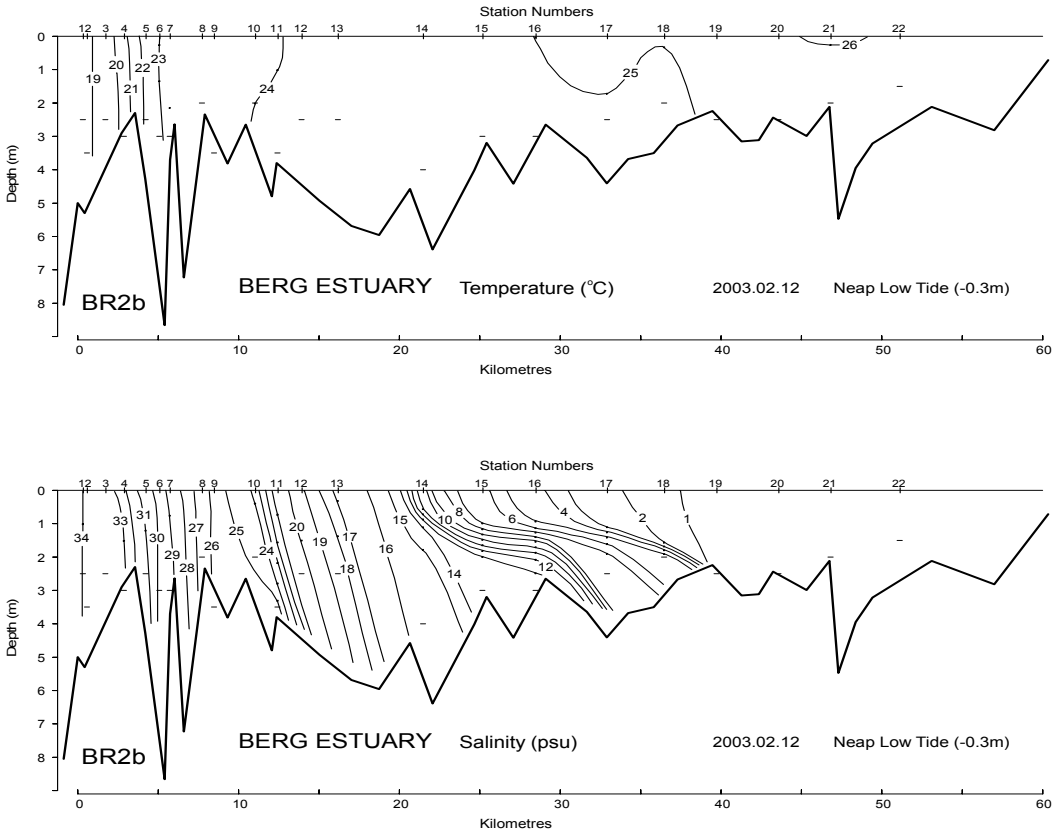


Figure A2.2.6 BR2b - NEAP LOW - Feb 2003

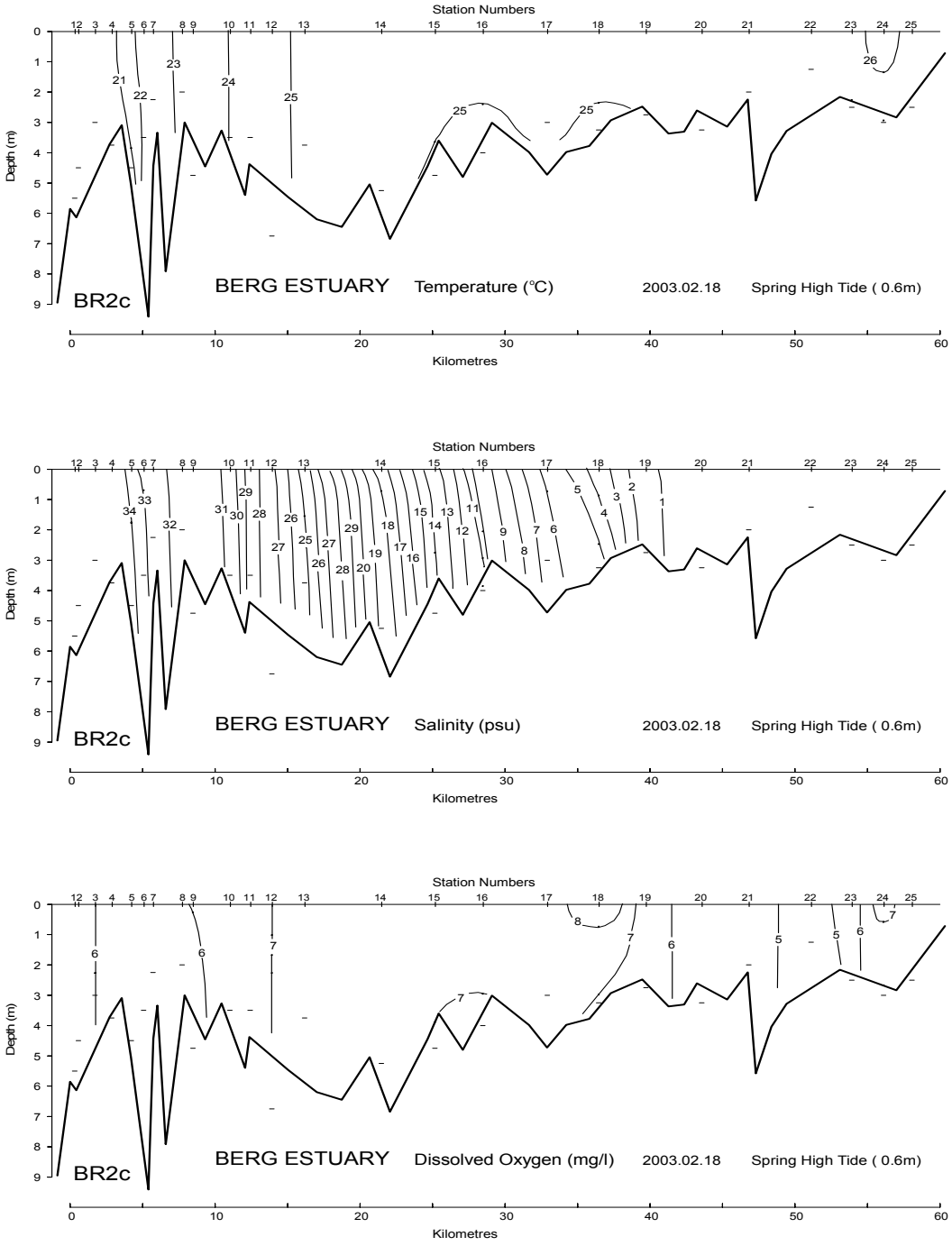


Figure A2.2.7 BR2c - SPRING HIGH - Feb 2003

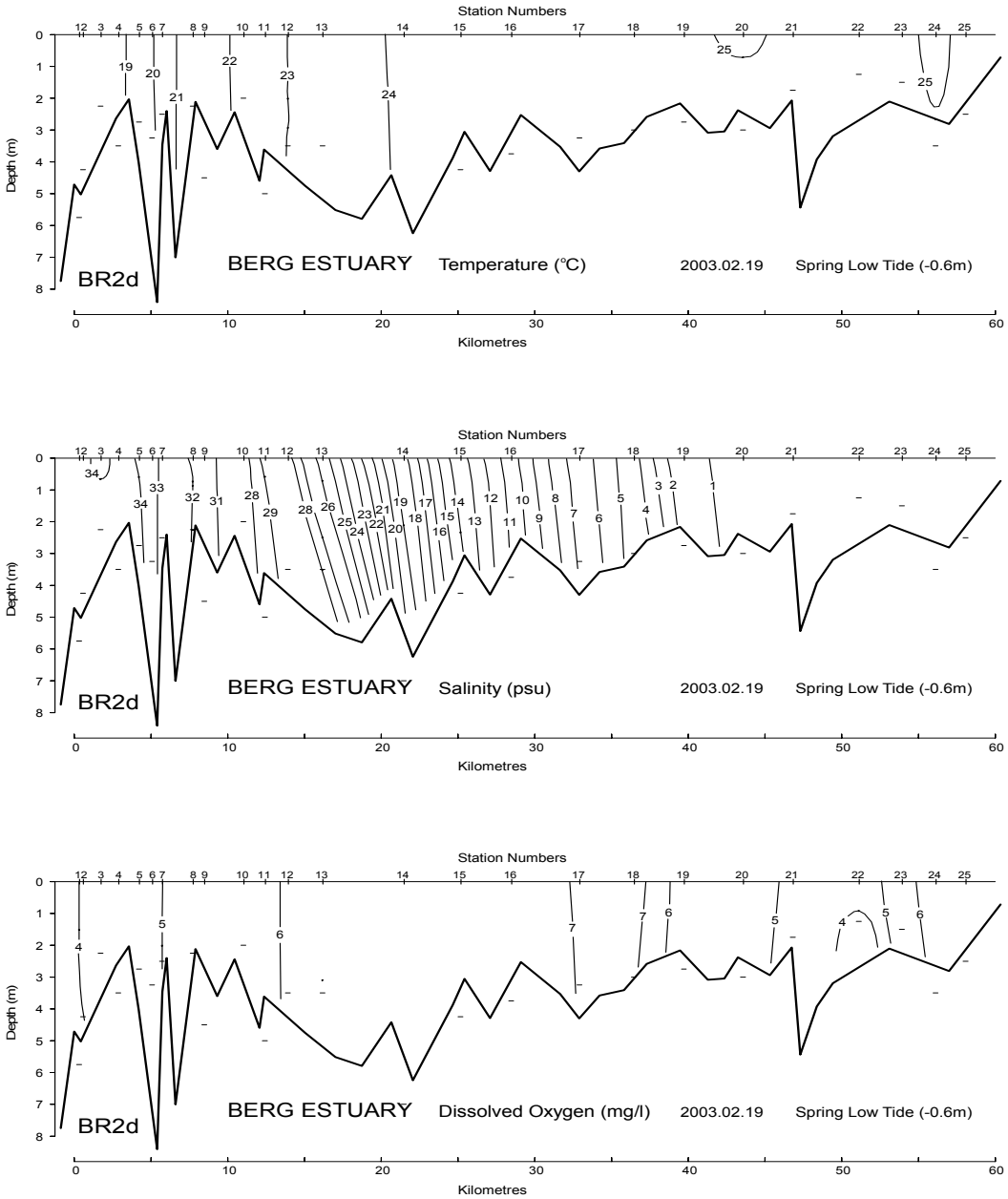


Figure A2.2.8 BR2d - SPRING LOW - Feb 2003

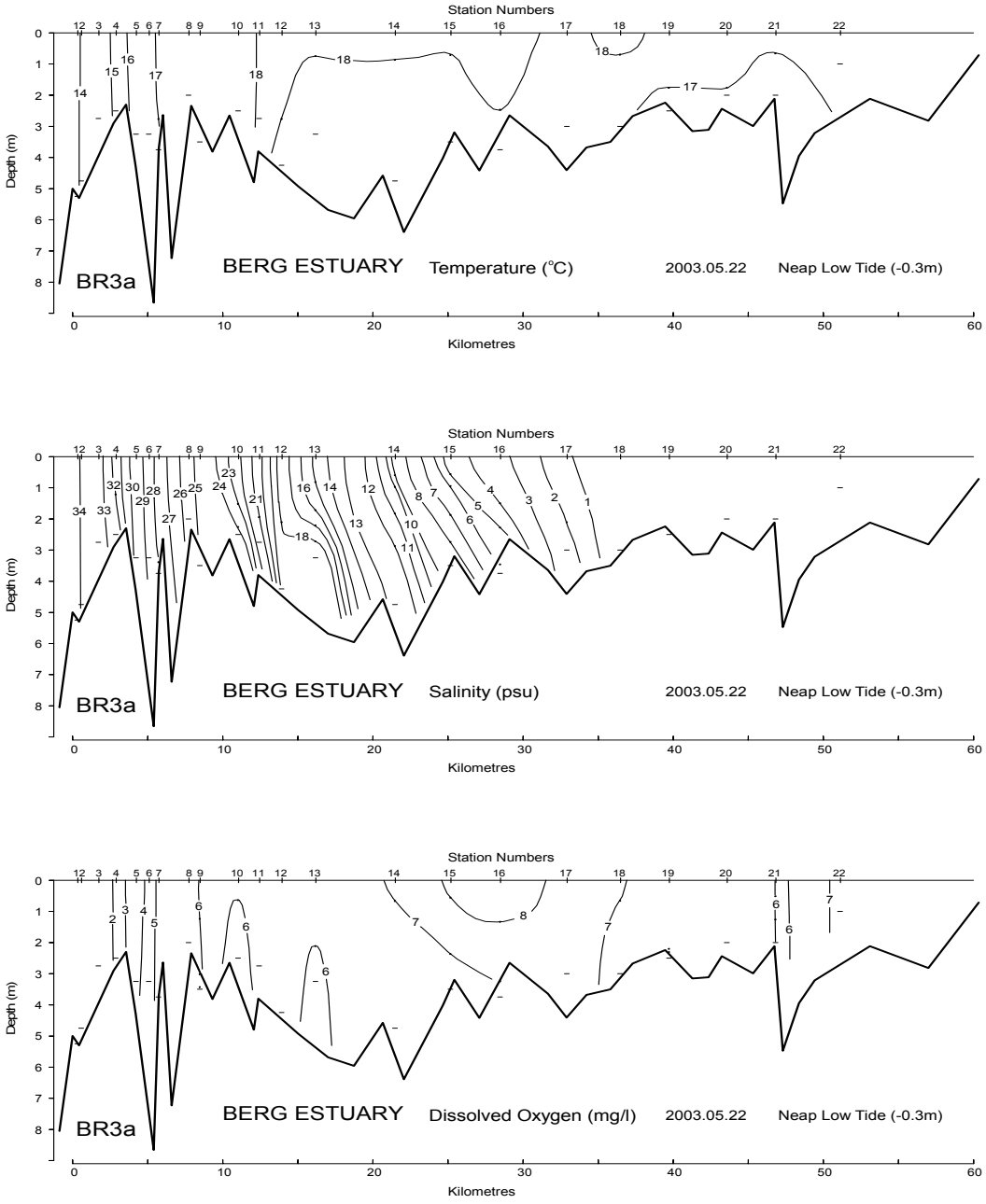


Figure A2.2.9 BR3a - NEAP LOW – May 2003

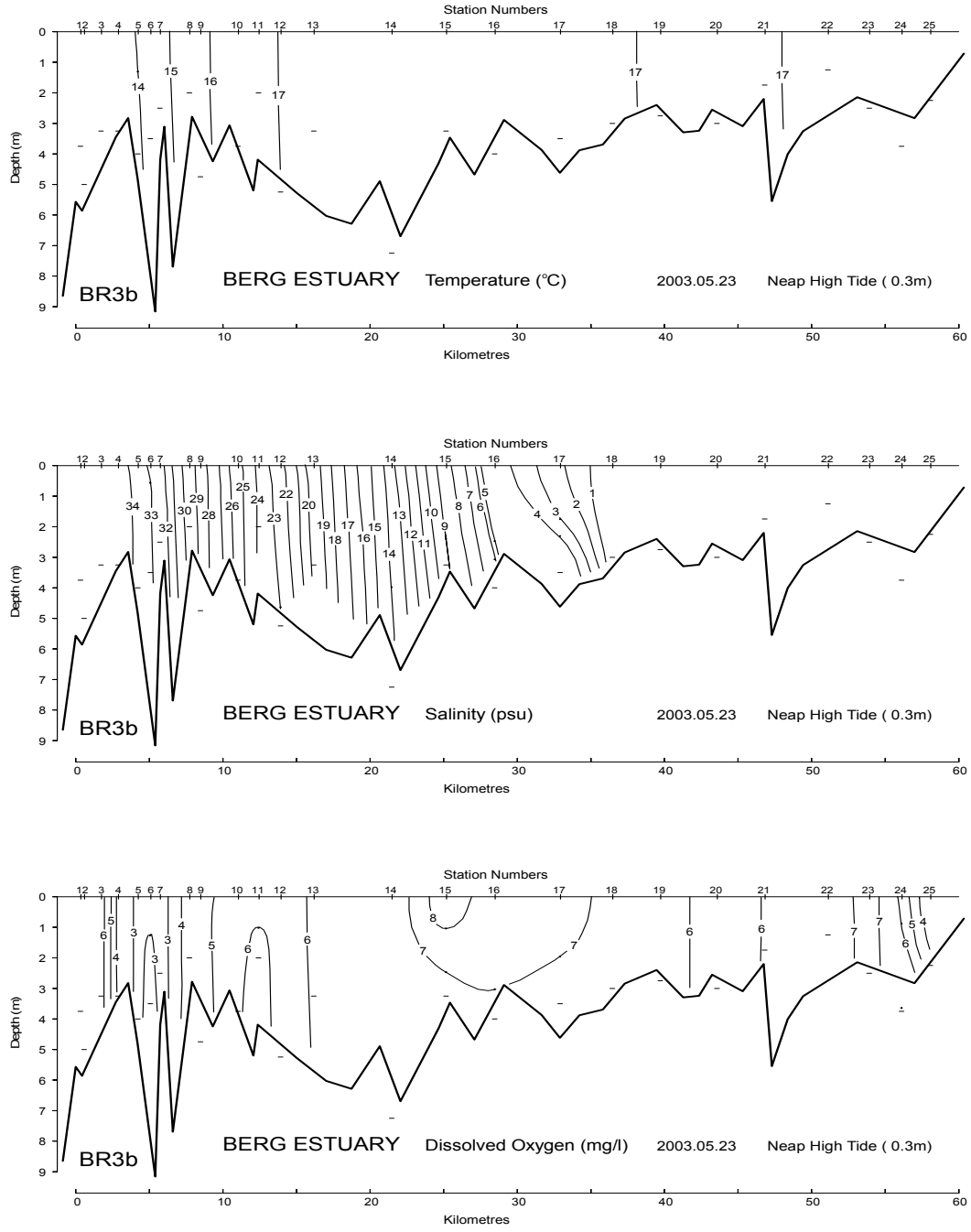
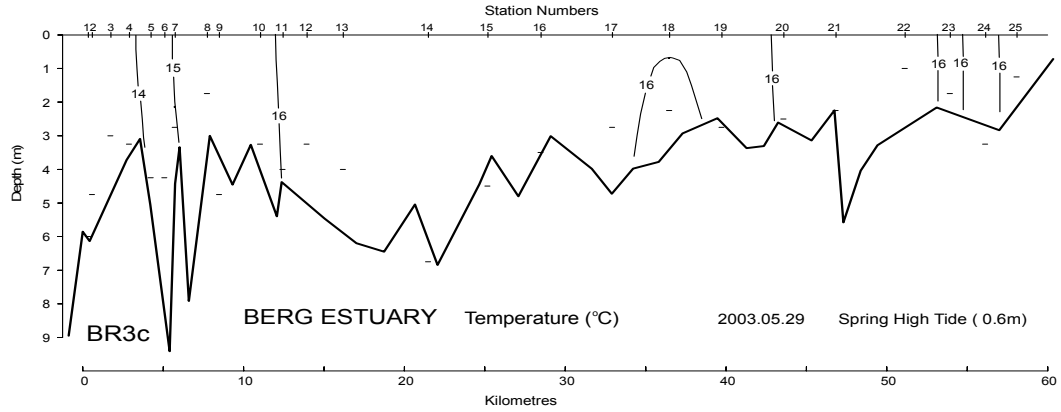
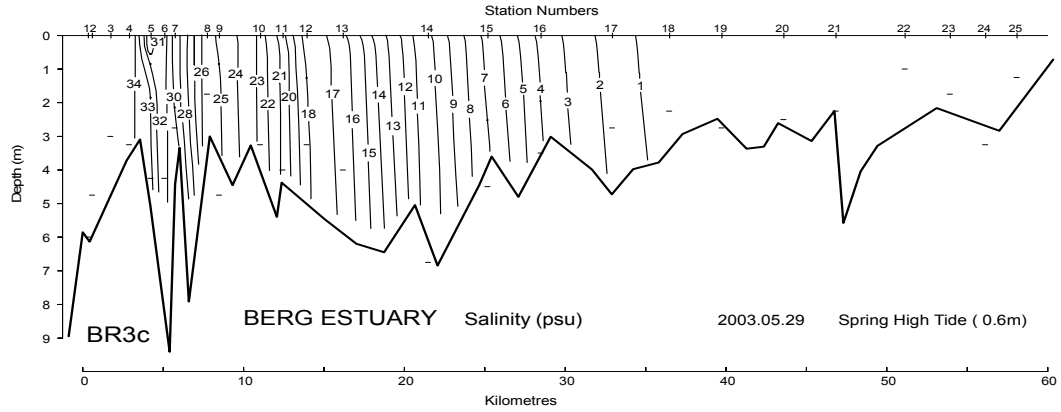


Figure A2.2.10 BR3b - NEAP HIGH – May 2003





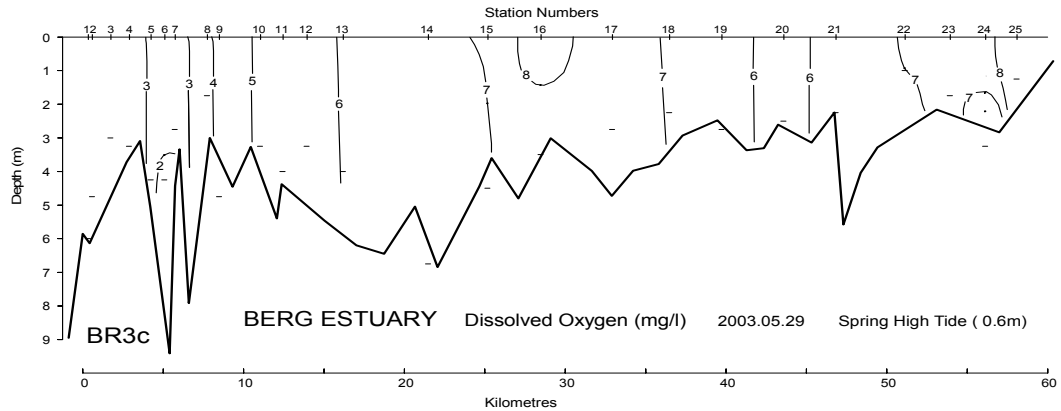


Figure A2.2.11 BR3c - SPRING HIGH – May 2003

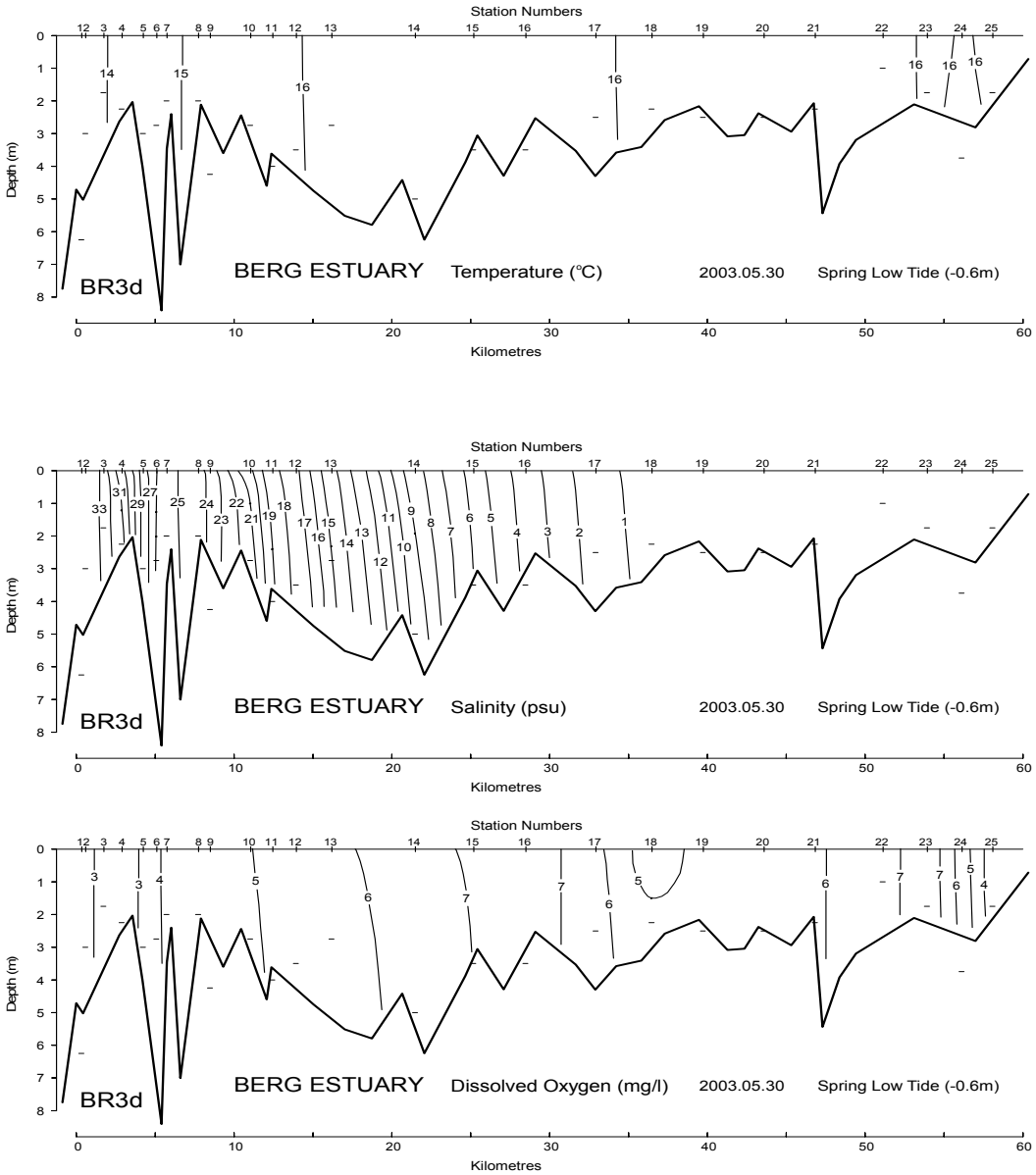


Figure A2.2.12 BR3d - SPRING LOW – May 2003

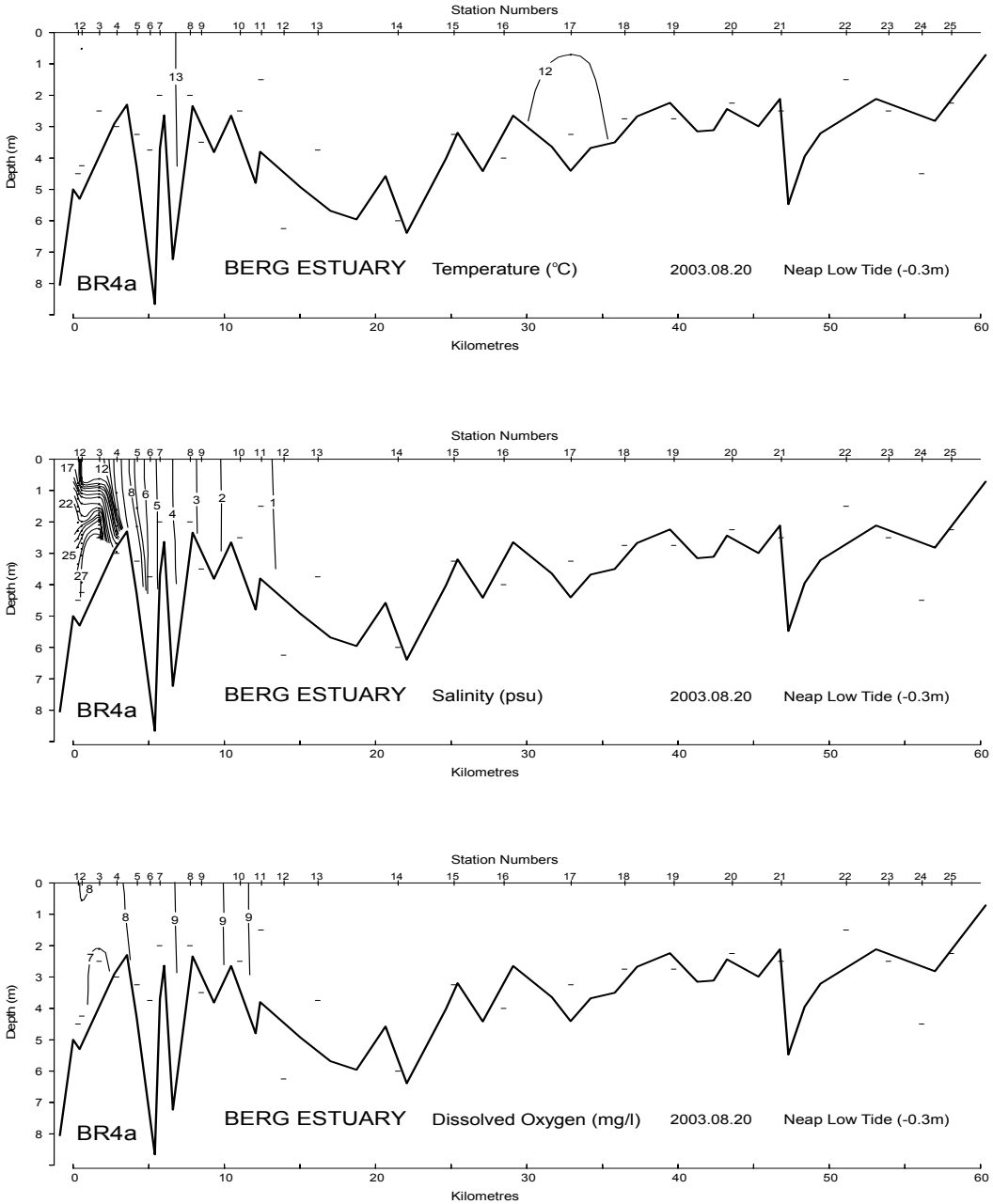


Figure A2.2.13 BR4a - NEAP LOW – Aug 2003

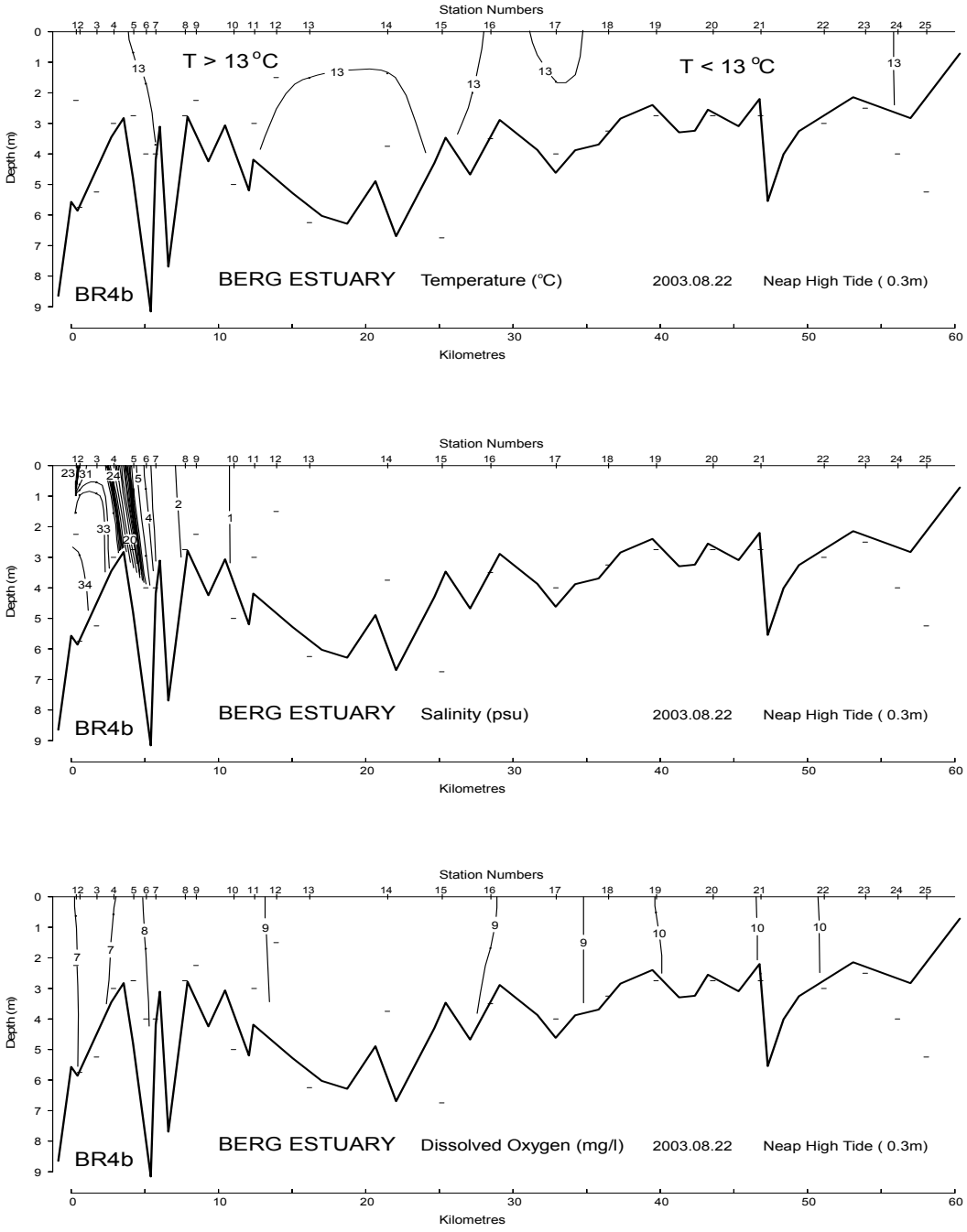


Figure A2.2.14 BR4b – NEAP HIGH – Aug 2003

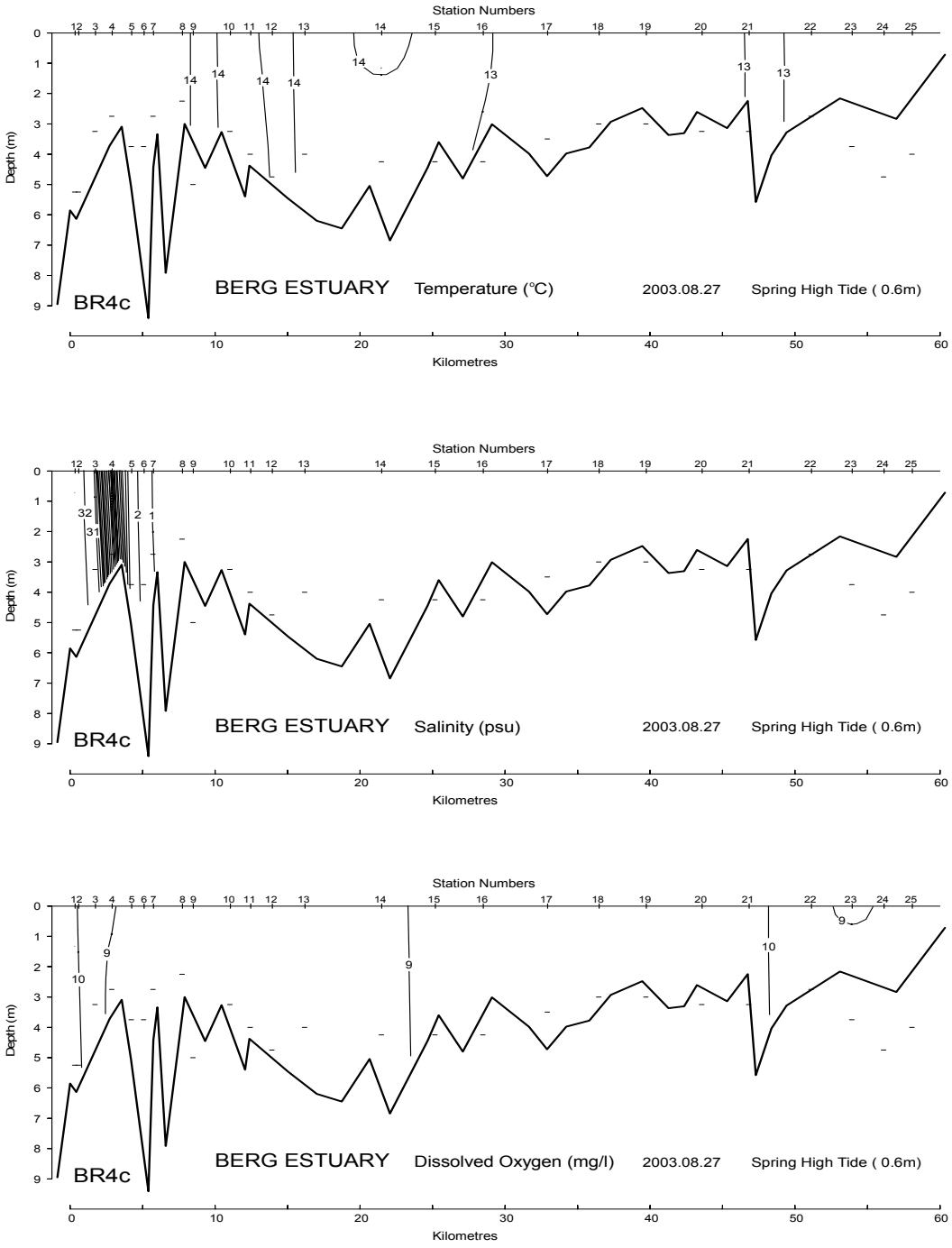


Figure A2.2.15 BR4c - SPRING HIGH – Aug 2003

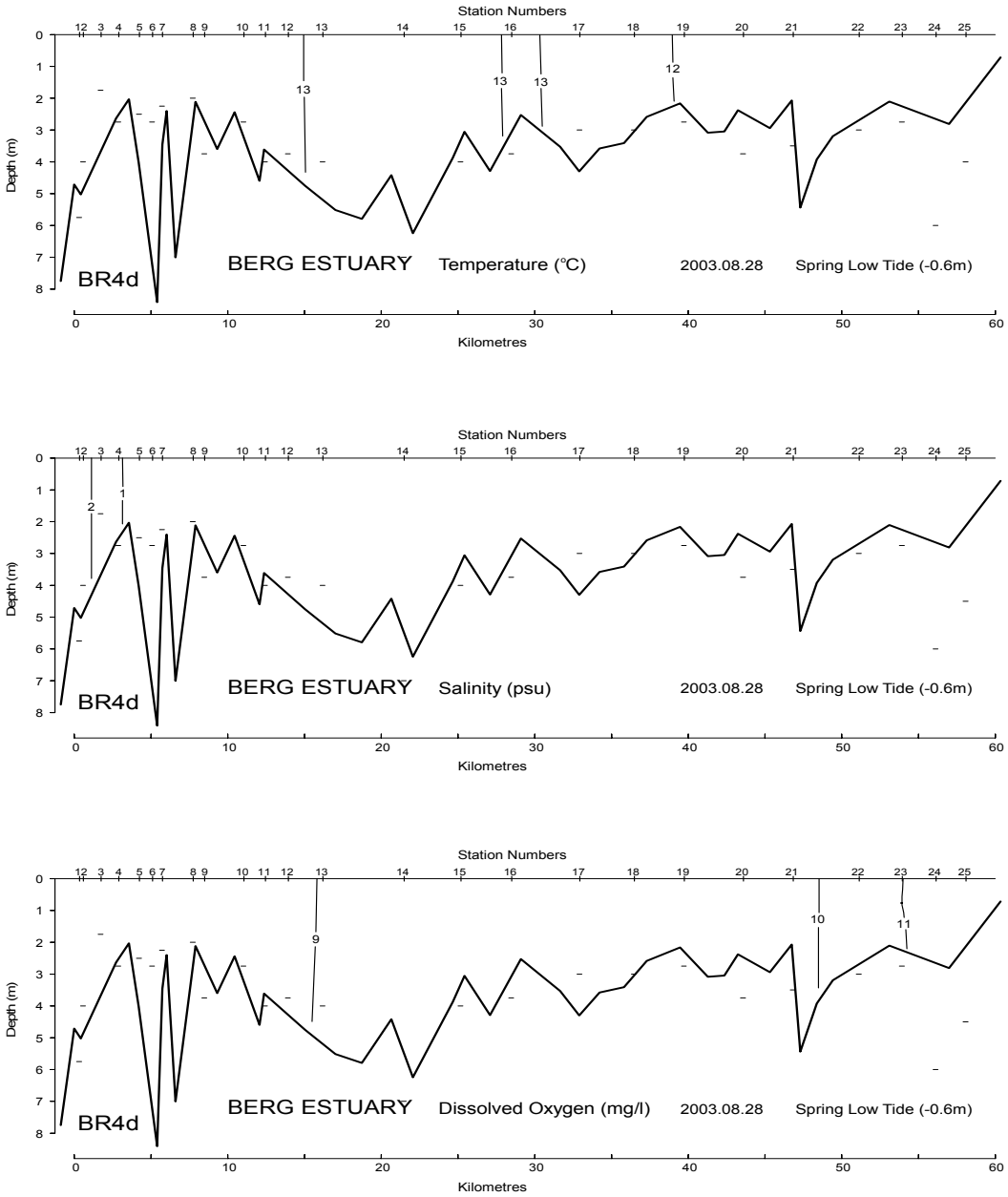


Figure A2.2.16 BR4d - SPRING LOW – Aug 2003

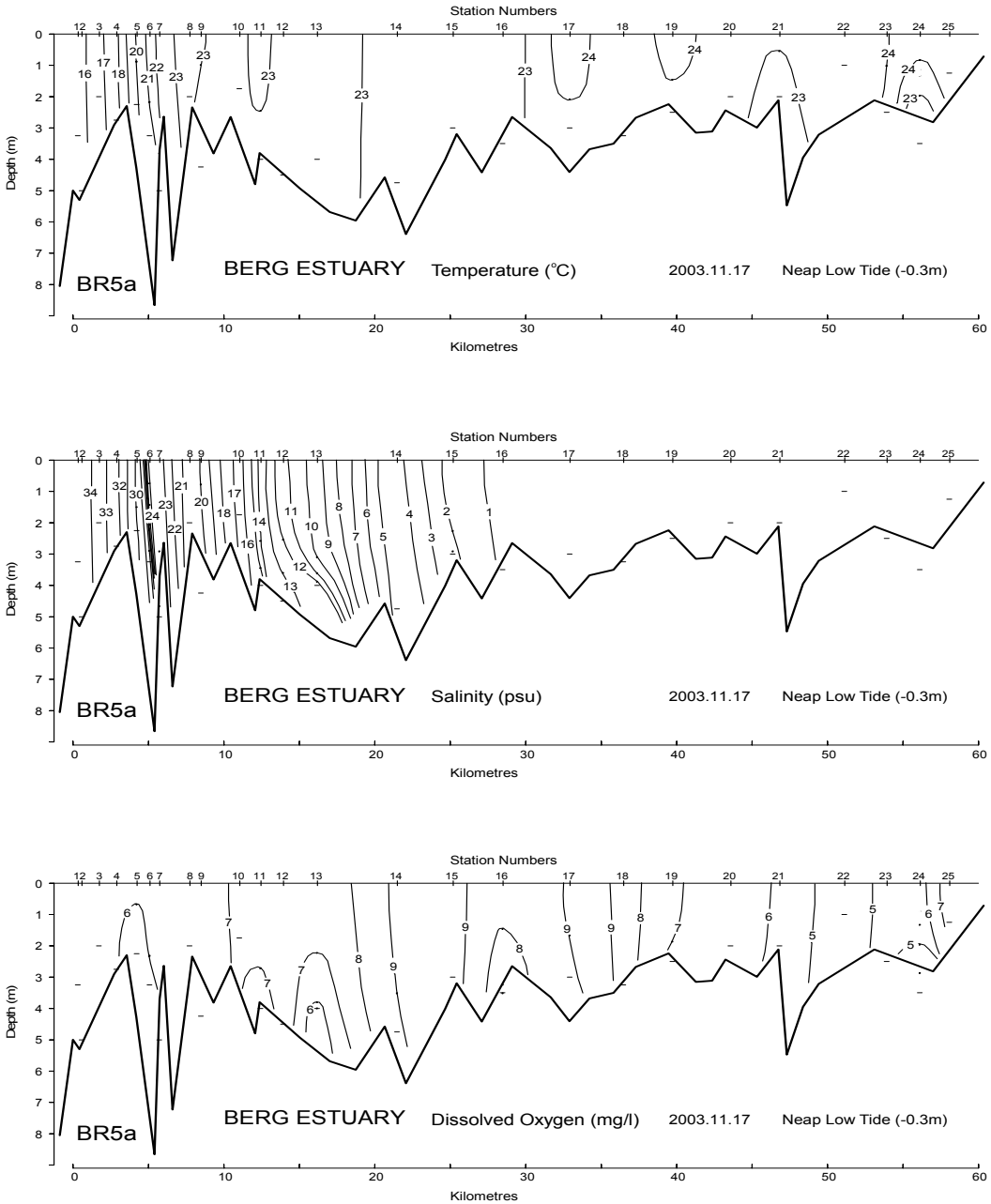


Figure A2.2.17 BR5a - NEAP LOW – Nov 2003

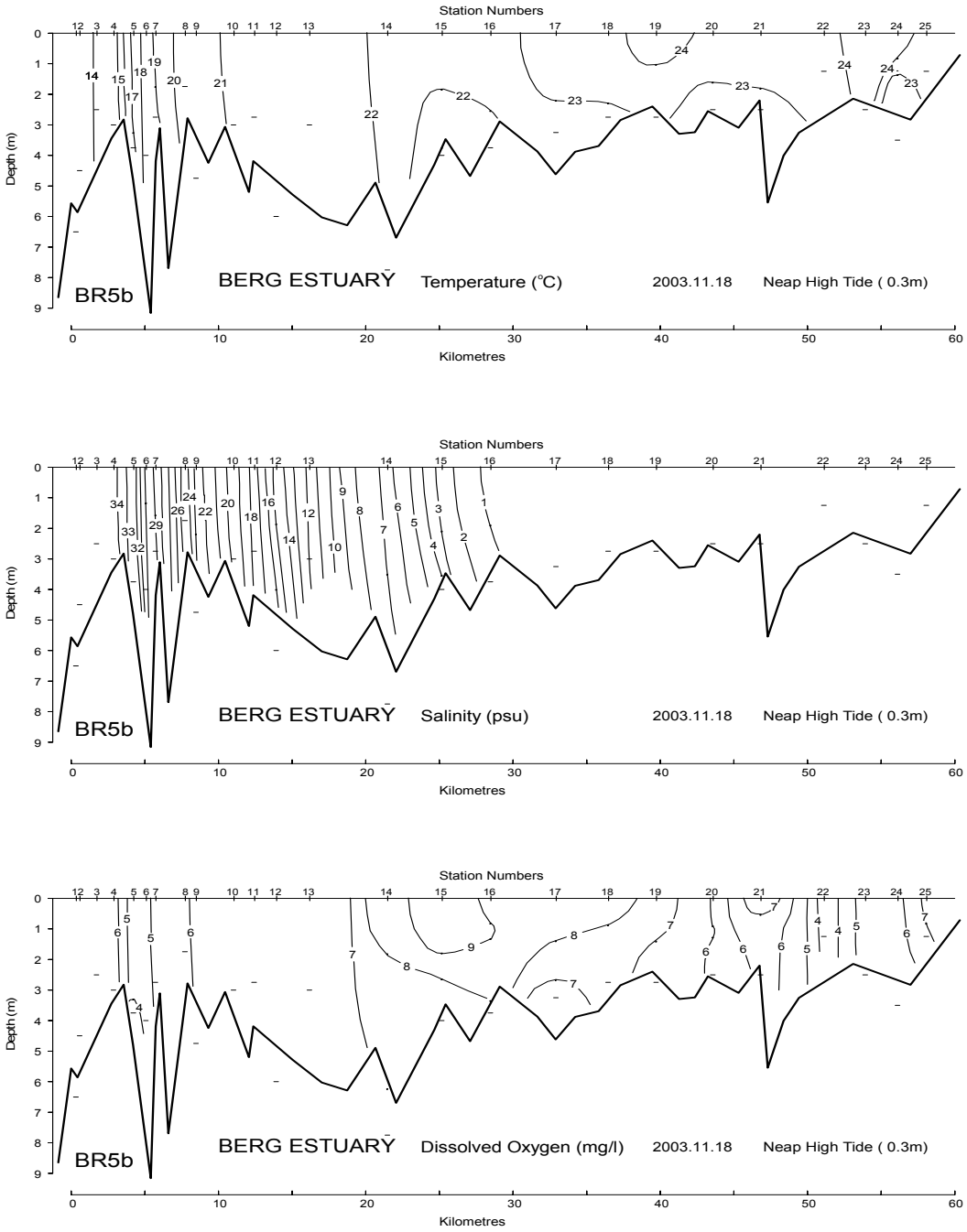


Figure A2.2.18 BR5b – NEAP HIGH – Nov 2003

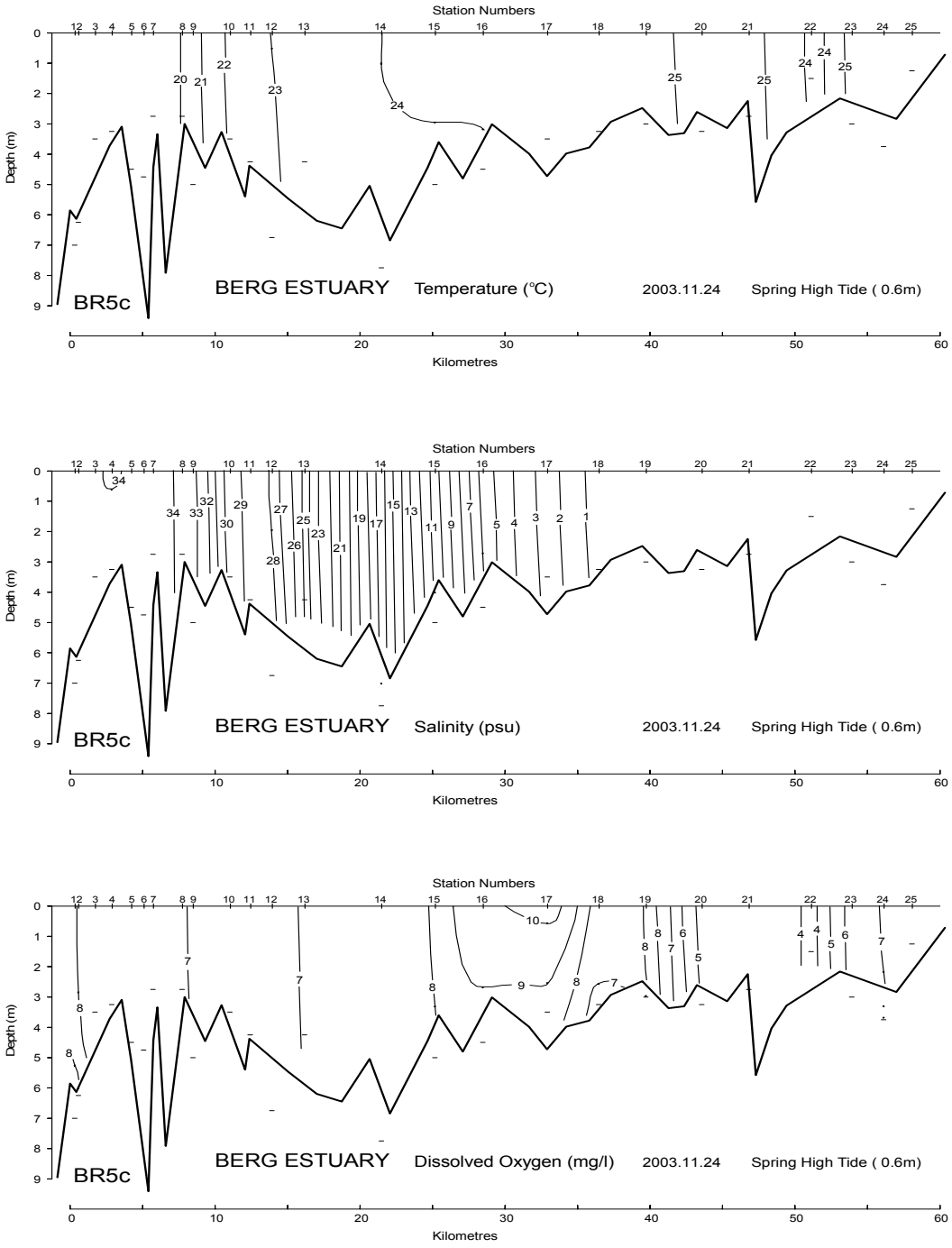
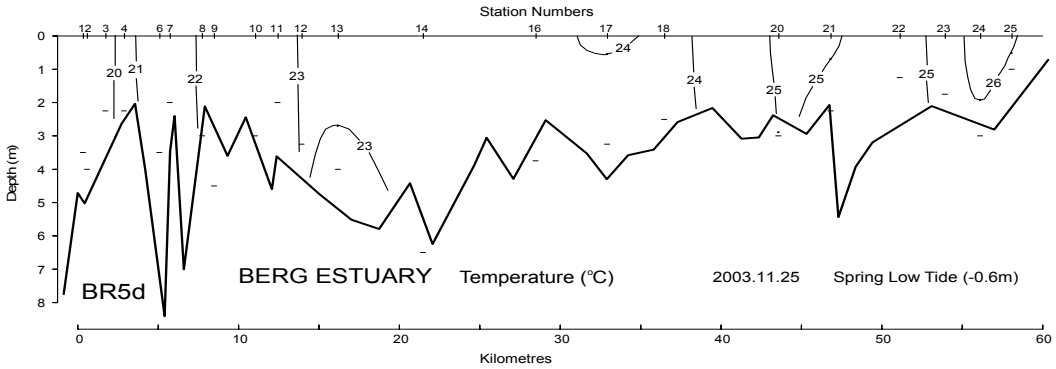
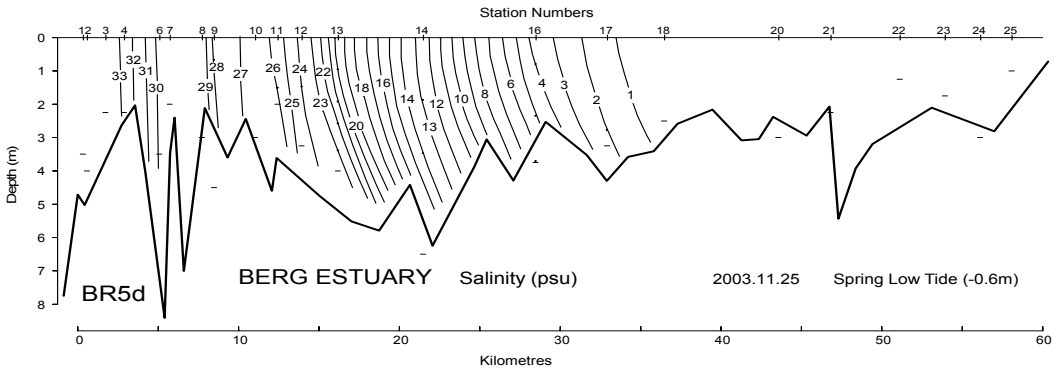


Figure A2.2.19 BR5c - SPRING HIGH – Nov 2003





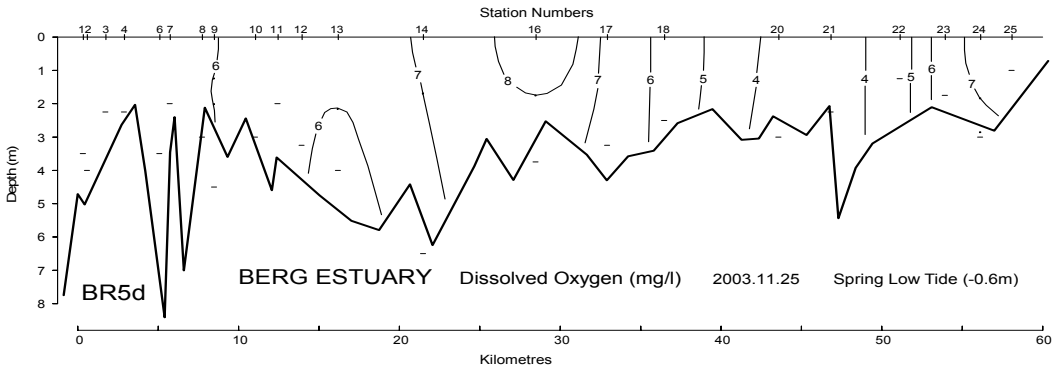


Figure A2.2.20 BR5d - SPRING LOW – Nov 2003

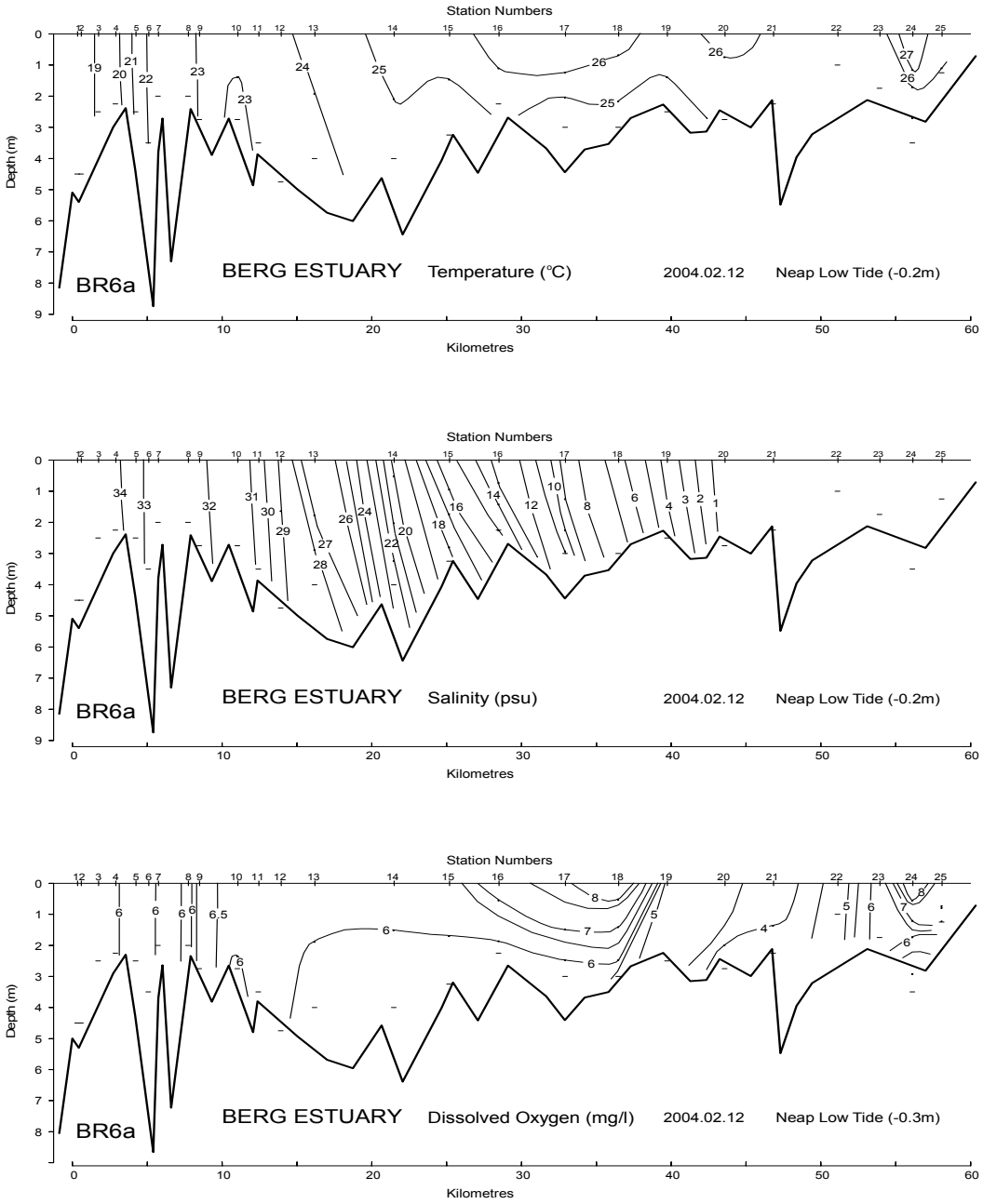


Figure A2.2.21 BR6a - NEAP LOW – Feb 2004

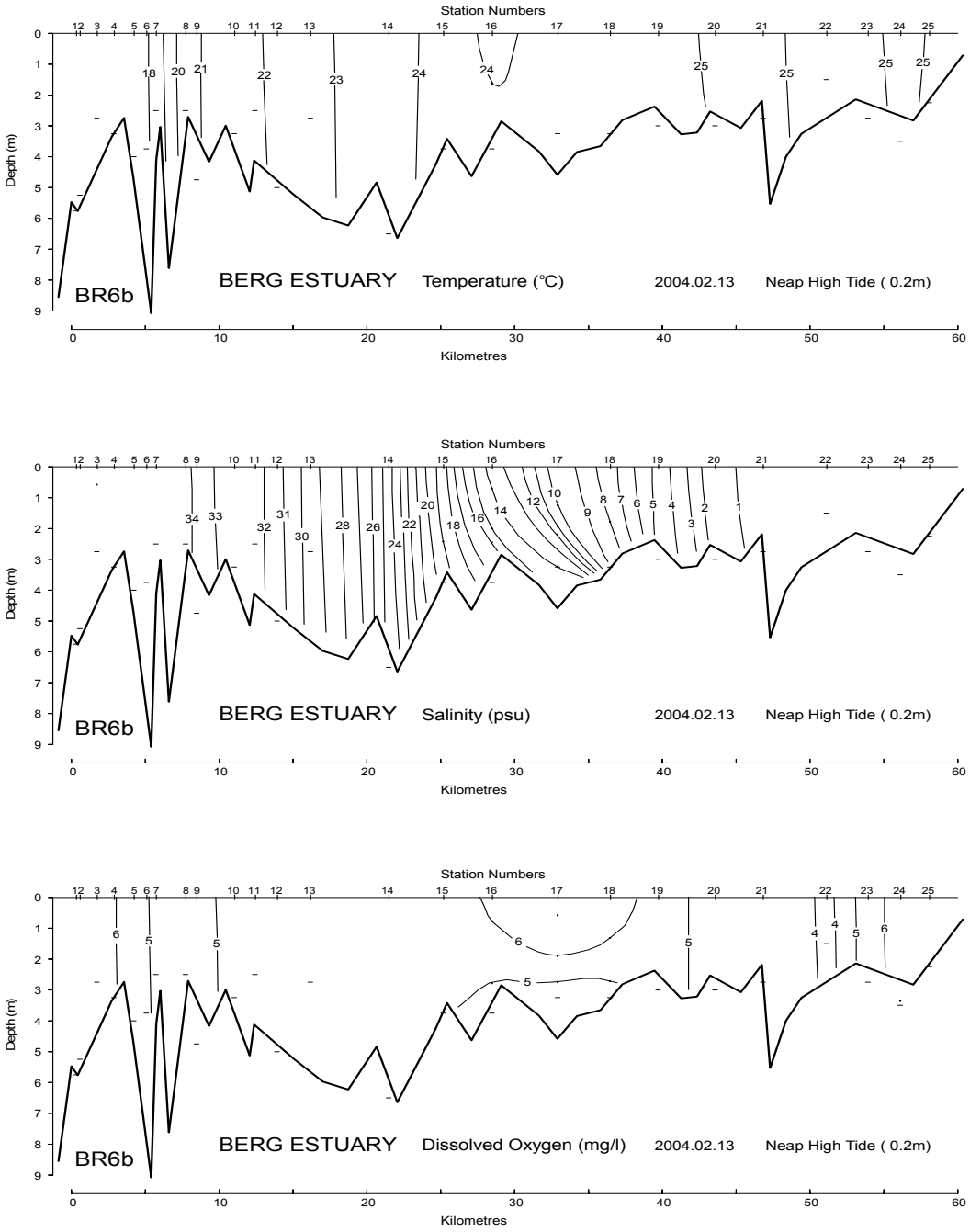


Figure A2.2.22 BR6b – NEAP HIGH – Feb 2004

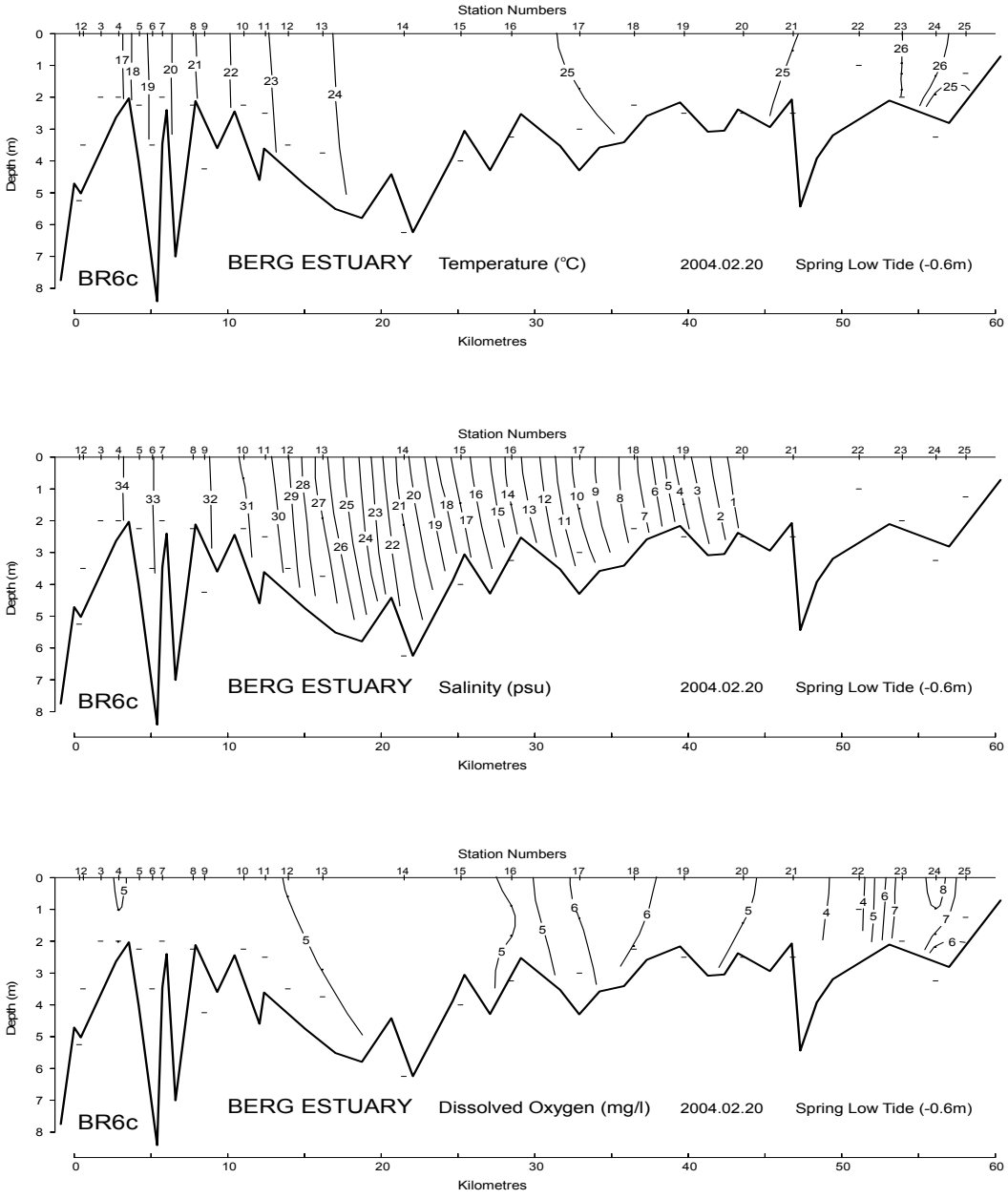


Figure A2.2.23 BR6c - SPRING LOW – Feb 2004

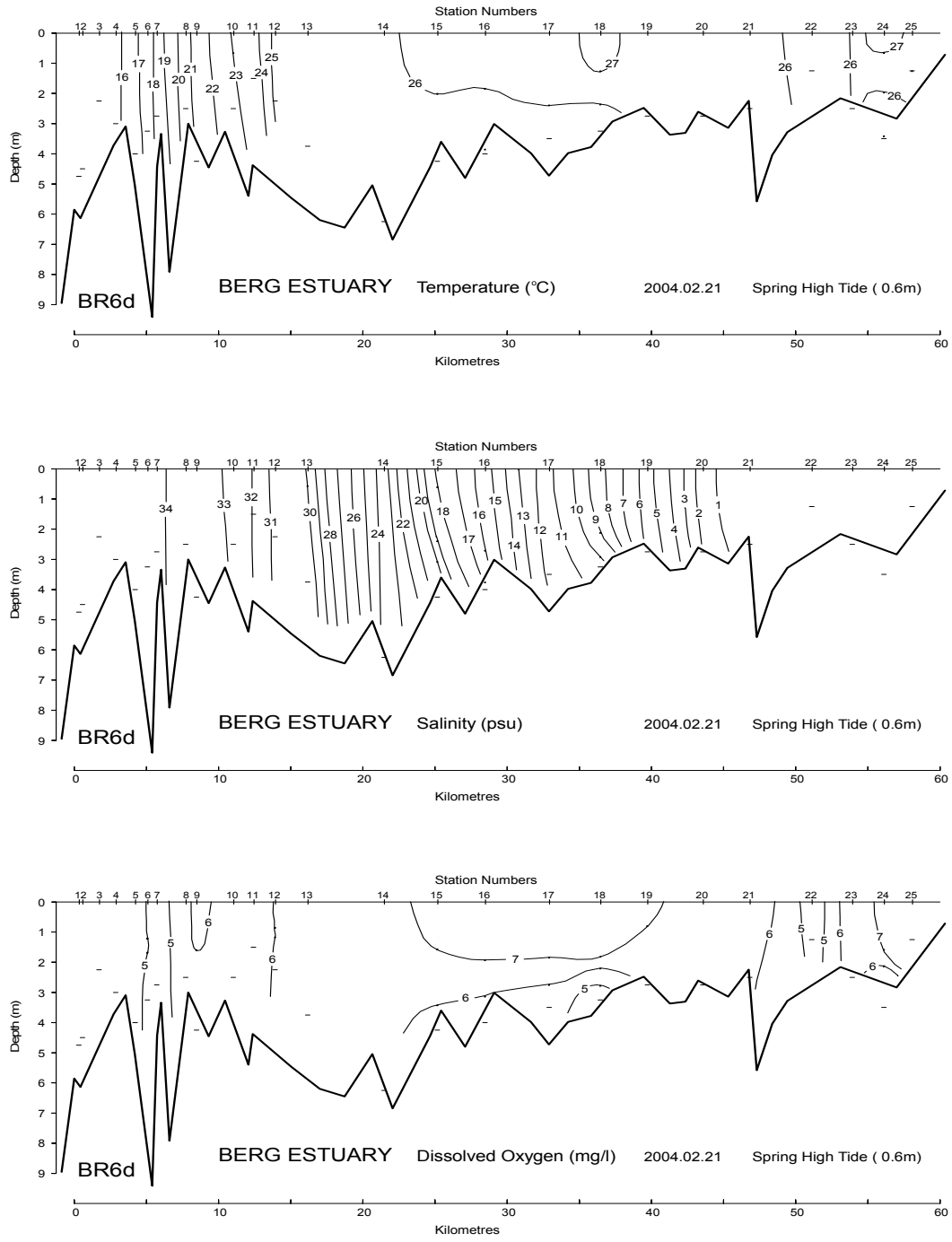
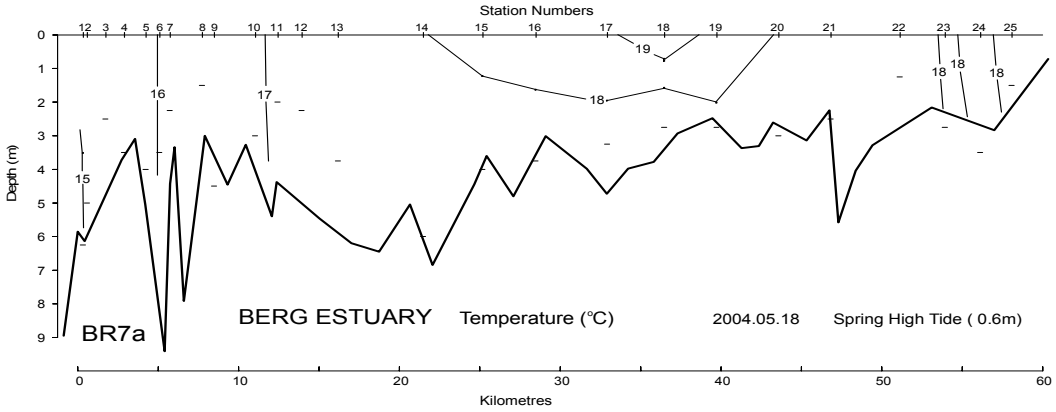
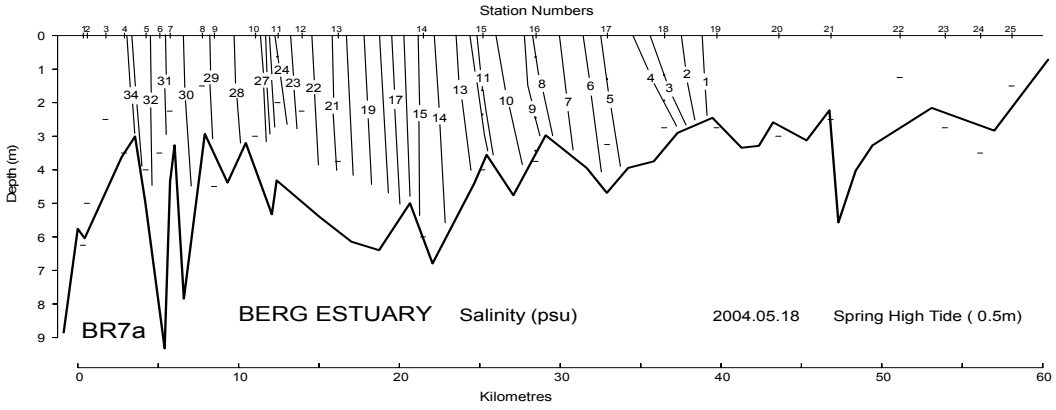


Figure A2.2.24 BR6d - SPRING HIGH – Feb 2004





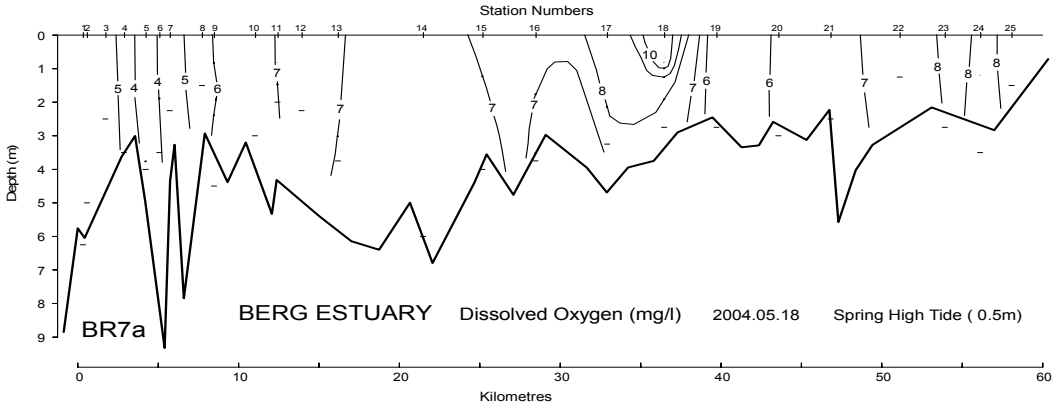
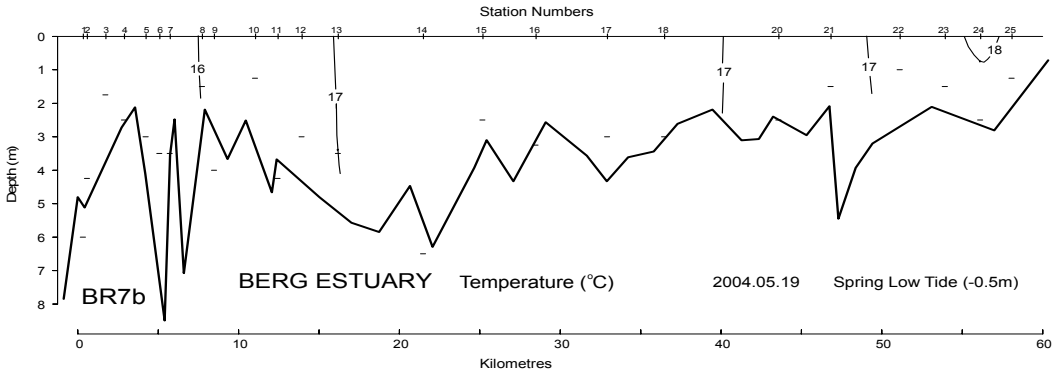
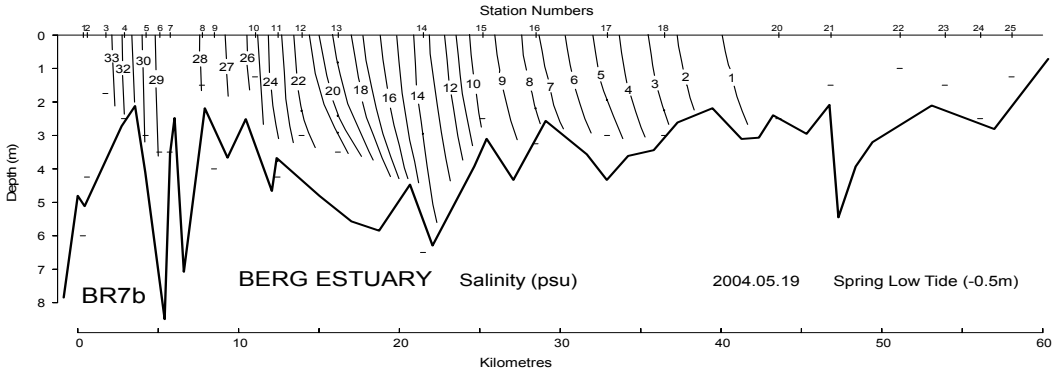


Figure A2.2.25 BR7a - SPRING HIGH – May 2004





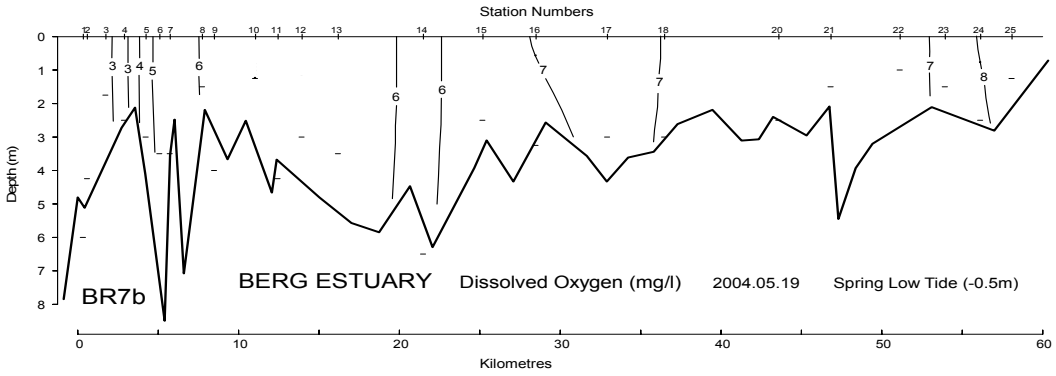


Figure A2.2.26 BR7b - SPRING LOW – May 2004

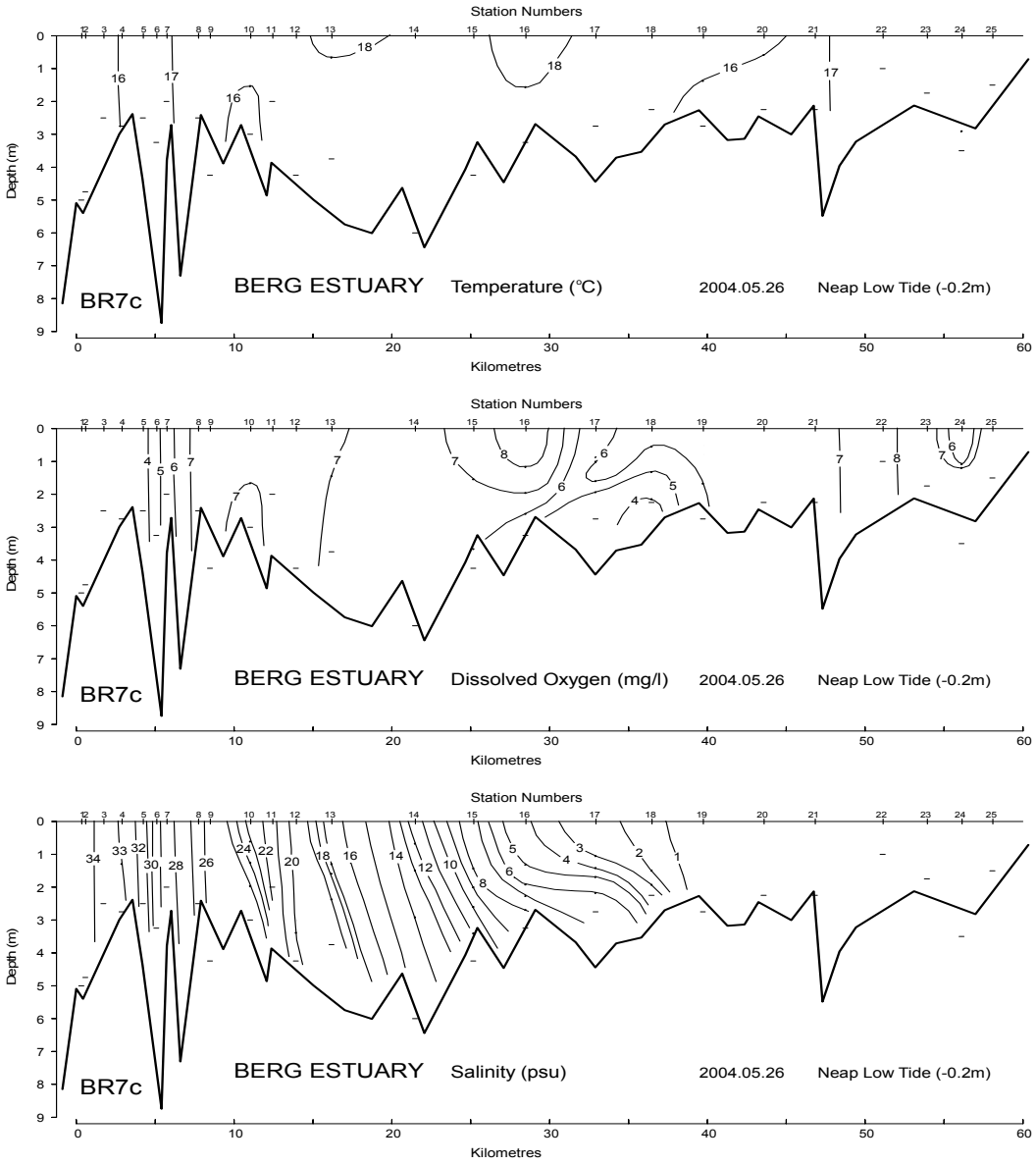


Figure A2.2.27 BR7c - NEAP LOW – May 2004

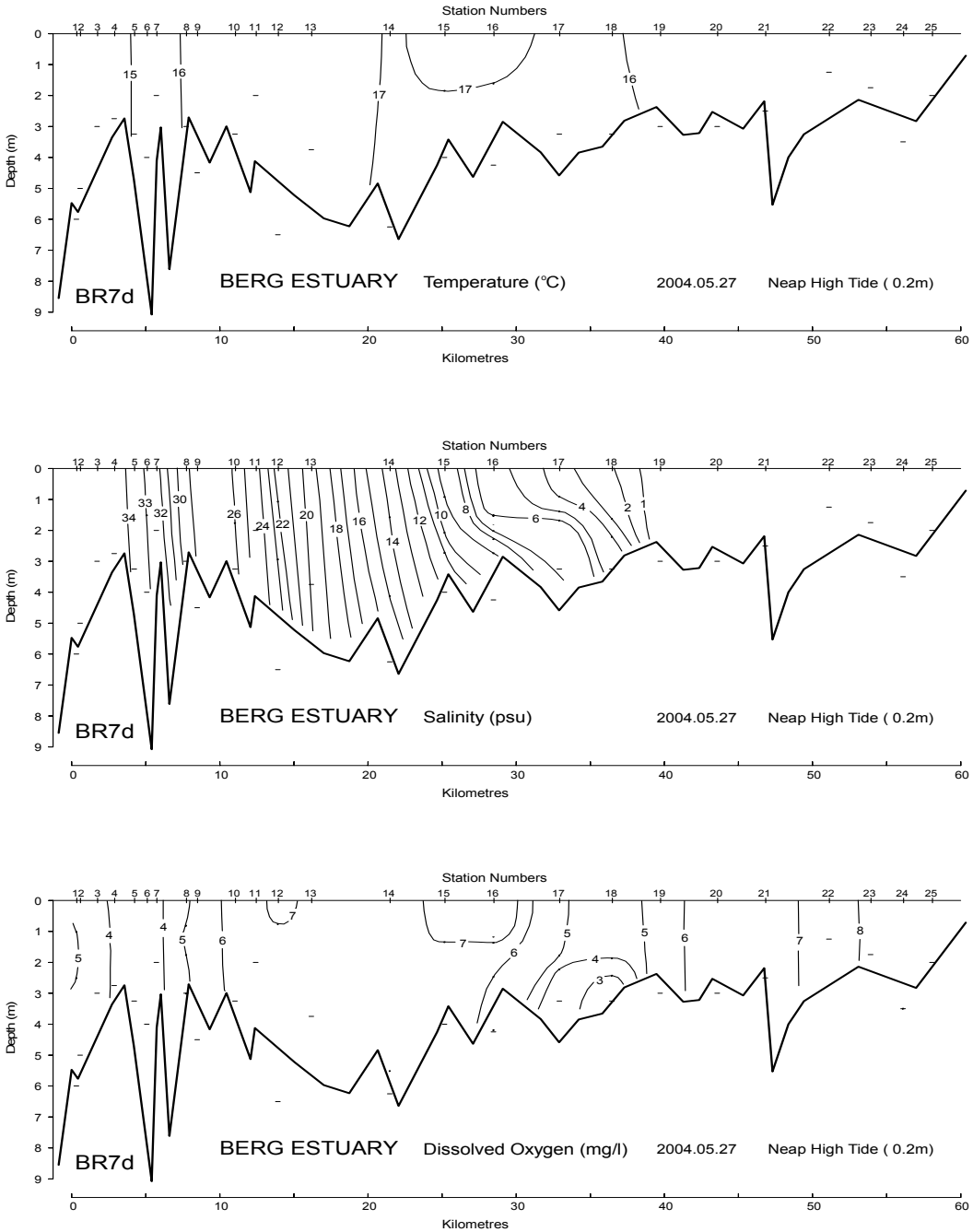


Figure A2.2.28 BR7d – NEAP HIGH – May 2004

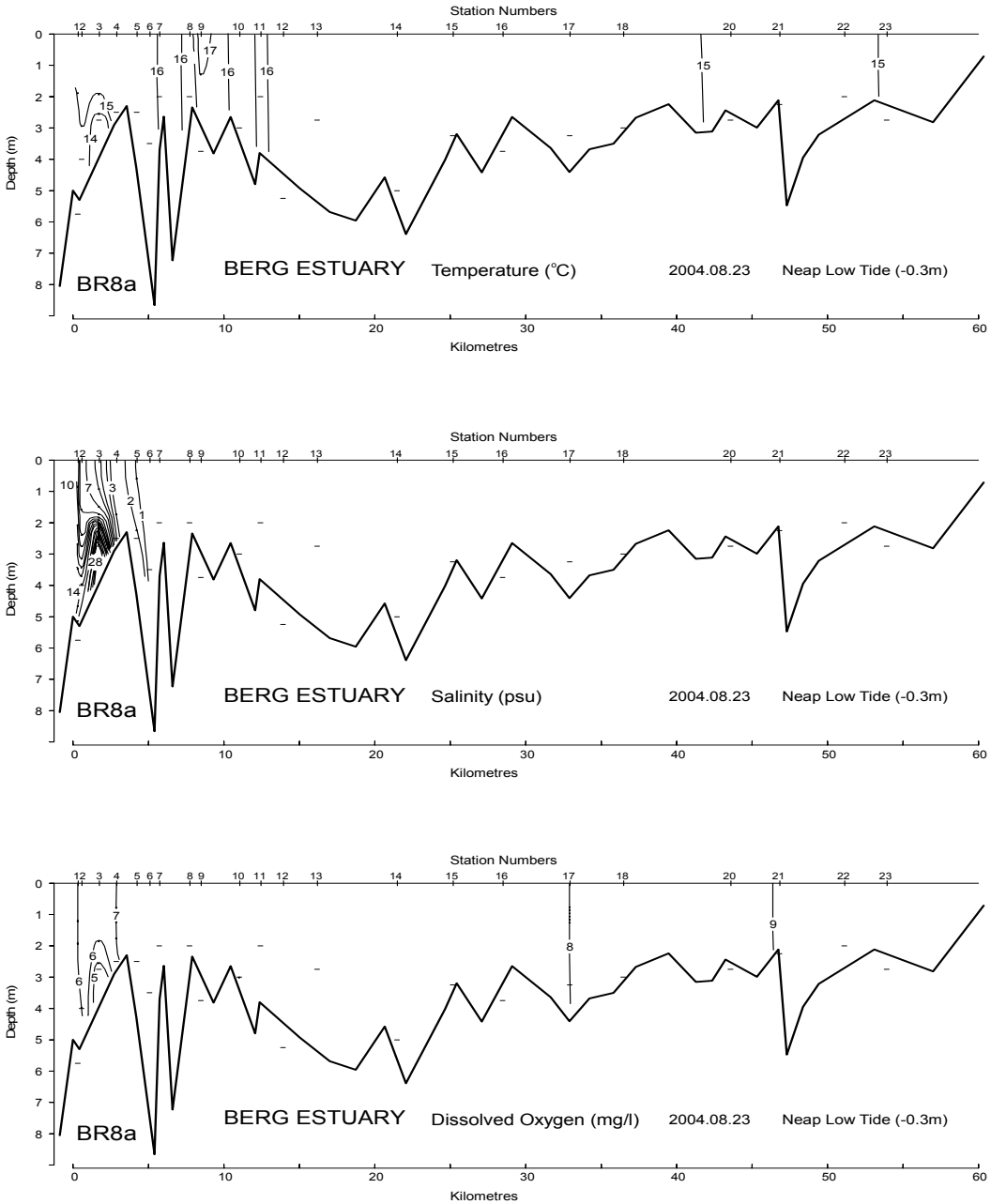


Figure A2.2.29 BR8a - NEAP LOW – Aug 2004

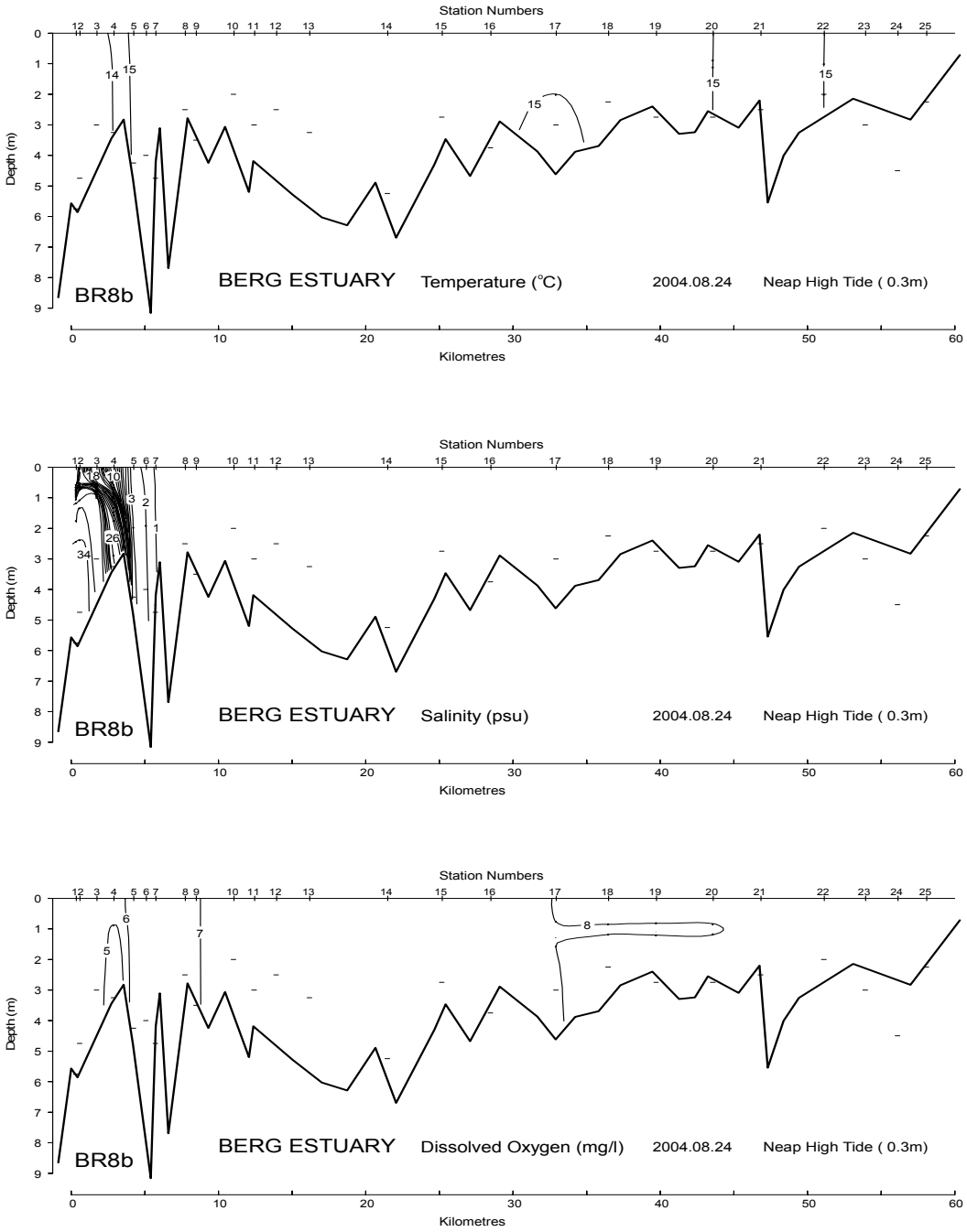
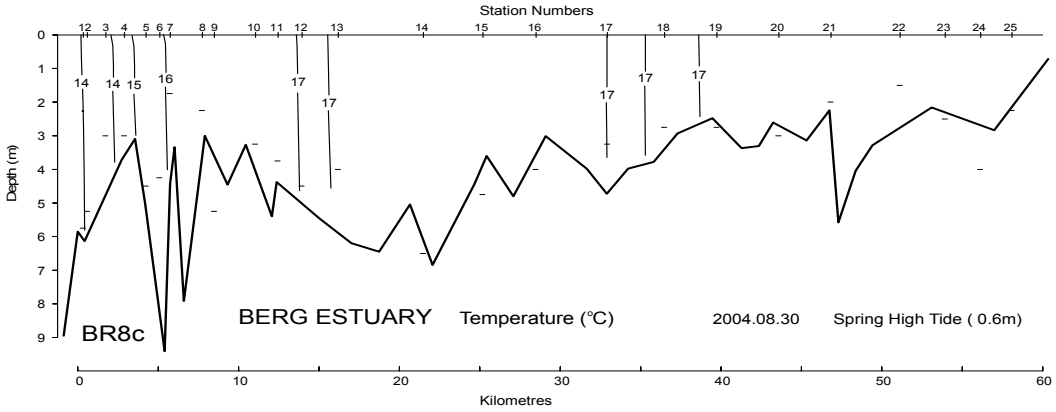
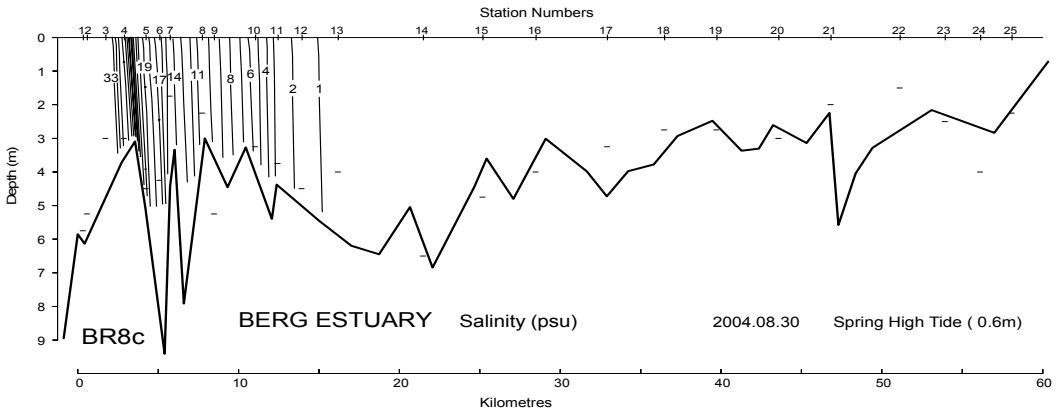


Figure A2.2.30 BR8b – NEAP HIGH – Aug 2004





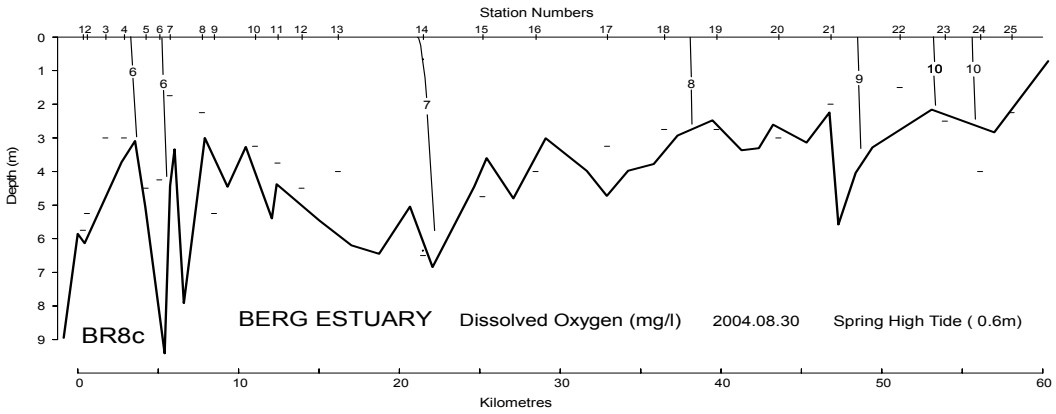


Figure A2.2.31 BR8c - SPRING HIGH – Aug 2004

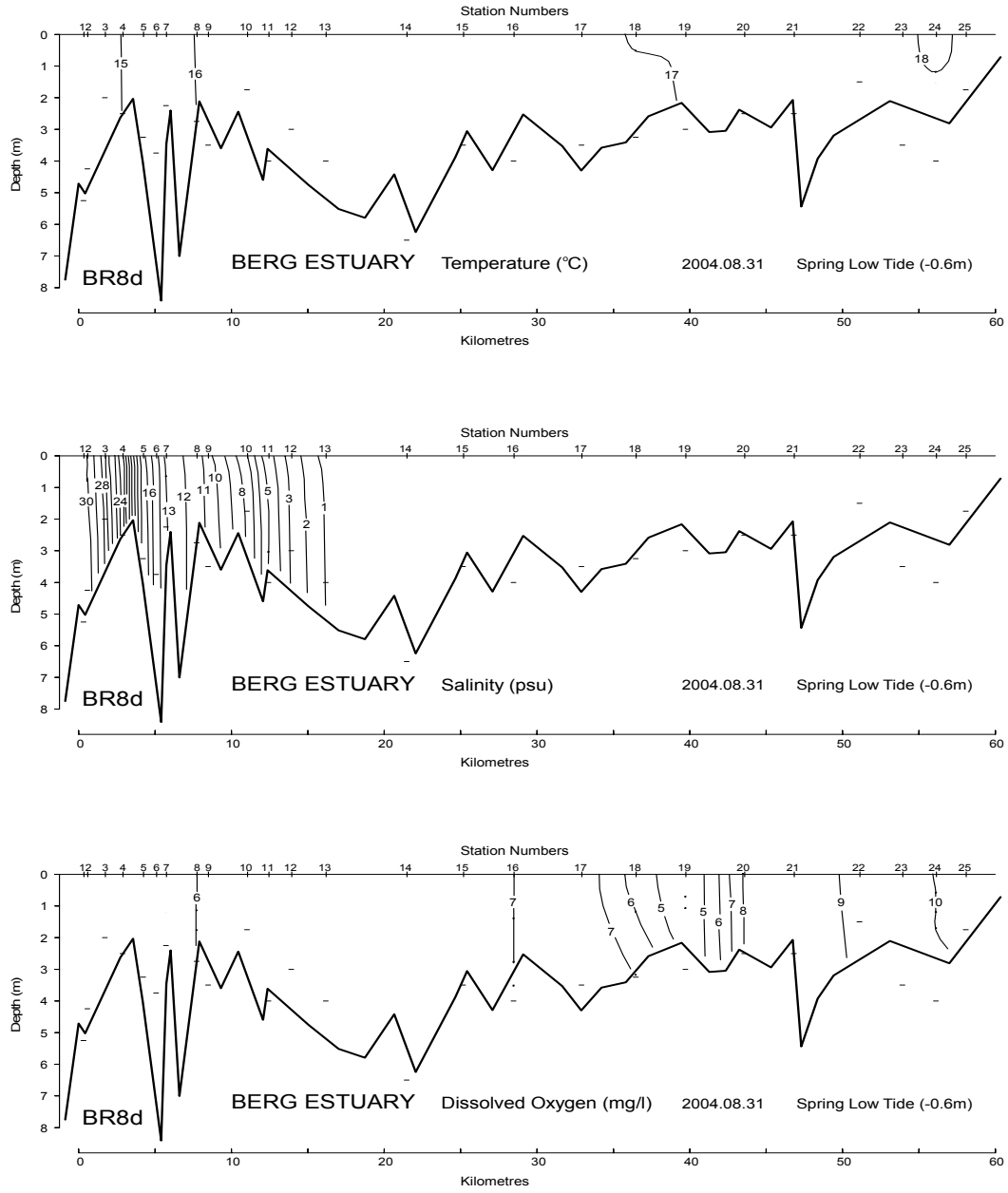
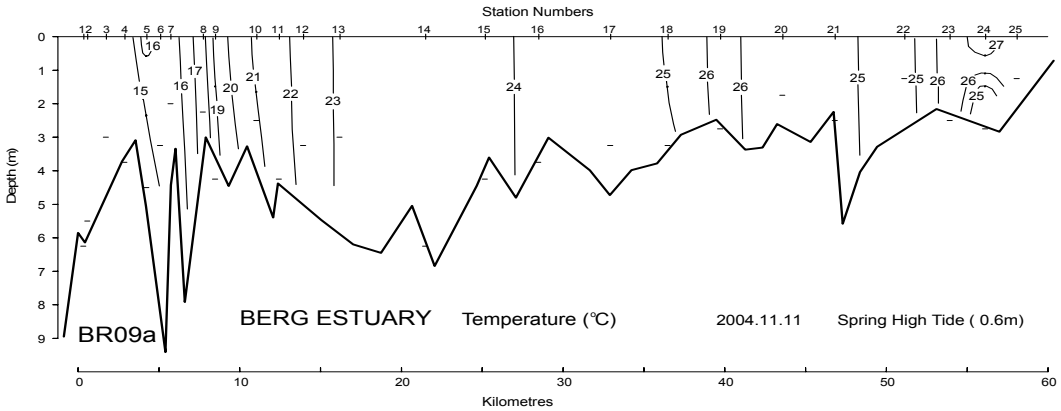
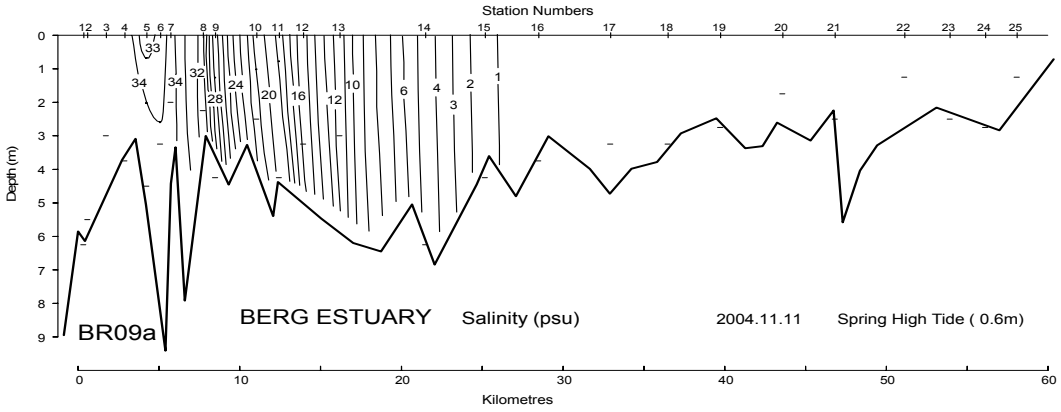


Figure A2.2.32 BR8d - SPRING LOW – Aug 2004





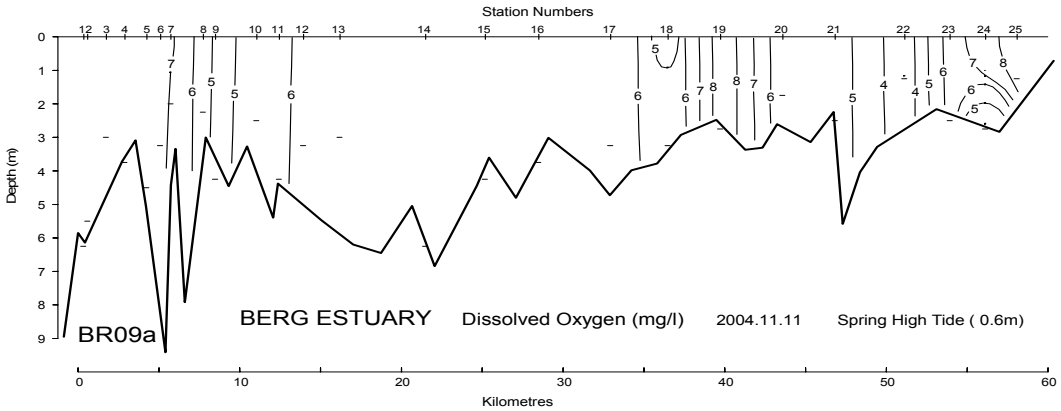
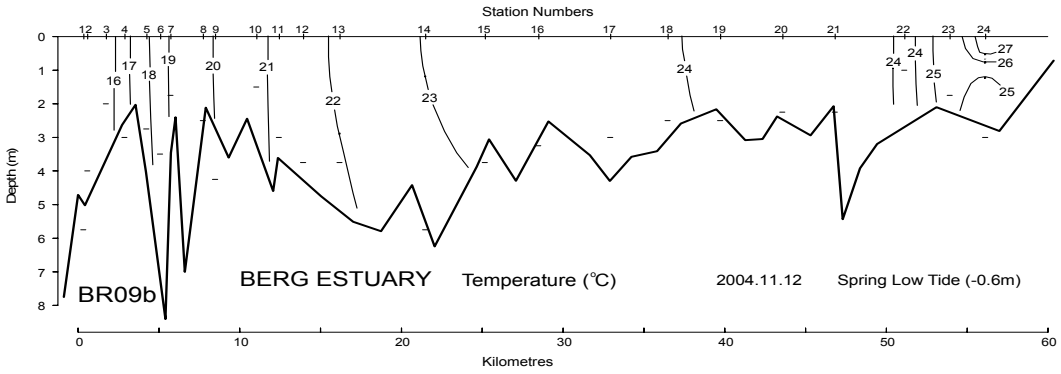
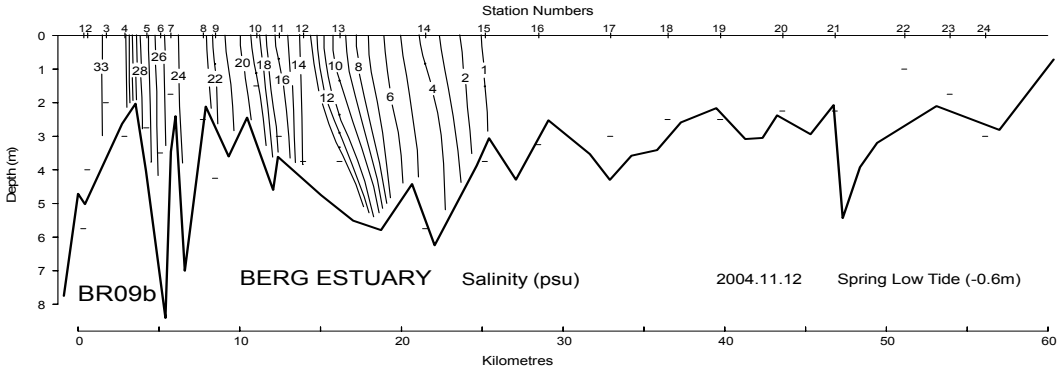


Figure A2.2.33 BR9a - SPRING HIGH – Nov 2004





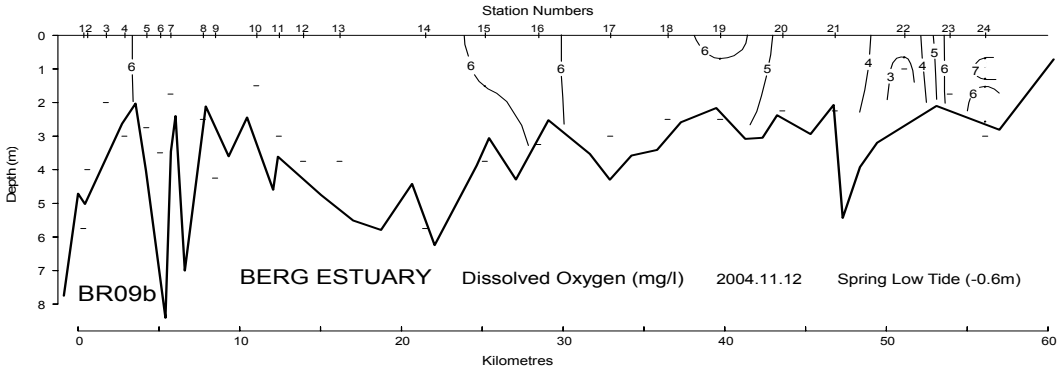


Figure A2.2.34 BR9b - SPRING LOW – Nov 2004

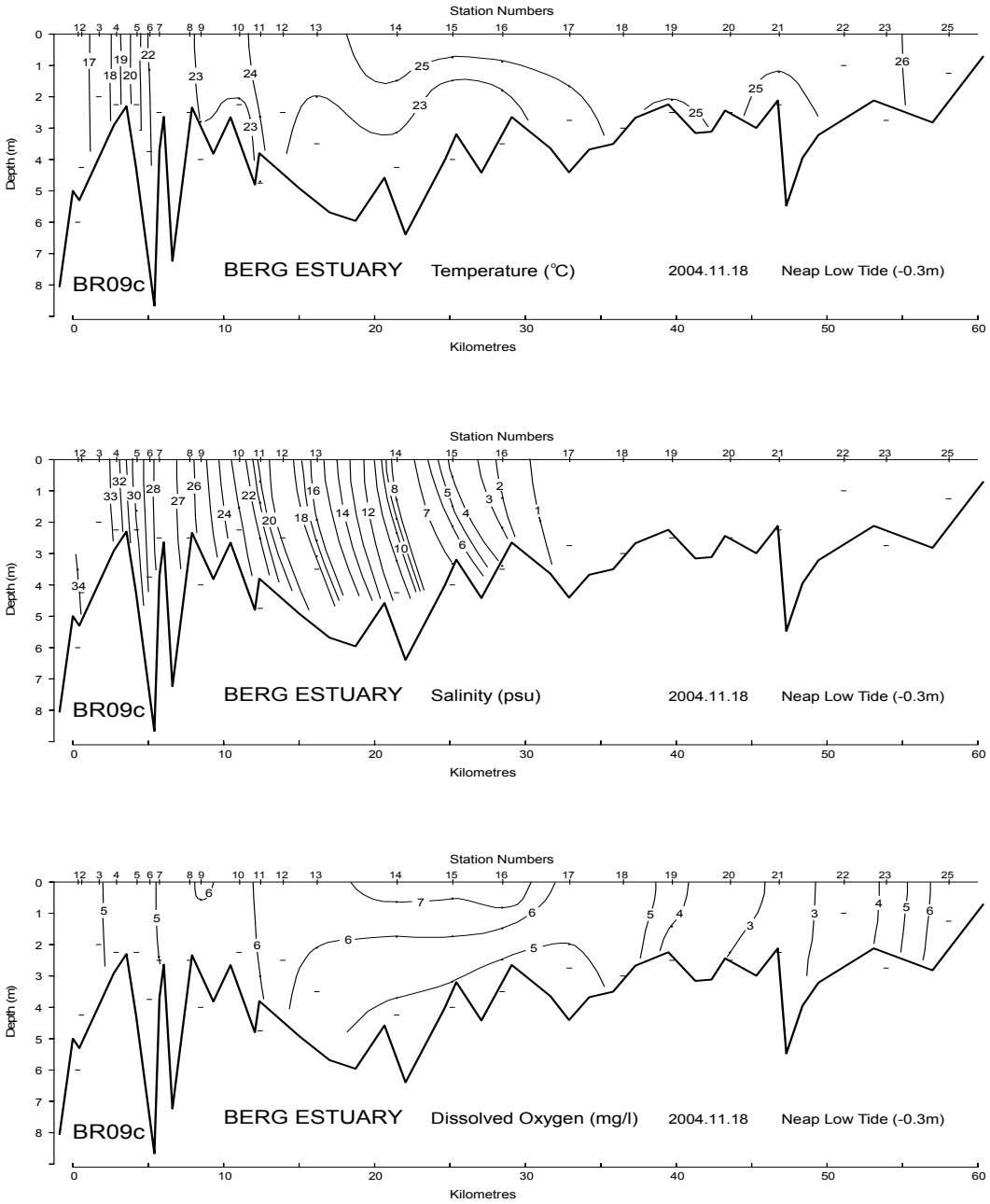


Figure A2.2.35 BR9c - NEAP LOW – Nov 2004

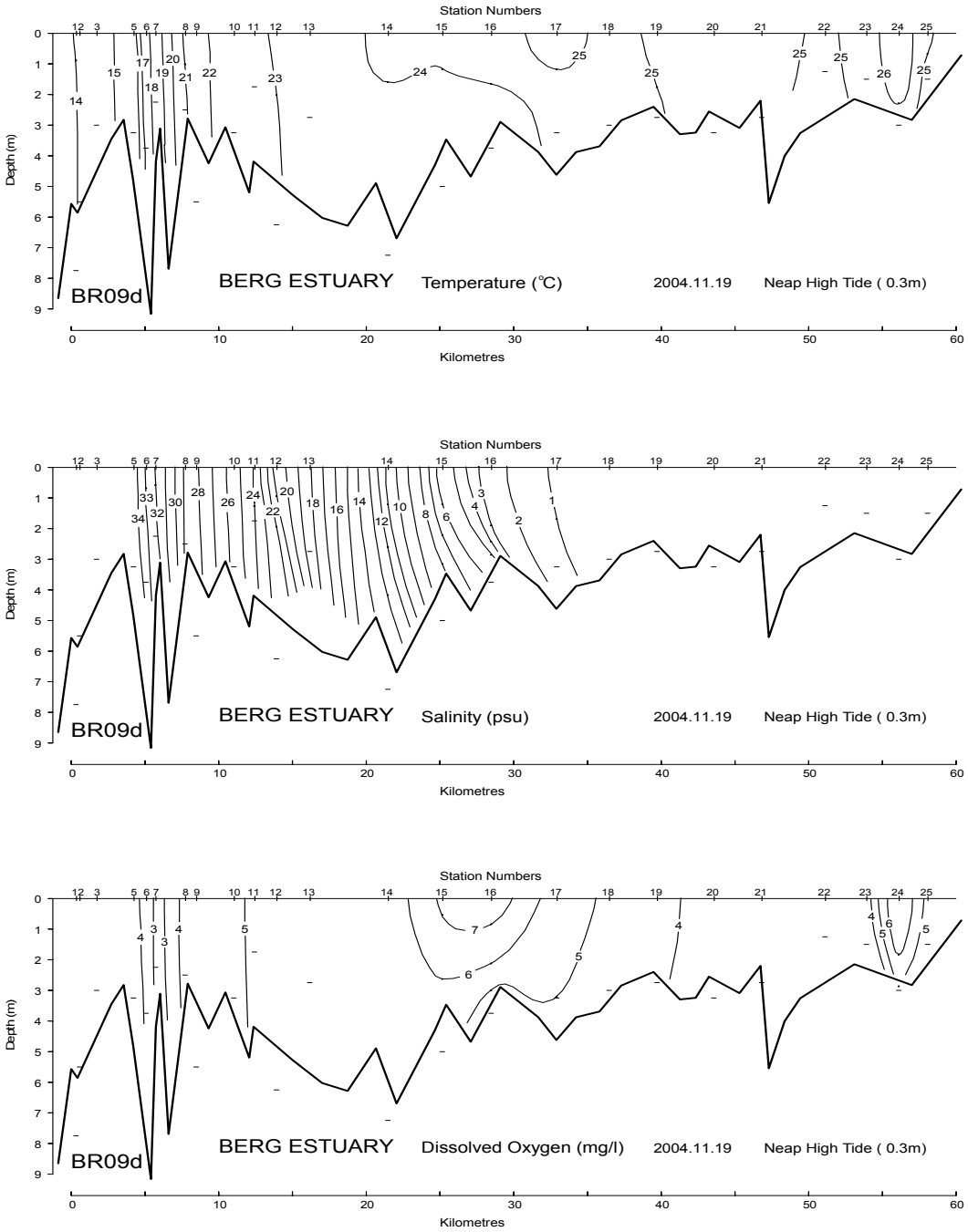
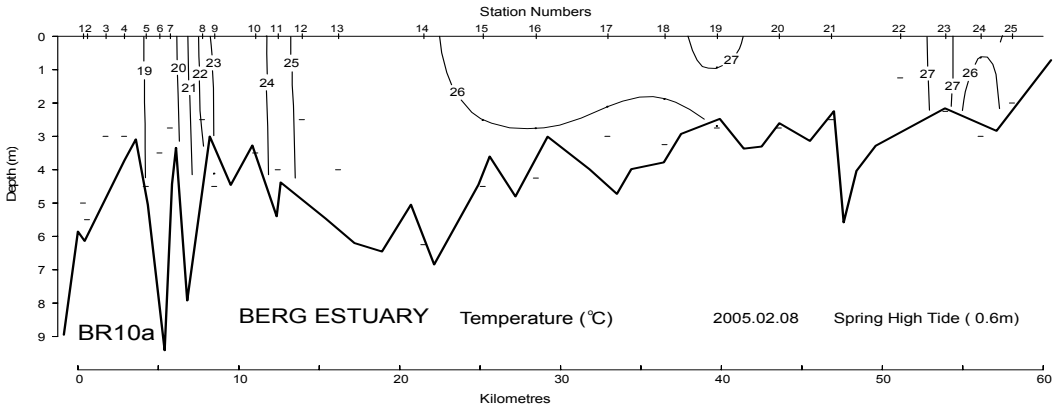
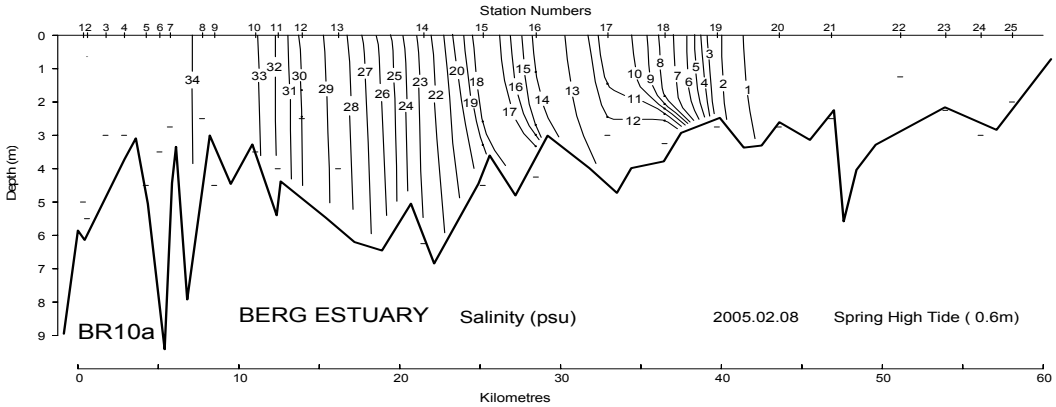


Figure A2.2.36 BR9d – NEAP HIGH – Nov 2004





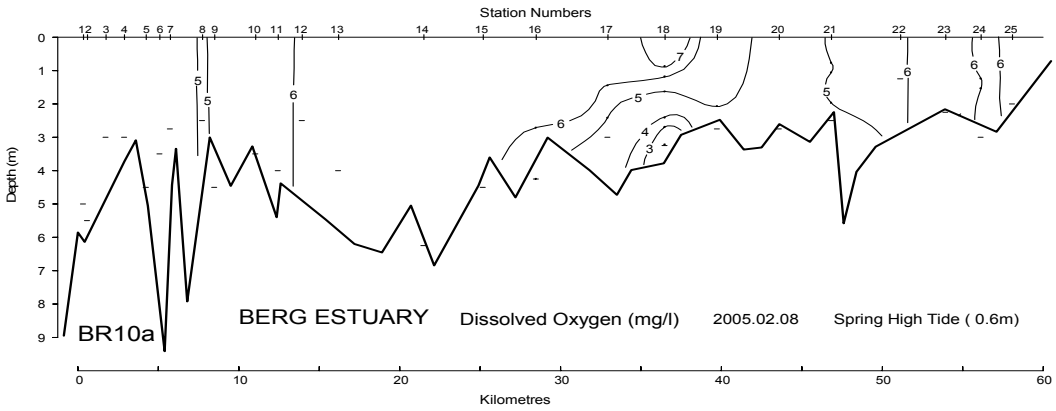


Figure A2.2.37 BR10a - SPRING HIGH – Feb 2005

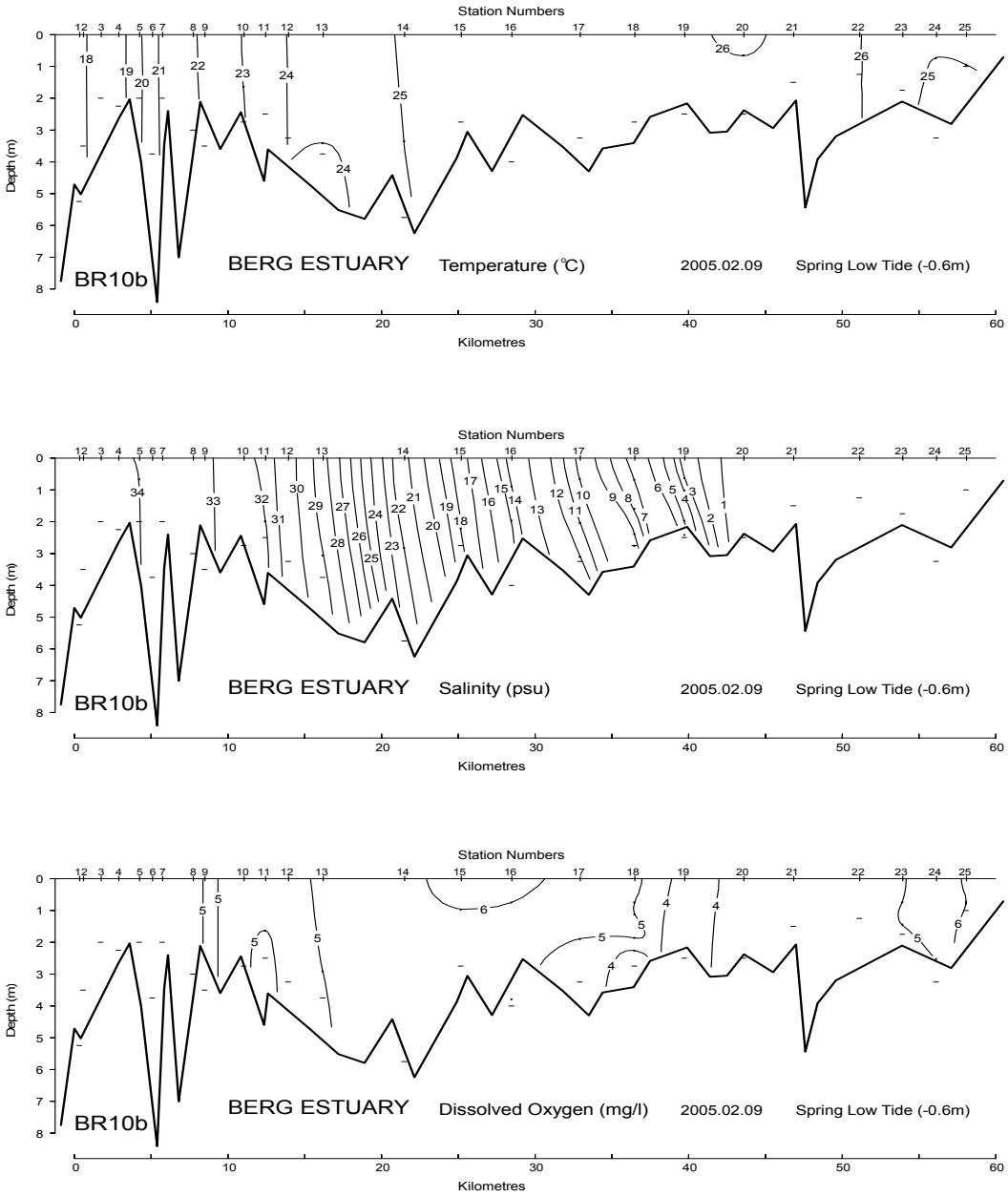


Figure A2.2.38 BR10b - SPRING LOW – Feb 2005

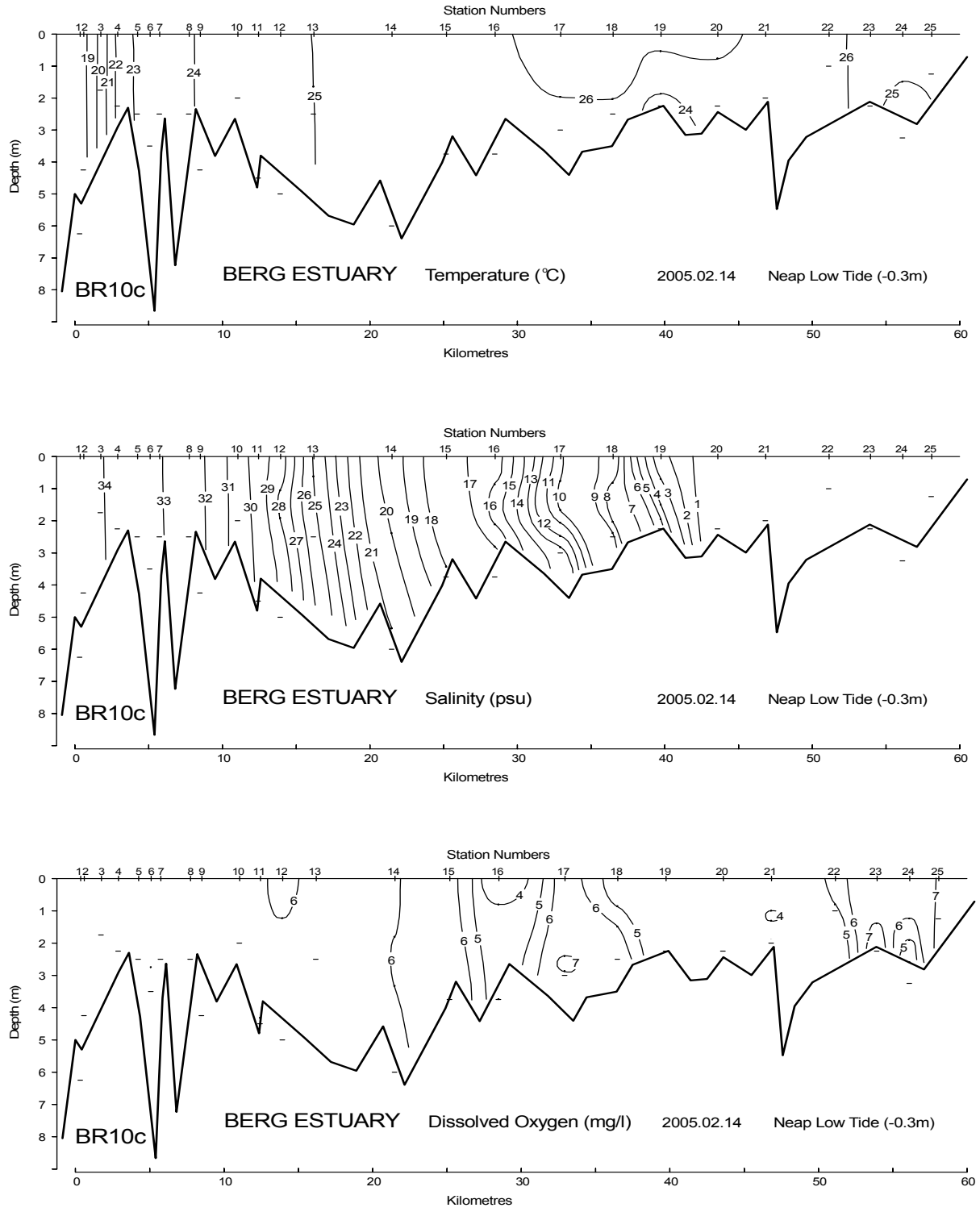


Figure A2.2.39 BR10c – NEAP LOW – Feb 2005

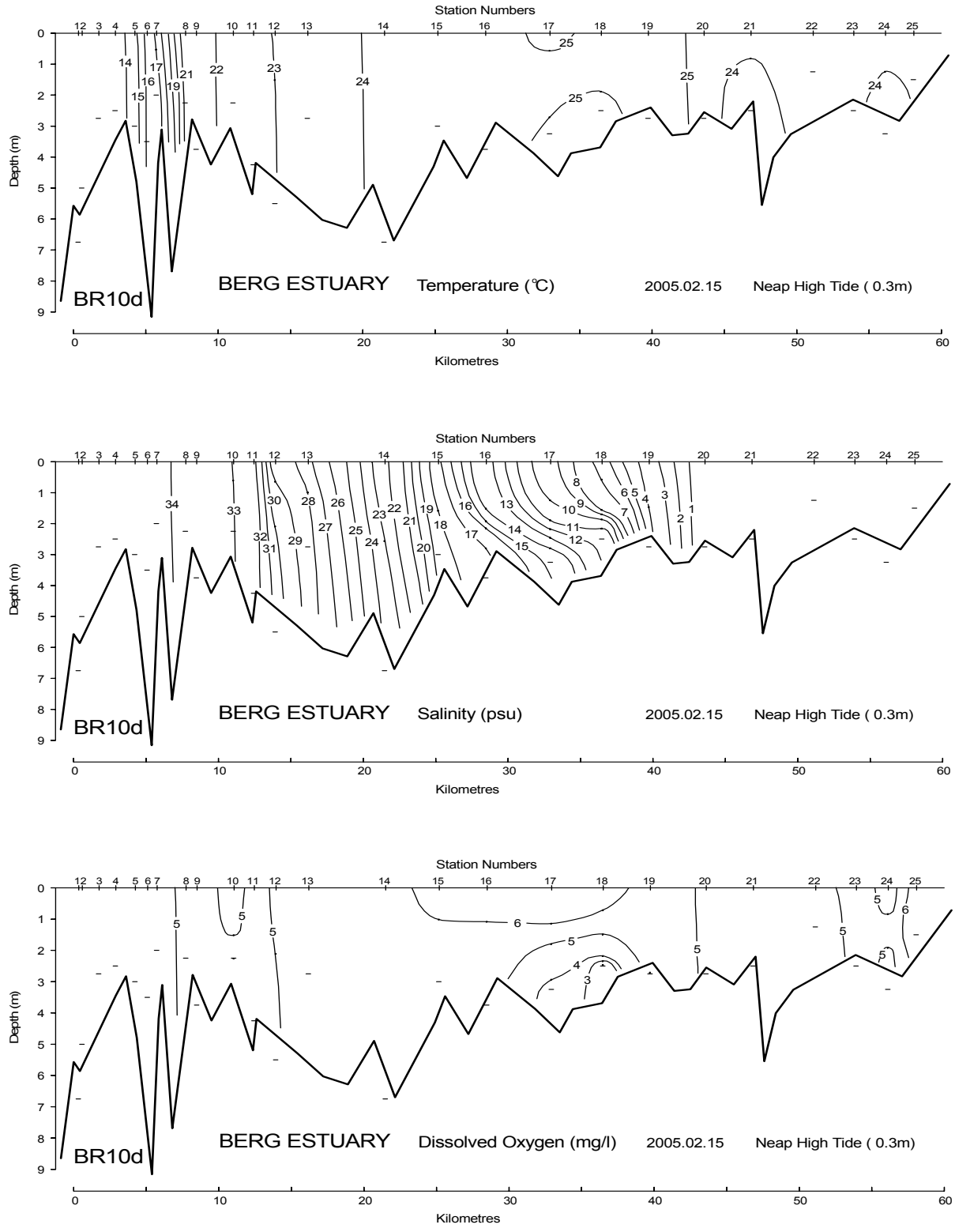


Figure A2.2.40 BR10d - NEAP HIGH – Feb 2005

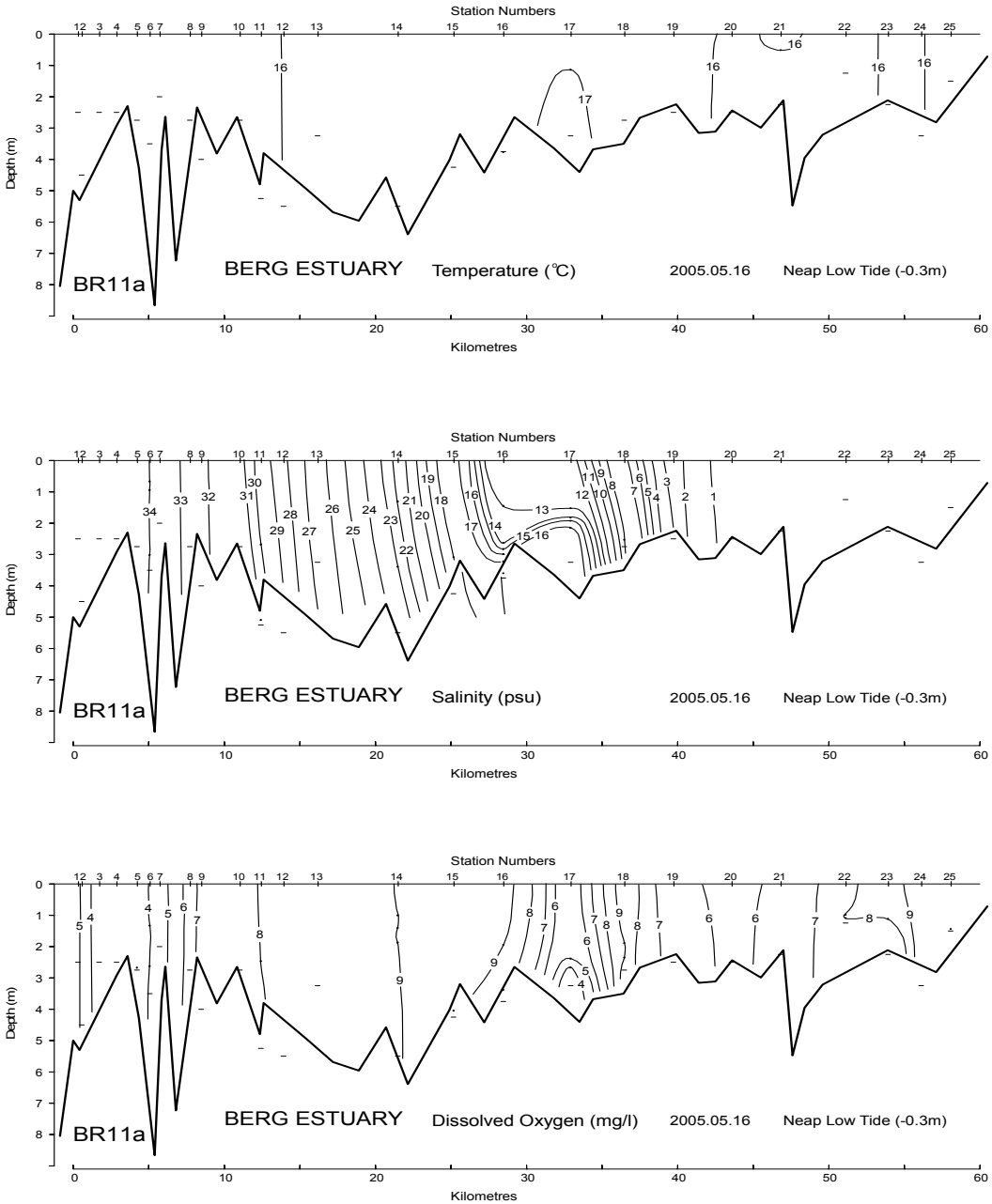


Figure A2.2.41 BR11a - NEAP LOW – May 2005

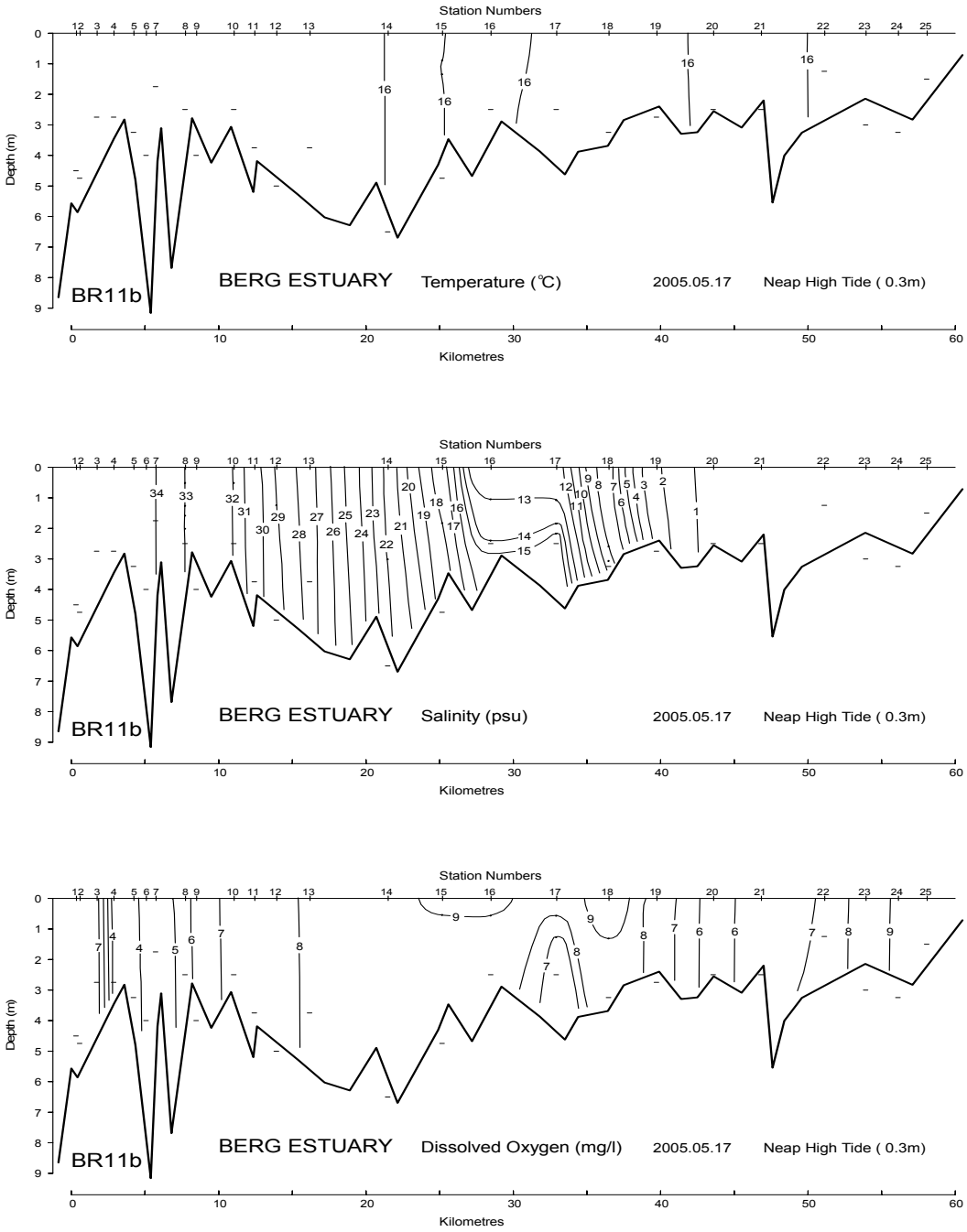


Figure A2.2.42 BR11b - NEAP HIGH – May 2005



Figure A2.2.43 BR11c - SPRING HIGH – May 2005

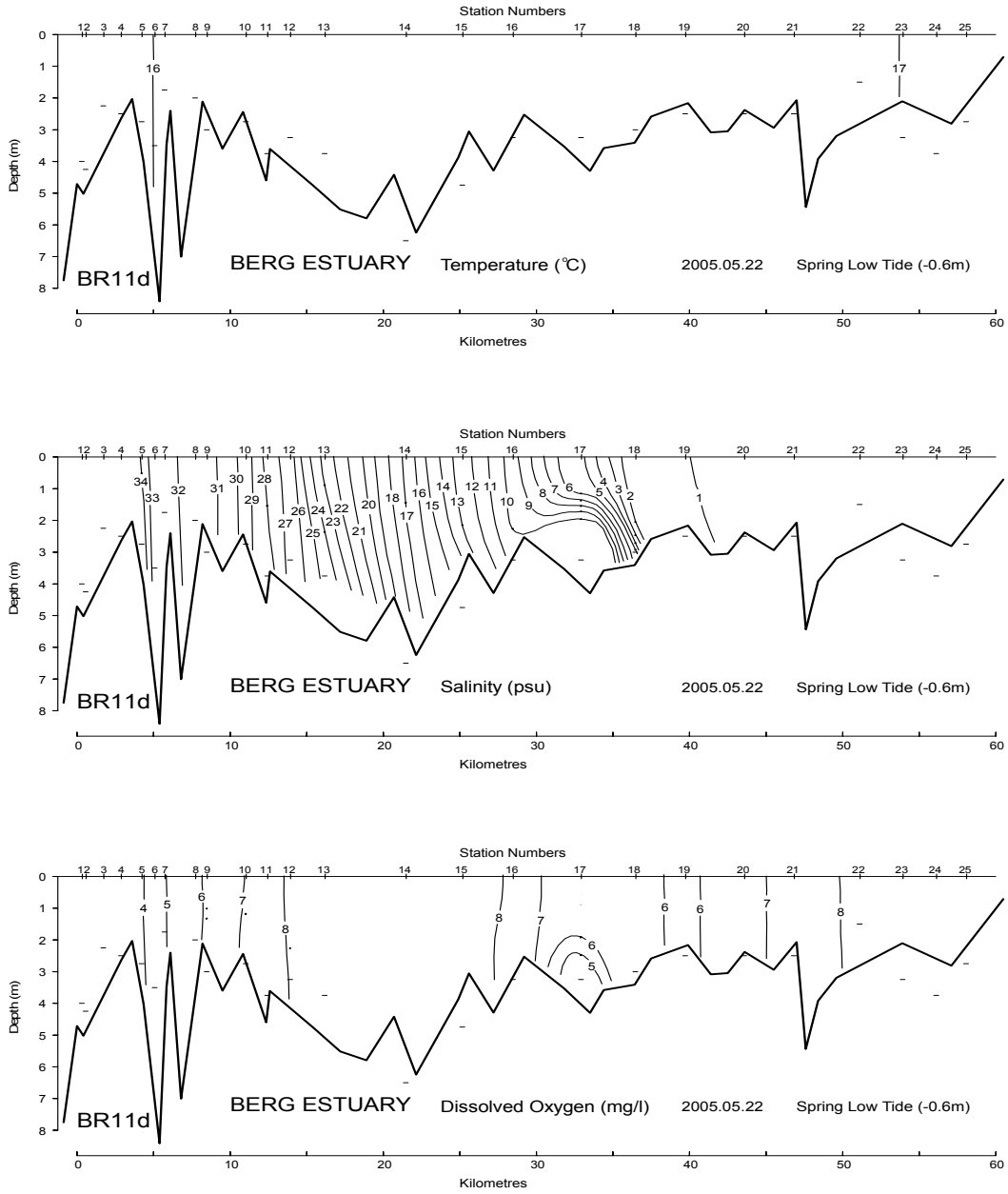


Figure A2.2.44 BR11d - SPRING LOW – May 2005

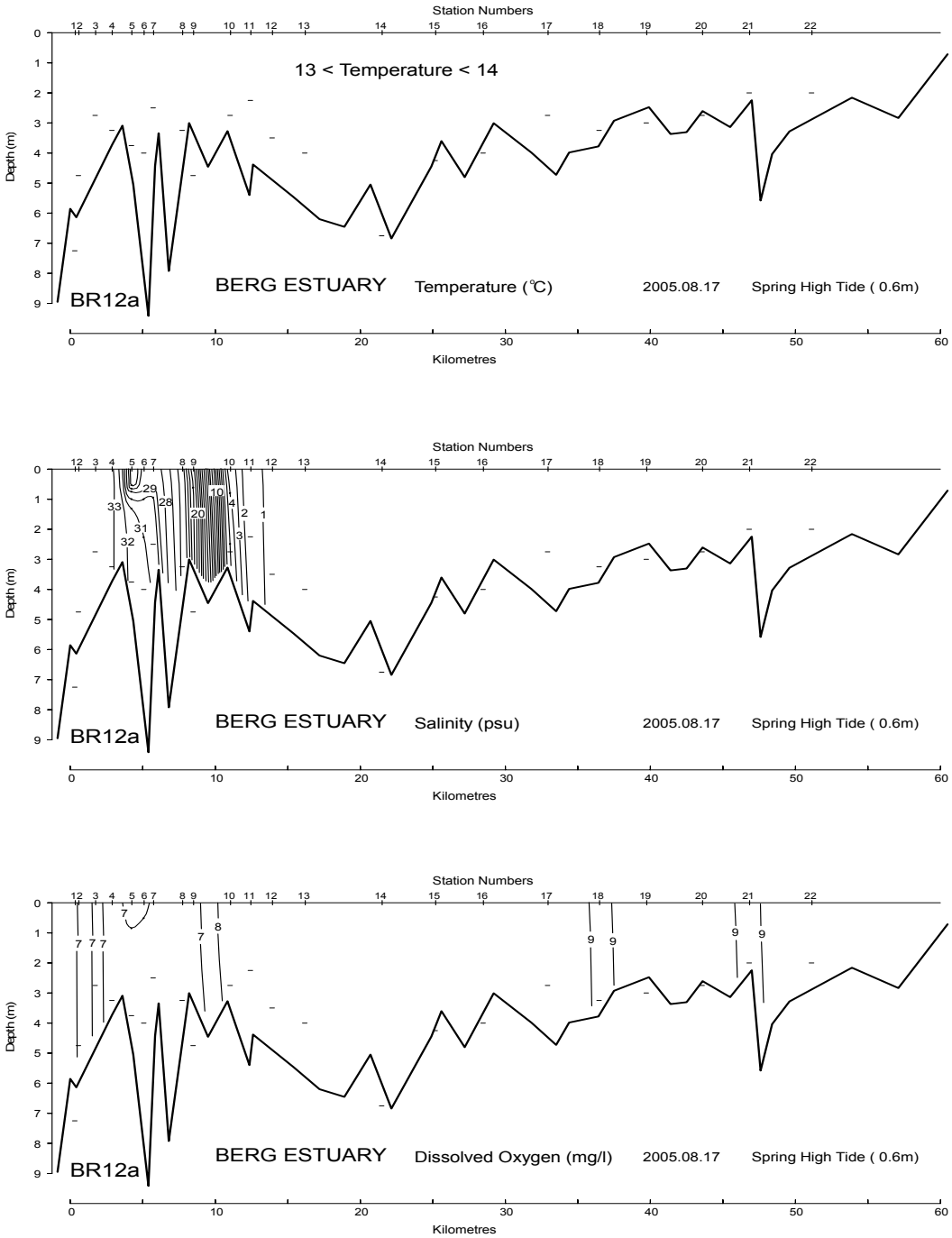


Figure A2.2.45 BR12a - SPRING HIGH – Aug 2005

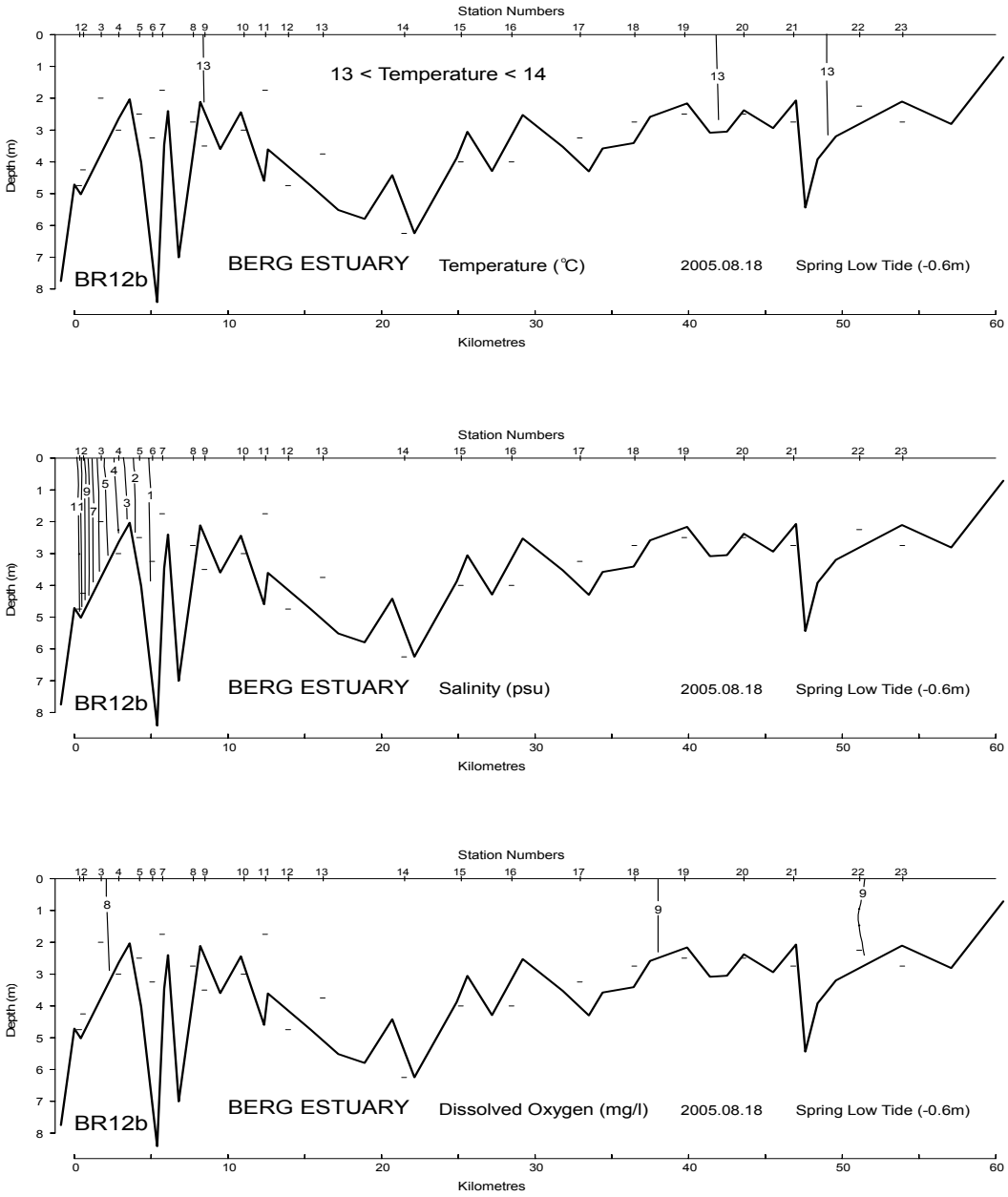


Figure A2.2.46 BR12b - SPRING LOW – Aug 2005

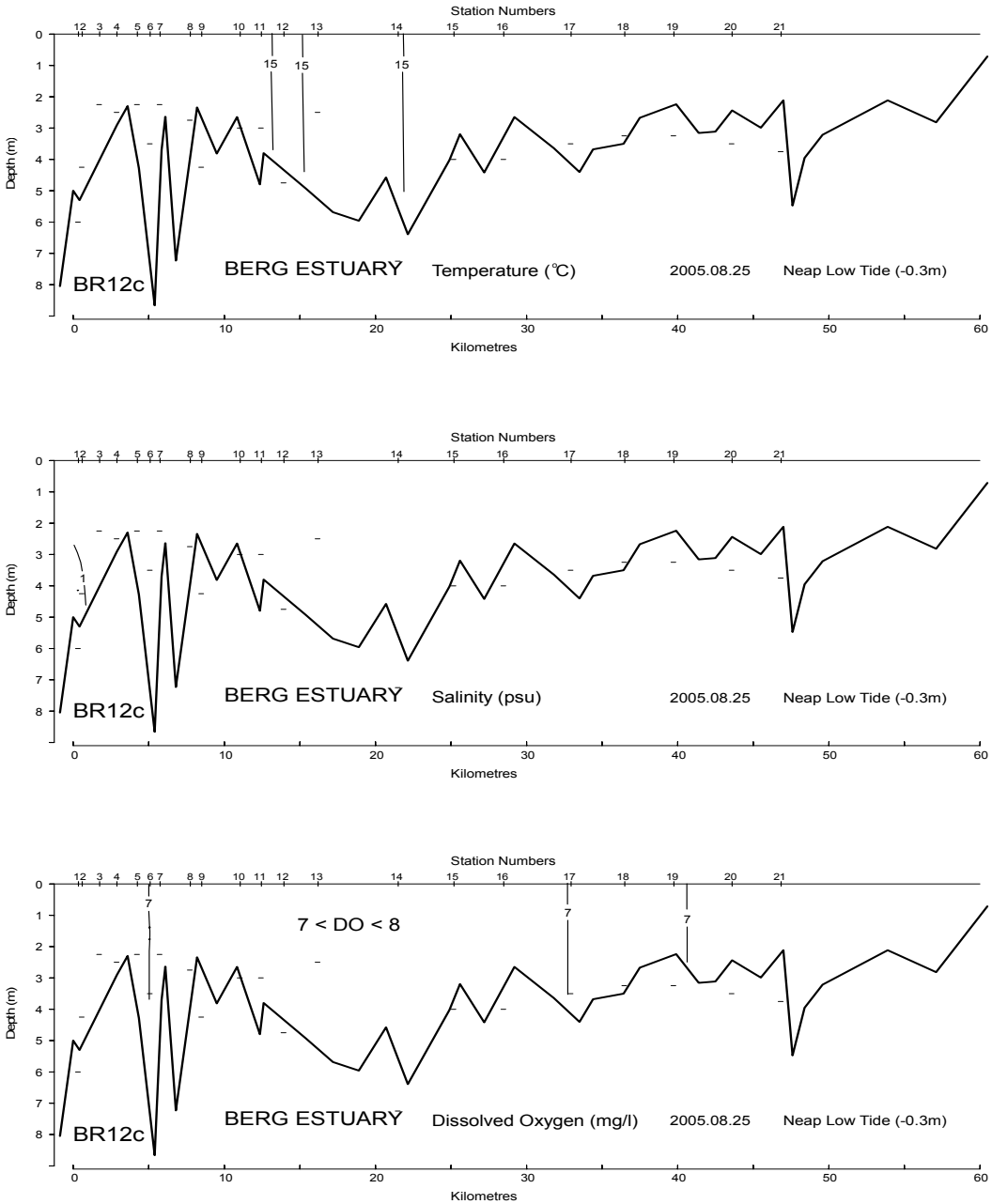


Figure A2.2.47 BR12c - NEAP LOW – Aug 2005

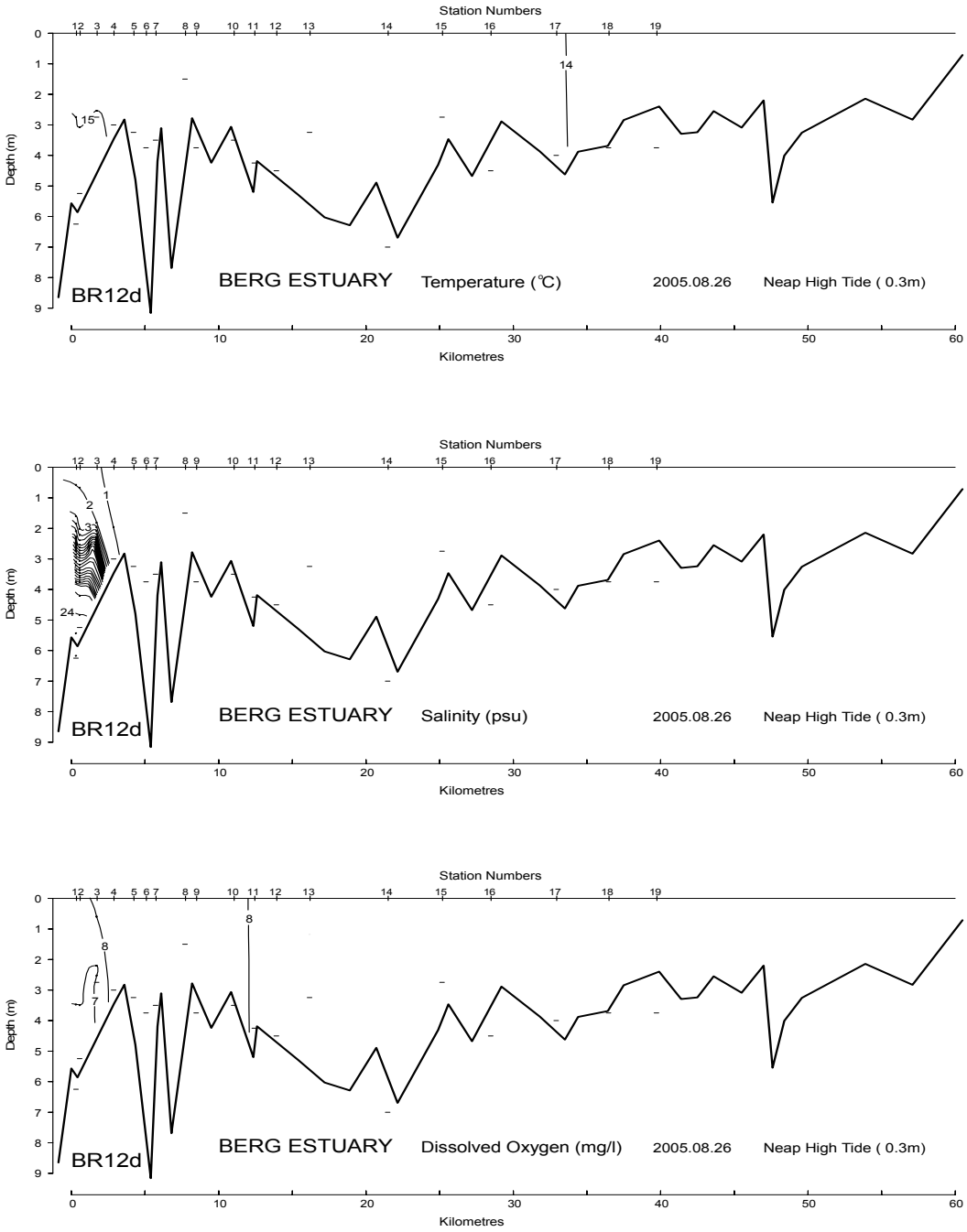


Figure A2.2.48 BR12d - NEAP HIGH – Aug 2005

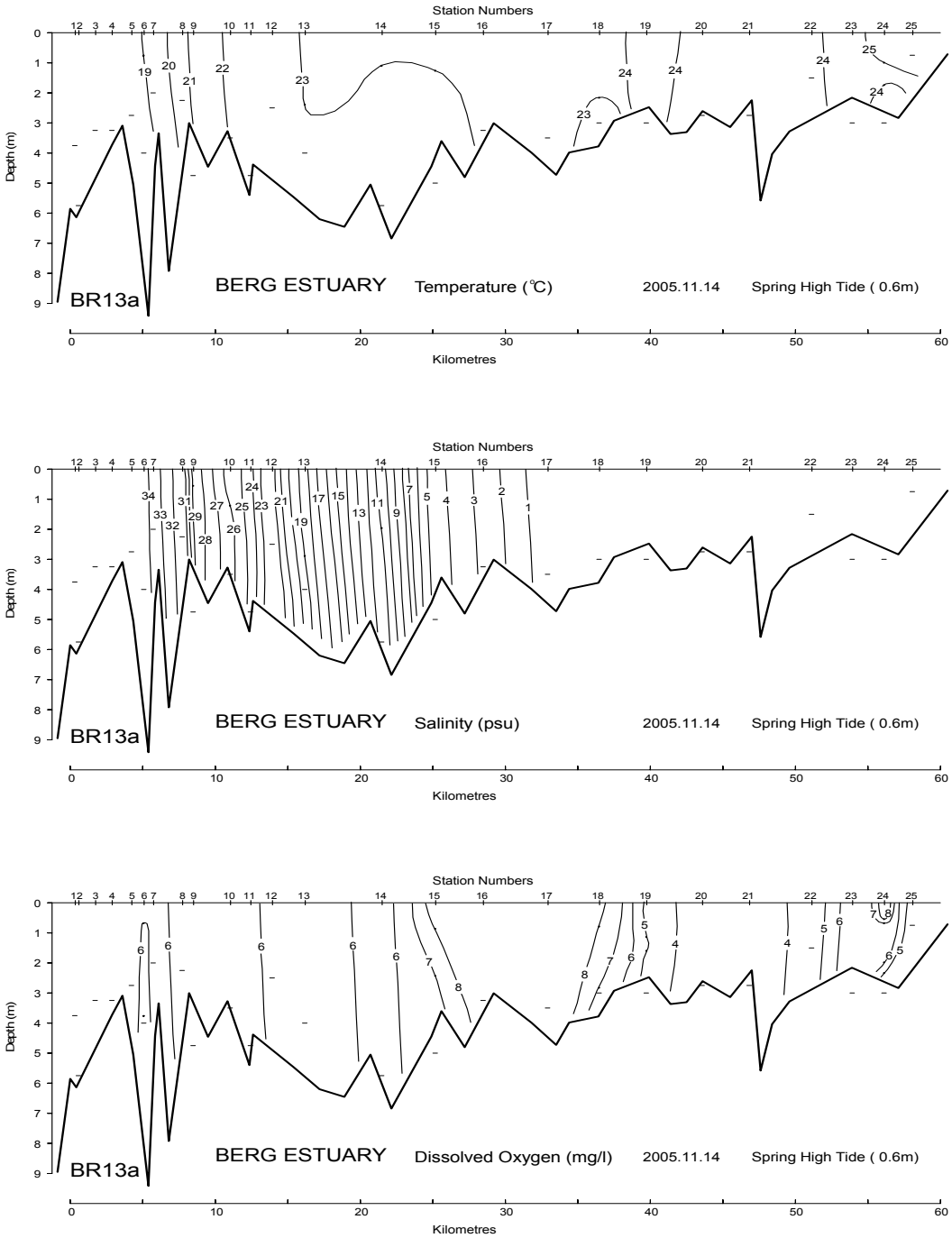


Figure A2.2.49 BR13a - SPRING HIGH – Nov 2005

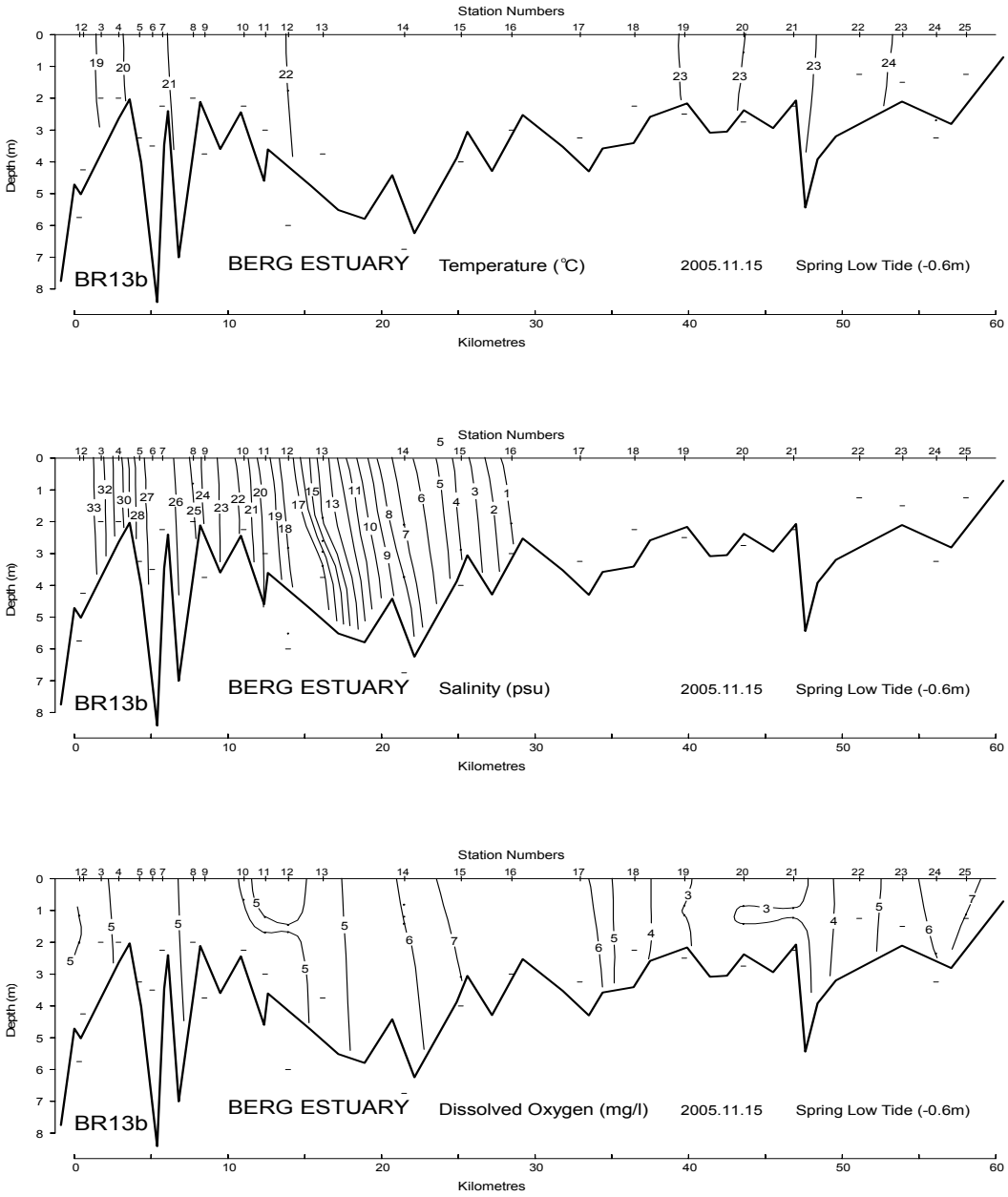


Figure A2.2.50 BR13b - SPRING LOW – Nov 2005

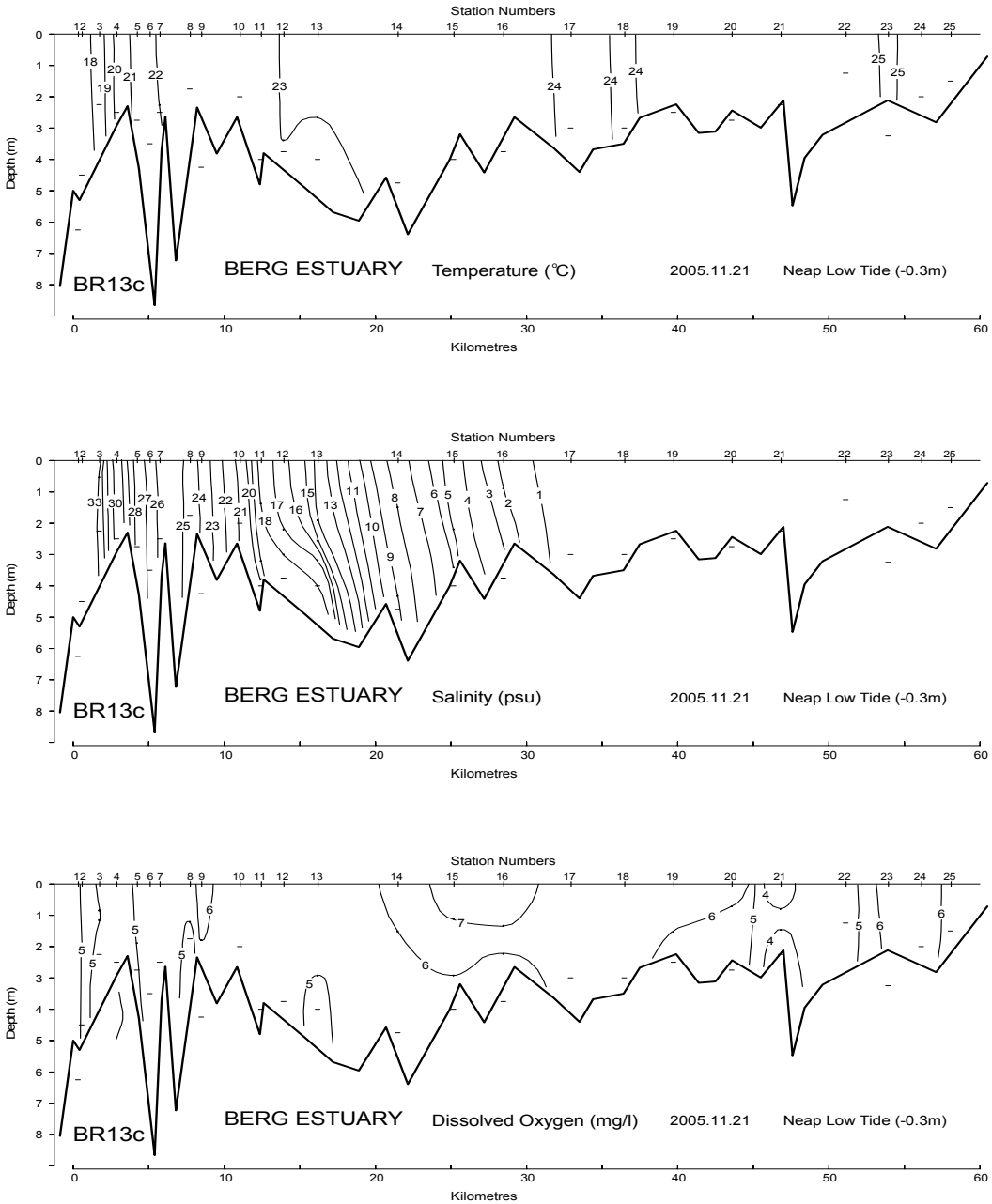


Figure A2.2.51 BR13c – NEAP LOW – Nov 2005

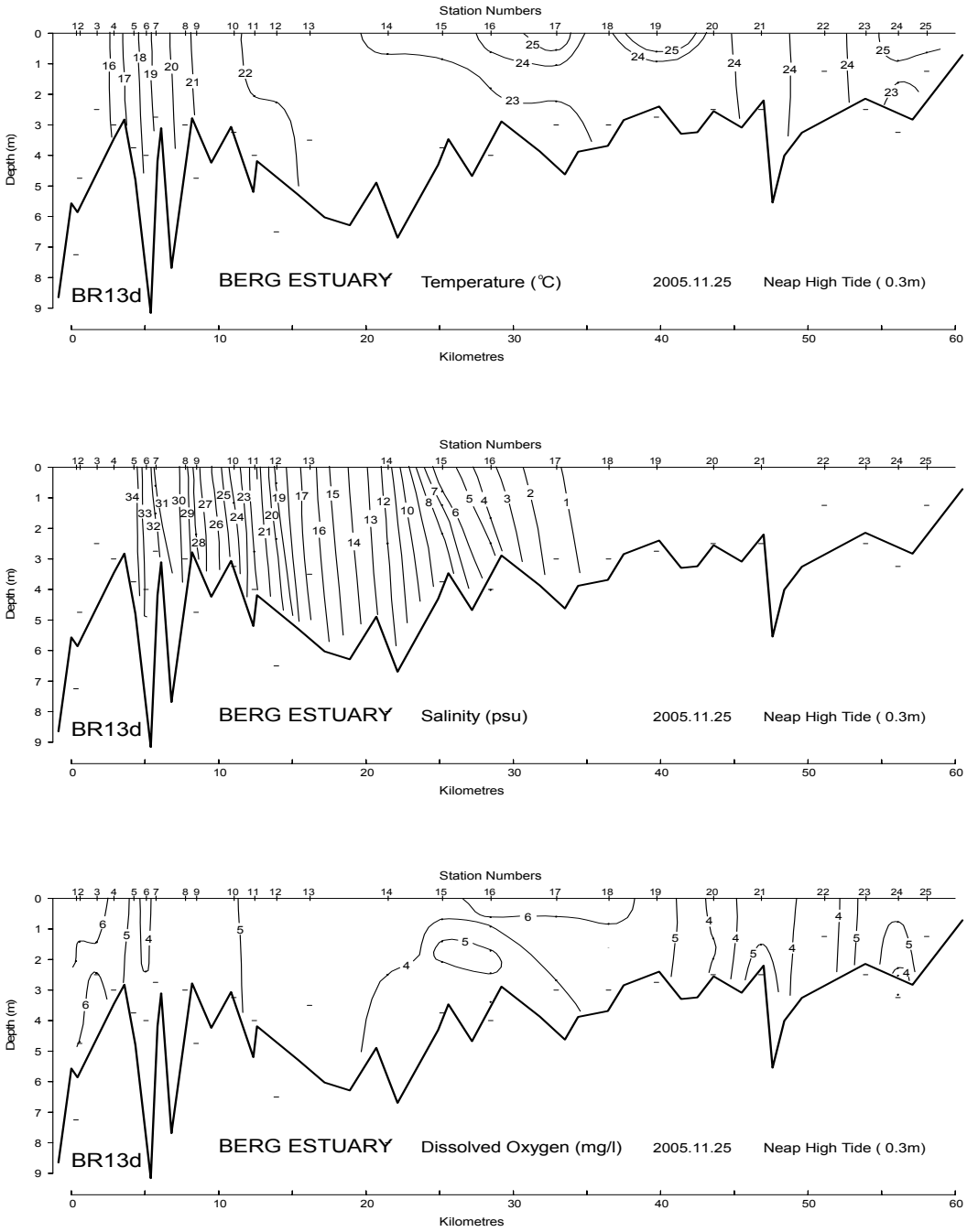


Figure A2.2.52 BR13d - NEAP HIGH – Nov 2005

APPENDIX 2.3

HISTORIC (1988-1995) WATER QUALITY BOAT SECTION DATA FOR THE BERG ESTUARY COLLECTED BY THE CSIR

A certain amount of historic water quality data for the Berg estuary was supplied by the CSIR from a measurement programme carried out on the Berg estuary from 1989 to 1995. There were 22 sections measured on 18 different days, with a boat stopping at specified stations and measuring depth profiles of particular variables. Temperature and salinity profiles were measured, while DO and pH were measured only at the surface and bottom, and in many instances only at the surface. Selected sections were chosen for more detailed analysis, depending on the sequence in which they were measured, the number of stations covered and the dates of other sections. These sections are indicated in Table 2.3.1.

Table A2.3.1 Details of data available from the CSIR. Abbreviations denote the following: T- temperature, S- salinity, and DO- dissolved oxygen. For the data used in these analyses the date of the closest lunar state is given (full, new, first quarter, last quarter), with the appropriate tide at the time of measurement (SH: spring high, SL: spring low, NH: neap high, NL: neap low). The sections labelled A to K under 'Sec' are discussed in the text.

Date	Sec	Variable	Start to End	Moon	Tide	Stations
1989.09.17		T, S	15:18 to 16:35			1,2,4,5,7,8
1989.09.18	A	T, S	11:07 to 12:57	15	SL 10:49	9,8,7,6,5,4,3,2,1
1989.09.18	A	T,S,DO,pH	15:00 to 20:00	15	SH 17:08	1,2,3,4,5,6,7,8,9,10
1989.09.19		T,S,DO,pH	11:24 to 12:55			10,9,8,7,6
1989.09.19		T,S,DO,pH	14:30 to 15:15			1,2,5,3,4
1989.09.19	B	T, S	16:55 to 18:45	15	SH 17:50	1,2,3,4,5,6,7,8,9
1989.09.20		T, S	11:21 to 15:37			1989.09.19
1990.01.29		T,S,DO,pH	15:00 to 20:05			1,2,3,4,5,6,7,8,9,10,11,12,13
1990.01.30		T,S,DO,pH	09:41 to 14:00			13,12,11,10,9,8,7,6,5,4,3,2,1
1990.01.31	C	T, S	10:52 to 15:59	26	NL 12:27	19,18,17,16,15,14,13,12,10,9,8,6,4,2,1
1990.02.01	D	T, S	07:09 to 11:31	2	NH 06:54	1,2,4,6,8,10,12,9,13,14,15,16,17,18,19
1990.03.20	E	T, S	10:37 to 17:16	19	NH 09:21	1,2,4,6,8,9,10,12,13,14,15,16,17,18,19,20
1994.03.21	F	T, S	10:14 to 17:04	21	NH 09:48	1,2,4,5,6,7,8,9,10,11,12,13,14,15,16,18,17,19
1995.08.14	G	T, S	16:55 to 18:24	10	SH 17:48	1,2,3,4,5,6,7,8,9
1995.08.15		T, S, DO	17:23 to 18:48			1,2,4,5,6,9,8,7
1995.08.16		T, S	00:30 to 22:40			2,2,2,2,2,1,2,2,4,5,6,7,8,9,2,2,2,2,2,2,2,2
		DO	11:48 to 13:43			1,2,4,5,6,7,8,9
1995.08.17	H	T, S	08:56 to 09:58	18	NH 07:26	1,2,4,5,6,7,8,9
1995.08.17		T, S	14:53 to 15:30			1,2,4,5,6,9
1995.08.27	I	T, S, DO	14:30 to 15:55	26	SH 16:02	1,2,4,5,6,9
1996.02.05	J	T, S, DO	11:45 to 15:30	4	SL 09:55	1,2,4,5,6,7,8,9,10,11,12
1996.02.21		T, S, DO	12:13 to 18:29			16,12,11,10,9,8,6,7,6,5,4,2,1
1996.03.04	K	T, S, DO	11:00 to 16:45	5	SL 09:04	1,2,4,5,6,7,8,9,10,11,12
1996.02.04 to 02.22		T, S, DO	Time Series			Kliphoek

In order to put the measurements into context in terms of the seasonal nature of the Berg estuary, the times of the sections have been inserted on the Jantjiesfontein tide gauge and Misverstand stream flow graphs of the appropriate years - see Figure 2.3.1. There does not appear to be any system in the measurement times, with five sections during the normal river flood months of August and September (A, B, G, H, I), and six during the dry months of January, February and March (C, D, E, F, J, K). As expected, there is a close correlation between the stream flow and the tide gauge reading, with a short lag of a day or two in the response at Jantjiesfontein.

The salinity sections are the best in terms of determining the flushing effect of the winter freshwater spates. Consequently Figures 2.3.2 and 2.3.3 depict the salinity sections for each of the identified days in Table 2.3.1.

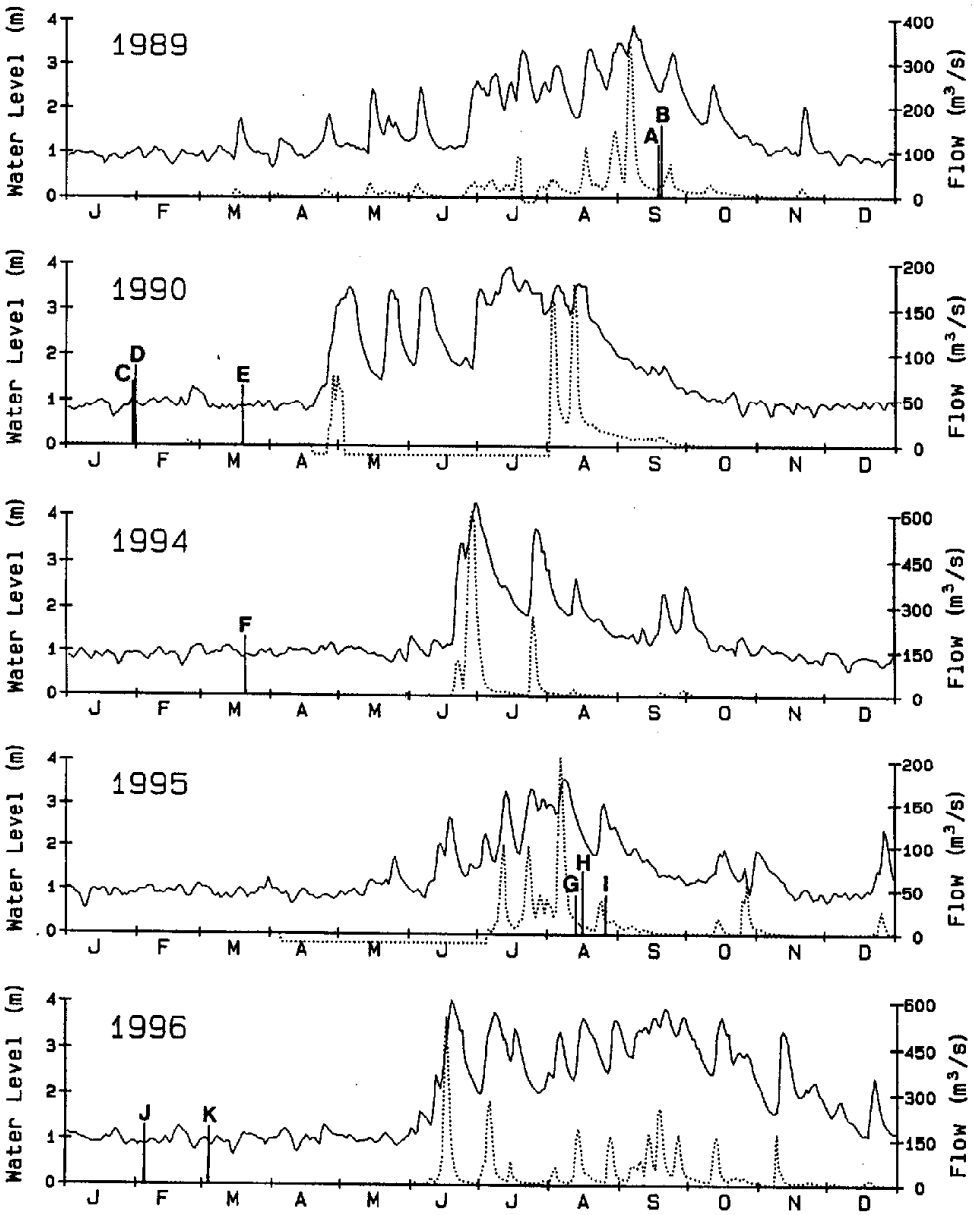


Figure A2.3.1 Measurements of water level made at Jantjiesfontein (solid line), and the stream flow measured at Misverstand (dotted line) over the years 1989, 1990, 1994, 1995 and 1996. The times at which the various sections were measured are also indicated (A to K). Note the different scales for the stream flow for the different years; where the dotted line is negative no measurements are available.

Figure A2.3.2 covers the sections A, B, G, H and I, i.e. the winter situations in 1989 and 1995.

Figure A2.3.1 shows that sections A and B were measured about 10 days after a spate which reached a peak flow of 354 m^3/s on 5 September, with 334 m^3/s recorded on 6 September.

Prior to the measurements there had been other substantial rainfalls in the catchment area, with three spates around or exceeding 100 × 10^6 m^3; Table 2.3.7 indicates that the total flow for 1989 was approximately average, i.e. 442 × 10^6 m^3 compared to an average of 435 × 10^6 m^3.

The sections on 18 and 19 September both indicate that the freshwater flow was sufficient to flush out most of the marine waters that were resident in the estuary, though it is important to note that there is no information on the effects of the previous spates, or to what extent marine waters had again intruded into the estuary in the days subsequent to the 5 and 6 September.

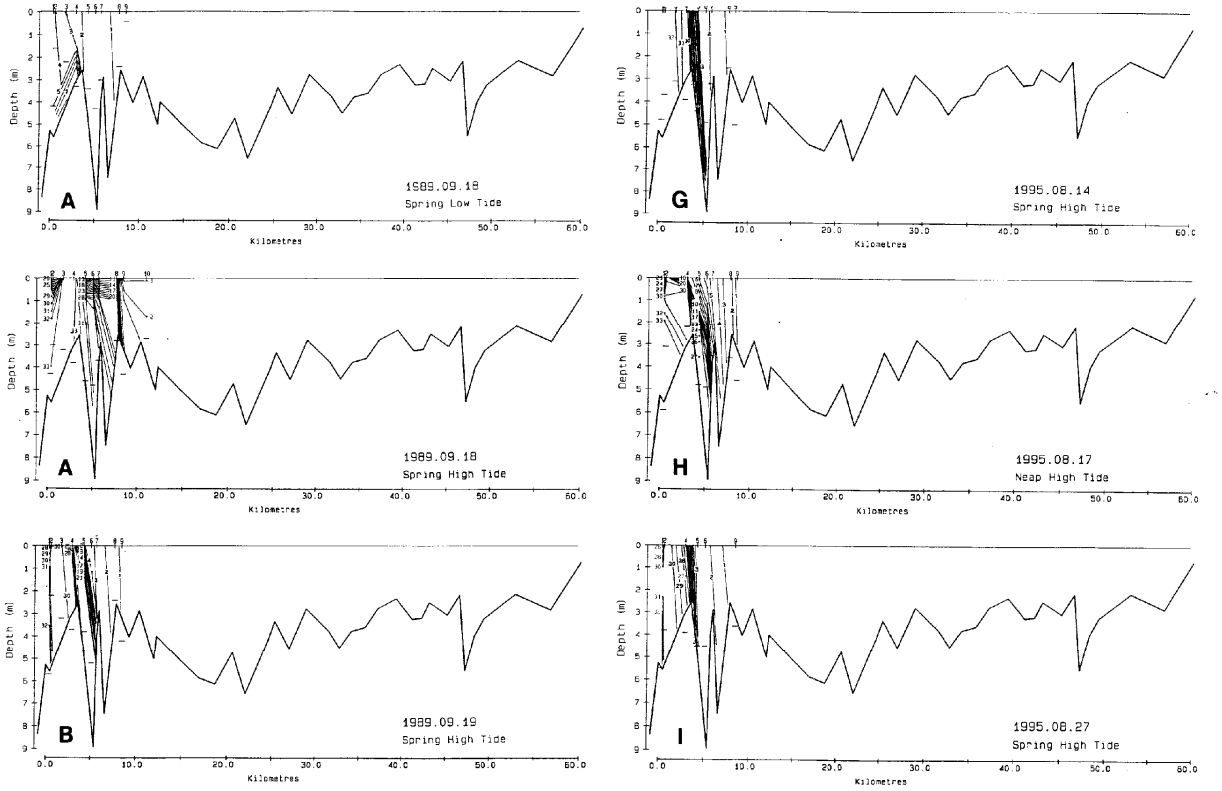


Figure A2.3.2 Salinity sections measured during the winter months (A,B,G,H,I). The station numbers where profiles were measured are given along the top, while the depth profile is that determined in the 2002 survey. The deepest measured depth on each station is indicated by a short horizontal line; often this does not agree with the depth profile, but is probably an indication of the variability in the estuary.

There is evidence of freshwater outflow in the surface layers on both days, though the peculiar structures on 18 September are probably due to the excessive time taken to measure the short section of 10 stations, namely 4½ hours.

The marked difference between flood and ebb tides is shown in the low tide section on 18 September, even though the stations were completed in the wrong order. Even at the mouth the measured salinity was no higher than 5, though there was some remnant deeper water at station 4, with a salinity higher than 8; Slinger and Taljaard (1994) speculate that this is due to the slower drainage of water from the Port Owen canals.

The measurements in 1995 (G and H) were taken after a spate on 6 August, which reached a maximum daily flow of 205 m^3/s, tailing off on 7 August to 170 m^3/s. The sections G and H, taken approximately at spring and neap high tides show that the freshwater spate had essentially flushed out the marine waters. Unfortunately there were no measurements during ebb flow, which on the evidence above would probably show the marine waters right out of the estuary mouth.

The neap high tide section on 17 August shows a greater intrusion of marine waters, even with the smaller tide, indicating the effect of reduced freshwater flow.

A further freshwater spate occurred on 24 August, when a flow of about 39 m^3/s was recorded. The spring high tide section measured on 27 August shows that this flow was sufficient to again drive out the marine water to the same extent as on 14 August.

Unfortunately, because of a loss of data in April, May and June, it is not known how the total freshwater inflow for 1995 compares to the long term average. Consequently, it cannot be stated with certainty that the three spates in July and August were sufficient in themselves to flush out the marine water.
Figure A2.3.3 shows salinity sections measured during the dry months, with little freshwater inflow recorded. Sections C and D were measured approximately at neap low tide and neap high tide, and again show the difference between the ebb and flood conditions. At the mouth the inflow of seawater extends to around station 13, with little impact higher upstream. In particular, the position of the 1 isohaline is little changed.

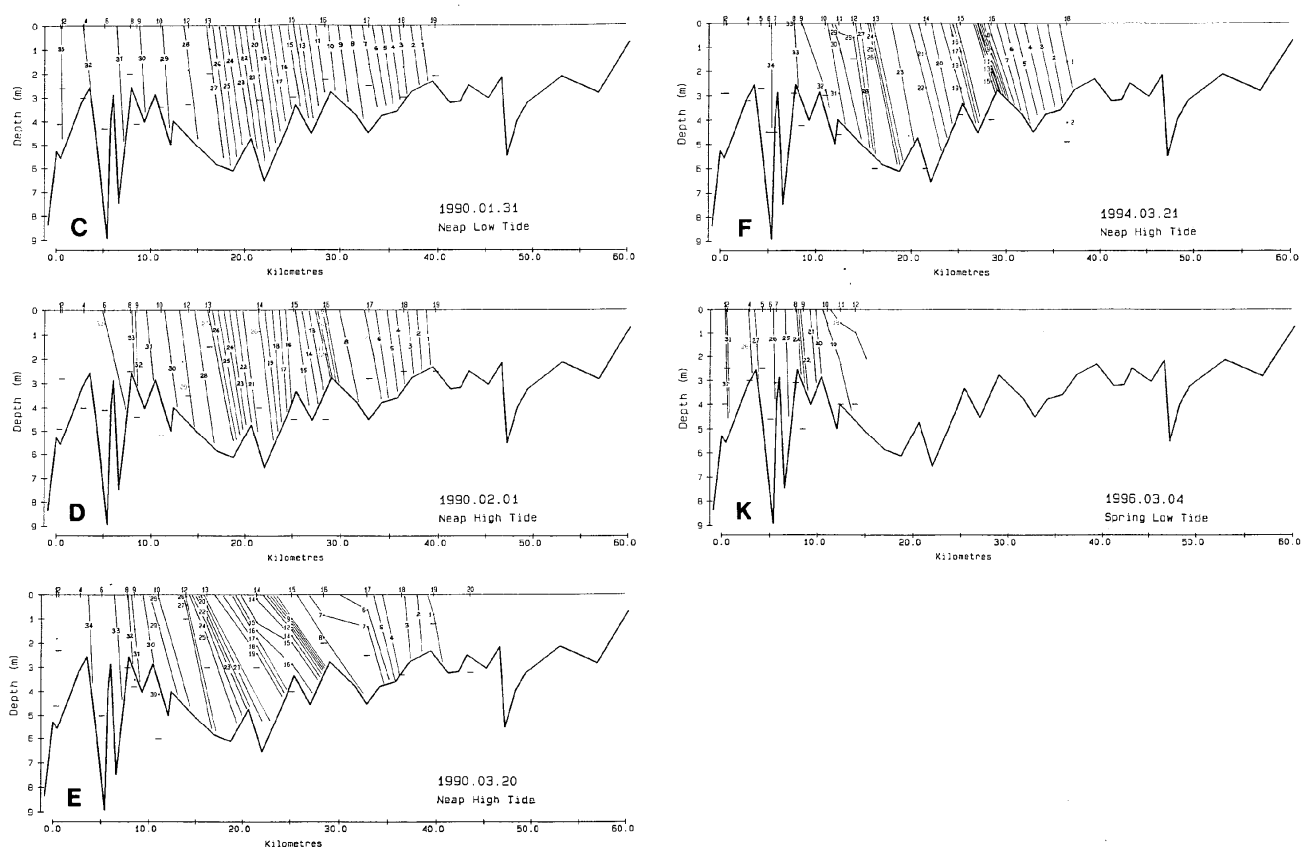


Figure A2.3.3 Salinity sections measured during the summer months (C,D,E,F,K). Details are as for Figure 2.3.11.

Section E, almost fifty days later shows that the 1 isohaline has progressed slightly farther upstream, beyond station 19. The significance is not clear, particularly since the isohalines around station 16 are farther downstream, and the surface waters appear fresher. There are no freshwater spates indicated, though there may have been local rainfall.

Section F, at about the same time in 1994, shows a similar structure to that in 1990, though the upstream position of the 1 isohaline was only at station 18.

Sections J and K have very similar structures, and only the later section K is shown; unfortunately measurements only extended to station 12.

Water temperature is not a conservative quantity, and is influenced substantially by the air temperatures presented in Figure A2.3.3.

It can therefore be expected that the most marked temperature structures will occur in summer when the much warmer river water meets the colder seawater. Selected temperature sections are shown in Figure A2.3.4.

Because of the apparent emphasis on salinity, none of the winter sections extend beyond station 10, and the temperature on section A is shown as representative of these conditions. There is an indication of increasing temperatures upstream, and possibly some diurnal heating in the surface layers.

In the summer period, sections C and F are shown here as examples of the conditions at this time. In both cases warmer water enters from the river side, with diurnal heating also affecting water resident in the area for some time. Section C extends the farthest upstream, and of interest is the apparent inversion situation at stations 15 and 16.

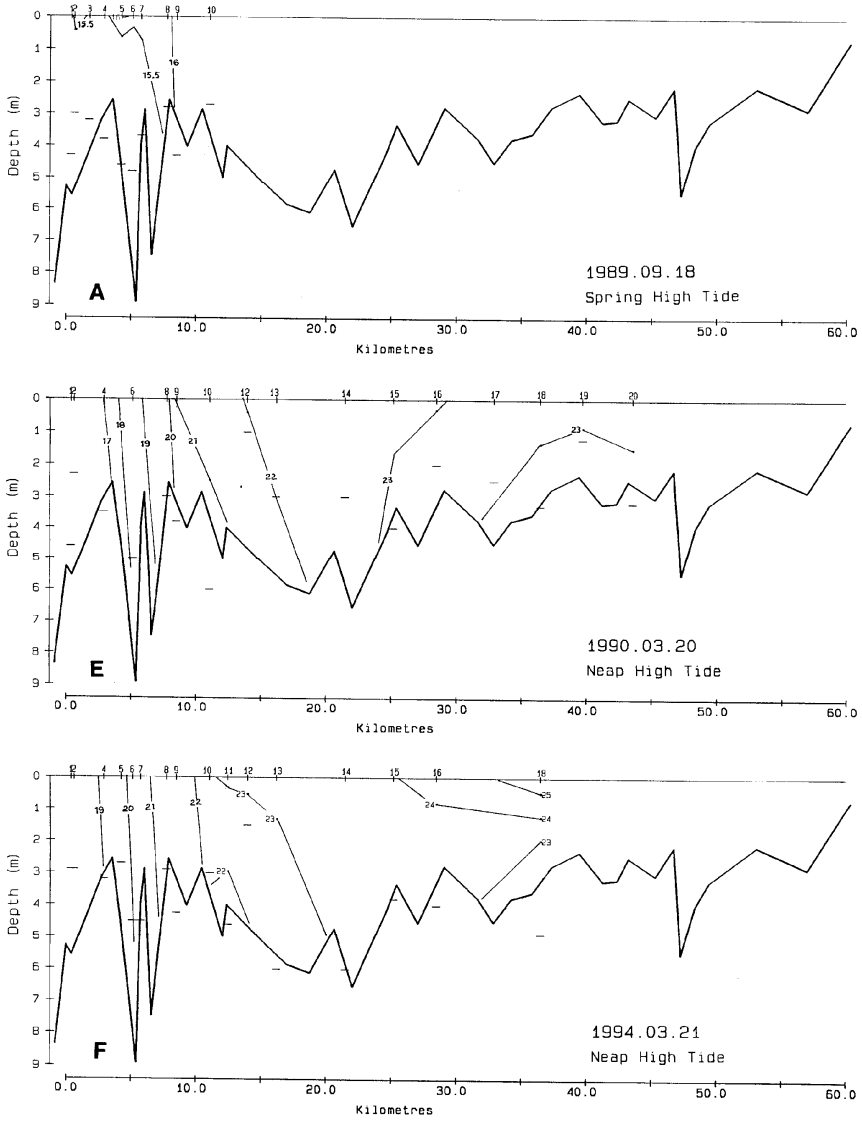


Figure A2.3.4 Temperature sections measured during the winter months (A), and during the summer months (E,F).

As indicated already, there are a limited number of DO and pH measurements. Results from the Gamtoos estuary (Pearce and Schumann, 2003) show that vertical stratification can result in low DO values at the bottom, particularly if rotting vegetation is present. The temperature and salinity structures in the Berg estuary indicate that the water column was well-mixed both in the winter and summer conditions, and correspondingly the pH and DO values differed little at the surface and bottom.

Table A2.3.2 provides surface and bottom values of DO and pH in all the sections where these variables were measured. The lowest values of DO occurred in 1996.03.04, and it is not clear why this happened, since temperatures were generally less than those in the section measured on 1994.13.21 (F).

Table A2.3.2 Maximum and minimum values of DO and pH measured on all the stations on the given dates.

Section Date	Top DO (mg/l) Max / min	Bottom DO (mg/l) max / min	Top pH max /min	Bottom pH max /min
1989.09.18	7.7 / 5.4	6.8 / 5.9	7.8 / 7.5	7.8 / 7.45
1989.09.19	7.8 / 7.0	7.7 / 6.1	7.8 / 7.35	7.8 / 7.4
1990.01.29	8.6 / 6.9	8.4 / 6.2	8.0 / 7.8	8.1 / 7.7
1990.01.30	7.0 / 5.4	6.7 / 5.1	8.0 / 7.7	7.9 / 7.7
1995.08.15	8.1 / 5.5			
1995.08.16	7.8 / 6.8	7.6 / 5.5		
1995.08.27	8.3 / 7.1			
1996.02.05	6.8 / 5.3	7.0 / 5.1		
1996.02.21	9.0 / 5.1	7.4 / 5.4		
1996.03.04	6.2 / 3.5	5.4 / 3.8		

APPENDIX 3

APPENDIX 3.1

1. INTRODUCTORY NOTES

The rationale behind the choice of transect location and reasons for annual deviations are summarised in Table 7.2. Full assessments of changes to transects presented below could only be done for transects that were formerly surveyed on an annual basis, while the rest are limited by this lack of the spatial change element.

Transects 1 — 19 were surveyed using a D-GPS in 2003.
Transects 3, 5, 7, 20, 21 and 22 were surveyed traditionally and geo-referenced in 2004.
Transects 3, 5, 6, 7, 20, 21, 22 and 25 were surveyed traditionally and georeferenced in 2005.
Transects were sampled during the following periods: 10-20 February 2003, 8-12 March 2004, 14-19 April 2005.

2. TRANSECT 1 (BLIND LAGOON)

This transect is located on the seaward edge of the Blind Lagoon along the route to the old natural mouth of the Berg River (Figures 7.1 & Figure A3.1.1).

Based on the coefficients of similarity of Jaccard and Sorenson, samples A and B remained unchanged in species complement during the monitoring period. The average similarity between samples along the whole transect over the three years is moderate (Table A3.1.1).

Table A3.1.1 The average similarity of samples between years on Transect 1 using Jaccard and Sorenson's Coefficients

Transect 1	No.of records	Ave Similarity 2003-04	Ave Similarity 2004-05	Ave Similarity 2003-05
Jaccard Similarity Co-efficient %	4, 5, 4	79%	67%	71%
Sorenson's Similarity Co-efficient %	4, 5, 4	87%	77%	79%

The following dominant communities (Table 7.1) were recorded at this site in the samples indicated:

1. *Zostera capensis* Aquatic beds (Inundated Mudflats) (sample A)
2. *Sarcocornia pillansii* Dwarf Succulent Shrubland (Floodplain) (sample D)
3. *Sarcocornia perennis* Saltmarsh (Sedge Marsh and Halophytic Saltmarsh)
   - 3.1 *Bassia diffusa-Sarcocornia perennis* Dwarf Shrubland typicum (Halophytic Saltmarsh) (sample B)
   - 3.2 *Limonium depauperatum-Triglochin striata* Herbland (Halophytic Saltmarsh) (sample C)
4. Sand Strandveld
   - 4.1 *Chrysanthemoides incana-Lycium ferocissimum* Alluvium Strandveld (Strandveld) (sample E)

The transect vegetation is illustrated in Figure 7.17. Samples C and D are mixed communities. *Bassia diffusa* was recorded in the most samples (six samples out of a potential 16), followed by *Atriplex cinerea* and *Sarcocornia perennis* in five samples each.

Four incidental species were recorded on a single occasion over the monitoring period. Sample E was the richest sample with seven species out of a potential 20 recorded along the transect (Table A3.1.2).

No record was taken of the adjacent dune vegetation in 2003. This was recorded in sample E in the succeeding years. Sample D1 is a downward movement of the dune E. It is intermingled with remnants of D1. The spring high tide wet up to the upslope end of C during monitoring in 2005.

Subjective comparison to O'Callaghan's (1994a) data collected close to this transect in 1 x 1 m sample plots shows the following differences from his data: O'Callaghan recorded eight species (Table A3.1.3) while 20 species were recorded in the present survey. Sampling method or environmental changes can result in changes to species richness, although, in this instance, one difference can be attributed to sampling the terrestrial edge in the current survey, which was not sampled by O'Callaghan. The disappearance of *Spartina maritima* could be attributed to a reduction in current strength as the blind lagoon is in the process of filling in following closure of the natural mouth that used to be located at the southern end of the Blind Lagoon.

Table A3.1.2 Floristic data recorded on Transect 1

Estuary Transect 1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Profile unit	A	A	A	B	B	B	C	C	C	D	D	D1	D2	E	E	E			
Year	2003	2004	2005	2003	2004	2005	2003	2004	2005	2003	2004	2005	2005	2003	2004	2005			
1. Jaccard Similarity Co-efficient %. Present year compared to previous year		100%	100%		100%	100%		60%	40%		57%	57%				40%			
2. Sorenson's Similarity Co-efficient %. Present year compared to previous year.		100%	100%		100%	100%		75%	57%		73%	73%				57%			
3. Jaccard Similarity Co-efficient %. Year 2005 compared to 2003.			100%			100%			40%			43%							
4. Sorenson's Similarity Co-efficient %. Year 2005 compared to 2003.			100%			100%			57%			60%							
Number of taxa of potential 20 in sample	**1**	**1**	**1**	**3**	**3**	**3**	**4**	**4**	**3**	**5**	**6**	**5**	**4**	**0**	**7**	**7**	**No. of records**		
Atriplex cinerea Poir.										+	+	+	1		2		5		
Bassia diffusa (Thunb.) Kuntze							4	4	3		3	3			+		6		
Carpobrotus edulis (L.) L.Bolus																R	1		
Chrysanthemoides monilifera (L.) Norl.																+	1		
Cladoraphis cyperoides (Thunb.) S.M. Phillips													+		3	3	3		
Cotula coronopifolia L.				2	2	1											3		
Disphyma crassifolium (L.) L.Bolus										+	2	3	R				4		
Felicia hyssopifolia (Berg.) Nees															+	1	2		
Helichrysum asperum (Thunb.) Hilliard																+	1		
Limonium depauperatum (Boiss.) R.A.Dyer							1	1				+					3		
Mesembryanthemum crystallinum L.										R							1		
Odyssea paucinervis (Nees) Stapf							2	1									2		
Ruschia sp.											+		+		R	R	4		
Sarcocornia perennis (Mill.) A.J.Scott				5	5	5		4	4								5		
Spergularia media (L.) C.Presl ex Griseb.										+	3	3					3		
Suaeda inflata Aellen										1	+				+		3		
Trachyandra divaricata (Jacq.) Kunth															1	1	2		
Triglochin bulbosa L.				1	+	1											3		
Triglochin striata Ruiz & Pav.							+		+								2		
Zostera capensis Setch.	3	4	4														3		

Table A3.1.3 O'Callaghan Transect B1 (Date for 5 March 1987)

Sample ID	A	C	D	E	F	I	J	K	L	M	N	O	P	Q	R	T	U	V	
Sample distance along Transect	0-1	11-12	12-13	13-14	14-15	18-19	19-20	20-21	21-22	22-23	23-24	24-25	25-26	26-27	27-28	29-30	30-31	31-32	
Present study community group (closest similarity)	A	A	A			B	B	B	B	C	C	C	C	C	C	C	C	C	
Number of taxa of potential 8 in sample =	**1**	**2**	**2**	**1**	**1**	**4**	**4**	**4**	**4**	**5**	**5**	**6**	**6**	**5**	**5**	**3**	**3**	**2**	**No. of records**
Bassia diffusa (Thunb.) Kuntze						1	+	+	+	+	+	1	2	3	3	3	5	4	13
Limonium depauperatum (Boiss) R.A. Dyer										1	1	R							3
Sarcocomia perennis (Mill.) A.J. Scott						5	5	5	3	1	1	1	2						8
Sarcocomia pillansil x S perennis												+	1	5	4	2	+		6
Spartina maritima (Curtis) Fernald		+	2	2	+	+	+	+	1	+	+	+	+	+	+				14
Sporobolus virginicus (L.) Kunth													R	+	+	2	+	2	6
Triglochin bulbosa L.						2	3	3	4	4	4	2	2	1	R				10
Szostera capensis Setch.	4	5	1																3



Figure A3.1.1 The Blind Lagoon at Transect 1 as recorded on 18 April 2005. Note the distinctive grey banding formed by the dominant halophytic dwarf succulent Bassia diffusa. The mobile dunes in the foreground are invading the saltmarsh vegetation.

3. TRANSECT 2 (BLIND LAGOON)

This transect is located at the south-eastern end of the Blind Lagoon along the shores of the previous natural mouth of the Berg River (Figures 7.1 & Figure A3.1.2).

Based on the coefficients of similarity of Jaccard and Sorenson, samples B & F (2004-2005) and A (2003-2005) remained unchanged in species complement during the monitoring period.

Generally samples 2004-2005 were very similar to each other in species composition (Table A3.1.4).

Table A3.1.4 The average similarity of samples between years on Transect 2 using Jaccard and Sorenson's Coefficients

Transect 2	No. of records	Average Similirity 2003-04	Average Similarity 2004-05	Average Similarity 2003-2005
Jaccard Similarity Co-eficient %	6	49%	85%	58%
Sorenson's Similarity Co-effient %	6	65%	91%	71%

The following dominant communities (Table 7.1) were recorded at this site in the samples indicated:

1. *Zostera capensis* Aquatic beds (Inundated Mudflats) (sample A)
2. *Sarcocornia pillansii* Dwarf Succulent Shrubland (Floodplain)
   - *2.1 Sarcocornia pillansii* Dwarf Shrubland (Xeric Floodplain) (samples D & E)
3. *Sarcocornia perennis* Saltmarsh (Sedge Marsh and Halophytic Saltmarsh)
   - *3.1 Bassia diffusa-Sarcocornia perennis* Dwarf Shrubland typicum (Halophytic Saltmarsh) (sample B)
   - *3.2 Limonium depauperatum-Triglochin striata* Herbland (Halophytic Saltmarsh) (sample C)
   - *3.3 Salicornia meyeriana-Triglochin bulbosa* Dwarf Shrubland (Open pan) (sample D)
   - *3.4 Odyssea paucinervis-Sarcocornia perennis* Grassland (Halophytic Marsh) (sample C)
4. Sand Strandveld
   - *4.1 Nylandtia spinosa--Cladoraphis cyperoides* Grassy Flats Strandveld (Strandveld) (sample F)

The transect vegetation is illustrated in Figure A3.1.2. *Odyssea paucinervis* was recorded in the most samples (10 out of a potential 18), followed by *Sarcocornia perennis* in eight and *Bassia diffusa* in seven samples respectively. One incidental species were recorded on a single occasion over the monitoring period. Sample E (2004) was the richest sample with 10 species out of a potential 23 in it (Table A3.1.5).

Notable changes in cover and density of the important species, *Bassia diffusa, Sarcocornia perennis* and *Salicornia meyeriana* has occurred in samples B, C and D respectively. This is indicative of environmental change at these stands which is probably related to the saltmarsh being inundated by tides at a lower frequency following generally lower water levels in the river in the last two monitoring periods (Figure A3.1.3).

Subjective comparison to O'Callaghan's (1994a) data collected close to this transect shows reatively little difference except for the following differences from his plot data: O'Callaghan recorded 15 species (Table A3.1.6) while 23 species were recorded in the present survey. The present study included the edge of terrestrial vegetation which was not sampled by O'Callaghan (1994a). *Carpobrotus acinaciformis* and *C. edulis* could be attributed to mistaken field identification due to non-flowering material being present during the survey period. *Sporobolus virginicus* is probably a misidentification of *Odyssea paucinervis.*

The hybrids between *Sarcocornia pillansii* and *S.perennis* were not recorded in the current study. The absence of *Zostera* in the O'Callaghan data is probably a seasonal effect.

Table A3.1.5 Floristic data recorded on Transect 2

Estuary Transect 2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	
Sample No.	A	A	A	B	B	B	C	C	C	D	D	D	E	E	E	F	F	F	
Year	2003	2004	2005	2003	2004	2005	2003	2004	2005	2003	2004	2005	2003	2004	2005	2003	2004	2005	
1. Jaccard Similarity Co-efficient %. Present year compared to previous year		50%	50%		75%	100%		38%	83%		50%	86%		40%	90%		43%	100%	
2. Sorenson's Similarity Co-efficient %. Present year compared to previous year.		67%	67%		86%	100%		55%	91%		67%	92%		57%	95%		60%	100%	
3. Jaccard Similarity Co-efficient %. Year 2005 compared to 2003.			100%			75%			50%			38%			40%			43%	
4. Sorenson's Similarity Co-efficient %. Year 2005 compared to 2003.			100%			86%			67%			55%			57%			60%	
Number of taxa of potential 23 in sample	**1**	**2**	**1**	**3**	**4**	**4**	**6**	**5**	**6**	**5**	**7**	**6**	**5**	**10**	**9**	**4**	**6**	**6**	**No. of records**
Algae	1	3	3																3
Atriplex cinerea Poir.													2	2	2				3
Bassia diffusa (Thunb.) Kuntze							2	2	2	+	3	4		+					7
Carpobrotus edulis (L.) L.Bolus																	R	+	2
Cladoraphis cyperoides (Thunb.) S.M. Phillips																	+	+	2
Cotula coronopifolia L.				2	2	R													3
Disphyma crassifolium (L.) L.Bolus										2	2	2		2	3				5
Ehrharta villosa Schult.f. var. villosa														R	R	2	2	2	5
Limonium depauperatum (Boiss.) R.A.Dyer							1	1	+		1	1							5
Lycium cinereum Thunb. sensu lato													+	1	+				3
Mesembryanthemum crystallinum L.													+	+	1				3
Moquiniella rubra (A.Spreng.) Balle														+	+				2
Nylandtia spinosa (L.) Dumort.																2	2	1	3
Odyssea paucinervis (Nees) Stapf					R	R		2	1		1	1		1	2		3	3	10
Ruschia subpaniculata L. Bolus																2	2	2	3
Salicornia meyeriana Moss								R	R	2	2								4
Sarcocornia perennis (Mill.) A.J.Scott				5	5	5	2	3	5		2	2							8
Sarcocornia pillansii (Moss) A.J.Scott													2	2	1				3
Spergularia media (L.) C.Presl ex Griseb.							1			3			3			4			4
Suaeda inflata Aellen							R			2	2	3		+	+				6
Triglochin bulbosa L.							2		1										2
Triglochin striata Ruiz & Pav.				1	1	+													3
Zostera capensis Setch.		R																	1

Table A3.1.6 O'Callaghan Transect B2 (Transect 2 this study) (Data for 5 March 1987)

Sample ID	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	
Sample distance along transect	34-35	35-36	36-37	37-38	38-39	39-40	40-41	41-42	44-45	45-46	46-47	47-48	48-49	49-50	50-51	51-52	52-53	53-54	54-55	55-56	56-57	57-58	58-59	59-60	60-61	61-62	
Present study community group (closest similarity)	B	B	B	B	B	B	C	C	C	C	C	C	C	C	C	C	D	D	D	D	D	E	E	E	E	F	
Number of taxa of potential 15 in sample =	1	1	2	2	3	4	6	6	6	4	5	4	5	5	7	6	6	7	5	4	3	4	4	4	3	2	No. records
Atriplex cinerea Poir.																								+	1		2
Bassia diffusa (Thunb.) Kuntze								+	+		R	R	+	1	1	1	+	1	1	1		+					13
Carpobrotus acinaciformis (L.) L.Bol.																					+					1	2
Cotula coronopifolia L.					+	1	1	1	+																		5
Disphyma crassifolium (L.) L.Bolus																	R	1	+	+	1	2					6
Limonium depauperatum (Boiss.) R.A.Dyer							+	1	1	1	2	2	1	1	1	+		R									11
Mesembryanthemum crystallinum L.																						+	+				2
Salicornia meyeriana Moss							+		+	+	2	1	2	2	1	+	1	1	+								12
Sarcocornia perennis (Mill.) A.J.Scott	3	5	5	1	4	2	5	4	4	4	2	1	1	1	+	+	1										17
Sarcocornia pillansii (Moss) A.J.Scott																						1	2	+	2		4
Sarcocornia pillansii x S.perennis																			+								1
Spergularia media (L.) C.Presl ex Griseb															+	+	+	+	+	+			1				7
Sporobolus virginicus (L.) Kunth															+	1	2	1	+	+	+	+	+	+	1	1	12
Triglochin bulbosa L.							+	1	1	1	1	1	+	+	+												9
Triglochin striata Ruiz & Pav.				4	+	1	+	1	+																		6



Figure A3.1.2 Saltmarsh vegetation along Transect 2 exposed during spring low tide on 10 February 2003.



Figure A3.1.3 Transect 2 inundated at spring high tide on 17 February 2003. The saltmarsh is wetted by seawater to the top of community E.

4. TRANSECT 3 (CEREBOS SALTWORKS)

This transect is located through the saltmarsh on the left (south) bank immediately downstream of the Carinus Bridge extending from the artificial saltworks dam wall bordering on the saltmarsh to the river channel (Figures 7.2 & Figure A3.1.4).

The average similarity of samples was 76% or 85% between 2003 and 2004 respectively using the Jaccard and Sorenson's Similarity Coefficients, 45% or 60% between 2004 and 2005 and 49% or 64% between 2003 and 2005 (Table A3.1.7). This shows a relatively low level of year to year change.

Table A3.1.7 The average similarity of samples between years on Transect 3 using Jaccard and Sorenson's Coefficients

Estuary Transect 3

	No. of records	Average similarity 2003-04	Average similarity 2004 – 05	Average similarity 2003 - 05
Jaccard similarity co-efficient %. Present year compared to previous year.	20, 8, 9	76%	45%	49%
Sorenson's similarity co-efficient %. Present year compared to previous year.	21, 8, 9	85%	60%	64%

Sampling along the transect revealed a total number of 11 plant species.

Extensive reductions in densities of *Salicornia meyeriana* occurred, for example, in samples A (3 in 2003 to '+' in 2005); C, D & O (1 in 2003 to absent in 2005); L & W (2 in 2003 to absent in 2005); X (3 in 2003 to absent in 2005). The changes in *Salicornia* can be due to it being short-lived exhibiting typical deaths as a reaction to drought years when salinity levels increase. A lack of spring high inundation, that reduces hypersalinity levels by flushing the salt build-up, would also contribute significantly to these deaths (see Boucher & Jones - BRBMP Vol 3 Ch 7 - for the inundation profile graph for Site 76 in this saltmarsh depicting wet versus dry periods). This salt build-up is particularly high along the outer foot of the saltworks dams from leakage of concentrated saline solutions through the wall and of droplets being blown over the wall from breaking waves in the saltdams. The soils exhibit typical high salinity friable texture when dry and change to a thick mud-like layer when wet.

The process of channels through a saltmarsh filling-in over time is evident in sample 3Z. This process starts with the channel sides collapsing and fill material accumulating in the channel. Later only a series of holes covered by vegetation mark the old route until it disappears totally.

Sometimes it was not possible or feasible to distinguish communities so they were subsequently (in the following year or two) lumped as one unit or split when they could be distinguished.

The following dominant communities recorded at this site all form part of the mosaic of stands forming the *Sarcocornia perennis* Saltmarsh (Chapter 7.3, Table 7.1):

3. *Sarcocornia perennis* Saltmarsh (Sedge Marsh and Halophytic Saltmarsh)

- *3.1* *Limonium depauperatum-Triglochin striata* Herbland (Halophytic Saltmarsh) (samples C – I)
- *3.2* *Salicornia meyeriana-Triglochin bulbosa* Dwarf Shrubland (Open pan) (samples A, C, D, F, G, L, M, W & X)
- *3.3* *Sporobolus virginicus-Sarcocornia perennis* Grassland (Sedge Marsh) (sample W)
- *3.4* *Juncus kraussii-Sarcocornia perennis* Sedgeland (Sedge Marsh) (samples D, H, S – U)

The transect vegetation community distributions a illustrated in Figure A3.1.5. *Sarcocornia perennis* (96%, 54 out of a potential 56), *Bassia diffusa* (79%, 44), *Triglochin striata* (73%, 41) were recorded most regularly in samples over the three years. Two incidental species were only recorded on a single occasion. Samples H (2003) and I (2005), with seven species, were the richest samples with the greatest number of species in them. Samples H – J and W — Y of 2003 were not distinguishable in the field as separate units in 2004 and information for these units is presented in samples H and W respectively in Table A3.1.8. Samples I — Y of 2005 were indistinguishable and are presented as I in Table 3.1.8. An unvegetated open water pan occurs between samples A and B (Figure A3.1.4). Sample B increased dramatically in species richness in 2005 with very low similarity in constituent species to the previous years. Seven samples, namely, A (2004), B (2004), C (2004), D (2004), G (2004), M (2004) and O (2004) were unchanged from the previous year in species content although not necessarily in the cover of the constituent species.

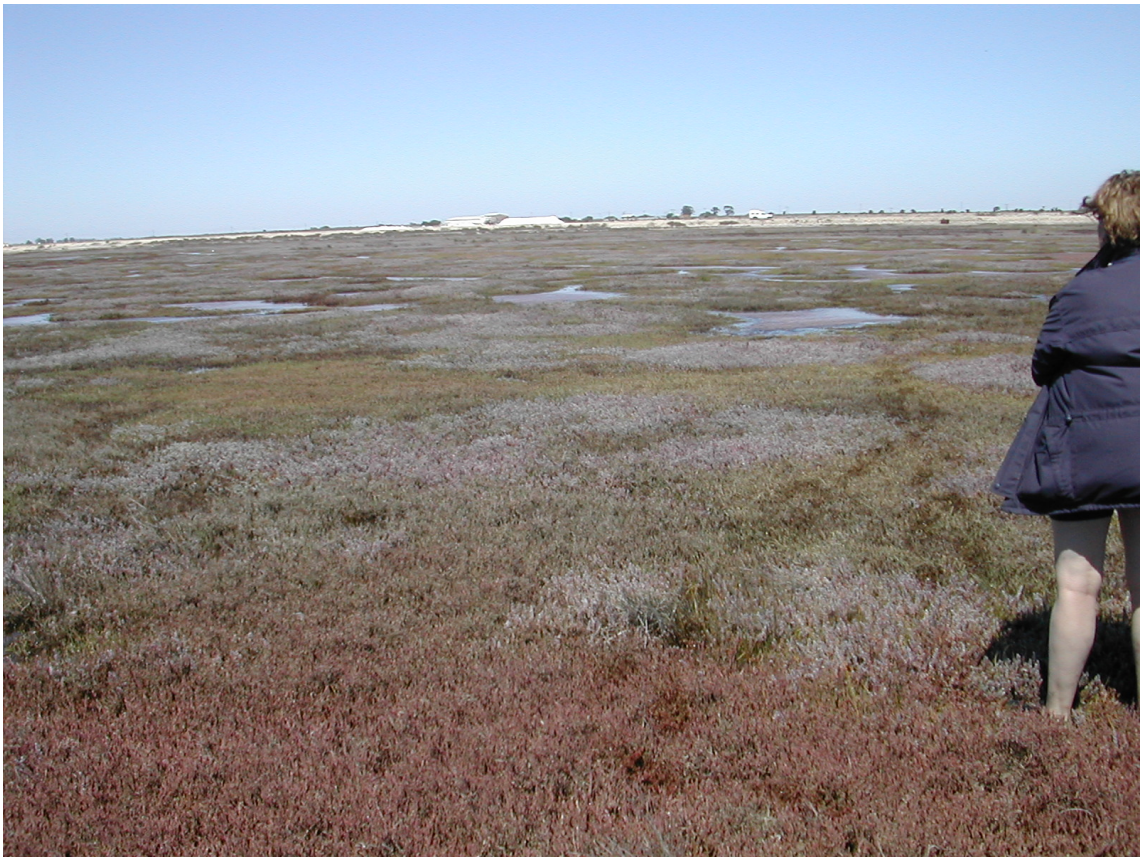


Figure A3.1.4 Transect 3 with a vehicle on the Cerebos saltworks dam wall in the distance. Note the residual pools on 9 March 2004 after a high tide.

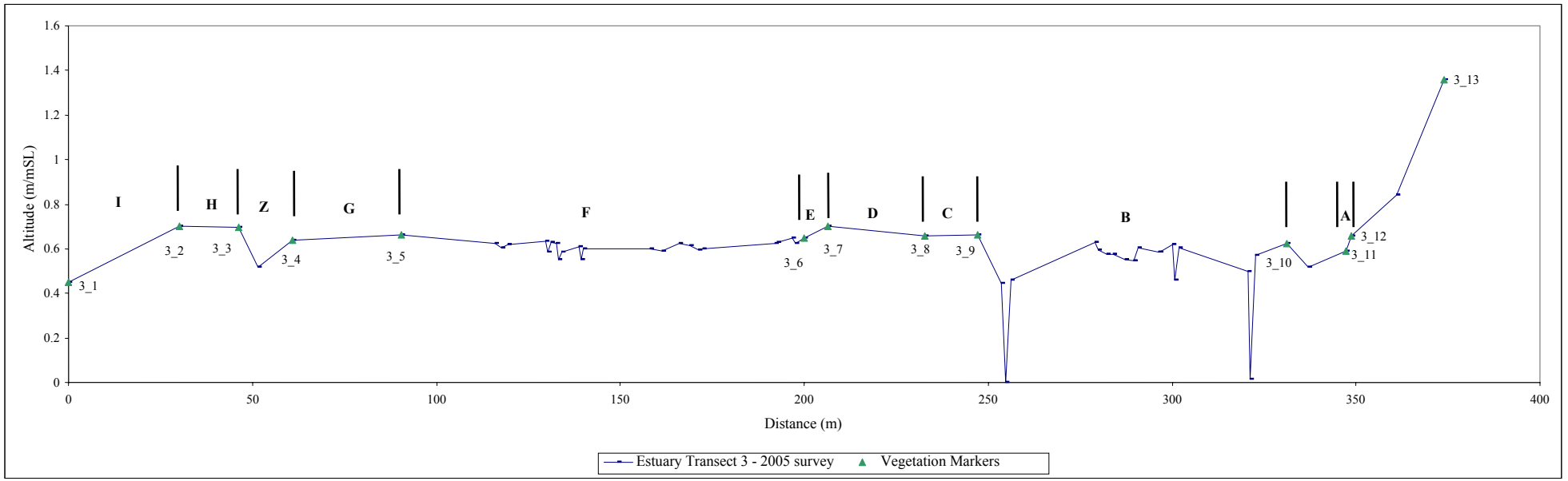


Figure A3.1.5 Cross-section profile of Transect 3 for 2005. Letters of the alphabet identify plant communities as numbered in Table A3.1.8.

Table A3.1.8 Floristic data recorded on Transect 3

| Estuary Transect 3 | 3 | 3 |

5. TRANSECT 4 (DIE PLAAT)

This transect is located on the right bank immediately downstream of the Sishen-Saldanha railway bridge (Figure 7.2).

Based on the coefficients of similarity of Jaccard and Sorenson, samples A to I over all the years and J (2003-2005) remained unchanged in species complement during the monitoring period. This contributed to exceptionally high similarity values exhibited in Table A3.1.9.

Table A3.1.9 The average similarity of samples between years on Transect 4 using Jaccard and Sorenson's Co-efficients

	Estuary Transect 4			
	No. of records	**Average similarity 2003-04**	**Average similarity 2004 – 05**	**Average similarity 2003 - 05**
Jaccard similarity co-efficient %.	13	89%	92%	90%
Sorenson's similarity co-efficient %.	13	93%	95%	93%

The transect vegetation is illustrated in Figure A3.16. The following dominant communities (Boucher & Jones - BRBMP Vol 3 Ch 7, Table 7.1) were recorded at this site in the samples indicated:

1. *Sarcocornia pillansii* Dwarf Succulent Shrubland (Floodplain)
   - 1.1 *Sarcocornia pillansii* Dwarf Shrubland (Xeric Floodplain) (samples L & M)
2. *Sarcocornia perennis* Saltmarsh (Sedge Marsh and Halophytic Saltmarsh)
   - 2.1 *Sporobolus virginicus-Sarcocornia perennis* Grassland (Sedge Marsh) (sample K)
   - 2.2 *Juncus kraussii-Sarcocornia perennis* Sedgeland (Sedge Marsh) (sample J)
3. *Schoenoplectus scirpoideus* Sedgeland (Short Reed Marsh) (samples A, B, D-H, I)
4. *Phragmites australis* Reedland (Reed Marsh)
   - 4.1 *Phragmites australis* Reedbed typicum (Tall Reed Marsh) (sample B-D, H)

Schoenoplectus scirpoideus was recorded in the most samples (29 samples out of a potential 39), followed by *Sarcocornia perennis* (18 samples) and *Phragmites australis* (12 samples). Eight incidental species were recorded on a single occasion over the monitoring period. Sample K was the richest sample with 12 species out of a potential 32 recorded along the transect in it (Table 3.1.10).

A tendency for change to drier conditions are indicated in samples J and K through changes over the monitoring period in the cover of *Samolus porosus, Sarcocornia perennis, Sporobolus virginicus* and *Tetragonia fruticosa*.

Extensive death of saltmarsh vegetation was observed during the monitoring period caused by dense deposits of *Eichhornia crassipes* debris along the spring high tide line (Figure A3.1.7). The destruction of the vegetation often results in subsequent bank erosion.

Table A3.1.10 Floristic data recorded on Transect 4

Estuary Transect 4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	
Sample No.	A	A	A	B	B	B	C	C	C	D	D	D	E	E	E	F	F	F	G	G	G	H	H	H	I	I	I	J	J	J	K	K	K	L	L	L	M	M	M	
Year	2003	2004	2005	2003	2004	2005	2003	2004	2005	2003	2004	2005	2003	2004	2005	2003	2004	2005	2003	2004	2005	2003	2004	2005	2003	2004	2005	2003	2004	2005	2003	2004	2005	2003	2004	2005	2003	2004	2005	
1. Jaccard Similarity Co-efficient %. Present year compared to previous year		100%	100%		100%	100%		100%	100%		100%	100%		100%	100%		100%	100%		100%	100%		100%	100%		100%	100%		75%	75%		60%	83%		67%	70%		57%	67%	
2. Sorenson's Similarity Co-efficient %. Present year compared to previous year.		100%	100%		100%	100%		100%	100%		100%	100%		100%	100%		100%	100%		100%	100%		100%	100%		100%	100%		86%	86%		75%	91%		80%	82%		73%	80%	
3. Jaccard Similarity Co-efficient %. Year 2005 compared to 2003.			100%			100%			100%			100%			100%			100%			100%			100%			100%			100%			57%			58%			50%	
4. Sorenson's Similarity Co-efficient %. Year 2005 compared to 2003.			100%			100%			100%			100%			100%			100%			100%			100%			100%			100%			73%			74%			67%	
Number of taxa of potential 32 in sample	**1**	**1**	**1**	**6**	**6**	**6**	**6**	**6**	**6**	**2**	**2**	**2**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**2**	**2**	**2**	**1**	**1**	**1**	**4**	**3**	**4**	**12**	**12**	**10**	**8**	**7**	**10**	**5**	**6**	**4**	**No. of records**
Asparagus capensis L.																																				R				1
Bassia diffusa (Thunb.) Kuntze							R	R	R																						R	R	R							6
Chenopodium album L.				+	+	+																																		3
Cotula coronopifolia L.				+	+	+																																		3
Cyperus textilis Thunb.							R	R	R																															3
Disphyma crassifolium (L.) L.Bolus																																		1	2	1	1	1	2	6
Drosanthemum floribundum (Haw.) Schwantes																																R	R	2	2	2	+	+	R	8
Frankenia repens (P.J.Bergius) Fourc.																																R	+							2
Galenia sarcophylla Fenzl																																			+	1				2
Hordeum marinum Huds.																																					+			1
Juncus kraussii Hochst.																												5	4	5										3
Lepidium africanum (Burm.f.)DC.																																					+	+		2
Leptochloa fusca (L.) Kunth																																R								1
Limonium depauperatum (Boiss.) R.A.Dyer																															2	2	2	1		+				5
Lycium cinereum Thunb. sensu lato																															+	+	+	1	1	1				6
Mesembryanthemum crystallinum L.																																				+				1
Nidorella foetida (L.) DC.							R	R	R																															3
Oncosiphon suffruticosum (L.) Källersjö																															+			+						2
Panicum sp.																															+									1
Phragmites australis (Cav.) Steud.				R	R	R	R	R	R	1	1	1										1	1	1																12
Plantago crassifolia Forssk.																															R	+	+							3
Poaceae (dead annuals)																																						+		1
Polygonum aviculare L				R	R	R																																		3
Psilocaulon coriarium (Burch. ex N.E.Br.) N.E.Br.																																				+				1
Romulea sp.																															+									1
Samolus porosus (L.f.) Thunb.																												1	2	2										3
Sarcocornia perennis (Mill.) A.J.Scott				R	R	R	R	R	R																			+	2	2	3	4	4	2	1	2	4	3	3	18
Sarcocornia pillansii (Moss) A.J.Scott																																						+	+	2
Schoenoplectus scirpoideus (Schrad.) Browning	+	+	+	3	3	3	5	5	5	5	5	5	5	5	5	3	3	3	5	4	5	5	5	5	5	5	5	+		R										29
Senecio burchellii DC.																															1	+								2
Suaeda inflata Aellen																															R	R	R	+	1	+				6
Sporobolus virginicus (L.) Kunth																															3	2	2							3
Tetragonia fruticosa L.																															R	R	+	+	R	+				6



Figure A3.1.6 Transect 4 at the top end of Die Plaat. The fence was used as a reference line marking the downstream edge of the transect.



Figure A3.1.7 Inundated Mudflats at De Plaat covered with mats of dead Eichhornia crassipes (water hyacinth). These mats smother living vegetation and lead to denudation of areas adjacent to the Inundated Mudflats.

6. TRANSECT 5 (KRUISPAD WEST NO. 1)

This transect is located on the farm Kruispad (Figure 7.2).

Based on the coefficients of similarity of Jaccard and Sorenson, there is an intermediate similarity in species complement between the years assessed in this period (Table A3.1.11).

Table A3.1.11 The average similarity of samples along Transect 5 between years using Jaccard and Sorenson's Coefficients

	Estuary Transect 5			
	No.of records	**Ave Similarity 2003-04**	**Ave Similarity 2004-05**	**Ave Similarity 2003-05**
Jaccard Similarity Co-efficient %	15, 13, 13	47%	70%	42%
Sorenson's Similarity Co-efficient %	15, 13, 13	61%	81%	55%

The transect vegetation is illustrated in Figure A3.1.8 including transect profiles for 2004 (Figure A3.1.9) and 2005 (Figure A3.1.10). An aerial photograph illustration with the transect as measured in 2003 is illustrated in Figure A3.1.11. The following dominant communities were recorded at this site in the samples indicated (Boucher & Jones - BRBMP Vol 3 Ch 7, Table 7.1):

1. *Sarcocornia pillansii* Dwarf Succulent Shrubland (Floodplain)
   - 1.1 *Sarcocornia pillansii* Dwarf Shrubland (Xeric Floodplain) (sample AA)
2. *Sarcocornia perennis* Saltmarsh (Sedge Marsh and Halophytic Saltmarsh)
   - *2.1 Bassia diffusa-Sarcocornia perennis* Dwarf Shrubland typicum (Halophytic Saltmarsh) (sample Z)
   - *2.2 Salicornia meyeriana-Triglochin bulbosa* Dwarf Shrubland (Open pan) (samples P & Y)
   - *2.3 Leptochloa fusca-Sarcocornia perennis* Grassland (Short Reed Marsh) (samples H & J)
3. *Schoenoplectus scirpoideus* Sedgeland (Short Reed Marsh, Figure A3.1.8) (Samples A-C, B, L, M, S, AB, T, U) (The following samples changed in composition over the period - O, P, R, W, X).
4. *Phragmites australis* Reedland (Reed Marsh)

Phragmites australis Reedbed typicum (Tall Reed Marsh) and the *Cyperus textilis-Cotula coronopifolia* Sedgeland (Sedge Marsh) (samples A-E, L, M, N; sample AB is a mixed stand).

The *Sporobolus virginicus-Sarcocornia perennis* Grassland and Juncus kraussii-*Sarcocornia perennis* Sedgeland (Sedge Marshes) communities regularly occur together in mixed stands (e.g. samples C-F, G, I, K, M, Q, U, V & W) (Figures A3.1.9, 26 & A3.1.11).

Samples M & T (2004-2005) and A (2003-2005) remained unchanged in species complement, although not necessarily in individual cover values, over the study period. Samples F – K; M – R and U – V of 2003 and 2005 were undistinguishable in the field and their contents are listed under F, M and U respectively in Table A3.1.12.

There is a general reduction in *Phragmites australis* over the three years with large scale deaths being prevalent (M -- P), but with S, AB, T developing as a new bed of *Phragmites australis*. The reason for the changes present are not clear. Sample AA represents the dry saline flats on the higher floodplain.

Samples W and Z had no plants in 2005 - presumably either disturbances or salinities have increased over the years 2004 and 2007. Downward movement of species occurred in sample C into B, as evidenced by *Juncus kraussii, Samolus porosus* and *Sarcocornia perennis* in particular, with *Typha capensis* moving upward from A to B.

Sarcocornia perennis (28 samples out of a potential 56), *Schoenoplectus scirpoideus* (26 samples), *Bolboeschoenus ma*ritimus (25 samples) and *Phragmites australis* (25 samples) were recorded in the most samples over the three years (Table A3.1.12). Six incidental species were recorded on a single occasion along the transect over the monitoring period. A maximum of 10 species were recorded in samples D-2005 and E-2003, out of a potential 24 recorded along the transect, namely in (Table A3.1.12).

Monotypic stands of *Phragmites australis* and of *Sarcocornia perennis* were recorded in samples N, X and Z. This is indicative of very specialized habitats. The distinction between *Schoenoplectus scirpoideus* and *Bolboeschoenus maritimus* was not always apparent during the summer survey period as these two sedges had died back in dormancy then.



Figure A3.1.8 Transect 5 on 14 April 2005 with Schoenoplectus scirpoideus Stand immersed for an extended period after spring high tide.

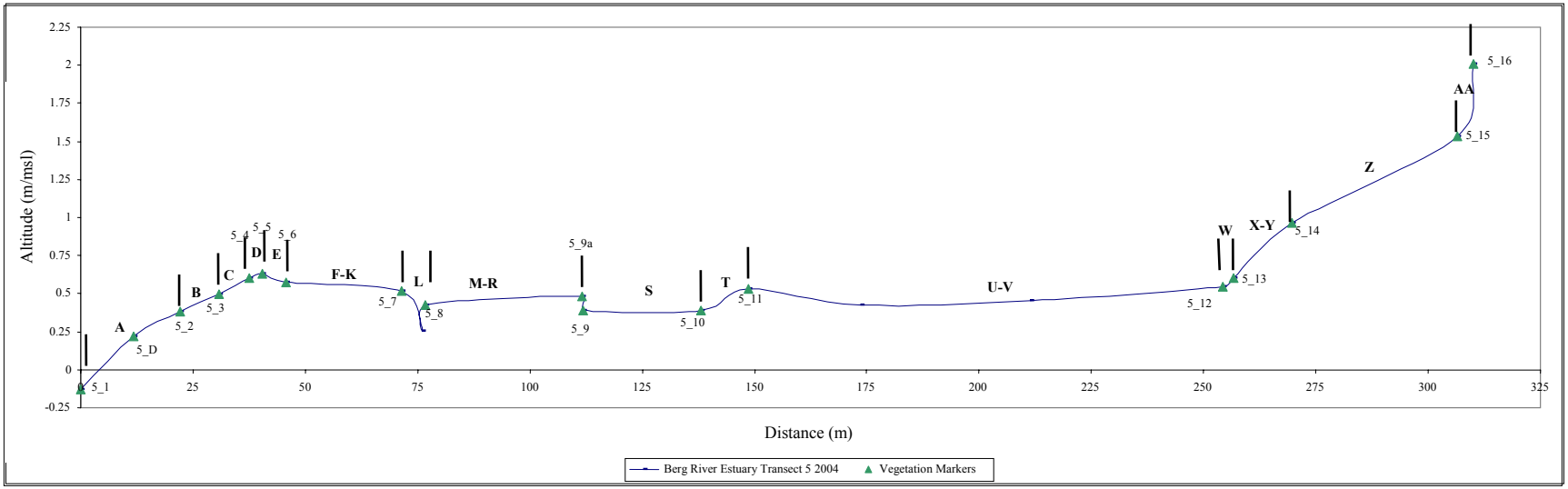


Figure A3.1.9 Cross-section profile of Transect 5 for 2004.

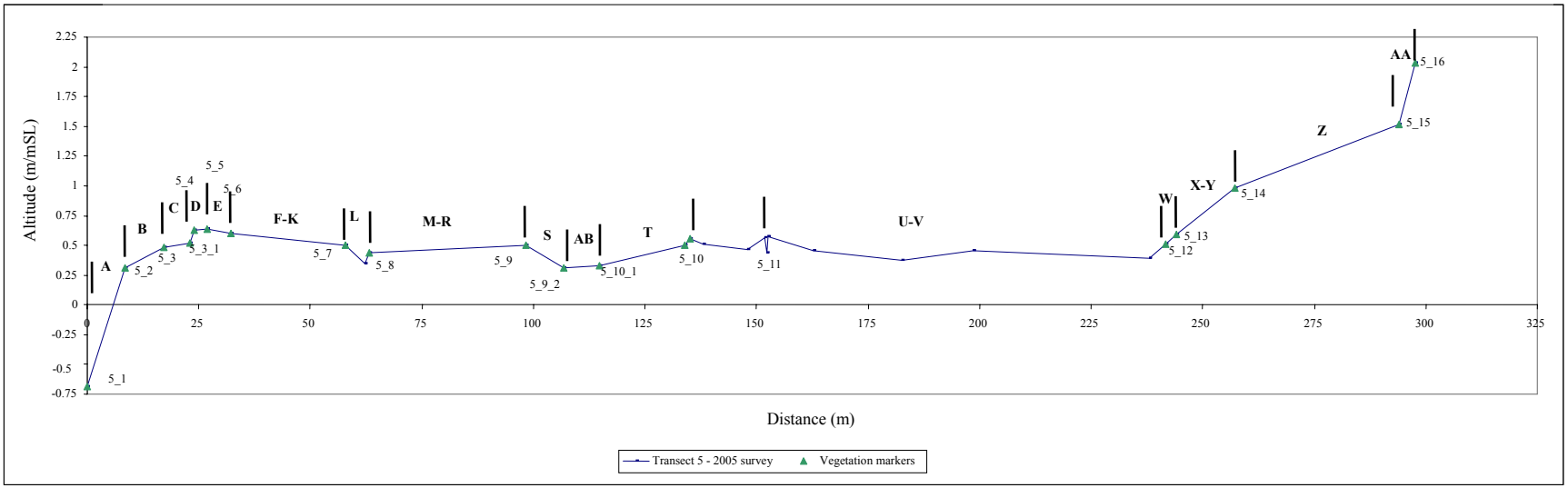


Figure A3.1.10 Cross-section profile of Transect 5 for 2005.

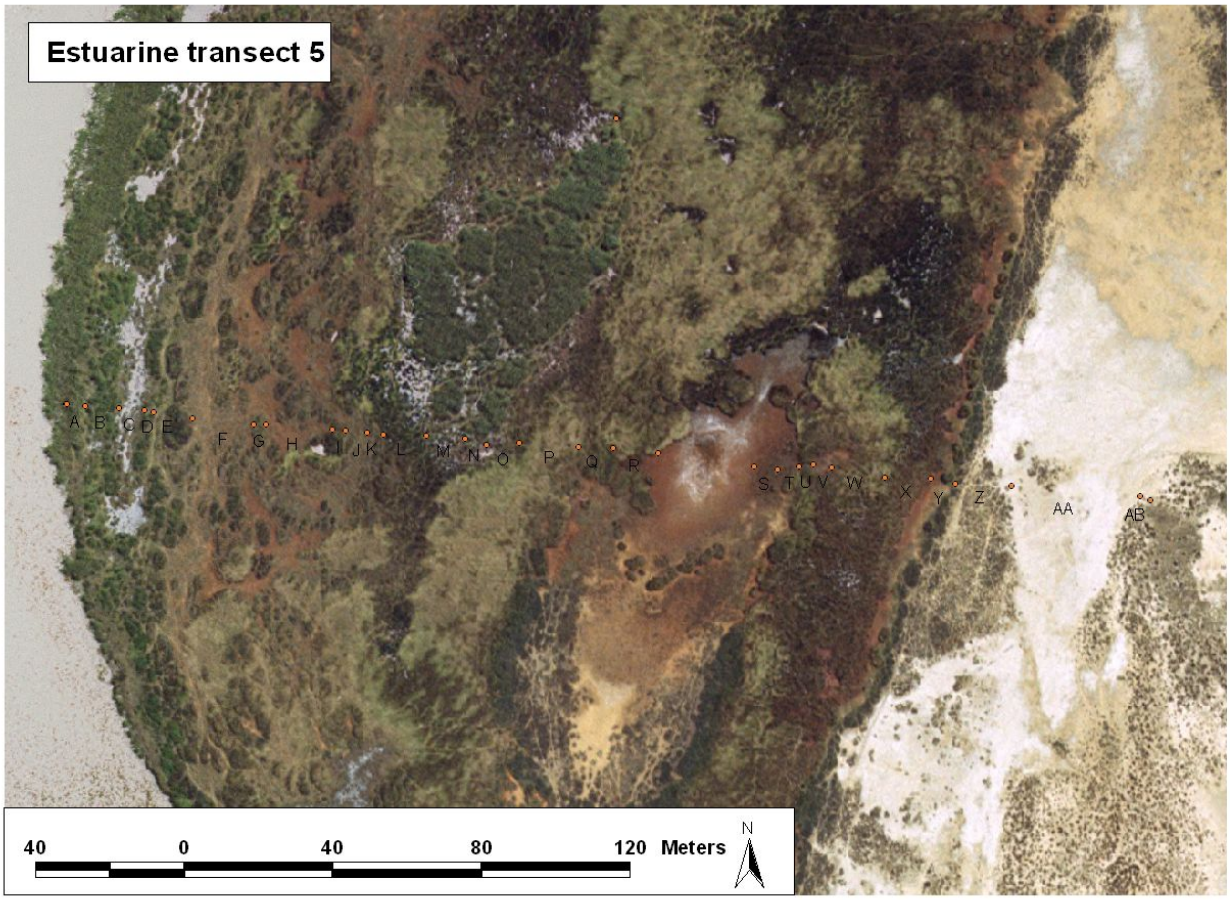


Figure A3.1.11 Location of cross-section profile (orange dots) of Transect 5 for 2003. Letters of the alphabet identify plant communities as numbered in Table A3.1.12.

Table A3.1.12 Floristic data recorded on Transect 5

| Transect 5 Kruispad West | 5 5 5

7. TRANSECT 6 (PORT OWEN)

This transect is located in the large saltmarsh to the west of the Port Owen development (Figures 7.2 & A3.1.12). Based on the coefficients of similarity of Jaccard and Sorenson, there is a high degree of similarity in species complement between the years assessed in this monitoring period (Table A3.1.13).

Table A3.1.13 The average similarity of samples along Transect 6 between years using Jaccard and Sorenson's Coefficients

	Estuary Transect 6			
	No. of records	**Average similarity 2003-04**	**Average similarity 2004 – 05**	**Average similarity 2003 - 05**
Jaccard similarity co-efficient %.	18, 12, 15	94%	98%	89%
Sorenson's similarity co-efficient %.	18, 12, 15	94%	99%	94%

The transect vegetation is illustrated in Figur A3.1.13. The following dominant communities (Boucher & Jones - BRBMP Vol 3 Ch 7, Table 7.1) were recorded at this site in the samples indicated:

- *Limonium depauperatum-Triglochin striata* Herbland (Halophytic Saltmarsh) (all samples except next)
- *Salicornia meyeriana-Triglochin bulbosa* Dwarf Shrubland (Open pan) (samples N-Q).

Samples Q (2003), M3 (2004, 2005) and NO (2004, 2005) were the richest samples with six species in each of them out of a potential seven recorded along the transect. Communities B, C, D of 2003; Q4 and R (2004) and N,O of 2004 & 2005 were undistinguishable in the field in 2005 and their contents are listed under BCD, Q4R and NO respectively, while Q (2003) was split into Q1-3 in 2004 and 2005 (Figure A3.1.14; Table A3.1.14).

Sarcocornia perennis (59 samples out of a potential 60), *Bassia diffusa* (55 samples) and *Triglochin striata* (53 samples) were the species most regularly recorded in the 60 samples over the three years. *Sporobolus virginicus* was only recorded on three occasions (Table A3.1.14).

Based on the coefficients of similarity of Jaccard and Sorenson, samples A, B, D, F, G, H, J, K, L, (2003-2004); A, BCD, E, F, G, H, I, K, L, M1, NO, P, (2004-2005); A, B, F, G, H, K, L and R (2003-2005) remained unchanged in species complement, although not necessarily in individual cover values, during the monitoring period.

The prevalence of single species dominance (e.g. sample 6A) is a typical adaptation by a single species to avoid competition by adapting to an area with a particularly severe stress such as that caused by hypersalinity or by long periods of immersion.

The high degree of similarity between samples in a saltmarsh such as this is because the coefficients of similarity applied here are based solely on species content and not on abundance. Saltmarsh communities are regularly distinguished by changes in dominance rather than by changes in species content. Saltmarsh conditions that suit one species more than another give it a competitive advantage and it rapidly becomes dominant (e.g. *Sarcocornia perennis* in sample J-2003 to J-2004). Changes to particular conditions quickly result in a change in the community. This reaction makes a saltmarsh a very sensitive indicator of changing environmental conditions. For example, the changes experienced in this saltmarsh could be attributed to the saltmarshes reacting to a generally drier cycle prevailing over the 2003-2004 period.

Spartina maritima regularly lines channels through the lower Berg River estuary saltmarshes, as in this transect. *Salicornia meyeriana* is usually associated with bare patches in saltmarshes here, such as those associated with local hypersaline conditions.

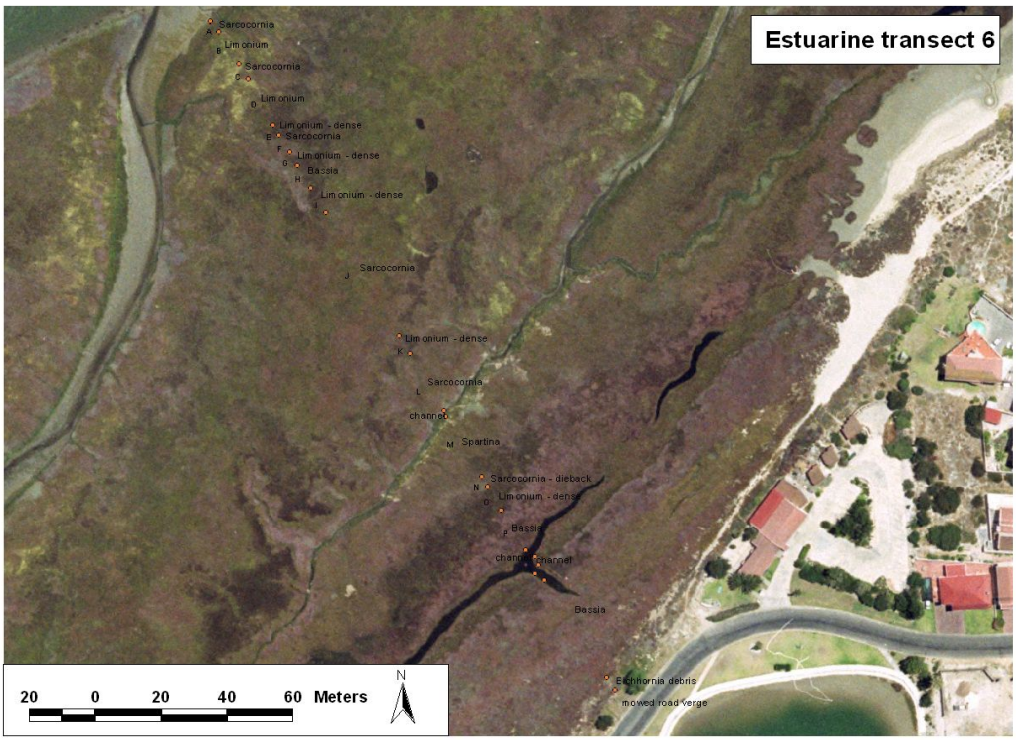


Figure A3.1.12 Cross-section profile of Transect 6 for 2003. Letters of the alphabet identify plant communities as numbered in Table A3.1.14.



Figure A3.1.13 Transect 6, as recorded on 14 April 2005, extends past the wooden stake to the road at Port Owen. Bassia diffusa is the dominant grey-leaved dwarf succulent-leaved shrub.

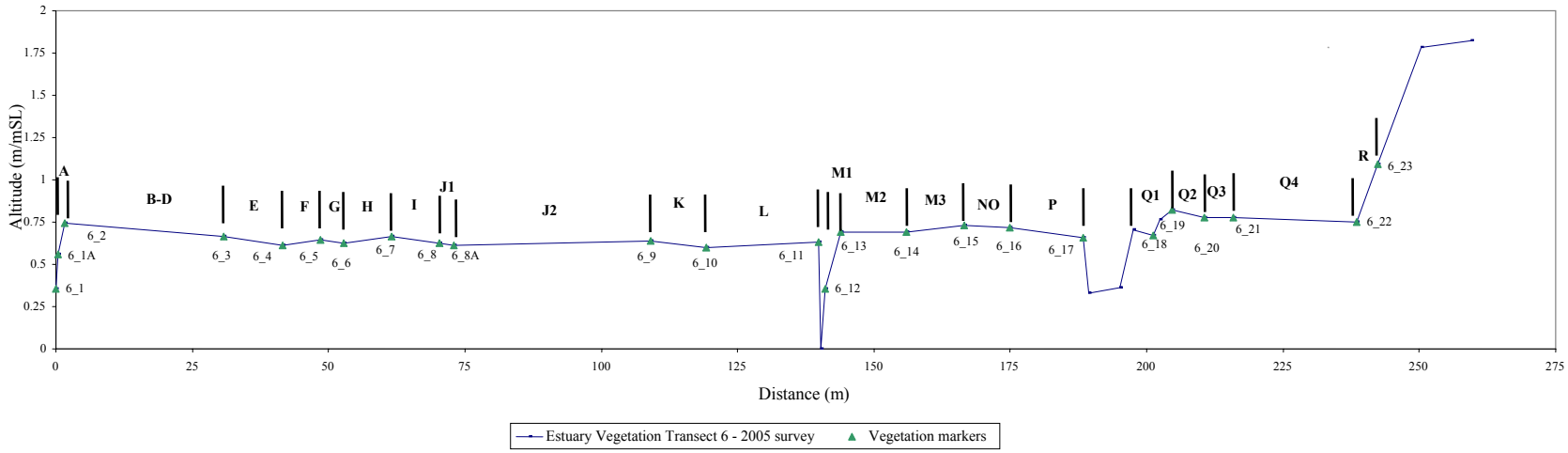


Figure A3.1.14 Cross-section profile of Transect 6 for 2005. Letters of the alphabet identify plant communities as numbered in Table A3.1.14.

Table A3.1.14 Floristic data recorded on Transect 6

| **Transect 6 (Port Owen)** | 6 | 6 | 6

8. TRANSECT 7 (KRUISPAD EAST NO. 1)

This transect is located near the eastern boundary of the farm Kruispad (Figure 7.3 & A3.1.15). Transect samples were more similar to each other in the 2004-2005 period than between 2003-2004 with 2003-2005 being most dissimilar (Table A3.1.15; Figures A3.1.16 & A3.1.17).

Table A3.1.5 The average similarity of samples along Transect 7 between years using Jaccard and Sorenson's Coefficients.

	Estuary Transect 7			
	No. of records	**Average similarity 2003-04**	**Average similarity 2004 – 05**	**Average similarity 2003 - 05**
Jaccard similarity co-efficient %.	9, 9, 9	58%	73%	54%
Sorenson's similarity co-efficient %.	9, 9, 9	71%	83%	67%

The transect vegetation is illustrated in Figures A3.1.5 & A3.1.27. The following dominant communities (Chapter 7.3, Table 7.1) were recorded at this site in the samples indicated:

- *Phragmites australis* Reedbed typicum (Tall Reed Marsh) (sample D).
- *Cyperus textilis-Cotula coronopifolia* Sedgeland (Short Reed Marsh), occur in samples G, I & J.
- *Sarcocornia pillansii* Dwarf Shrubland (Xeric Floodplain) (sample A) (Figure A3.1.18).
- Mixed communities with various combinations of *Phragmites australis* Reedbed, *Sporobolus virginicus-Sarcocornia perennis* Grassland, *Juncus kraussii-Sarcocornia perennis* Sedgeland and *Leptochloa fusca-Sarcocornia perennis* Grassland occur together in stands B, C, E, F & H.

Samples B (2004-2005), G (2003-2004), G (2003-2005) and G (2004-2005) were dominated exclusively by *Cyperus textilis* and *Phragmites australis* over the whole monitoring period. Sample B remained unchanged in species complement, but not necessarily in individual cover values, during the 2004-2005 period. Samples C & D (2003) were indistinguishable in the field in 2004 or 2005 and their contents are listed under CD in Table A3.1.16.

Heavy grazing, with accompanying trampling has reduced the grazable grass cover in this wetland e.g. of *Leptochloa fusca* in samples E, F and H. *Phragmites australis* shows similar reduction except in sample J. *Cyperus textilis* in sample J decreasing as *Phragmites australis* becomes denser. After a period, farmers periodically set dense *Phragmites australis* patches alight to rejuvenate them to increase young grazable shoots after a fire the cover of *Cyperus textilis* would increase initially. Sample A represents the dry saline flats on the higher floodplain (Table A3.1.16).

Phragmites australis was recorded in the most samples (23 samples out of a potential 28), followed by *Cotula coronopifolia* and *Juncus kraussii* in 15 samples each. Ten incidental species were recorded on a single occasion. Sample E was the richest with 10 species out of a potential 29 (Table A3.1.16).

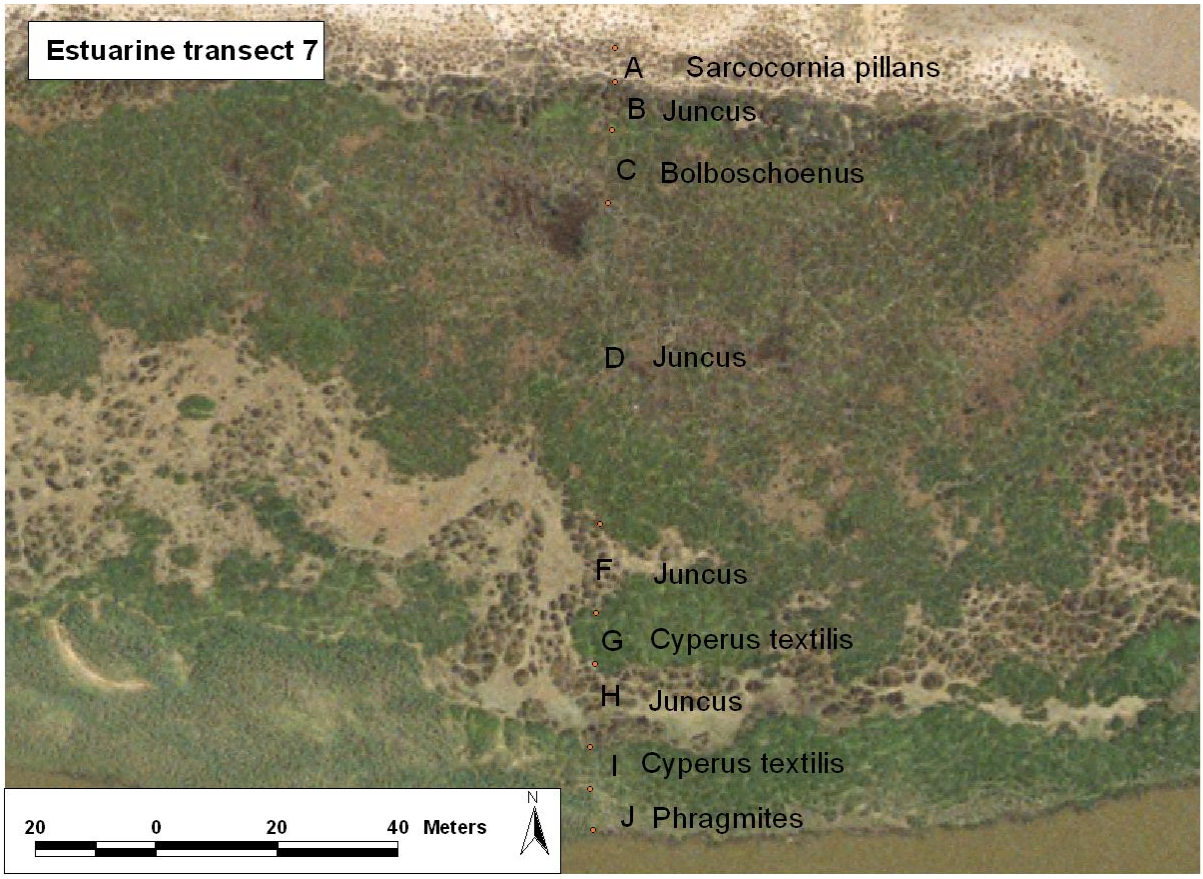


Figure A3.1.15 Aerial photograph to indicate the location of Transect 7 for 2003. Letters of the alphabet identify plant communities as numbered in Table A3.1.16.

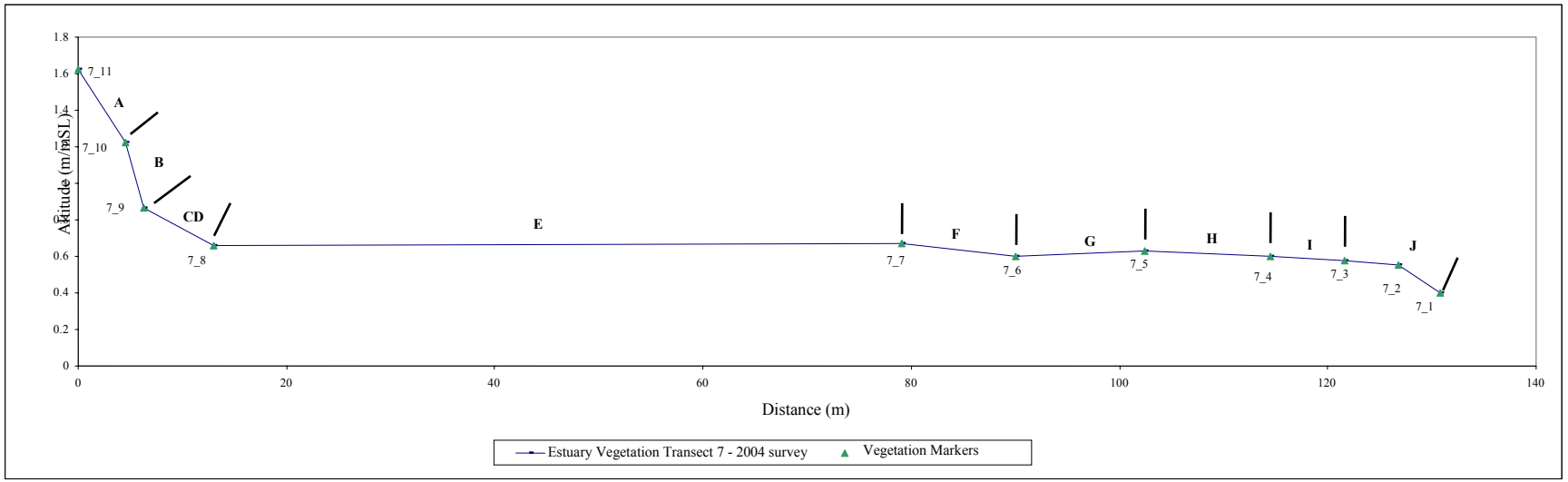


Figure A3.1.16 Cross-section profile of Transect 7 for 2004. Letters of the alphabet identify plant communities as numbered in Table A3.1.16.

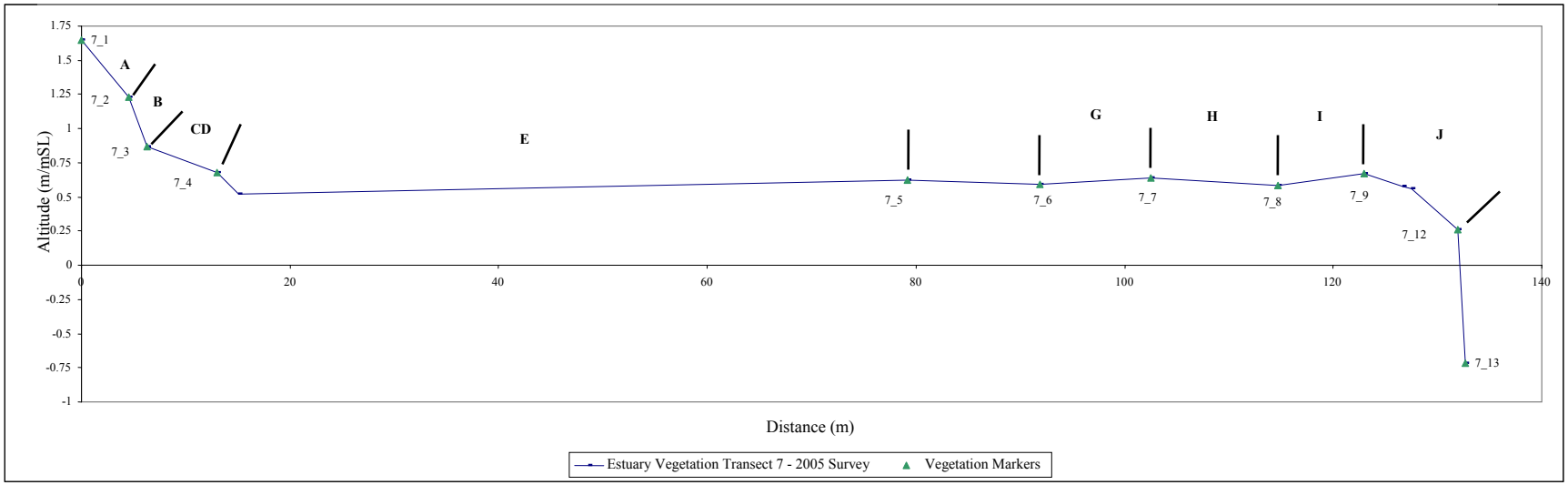


Figure A3.1.17 Cross-section profile of Transect 7 for 2005. Letters of the alphabet identify plant communities as numbered in Table A3.1.16.

Table A3.1.16 Floristic data recorded on Transect 7

Transect 7 (Kruispad East)	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	
Sample No.	A	A	A	B	B	B	C	C D	C D	D	D	D	E	E	E	F	F	F	G	G	G	H	H	H	I	I	I	J	J	J	
Year	2003	2004	2005	2003	2004	2005	2003	2004	2005	2003	2004	2005	2003	2004	2005	2003	2004	2005	2003	2004	2005	2003	2004	2005	2003	2004	2005	2003	2004	2005		
1. Jaccard Similarity Co-efficient %. Present year compared to previous year		44%	43%		57%	100%		33%	57%					64%	75%		63%	67%		100%	100%		80%	78%		60%	67%		25%	67%		
2. Sorenson's Similarity Co-efficient %. Present year compared to previous year.		62%	60%		73%	100%		50%	73%					78%	86%		77%	80%		100%	100%		89%	88%		75%	80%		40%	80%		
3. Jaccard Similarity Co-efficient %. Year 2005 compared to 2003.			18%			57%			43%						50%			63%			100%			78%			50%			29%		
4. Sorenson's Similarity Co-efficient %. Year 2005 compared to 2003.			31%			73%			60%						67%			77%			100%			88%			67%			44%		
Number of taxa of potential 29 in each sample =	**8**	**5**	**5**	**7**	**4**	**4**	**2**	**6**	**5**	**4**	**0**	**0**	**10**	**8**	**6**	**8**	**5**	**5**	**2**	**2**	**2**	**9**	**9**	**7**	**5**	**3**	**2**	**7**	**3**	**2**		**No. of records**
Asparagus capensis L.		R	+																										R			**3**
Atriplex semibaccata R.Br.			R																													**1**
Berula erecta (Huds.) Coville																							R		+	1		1				**4**
Bolboeschoenus maritimus (L.) Palla							R						R	R																		**3**
Centella asiatica (L.) Urb.																						+	+		+			+				**4**
Chenopodium album L.				R												R						+	R	1								**5**
Cotula coronopifolia L.				+				1	+	+			R	1	1	+	2	1				1	2	1	1			1				**15**
Cyperus textilis Thunb.								+					5	5	5				5	5	5				4	5	5	2	+	+		**13**
Disphyma crassifolium (L.) L.Bolus	+																															**1**
Drosanthemum floribundum (Haw.) Schwantes	1	+	1																													**3**
Ehrharta delicatula (Nees) Stapf	+	R																														**2**
Eichhornia crassipes (Mart.) Solms																												R				**1**
Eragrostis curvula (Schrad.) Nees				1				1		+																						**3**
Juncus kraussii Hochst.				3	2	2		3	4	+			R	+	+	3	3	4				3	4	4								**15**
Kniphofia uvaria (L.) Oken																						R										**1**
Leptochloa fusca (L.) Kunth														1	+	4	3	1				2	2	R								**8**
Limonium depauperatum (Boiss.) R.A.Dyer	+												R	1																		**3**
Lycium cinereum Thunb. sensu lato	R																															**1**
Persicaria lapathifolia (L.) Gray																												+				**1**
Phragmites australis (Cav.) Steud.				1	+	+		1	+				2	2	1	1	2	1	1	1	1	+	1	1	1	1	1	3	5	5		**23**
Poaceae sp.													R																			**1**
Sarcocornia perennis (Mill.) A.J.Scott	R	R		2	3	4			2	+						1		1				+	R	+								**12**
Sarcocornia pillansii (Moss) A.J.Scott	4	4	4																													**3**
Schoenoplectus scirpoideus (Schrad.) Browning													R																			**1**
Spergularia media (L.) C.Presl ex Griseb.	R																															**1**
Sporobolus virginicus (L.) Kunth			R	1	+	1		1	+							+						+	2	+								**10**
Triglochin bulbosa L.													R																			**1**
Triglochin striata Ruiz & Pav.																R	R															**2**
Typha capensis (Rohrb.) N.E.Br.							R						R	R	R																	**4**



Figure A3.1.18 Transect 7 on Farm Kruispad. The dominant reddish succulent-leaved dwarf shrub in the foreground is Sarcocornia pillansii.

9. TRANSECT 8 (JANTJIESKRAAL)

This transect is located on the left bank of the farm Jantjieskraal (Figure 7.3, Figure A3.1.19). The whole site was never formally surveyed. It was measured using a D-GPS during 2003. The river is incised here with a floodplain plateau. This plateau was not sampled during 2004 and the site was excluded from monitoring during 2005 due to rationalisation of the monitoring programme because the site was very distant from any other transects and was deemed too time consuming to continue monitoring especially as no formal survey information was available. Furthermore, it was found to be above tidal influence and was thus of little value for monitoring the estuary and its adjacent floodplain, the primary concern of this project.

Cynodon dactylon was recorded in the most samples (seven samples out of a potential 10), followed by *Alternanthera sessilis* (six samples) (Table A3.1.17). Ten incidental species were recorded on a single occasion over the monitoring period. Sample A - 2003 was the richest sample with 12 species out of a potential 28 in it. Heavy under-cutting with slumping of the bank continued over the study period. *Paspalum distichum* and *Phragmites australis* increased in density in the channel probably due to the lack of flushing floods over the 2003-2004 wet season (Site 17 in Chapter 2).

The transect vegetation is illustrated in Figure A3.1.21. The following dominant communities (Boucher & Jones - BRBMP Vol 3 Ch 7, Table 7.1) were recorded at this site in the samples indicated:

1. *Phragmites australis* Reedland (Reed Marsh) (samples C to E-2003; B & C-2004)
2. *Eleocharis limosa* Inland Sedge Marsh (2003 samples B, C & D)

3. Azonal Riparian Woodland

3.1 *Xanthium strumarium-Paspalum distichum* Riparian Herbland (Riparian Woodland) (sample B-2003 & A-2004)

3.2 *Athanasia trifurcata- Rhus angustifolia* Riparian Woodland (Riparian Woodland) (samples A, F & G -2003)



Figure A3.1.19 Transect 8 on the farm Jantjieskraal.

Table A3.1.17 Floristic data recorded on Transect 8

Estuary Transect 8	8	8	8	8	8	8	8	8	8	8	
Sample No.	B	A	C	B	D	E	C	F	G	A	
Year	2003	2004	2003	2004	2003	2003	2004	2003	2003	2003	
Lateral Riparian Vegetation Zone	LWB	LWB	UWB	UWB	LD	LD	LD	TS	TS	TS	
Number of taxa of potential 18 in sample	**6**	**4**	**4**	**4**	**2**	**4**	**4**	**6**	**3**	**12**	**No. of records**
Alternanthera sessilis (L.) DC.	1		+	2	+	+		1		R	6
Asparagus capensis L.										R	1
Athanasia trifurcata (L.) L.							+		1	+	3
Berkheya armata (Vahl) Druce										R	1
Bolboeschoenus maritimus (L.) Palla	+					4		R			2
Cynodon dactylon (L.) Pers.	+		2	1		+	1	4	1	5	7
Eleocharis limosa (Schrad.) Schult.	4		2		5	+					3
Geophytes various										1	1
Gymnosporia buxifolia (L.) Szyszyl.										+	1
Juncus kraussii Hochst.								1		+	2
Leptochloa fusca (L.) Kunth	+									R	1
Lolium multiflorum Lam.	1						1	3	1	2	4
Micranthus junceuS (Baker) N.E.Br.								+			1
Moraea lewisiae (Goldblatt) Goldblatt										R	1
Ornithogalum sp.										R	1
Paspalum distichum L.		5									1
Phragmites australis (Cav.) Steud.		1	3	5			+				4
Sesbania punicea (Cav.) Benth.		R									1
Xanthium strumarium L.		1		+							2

10. TRANSECT 9 (ZOUTKLOOF EAST)

This transect is located on the right bank of the river on the farm Zoutkloof near its eastern boundary (Figures 7.4 & A3.1.20). Transect 10 is located on the left bank directly opposite this one. The river here is well-known for the deep pool. The bank is undercut and collapsing here compared to accretion through sand deposition along the opposite left bank (Figure A3.1.21).

Based on the coefficients of similarity of Jaccard and Sorenson the average similarity was intermediate (Table A3.1.15), sample B-2004 was most similar to B-2003, while the greatest dissimilarity in stands was between E-2005 and E-2003 (Table A3.1.16). Absence of cover in the Back Dynamic Zone in 2004 (E & F - 2004) is attributed to a fire shortly before the site was assessed (compare Figure A3.1.22 in 2003 with Figure A3.1.23 in 2004 after fire). This part of the site had not recovered yet by 2007. This is indicative of environmental change in these stands.

Table A3.1.18 Average similarity of samples along Transect 9 between years using Jaccard and Sorenson's Coefficients

	Estuary Transect 9			
	No. of records	**Average similarity 2003-04**	**Average similarity 2004 – 05**	**Average similarity 2003 - 05**
Jaccard similarity co-efficient %.	4, 4, 7	55%	52%	53%
Sorenson's similarity co-efficient %.	4, 4, 7	70%	68%	67%

The transect vegetation is illustrated in Figures A3.1.21 and A3.1.22. *Bolboeschoenus maritimus* was recorded in the most samples (11 samples out of a potential 16), followed by the exotic *Alternanthera sessilis* and *Sesbania punicea* each in 10 samples (Table A3.1.19). Eight incidental species were recorded on a single occasion over the monitoring period. Sample 9C (2004) (Lower Dynamic Zone) was the richest sample with 17 species out of a potential 37 recorded along the transect. Considerable changes in the density of the annual *Xanthium strumarium* are often recorded along Western Cape rivers.

The communities recorded at this site all belong to the Azonal Riparian Woodland Group (as described in Chapter 7.3).

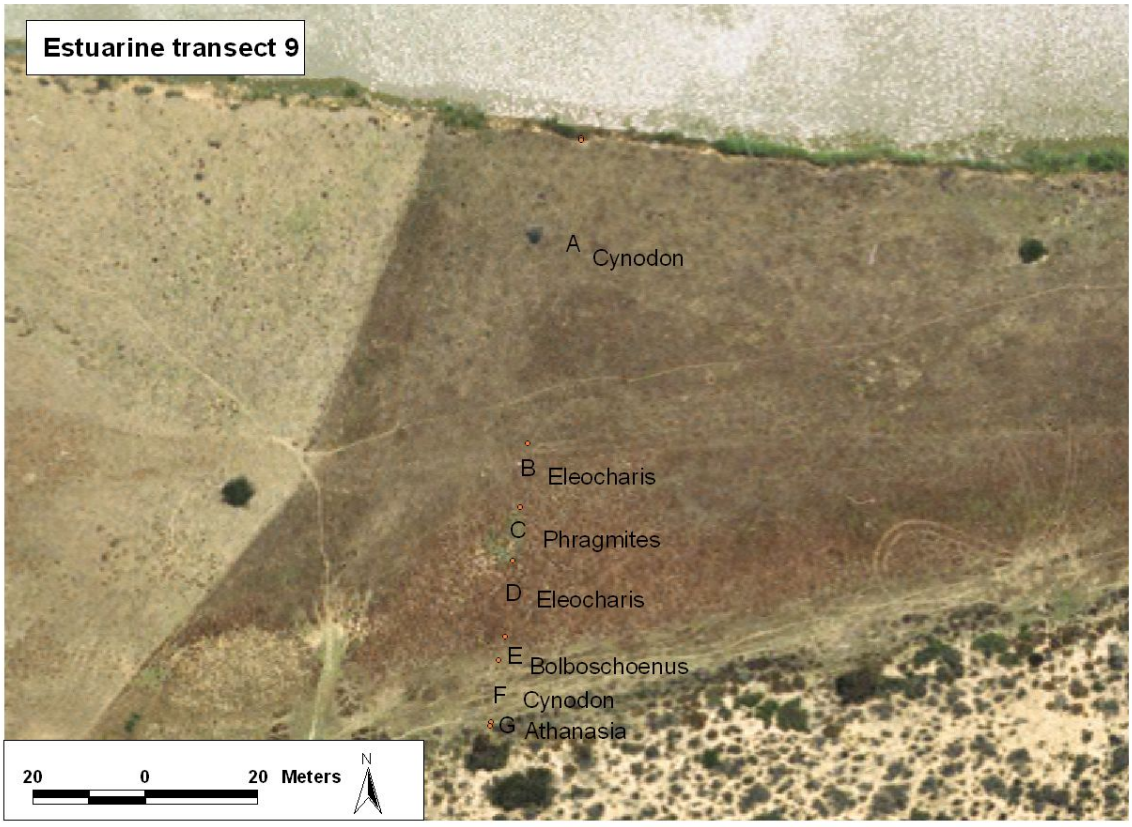


Figure A3.1.20 Aerial photograph indicating Transect 9 in 2003. The letters of the alphabet identify the plant communities as numbered above and in Table 3.1.19.



Figure A3.1.21 Eroding bank of Berg River on 10 March 2004 along Transect 9 on the farm Zoutkloof.



Figure A3.1.22 Floodplain along Transect 9 on the farm Zoutkloof on 12 February 2003.



Figure A3.1.23 Burnt floodplain along Transect 9 on the farm Zoutkloof on 10 March 2004.

Table A3.1.19 Floristic data recorded on Transect 9

Estuary Transect 9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	
Sample No.	A	A	A	B	B	B	C	C	C	D	D	D	E	E	E	F	F	F	
Year	2003	2004	2005	2003	2004	2005	2003	2004	2005	2003	2004	2005	2003	2004	2005	2003	2004	2005	
Lateral Zone	LWB	LWB	LWB	UWB	UWB	UWB	LD	LD	LD	TS	TS	TS	BD1	BD1	BD1	BD2	BD2	BD2	
1. Jaccard Similarity Co-efficient %. Present year compared to previous year		57%	44%		71%	57%		45%	69%		46%	38%							
2. Sorenson's Similarity Co-efficient %. Present year compared to previous year.		73%	62%		83%	73%		63%	82%		63%	55%							
3. Jaccard Similarity Co-efficient %. Year 2005 compared to 2003.			67%			83%			46%			50%			28%			43%	
4. Sorenson's Similarity Co-efficient %. Year 2005 compared to 2003.			80%			91%			63%			67%			43%			60%	
Number of taxa of potential 37 in sample	**4**	**7**	**6**	**6**	**6**	**5**	**10**	**17**	**9**	**12**	**7**	**15**	**13**	**0**	**10**	**5**	**0**	**5**	**No. of records**
Alternanthera sessilis (L.) DC.		+		1	1	+	+	1	2			1	+		R				10
Asparagus kraussianus (Kunth) J.E.Macbr.								R		1	3	2						+	5
Athanasia trifurcata (L.) L.							1	+	1	3	2	2	+		+	1			9
Atriplex semibaccata R.Br.												1			+				2
Berkheya armata (Vahl) Druce										+		R	2						3
Bolboeschoenus maritimus (L.) Palla	3	2	2	3	3	4	+	1	2			R	+						11
Centella asiatica (L.) Urb.		+						1											2
Chenopodium album L.													R						1
Chenopodium ambrosioides L.			R					+	+			+							4
Conyza canadensis (L.) Cronquist							R	+											2
Cybistetes sp.										+	R								2
Cynodon dactylon (L.) Pers.					2		+	+			R	+				+		+	7
Cyperus textilis Thunb.				1	2	2		1	+				+						6
Eragrostis curvula (Schrad.) Nees															2				1
Felicia sp.															R				1
Ficinia nodosa (Rottb.) Goetgh., Muasya & D.A.Simpson													4		+			+	3
Galenia africana L.										+		+			R				3
Geranium sp.													R		R				2
Hordeum capense Thunb.													R		+	1		R	4
Lepidium africanum (Burm.f.) DC.										+		+							2
Lolium multiflorum Lam.							1	R	2	2	R	+				3		R	8
Ornithogalum sp.															+	+			2
Paspalum distichum L.	3	+	1	+		+													5
Pennisetum clandestinum Hochst. ex Chiov.								+	+										2
Pennisetum macrourum Trin.							1	+	2	+		+							5
Pseudognaphalium luteo-album (L.) Hilliard & B.L. Burtt			R					R											2
Rhus angustifolia L.										4	4	4							3
Ricinus communis L.										1			R						2
Rumex crispus L.							+	R					+						3
Salix mucronata Thunb.	+	2	1																3
Salsola kali L.												R							1
Salvia sp.										+									1
Sesbania punicea (Cav.) Benth.				2	2	3	1	4	4	1	1	R	+						10
Watsonia meriana (L.) Mill.													1						1
Xanthium spinosum L.								R											1
Xanthium strumarium L.	+	R	R	+	2		+	3											7
Zantedeschia aethiopica L.		R																	1

11. TRANSECT 10 (CALEDONIA)

This transect is located on the left bank on the farm Caledonia opposite Transect 8 on Jantjieskraal (Figure 7.3, A3.1.24).

The communities are all freshwater related Azonal Riparian communities. This site is naturally dynamic as it is depositional by nature being on the inside of a bed in the river, additionally, it has an extensive white sandy beach that is used for recreation. Subsequent to 2003, the farmer developed a picnic area at the site that included large-scale terracing (compare Figures A3.1.24 to A3.1.25). A fire burnt the vegetation in the Tree-shrub and Back Dynamic lateral riparian bank zones during 2004 further reducing the value of this site. Changes in Drybank vegetation caused by flows cannot be deduced from these data.

Based on the coefficients of similarity of Jaccard and Sorenson, no samples remained unchanged in species complement during the monitoring period in fact similarity between transects over the monitoring period was relatively low with 2004-2005 being more similar on average (Table A3.1.20).

Table A3.1.20 Average similarity of samples along Transect 10 between years using Jaccard and Sorenson's Coefficients

	Estuary Transect 10			
	No. of records	**Average similarity 2003-04**	**Average similarity 2004 – 05**	**Average similarity 2003 - 05**
Jaccard similarity co-efficient %.	7, 7, 10	34%	57%	35%
Sorenson's similarity co-efficient %.	7, 7 , 10	49%	71%	51%

Samples G, H & I - 2004 were not distinguished in the field because they were recently burnt and their contents are listed jointly under F - 2004 in Table A3.1.21. Notable changes in cover and density of the important species in the Wetbank Zones are related to lack of flushing flows during the preceding wet season and related stresses caused to the other species, such as increased cover of *Eragrostis elatior, Hemarthria altissima, Paspalum distichum* and *Sesbania punicea* in sample A – 2005 (Table A3.1.21).

The transect vegetation is illustrated in Figures A3.1.25 and A3.1.26. *Cynodon dactylon* was recorded in the most samples (22 samples out of a potential 29), followed by *Xanthium strumarium* (16 samples) and *Sesbania punicea* in 14 samples each. The wide distribution of these species is a direct result of large-scale stresses, particularly through physical disturbance on site. Fourteen incidental species were recorded on a single occasion over the monitoring period. Sample J - 2003 was the richest sample with 17 species out of a potential 48 in it (Table A3.1.21).

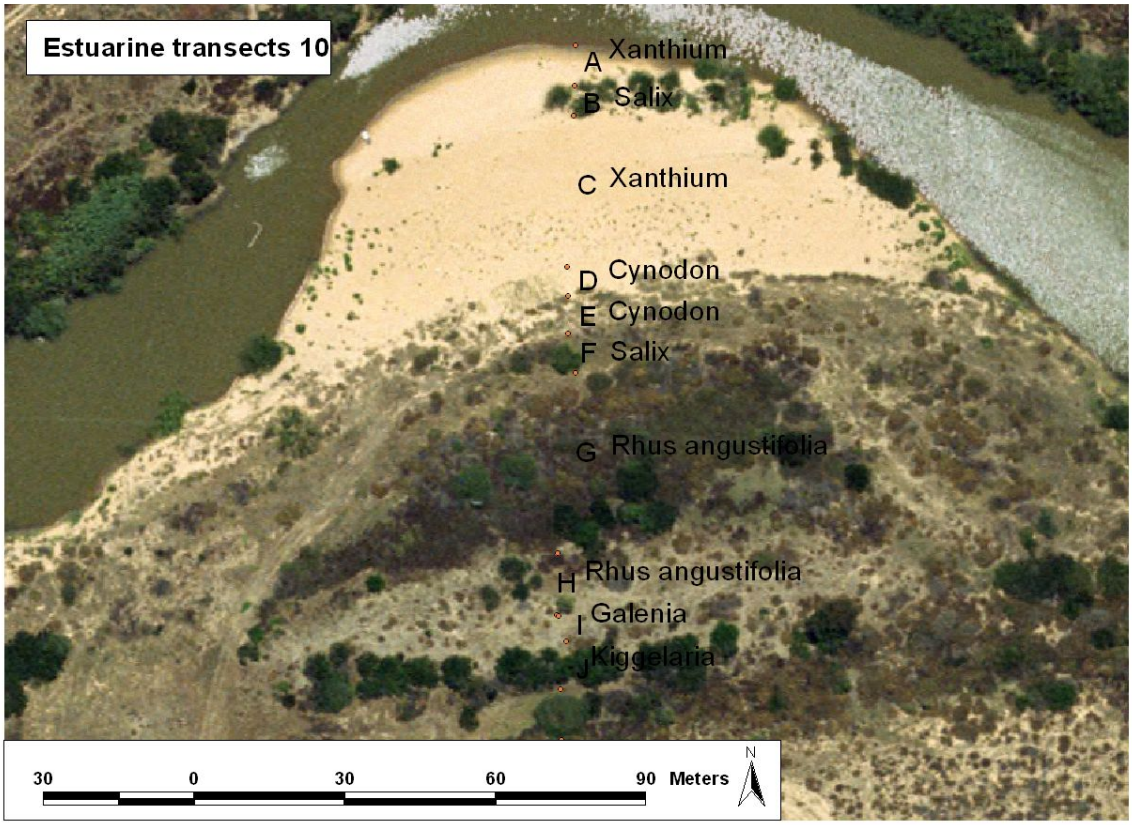


Figure A3.1.24 Aerial photograph indicating Transect 10 in 2003. The letters of the alphabet identify the plant communities as numbered in Table A3.1.21.



Figure A3.1.25 Transect 10 on the farm Caledonia on 12 February 2003.



Figure A3.1.26 By 10 March 2004 Transect 10 had been altered into a picnic site while a fire burnt through the site later that year.

Table A3.1.21 Floristic data recorded on Transect 10

| **Estuary Transect 10** | 10 | 10 | 10

12. TRANSECT 11 (LANGRIETVLEI)

This transect is through portion of a tidal pan located on the left bank floodplain of the Farm Langrietvlei (Figure 7.3, Figure A3.1.27). It was only sampled during 2003 as it was deemed to be too far from other transects to justify time spent to get to it particularly as four transects were located nearby on the opposite bank on the Farm Kruispad.

The transect vegetation is illustrated in Figure A3.1.28. *Juncus kraussii* and *Sarcocornia perennis* were both recorded in the most samples (5 out of a potential 10 samples). Twenty incidental species were recorded on a single occasion in 2003. Sample J was the richest sample with 12 species out of a potential 31 in it (Table A3.1.22).

The following dominant communities (Chapter 7.3, Table 7.1) were recorded at this site in the samples indicated:

1. *Sarcocornia pillansii* Dwarf Succulent Shrubland (Xeric Floodplain) (sample I, J)
2. *Sarcocornia perennis* Saltmarsh (Sedge Marsh and Halophytic Saltmarsh)
   - *2.1 Bassia diffusa-Sarcocornia perennis* Dwarf Shrubland typicum (Halophytic Saltmarsh) (sample H)
   - *2.2 Salicornia meyeriana-Triglochin bulbosa* Dwarf Shrubland (Open pan) (sample F, G)
   - *2.3 Sporobolus virginicus-Sarcocornia perennis* Grassland (Sedge Marsh) (sample D, E)
   - *2.4 Juncus kraussii-Sarcocornia perennis* Sedgeland (Sedge Marsh) (sample B, C, F)
3. *Cyperus textilis-Cotula coronopifolia* Sedgeland (Sedge Marsh) (sample A, B)
4. Azonal Riparian Woodland
   - 4.1 *Xanthium strumarium-Paspalum distichum* Riparian Herbland (Riparian Woodland) (sample C)
   - 4.2 *Chrysanthemoides incana-Lycium ferocissimum* Alluvium Strandveld (Strandveld) (sample J)

Sample B is a combination of communities 2.4 and 3 above. Sample C is a combination of communities 2.4 and 4.1 above. Sample F is a combination of communities 2.2 and 2.4 above. Sample J is a combination of communities 1 and 4.2 above.

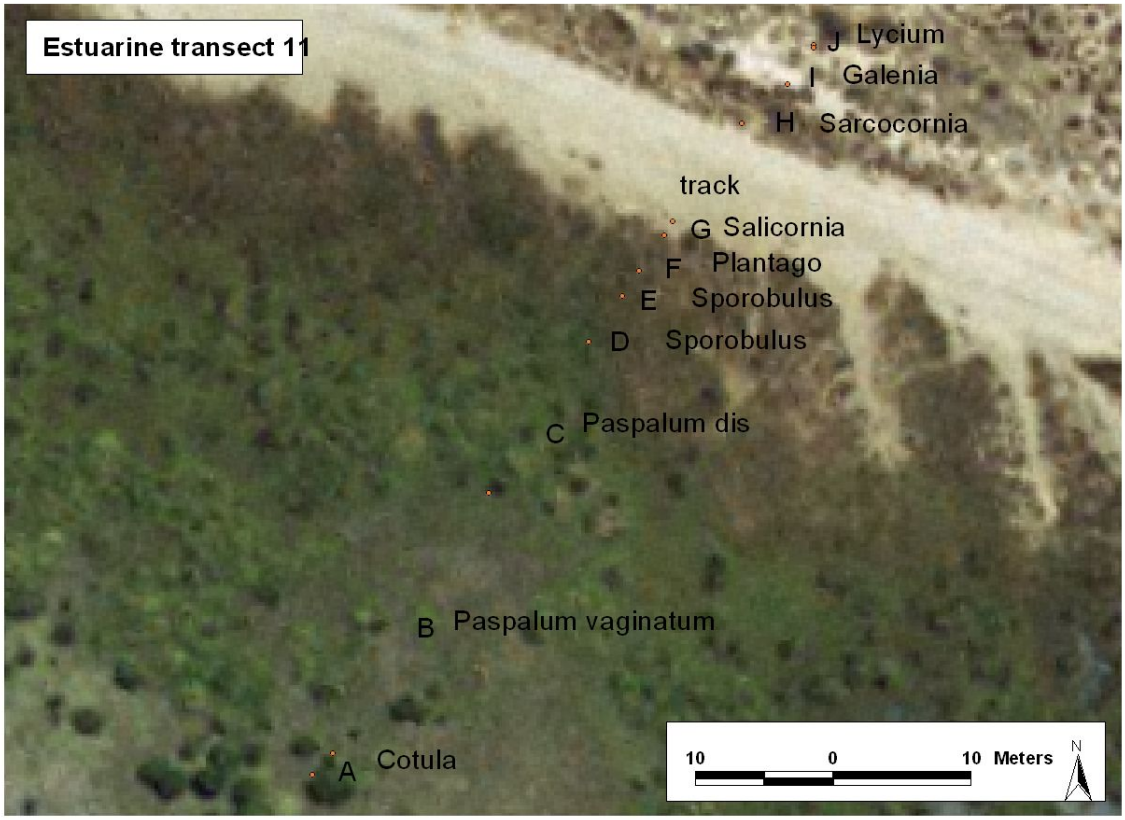


Figure A3.1.27 Aerial photograph indicating the location of Transect 11 for 2003. Letters of the alphabet identify plant communities as numbered in Table A3.1.22.



Figure A3.1.28 Transect 11 through the edge of the tidal pan on Langrietvlei on 13 February 2003.

Table 3.1.22 Floristic data recorded on Transect 11

Estuary Transect 11	11	11	11	11	11	11	11	11	11	11	
Sample No.	A	B	C	D	E	F	G	H	I	J	
Number of taxa of potential 31 in sample	**5**	**6**	**5**	**5**	**6**	**4**	**2**	**3**	**6**	**12**	**No. of records**
Asparagus capensis L.										+	1
Aster sp.					+						1
Berula erecta (Huds.) Coville	1	1	2								3
Bromus pectinatus Thunb.										1	1
Cephalophyllum sp.										1	1
Cotula coronopifolia L.	3	3	+	+							4
Crassula sp.								+			1
Cyperus sp.					R						1
Cyperus textilis Thunb.	3	1									2
Drosanthemum floribundum (Haw.) Schwantes									+	+	2
Ehrharta calycina Sm.										1	1
Eichhornia crassipes (Mart.) Solms	1										1
Frankenia repens (P.J.Bergius) Fourc.									R		1
Galenia sarcophylla Fenzl									3	1	2
Isolepis verrucosula (Steud.) Nees								1			1
Juncus kraussii Hochst.		1	2	+	+	R					5
Limonium depauperatum (Boiss.) R.A.Dyer										R	1
Lolium multiflorum Lam.									1		1
Lycium ferocissimum Miers										2	1
Manochlamys albicans (Aiton) Aellen									R	R	2
Panicum sp.					R						1
Paspalum distichum L.			4								1
Paspalum vaginatum Sw.		3									1
Plantago crassifolia Forssk. var. crassifolia						R					1
Rumex crispus L.										R	1
Salicornia meyeriana Moss						R	2				2
Sarcocornia perennis (Mill.) A.J.Scott				1	3	4	1	4			5
Sarcocornia pillansii (Moss) A.J.Scott										3	1
Spergularia media (L.) C.Presl ex Griseb.										+	1
Sporobolus virginicus (L.) Kunth				4	3				+		3
Triglochin bulbosa L.	+	+	+	R							4

13. TRANSECT 12 (VELDDRIF ABOVE CARINUS BRIDGE)

This transect is located at the site of an earlier Transect B6 recorded by O'Callaghan (1994a). It is located on the right bank opposite a parking area upstream of the Carinus Bridge (Figures 7.1 & 7.2).

Based on the coefficients of similarity of Jaccard and Sorenson, samples E, G, L (2003-2004); D, E (2004-2005); E, I (2003-2005) remained unchanged in species complement during the monitoring period. Generally, based on these two similarity co-efficients, the samples remained relatively similar over the monitoring period (Table A3.1.23)

Table A3.1.23 Average similarity of samples recorded along Transect 12 over 2003-2005 using Jaccard and Sorenson's Coefficients

	Transect 12			
	No.of records	**Ave Similarity 2003-04**	**Ave Similarity 2004-05**	**Ave Similarity 2003-05**
Jaccard Similarity Co-efficient %	12, 8, 8	76%	80%	81%
Sorenson's Similarity Co-efficient %	12, 8, 8	83%	87%	88%

Sarcocornia perennis was recorded in the most samples (36 samples out of a potential 37), followed by *Juncus kraussii* (29 samples) and *Bassia diffusa* (25 samples). One incidental species were recorded on a single occasion over the monitoring period. Sample H - 2003 is the richest sample with 7 species out of a potential 11 recorded over the whole transect (Table A3.1.24).

Sample A differentiated into two stands in 2004 and into three by 2005. Sample B was initially distinguished by a dense patch of *Juncus kraussii*, but this reduced in 2004 and had almost disappeared by 2005 while the cover of *Triglochin striata* increased. The reverse change in dominance occurred in samples I & J with *Juncus* increasing and *Triglochin* reducing. This has resulted in B & C becoming a single stand. *Bassia diffusa* has disappeared from G and E, F & G of 2003 became indistinguishable by 2005. All these changes are probably related to a generally lowering of inundation levels (see inundation graph 71), hence the advancement of the saltmarsh into the channel (stand A) and associated in-filling of drainage channels leaving pools with higher salinities in the parts of saltmarshes distant from the main channel (stand K) (Table A3.1.24).

The transect location is illustrated in Figure A3.1.29 and the vegetation in Figure A3.1.30. The following dominant communities (Boucher & Jones - BRBMP Vol 3 Ch 7, Table 7.1) were recorded at this site in the samples indicated:

1. *Zostera capensis* Aquatic beds (Inundated Mudflats) (observed in deeper water but not sampled)
2. *Sarcocornia perennis* Saltmarsh (Sedge Marsh and Halophytic Saltmarsh)
   - *2.1 Bassia diffusa-Sarcocornia perennis* Dwarf Shrubland typicum (Halophytic Saltmarsh) (sample A)
   - *2.2 Sporobolus virginicus-Sarcocornia perennis* Grassland (Sedge Marsh) (sample H)
   - *2.3 Juncus kraussii-Sarcocornia perennis* Sedgeland (Sedge Marsh) (sampleS D-G, I-K)
3. Sand Strandveld
   - *3.1 Chrysanthemoides incana-Lycium ferocissimum* Alluvium Strandveld (Strandveld) (sample L).

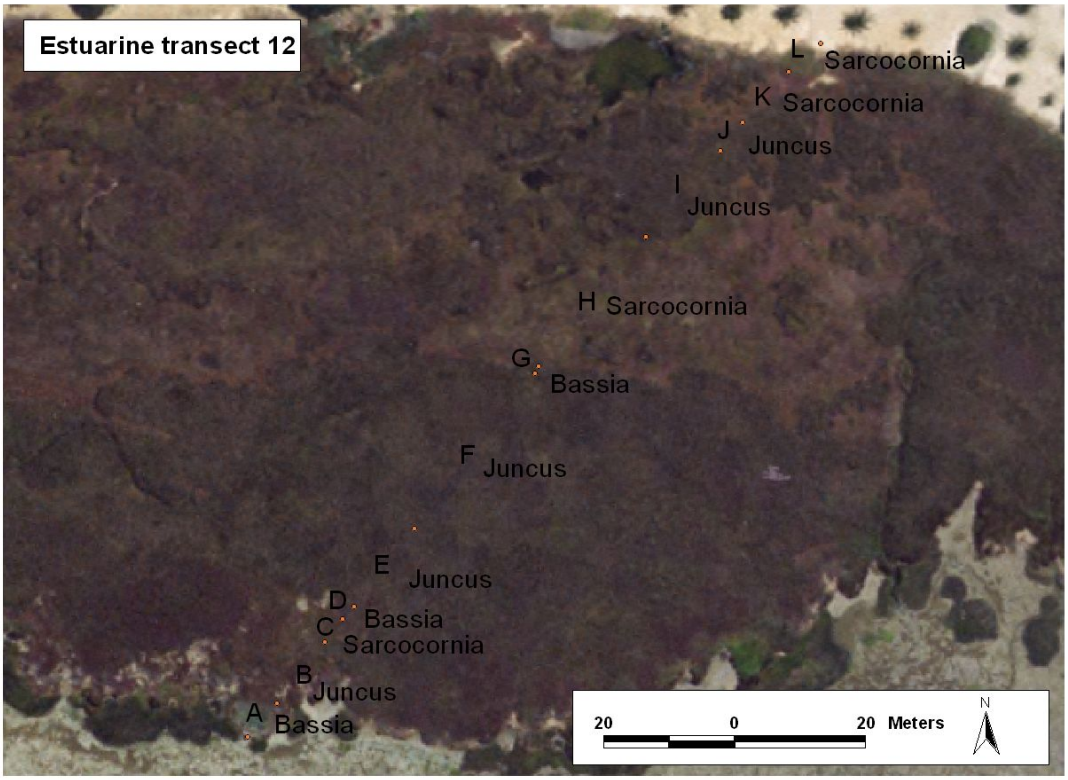


Figure A3.1.29 *Aerial photograph of Transect 12 for 2003. The letters of the alphabet identify the plant communities as numbered in the text above and in Table A3.1.24. The orange points separate the stands.*



Figure A3.1.30 *Saltmarsh vegetation along Transect 12 on 13 February 2003. Note typical erosion step in saltmarsh foreground. The dominant tall sedge in the middle distance is Juncus kraussii.*

Table A3.1.24 Floristic data recorded on Transect 12

| **Estuary Transect 12** | 12 | 12 | 12

14. TRANSECT 13 (KRUISPAD PAN)

This site is located on a pan on the right bank floodplain of the Farm Kruispad (Figure 7.2). As the pan is roughly circular it was measured as a single unit being a total of 1732.976 m^2 in area. These pans occur sporadically through the floodplain.

The boundary of each zone was measured using an Omnistar D-GPS to determine the dimensions of the pan and to provide a reasonably accurate measure against which to quantify changes (Figure A3.1.31). The inner pan community (A on map) had an area of 649.823 m^2 and community B an area of 1083.153 m^2. The three samples supported 11 species (Table A3.1.25).

The following dominant communities (Boucher & Jones - BRBMP Vol 3 Ch 7, Table 7.1) were recorded at this site in the samples indicated:

1. Depauperate disturbed *Sporobolus virginicus-Sarcocornia perennis* Grassland Pan (Sedge Marsh) (sample A)
2. *Sarcocornia perennis* Saltmarsh (Halophytic Saltmarsh) (sample B)
3. *Sarcocornia pillansii* Dwarf Succulent Shrubland (Xeric Floodplain) (sample C) (Figure A3.1.32)

The pan community has relatively low cover (Figure A3.1.31) and the grass component has been heavily grazed consequently exotic annual grasses instead of the perennial grass, *Sporobolus virginicus* are abundant.

Table A3.1.25 Floristic data recorded on Transect 13

Estuary Transect 13	13	13	13	
Sample No.	A	B	C	
Number of taxa of potential 11 in sample	**5**	**5**	**4**	**No. of records**
Bromus pectinatus Thunb.		1		1
Drosanthemum floribundum (Haw.) Schwantes			+	1
Galenia secunda (L.F.) Sond.	3			1
Hordeum capense Thunb.		2	+	2
Lolium multiflorum Lam.	R			1
Medicago polymorpha L.	2			1
Poaceae annual grasses (dead)	2	3	3	3
Oncosiphon suffruticosum (L.) Källersjö		R		1
Sarcocornia perennis (Mill.) A.J.Scott		4		1
Sarcocornia pillansii (Moss) A.J.Scott			4	1
Sporobolus virginicus (L.) Kunth	R			1

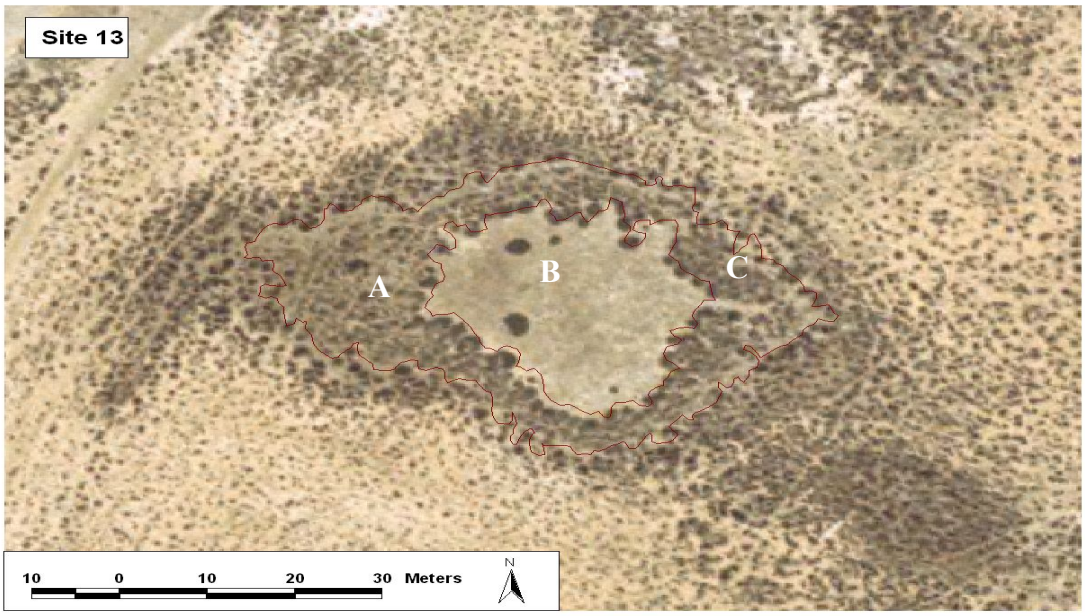


Figure A3.1.31 Kruispad Pan with the 2003 survey points in Transect 13 outlined. Communities A, B and C are identified in the text (Table A3.1.25).

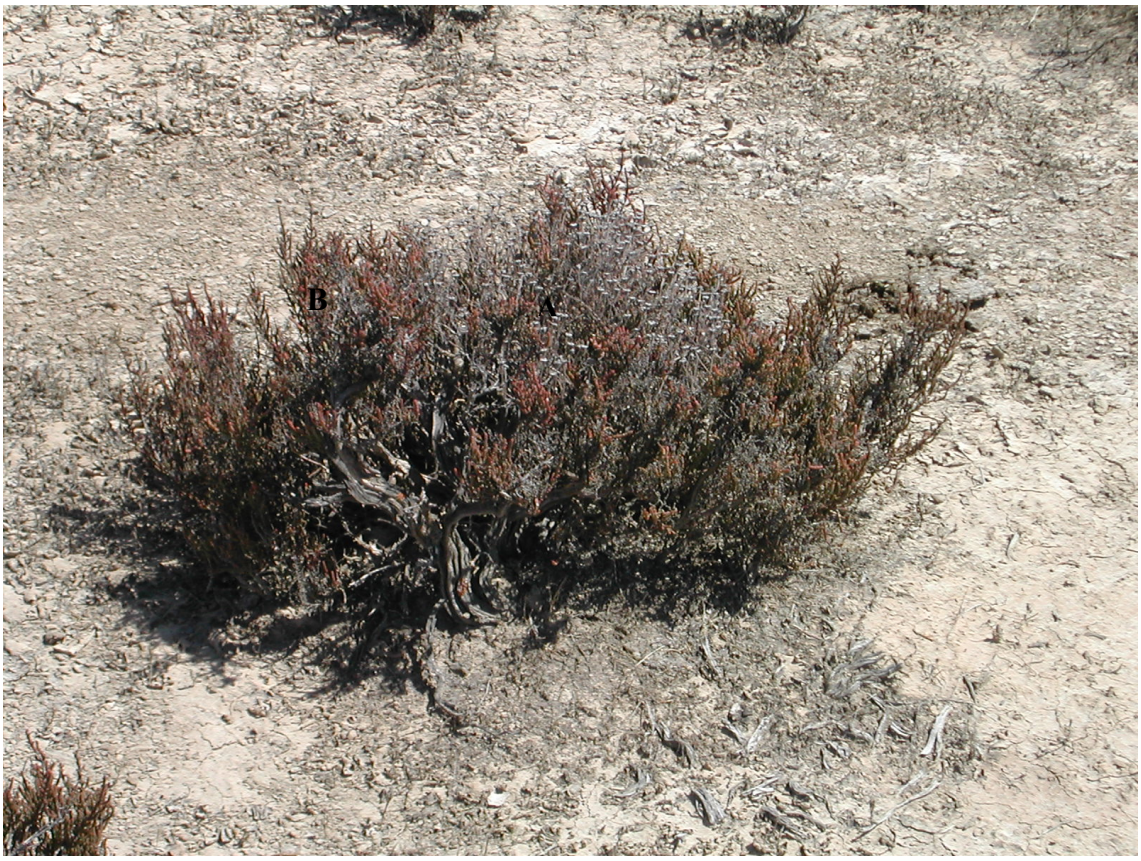


Figure A3.1.32 Sarcocornia pillansii on Kruispad pan.

15. *PHRAGMITES AUSTRALIS* AT TRANSECTS 14, 15 & 16 (DIE PLAAT, BOVENPLAAT)

These sites are located on the right bank of the river on the Farm Bovenplaat downstream of the Sishen-Saldanha railway line (Figures 7.1 & 7.3). They were sampled in 2003 to enable monitoring of changes in patch sizes of *Phragmites australis* (Figure A3.1.33). This species is an important biological component, habitat provider and visual feature along the lower river course. No subsequent assessment of these clumps was undertaken due to financial constraints placed on the surveying budget, never-the-less the primary assessment has been done and changes should be monitored by future surveyors given adequate budgets or even by accurate aerial surveying techniques, which are probably preferable from an aerial area determination, although not from a ground-truthing consequences or causes perspective.

Areas occupied by the different *Phragmites* clumps in 2003 are indicated below:

Transect 14 - 148.509 m^2
Transect 15 - 227.515 m^2
Transect 16 – Live plant only that is too small to measure its area

These clumps are all classified as *Phragmites australis* Reedlands (Reed Marshes) (Figure A.3.1.34, A3.1.35, A3.1.36).

It is worth recording that, based on field observations in 2003, piles of *Eichhornia crassipes* debris at site 15 were considered to be having a negative effective, depressive effect on the expansion of this reedbed killing the reedbeds and even secondarily resulting in erosion at sites 14 and 16 because of the subsequent unprotected substrate.



Figure A3.1.33 Phragmites australis at Transect 16 on Bovenplaat Farm.

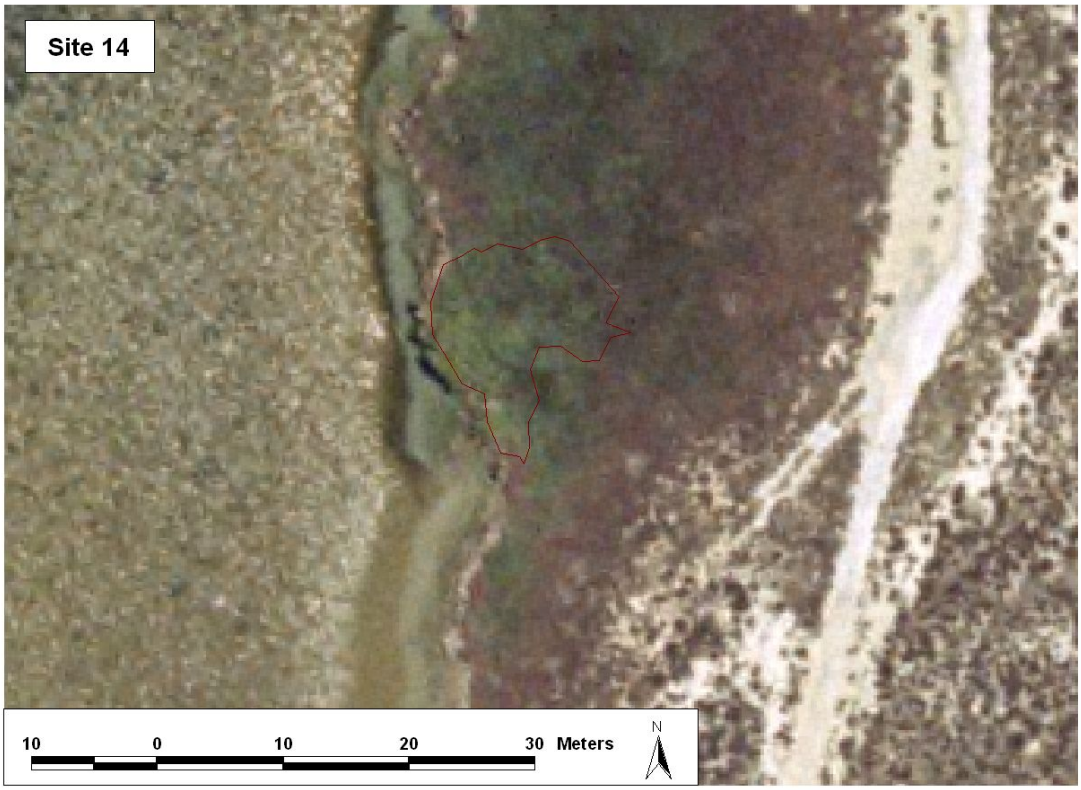


Figure A3.1.34 Phragmites australis stand on Bovenplaat (Transect 14) outlined using 2003 measurements.

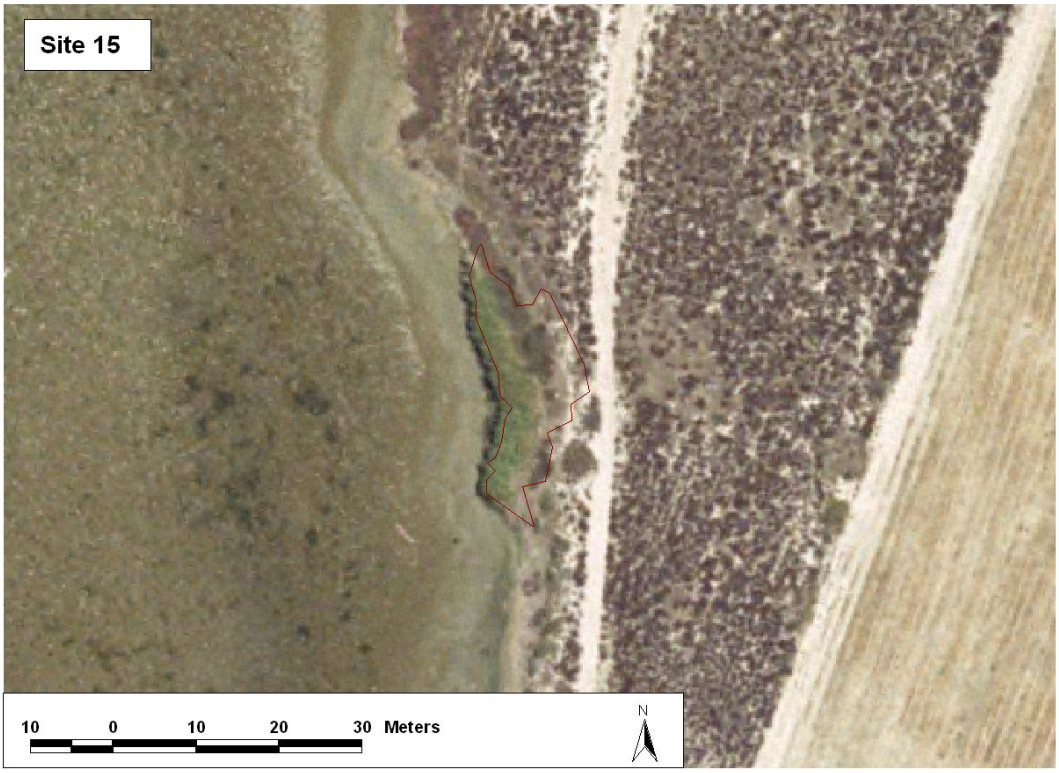


Figure A3.1.35 Phragmites australis stand on Bovenplaat (Transect 15) outlined using 2003 measurements.



Figure A3.1.36 Phragmites australis stand on Bovenplaat (Transect 16) outlined using 2003 measurements.

16. *CYPERUS TEXTILIS* AT TRANSECT 17 (BOVENPLAAT FARM)

This transect is located along the right bank immediately upstream of the Sishen-Saldanha railway bridge (Figure 7.2). It was sampled in 2003 to enable monitoring of changes in patch sizes of *Cyperus textilis*, an important species fringing open fresher water bodies and counteracting erosion from wave action. This particular clump was the nearest to the estuary observed during the 2003 survey.

The areas occupied by this particular *Cyperus textilis* clump in 2003 (Figure A3.1.37) was calculated as being 0.778 m^2. No subsequent assessment of this clump was undertaken due to financial constraints placed on the surveying budget, never-the-less the primary assessment has been done and changes should be monitored by future surveyors.

This clump (Figure A3.1.38) is classified as belonging to the *Cyperus textilis-Cotula coronopifolia* Sedgeland (Sedge Marsh) community (Boucher & Jones - BRBMP Vol 3 Ch 7, Table 7.1)

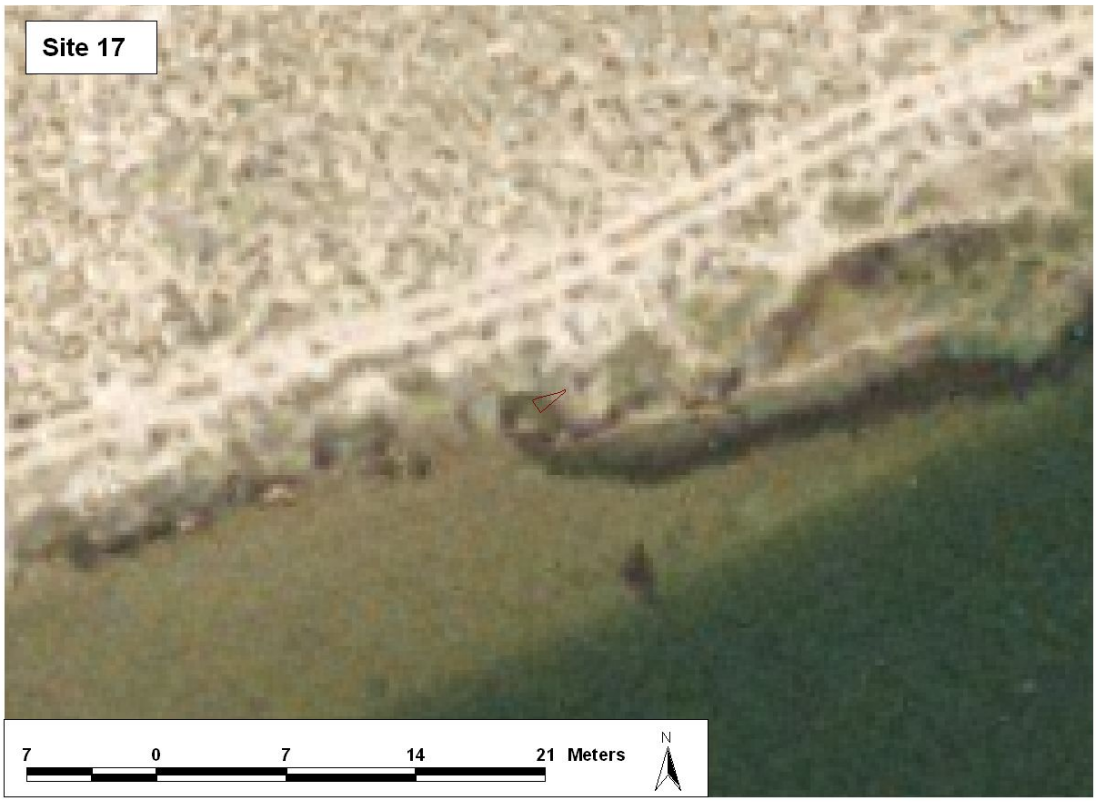


Figure A3.1.37 *Cyperus textilis stand on Bovenplaat (Transect 17) outlined using 2003 measurements. This appears to be the lowest stand of Cyperus textilis nearest the Berg River mouth at the limits of its salinity tolerances.*



Figure A3.1.38 *The lowest living clump of Cyperus textilis observed and measured along the lower Berg River during the 2003 survey.*

17. *TYPHA CAPENSIS* AT TRANSECT 18 (KRUISPAD EAST)

This transect is located on the Farm Kruispad near the eastern boundary of the property along the Berg River course (Figure 7.2). *Typha capensis* regularly becomes a dominant species along the margins of freshwater wetland systems in the Cape. This species is not understood to be tolerant of prolonged exposure to saline water. It was deemed useful to monitor the performance of this particular patch of the species as it was located in the Berg estuary and would add to the information of importance in applying the species for monitoring changes to water quality. In all four clumps of *Typha capensis* were measured during 2003 at this site.

These clumps are classified as belonging to the *Phragmites australis* Reedlands (Reed Marsh). The area occupied by the four *Typha capensis* groups, with a total estimated at 40 individuals, at this site in 2003, identified in Figure 3.1.39, was calculated as totalling 31.647 m^2.

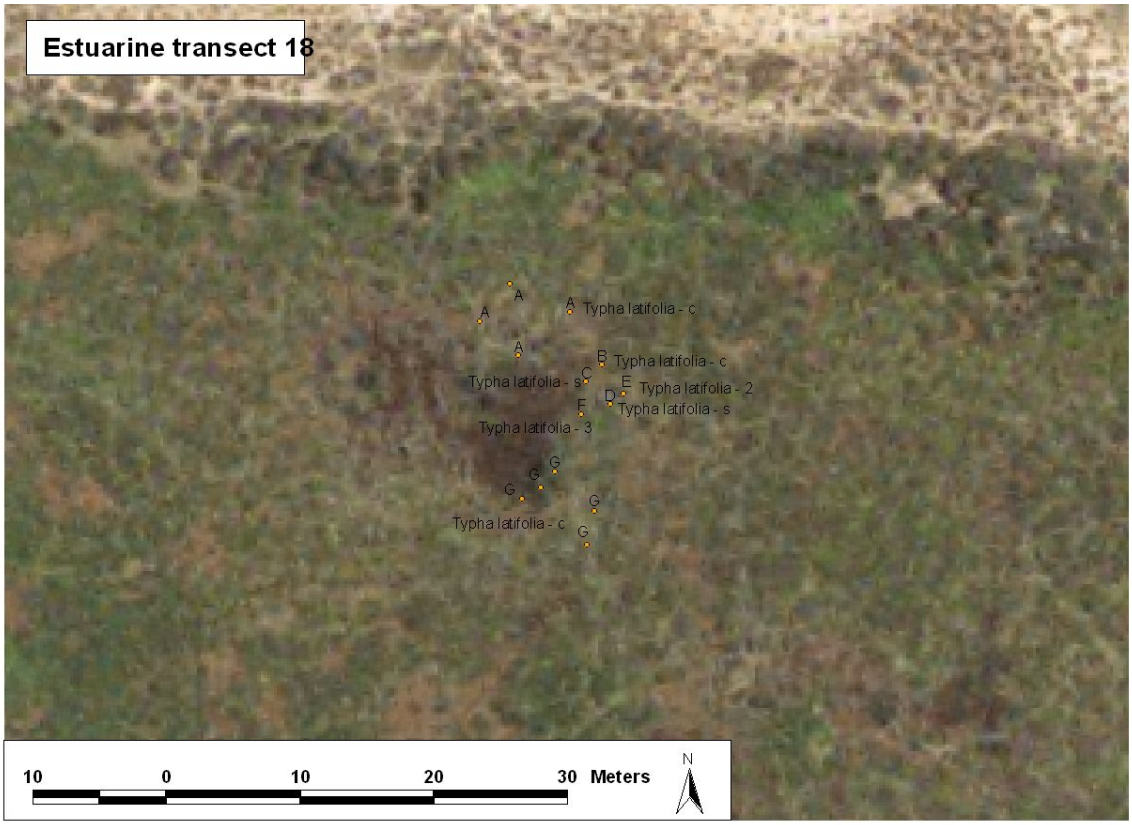


Figure A3.1.39 Aerial photograph showing the outlines of clumps of Typha capensis measured at Kruispad East (Transect 18) in 2003. The orange points outline the boundaries of the clumps.

18. *PRIONIUM SERRATUM* AT TRANSECT 19 (KERSEFONTEIN)

This transect is located near the downstream boundary of the Farm Kersefontein (Figures 7.4 & A3.1.40). *Prionium serratum* is a common species that forms dense fringing stands along Western Cape rivers, frequenting waters that are acid, non-saline and originating from sandstones, preferring unshaded areas (Boucher & Withers 2004). The particular clumps measured here (Figure A3.1.41) were observed in 2003 to be the lowest occurring down the Berg River and were therefore ideally suited to monitor environmental change, particularly given their perceived water requirements. Should an excessive reduction in fresh water occur, then this clump should respond by degenerating, reducing in size and eventually dying.

This species forms part of the Western Cape Azonal Riparian Woodland community (Chapter 7.3, Table 7.1). It was recorded at this site in the samples indicated with a calculated area of 49.329 m^2.

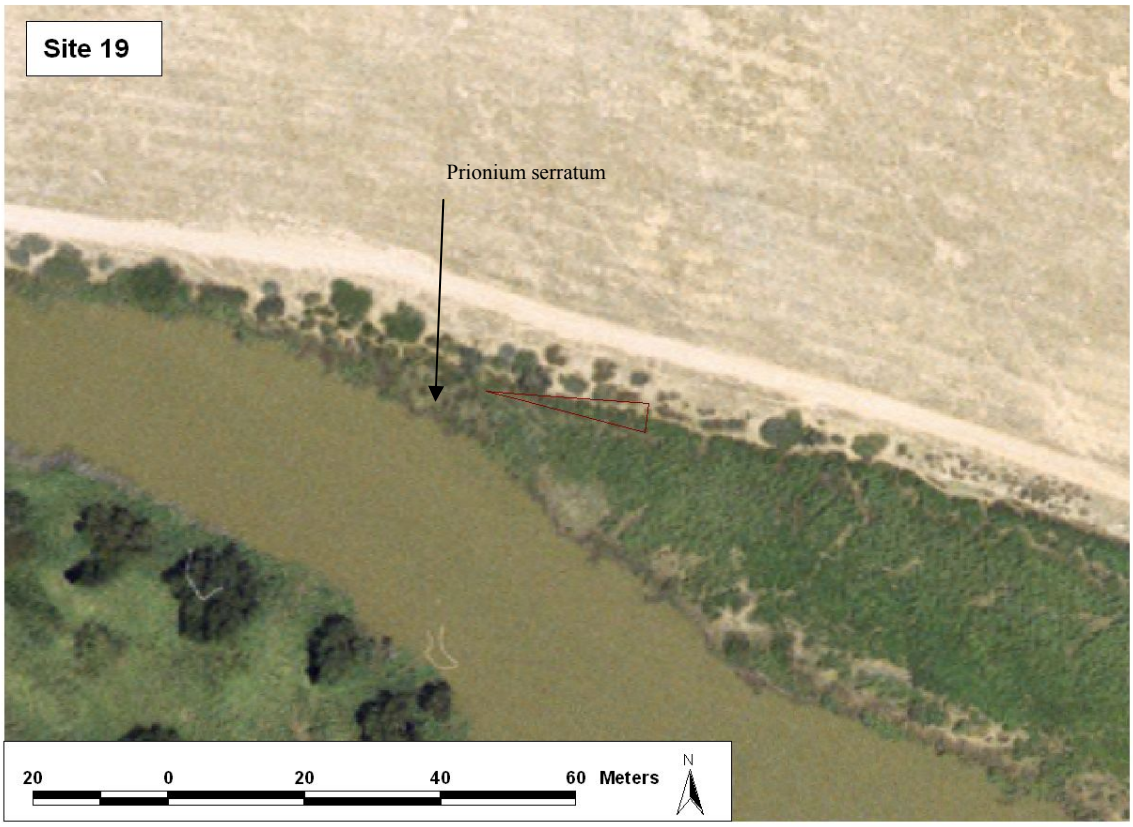


Figure A3.1.40 Aerial photograph showing the location of clumps of Prionium serratum, the nearest to the Berg River mouth, measured at Kersefontein (Transect 19) in 2003.



Figure A3.1.41 One of the lowest surviving clumps of Prionium serratum along the Berg River on Kersefontein Farm.

19. TRANSECT 20 (KRUISPAD EAST NO. 2)

This transect is located near the eastern boundary of the farm Kruispad (Figure 7.2).

Based on the Jaccard and Sorenson Coefficients of Similarity, samples B and H (2004-2005) remained unchanged in species complement although not necessarily in individual species cover, during the monitoring period (Table A3.1.26).

Table A3.1.26 Average similarity of samples along Transect 20 between years 2003-2005 using Jaccard and Sorenson's Coefficients

Estuary Transect 20 (2)		
	No.of records	**Ave Similarity 2004-05**
Jaccard Similarity Co-efficient %	20	73%
Sorenson's Similarity Co-efficient %	20	84%

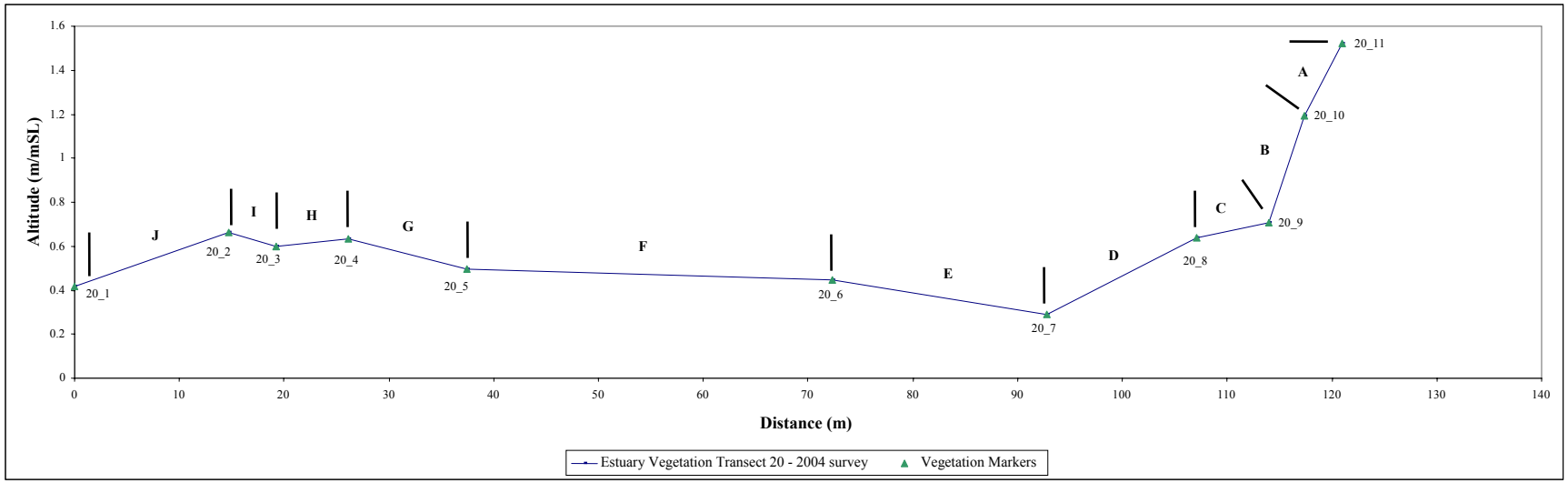
The following dominant communities (Boucher & Jones - BRBMP Vol 3 Ch 7, Table 7.1) were recorded at this site in the samples indicated:

- *Sarcocornia pillansii* Dwarf Shrubland (Xeric Floodplain) (sample A)
- *Sporobolus virginicus-Sarcocornia perennis* Grassland (Sedge Marsh) (sample B)
- *Juncus kraussii-Sarcocornia perennis* Sedgeland (Sedge Marsh) (sample C & G)
- *Leptochloa fusca-Sarcocornia perennis* Grassland (Reed Marsh – Short) (sample I).
- *Cyperus textilis-Cotula coronopifolia* Sedgeland (Reed Marsh – Short) (samples D, E, F, H & J).

While, in some instances, other non-dominant communities were also present at different stands. These could be an indication of changes in progress at the site. The location of vegetation stands along the transects in 2004 and 2005 are illustrated in Figures A3.1.42 & A3.1.43. The following additional, non-dominant, communities were recorded at stands D & E (*Leptochloa fusca-Sarcocornia perennis* Grassland), G & I (*Cyperus textilis-Cotula coronopifolia* Sedgeland, while G also had *Sporobolus virginicus-Sarcocornia perennis* Grassland. *Phragmites australis* Reedlands were present to varying degrees at all the stands from C to J (Table A3.1.27).

Heavy grazing and trampling resulted in *Leptochloa fusca*, a very palatable grass, not being found in samples E and G in 2005, although it was abundant in 2004. *Cyperus textilis* generally did not occur together with *Chenopodium album, Juncus kraussii* and *Sarcocornia perennis* with the latter species possibly preferring the areas with higher salinity levels (Figure A3.1.44). Sample A represents the dry saline flats on the higher floodplain (Table A3.1.27).

Sample G (2004) was the richest sample with seven out of a potential 17 species recorded along the transect in it. *Phragmites australis* was recorded in the most samples (16 out of potential 20 samples), followed by *Cyperus textilis* in ten samples each. Six incidental species were recorded on a single occasion over the monitoring period (Table A3.1.27).



FigureA3.1.42 Cross-section profile of Transect 20 for 2004. Letters of the alphabet identify plant communities as numbered in Table A3.1.27.

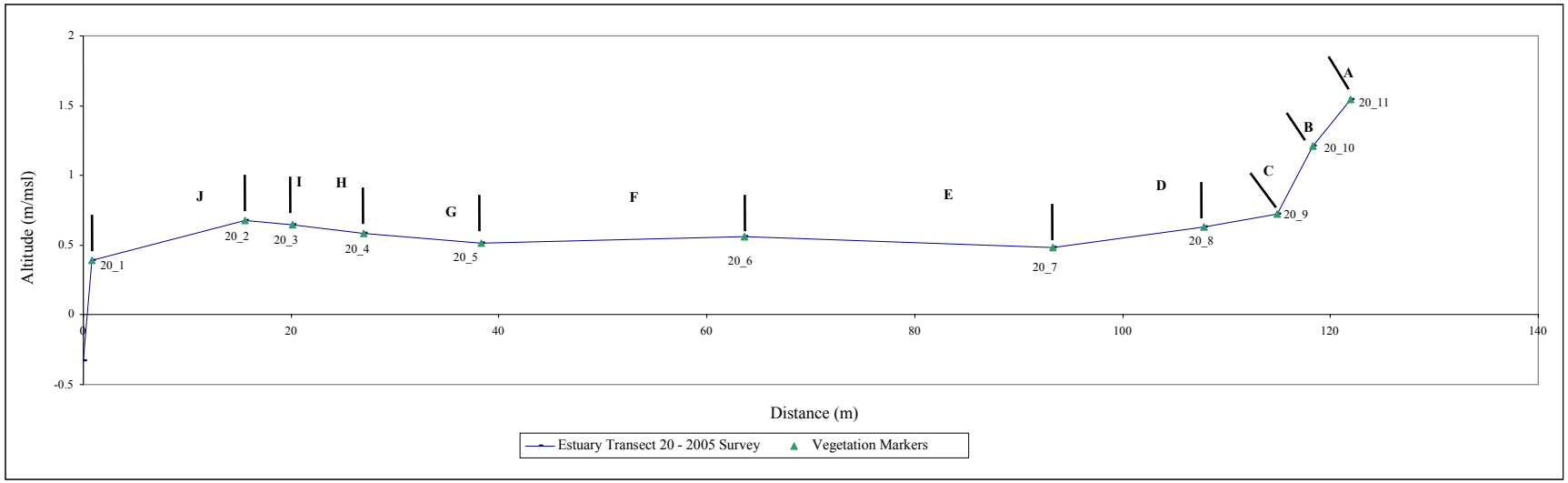


Figure A3.1.43 Cross-section profile of Transect 20 for 2005. Letters of the alphabet identify plant communities as numbered in Table A3.1.27.

Table A3.1.27 Floristic data recorded on Transect 20

Transect 20 (Kruispad East No. 2)	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	
Sample No.	A	A	B	B	C	C	D	D	E	E	F	F	G	G	H	H	I	I	J	J	
Year	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005	
1. Jaccard Similarity Co-efficient %. Present year compared to previous year		60%		100%		80%		75%		50%		75%		71%		100%		75%		50%	
2. Sorenson's Similarity Co-efficient %. Present year compared to previous year.		75%		100%		89%		86%		67%		86%		83%		100%		86%		67%	
Number of taxa of potential 17 in each sample =	**5**	**3**	**2**	**2**	**4**	**5**	**4**	**3**	**4**	**2**	**4**	**3**	**7**	**5**	**2**	**2**	**3**	**4**	**5**	**4**	**No. of records**
Atriplex semibaccata R.Br.	R																				**1**
Berula erecta (Huds.) Coville																			R		**1**
Bolboeschoenus maritimus (L.) Palla									R												**1**
Chenopodium album L.					1	1							+	+							**4**
Cotula coronopifolia L.							+				1	+	2	+			1	+	1	+	**9**
Cyperus textilis Thunb.							5	4	R	2	5	5			5	5			5	5	**10**
Drosanthemum floribundum (Haw.) Schwantes	+																				**1**
Juncus kraussii Hochst.					5	5					R		4	5							**5**
Leptochloa fusca (L.) Kunth							+	+	2				2				5	4			**6**
Lycium cinereum Thunb. sensu lato	1	1																			**2**
Phragmites australis (Cav.) Steud.					+	+	2	2	3	3	2	2	1	1	1	1	+	+	1	1	**16**
Poaceae sp.	R	R																			**2**
Sarcocornia perennis (Mill.) A.J.Scott			5	4	2	2							+	+							**6**
Sarcocornia pillansii (Moss) A.J.Scott	3	3																			**2**
Schoenoplectus scirpoideus (Schrad.) Browning																				+	**1**
Sporobolus virginicus (L.) Kunth			+	+		R							1					1			**5**
Triglochin striata Ruiz & Pav.																			R		**1**



Figure A3.1.44 Transect 20 on Kruispad Farm on 11 March 2004. The tall clumps of Juncus kraussii generally occupied different areas to the low-growing succulent-leaved Sarcocornia perennis.

20. TRANSECT 21 (KRUISPAD WEST 2)

This transect is located in the marsh located south of the Kruispad Farm homestead (Figure 7.2).

Based on the Jaccard and Sorenson Coefficients of Similarity samples C & O remained unchanged in species complement over the two year monitoring period, but not necessarily in individual cover values (Table A3.1.28).

Table A3.1.28 Average similarity of samples along Transect 21 between years 2004-2005 using Jaccard and Sorenson's Coefficients

Estuary Transect 21		
	No.of records	**Ave Similarity 2004-05**
Jaccard Similarity Co-efficient %	13	77%
Sorenson's Similarity Co-efficient %	13	86%

The following dominant communities (Boucher & Jones - BRBMP Vol 3 Ch 7, Table 7.1) were recorded in the samples indicated at this site (the location of samples along profiles are indicated in Figures A3.1.45 and A3.1.46):

- *Sarcocornia pillansii* Dwarf Shrubland (Xeric Floodplain) (sample O).
- *Sarcocornia perennis* Saltmarshes (Sedge Marsh) (sample N was undifferentiated)
- *Sporobolus virginicus-Sarcocornia perennis* Grassland (Sedge Marsh) (sample M).
- A mosaic of two communities *Sporobolus virginicus-Sarcocornia perennis* Grassland (Sedge Marsh) & *Juncus kraussii-Sarcocornia perennis* Sedgeland (Sedge Marsh) (samples I & L).
- A mosaic of two communities *Schoenoplectus scirpoideus* Sedgeland (Reed Marsh – Short) & *Cyperus textilis-Cotula coronopifolia* Sedgeland (Reed Marsh – Short) (samples A & B).
- A mosaic of three or more sedge or short reed marsh communities, including *Sporobolus virginicus-Sarcocornia perennis* Grassland (Sedge Marsh), *Juncus kraussii-Sarcocornia perennis* Sedgeland (Sedge Marsh) and *Leptochloa fusca-Sarcocornia perennis* Grassland (Reed Marsh – Short), *Cyperus textilis-Cotula coronopifolia* Sedgeland (Reed Marsh – Short), *Schoenoplectus scirpoideus* Sedgeland (Reed Marsh – Short) (samples C–F, J & K)

Samples F – H of 2004 were indistinguishable in the field in 2005, therefore their contents are listed jointly under F in 2005 (Table A3.1.29). Sample N had undergone change by 2005 and was subdivided into two monotypic stands. Differentiation of N2 into another community is probably in progress here (Table A3.1.29).

The transect vegetation is illustrated in Figure 7.63. *Juncus kraussii* mostly showed a reduction in cover over the 2 years except notably in stand L where it increased slightly. Stand E (2005) was the richest sample with 10 species in it out of a potential 19. *Sarcocornia perennis* and *Sporobolus virginicus* (each recorded in 19 samples out of a potential 29) and *Juncus kraussii* (17 samples) were recorded in the most samples over the two years. A single incidental species (*Berula erecta*) was recorded on a one occasion along the transect over the monitoring period (Table A3.1.29).

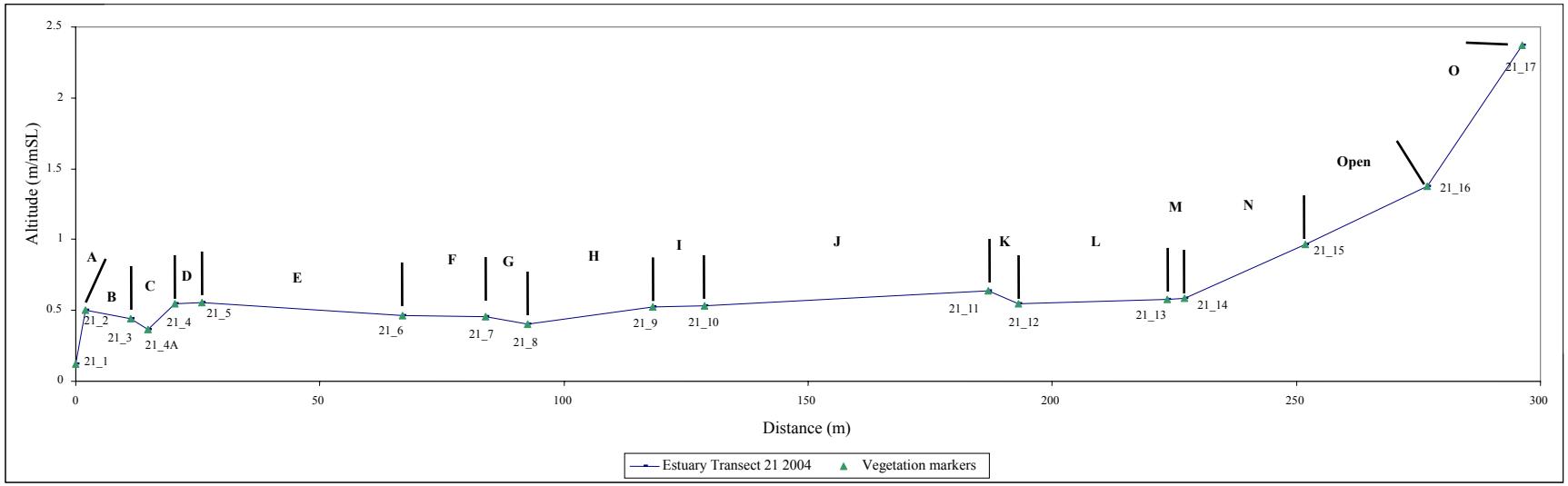


Figure A3.1.45 Cross-section profile of Transect 21 for 2004. Letters of the alphabet identify plant communities as numbered in Table A3.1.29.

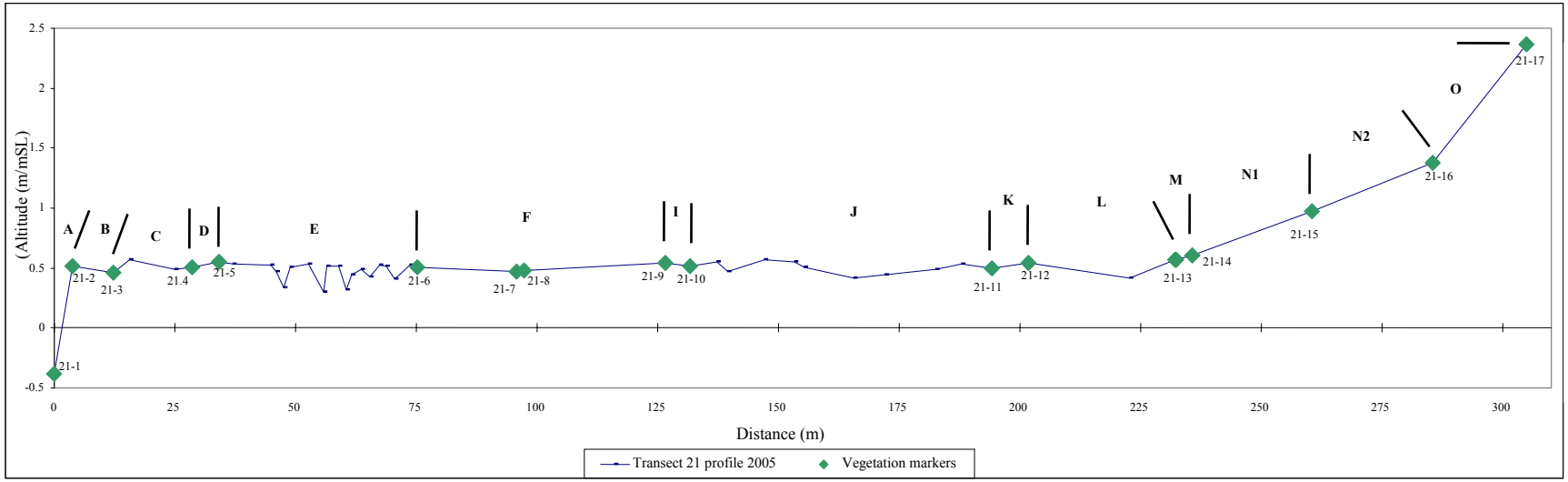


Figure A3.1.46 Cross-section profile of Transect 21 for 2005. Letters of the alphabet identify plant communities as numbered in Table A3.1.29.

Table A3.1.29 Floristic data recorded on Transect 21

Transect 21 Kruispad West (2)	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	
Sample No.	A	A	B	B	C	C	D	D	E	E	F	F	G	G	H	H	I	I	J	J	K	K	L	L	M	M	N	N 1	N 2	O	O	
Year	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005	2005	2004	2005		
1. Jaccard Similarity Co-efficient %. Present year compared to previous year		80%		43%		100%		67%		73%		56%						80%		67%		80%		80%		75%		100%			100%		
2. Sorenson's Similarity Co-efficient %. Present year compared to previous year.		89%		60%		100%		80%		84%		71%						89%		80%		89%		89%		86%		100%			100%		
Number of taxa of potential 19 in sample =	**4**	**5**	**4**	**6**	**7**	**7**	**8**	**7**	**9**	**10**	**6**	**8**	**4**	**0**	**1**	**0**	**4**	**5**	**4**	**6**	**4**	**5**	**5**	**4**	**4**	**3**	**1**	**1**	**1**	**3**	**3**	**No. of records**
Asparagus capensis L.																														+	+	2
Berula erecta (Huds.) Coville			R																													1
Bolboeschoenus maritimus (L.) Palla									R	1		1	3				1	1	+	2	1	1	4	3								12
Chenopodium album L.							1	+		1	+																					4
Cotula coronopifolia L.	3	2	3	1	4	4	1		1																							8
Cynodon dactylon (L.) Pers.		1		R																												2
Cyperus textilis Thunb.	2	2	4	4			3	2																								6
Disphyma crassifolium (L.) L.Bolus																														R	R	2
Drosanthemum floribundum (Haw.) Schwantes																														1	1	2
Juncus kraussii Hochst.					+	+	3	3	4	3	2	1	2				3	2	3	2	4	3	2	3								17
Leptochloa fusca (L.) Kunth					+	+	+		2	2	R	+	2						1	1					+							11
Phragmites australis (Cav.) Steud.	3	2	2	2	1	1						+																				7
Samolus porosus (L.f.) Thunb.							1	2	+	+								+														5
Sarcocornia perennis (Mill.) A.J.Scott				+			2	2	2	2	2	2					4	3		1	3	3	+	1	2	R	4	4	+			19
Sarcocornia pillansii (Moss) A.J.Scott																														2	2	2
Schoenoplectus scirpoideus (Schrad.) Browning	3	2		1	3	3				+	3	4			4					+		3										11
Senecio burchellii DC.								+	R	+																						3
Sporobolus virginicus (L.) Kunth					1	1	2	2	2	2	1	+	1				2	2	+	1	1	1	1	+	2	+						19
Triglochin striata Ruiz & Pav.					+	+			R	+		R											1		1	+						8



Figure A3.1.47 Transect 21 on Kruispad Farm inundated on 14 April 2005 after spring high tide.

21. TRANSECT 22 (CEREBOS - 2)

This transect is located in the large saltmarsh extending from the edge of the Cerebos salt dams to the primary river channel (Figure 7.1 & 7.2).

Based on the coefficients of similarity of Jaccard and Sorenson, 50% of the samples remained unchanged in species complement during the monitoring period. The average Jaccard Similarity Coefficient for all the samples was 81% and the Sorenson Similarity Coefficient 88%. These are exceptionally high degrees of similarity showing little overall change in species complement although this was not the case for cover-abundance values (Table A3.1.30).

Table A3.1.30 Average similarity of samples along Transect 22 between years 2004-2005 using Jaccard and Sorenson's Coefficients

Estuary Transect 22		
	No.of records	**Ave Similarity 2004-05**
Jaccard Similarity Co-efficient %	16	81%
Sorenson's Similarity Co-efficient %	16	88%

The transect vegetation is illustrated in Figure A3.1.48. The following dominant communities (Boucher & Jones - BRBMP Vol 3 Ch 7, Table 7.1) were recorded in the samples indicated at this site (Figures A3.1.49 & A3.1.50).

They belong to the general Halophytic saltmarsh and Sedge Marsh groups:

- *Bassia diffusa-Sarcocornia perennis* Dwarf Shrubland typicum (Halophytic Saltmarsh) (sample H)
- *Salicornia meyeriana-Triglochin bulbosa* Dwarf Shrubland (Open pan) (samples N -- P)
- *Limonium depauperatum-Triglochin striata* Herbland (Halophytic Saltmarsh) (samples B, C, K & M)
- *Juncus kraussii-Sarcocornia perennis* Sedgeland (Sedge Marsh) (samples E & F)

A mosaic of two communities with either or both of the following communities dominant: *Triglochin striata-Limonium depauperatum* Herbland (Halophytic Saltmarsh) & *Juncus kraussii-Sarcocornia perennis* Sedgeland (Sedge Marsh) (samples D, G, I, J & L).

Samples K1and K2 of 2004 were indistinguishable in the field during 2005 and their contents are listed jointly the 2nd year in Table A3.1.31.

Sarcocornia perennis was recorded in all the 33 samples along this transect, followed by *Bassia diffusa* in 29 and *Triglochin striata* in 24 samples. Two incidental species were recorded on a single occasion over the monitoring period. Sample I (2005) was the richest sample with seven out of a potential ten species in it (Table A3.1.31).

Notable changes in cover and density of the important species, *Bassia diffusa, Limonium depauperatum, Sarcocornia perennis* and *Triglochin striata* has occurred at samples E, I, L, N and O. This is indicative that environmental change is probably taking place at these stands, but a longer monitoring period is required to determine the direction and causes of the probable change (Table a3.1.31).

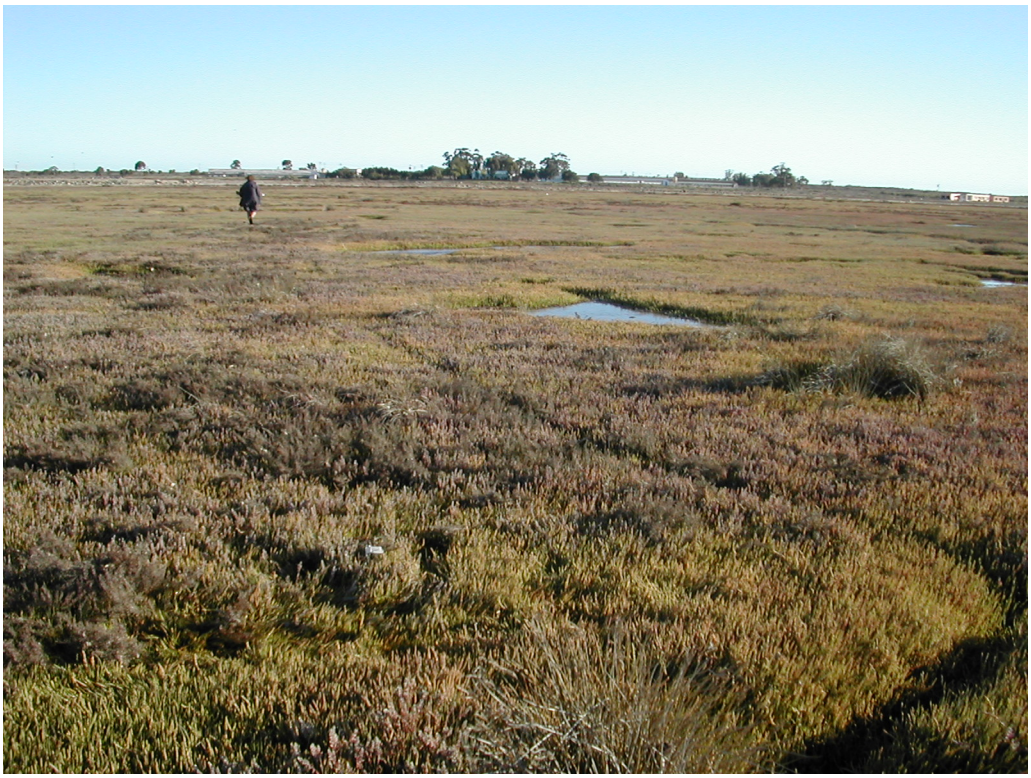


Figure A3.1.48 Transect 22 on the saltmarsh adjacent to Cerebos saltworks on 11 March 2004.

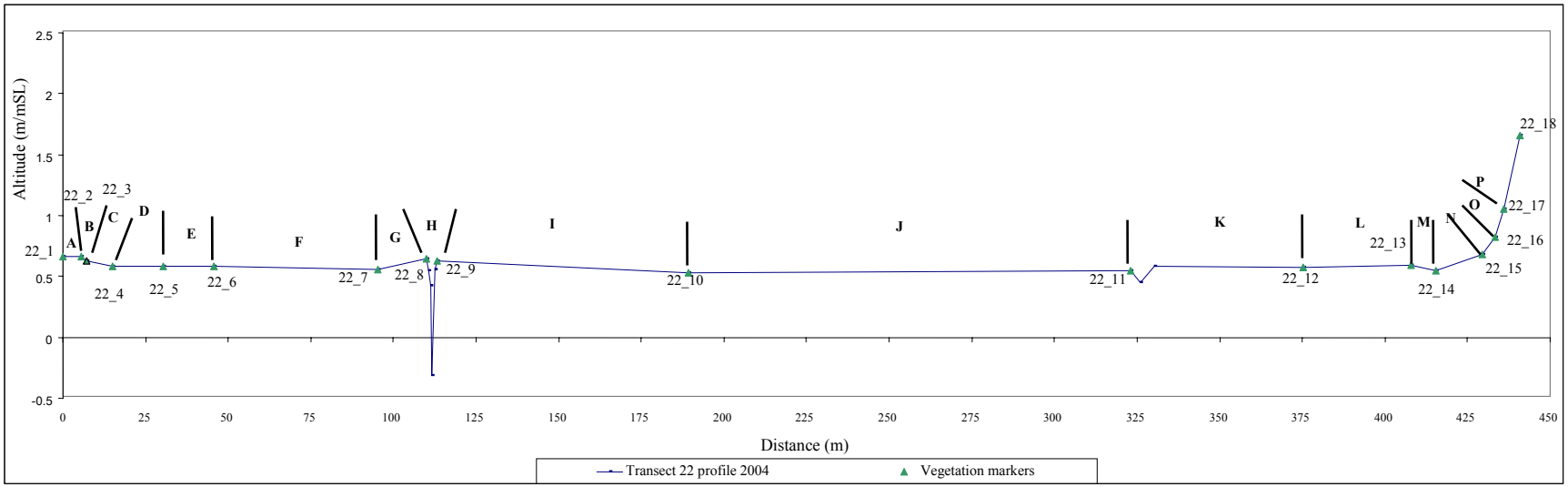


Figure A3.1.49 Cross-section profile of Transect 22 for 2004. Letters of the alphabet identify plant communities as numbered in Table A3.1.31.

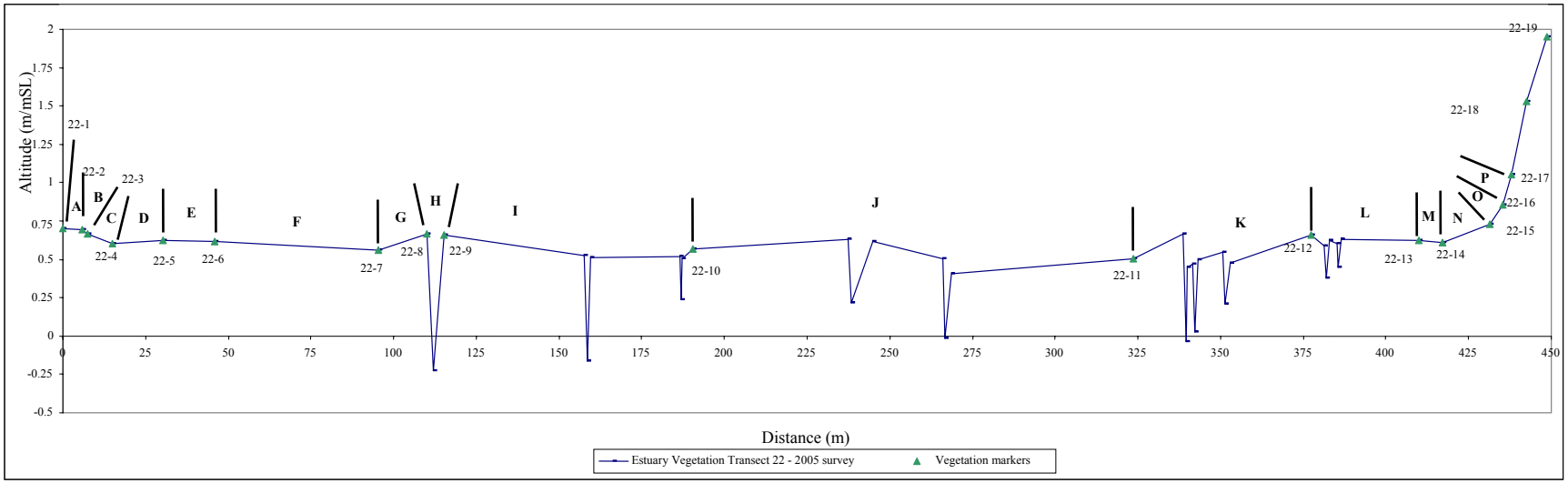


Figure A3.1.50 Cross-section profile of Transect 22 for 2005. Letters of the alphabet identify plant communities as numbered in Table A3.1.31.

Table A3.1.31 Floristic data recorded on Transect 22

Estuary Transect 22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	
Profile unit	A	A	B	B	C	C	D	D	E	E	F	F	G	G	H	H	I	I	J	J	K 1	K	K 2	L	L	M	M	N	N	O	O	P	P	
Year	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005	2004	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005	
1. Jaccard Similarity Co-efficient %. Present year compared to previous year		100%		100%		80%		100%		100%		75%		100%		50%		57%		100%		60%			100%		80%		100%		67%		50%	
2. Sorenson's Similarity Co-efficient %. Present year compared to previous year.		100%		100%		89%		100%		100%		86%		100%		67%		73%		100%		75%			100%		89%		100%		80%		67%	
Number of taxa of potential 10 in sample =	**4**	**4**	**3**	**3**	**4**	**5**	**5**	**5**	**4**	**4**	**4**	**3**	**5**	**5**	**3**	**3**	**4**	**7**	**5**	**5**	**3**	**5**	**4**	**5**	**5**	**5**	**4**	**4**	**4**	**3**	**2**	**1**	**2**	**No records**
Bassia diffusa (Thunb.) Kuntze	5	5	1	1	2	2	2	2	+	1	3	2	+	1	3	3	+	1	2	2		2	2	3	2	3	2	1	2	R				29
Cotula coronopifolia L.																						+												1
Juncus kraussii Hochst.	+	+					1	+	2	2	4	5	+	+			2	2	R	+				R	R										16
Limonium depauperatum (Boiss.) R.A.Dyer					2	3	+	+					+	+				+	2	2	R	+	R	2	3	4	3							16
Pycreus polystachyos (Rottb.) P.Beauv.															1		+	+																3
Salicornia meyeriana Moss																										+		2	2	+	2		+	6
Samolus porosus (L.f.) Thunb.																		R																1
Sarcocornia perennis (Mill.) A.J.Scott	2	1	5	5	3	3	4	4	4	5	2	2	5	5	3	5	4	4	3	3	3	5	4	4	2	2	1	4	3	R	+	4	4	33
Sporobolus virginicus (L.) Kunth	+	+				+																												3
Triglochin striata Ruiz & Pav.			+	+	+	3	2	2	1	2	2		3	3		+		1	3	3	4	2	2	1	3	2	2	1	2					24

22. TRANSECT 25 (CEREBOS SALTMARSH EXTENSION)

This transect is a short extension to Transect 22 located on the left river bank of the saltmarsh opposite the Cerebos Saltworks main dam wall (Figures 7.1 & 7.2). It was measured when it became apparent in 2005 that existing bank transects through this saltmarsh didn't coincide exactly with that through the channel. This short extension rectified that situation. These samples (Table A3.1.32) must replace samples 22A to 22C which differ slightly in species presence and cover-abundance values. All the data collected along Transects 3 and 22 have been retained as they have data collected over a longer period and therefore have value to indicate changes over the 2003-2005 period, which has monitoring value.

Total number of species = 6

Table A3.1.32 Floristic data recorded on Transect 25

Estuary Transect 25	25	25	25	
Profile unit	A	B	C	
Number of taxa in sample = 6	**3**	**4**	**4**	**No records**
Bassia diffusa (Thunb.) Kuntze	5	2	1	3
Disphyma crassifolium (L.) L.Bolus	1			1
Juncus kraussii Hochst.			3	1
Limonium depauperatum (Boiss.) R.A.Dyer		2		1
Sarcocornia perennis (Mill.) A.J.Scott	+	4	4	3
Triglochin striata Ruiz & Pav.		2	1	2

The transect vegetation is illustrated in Figure A3.1.51. The communities presented here (Chapter 7.3, Table 7.1) were recorded in the samples indicated at this site:

- *Bassia diffusa-Sarcocornia perennis* Dwarf Shrubland typicum (Halophytic Saltmarsh) (sample A)
- *Limonium depauperatum-Triglochin striata* Herbland (Halophytic Saltmarsh) (sample B)
- *Juncus kraussii-Sarcocornia perennis* Sedgeland (Sedge Marsh) (sample C)



Figure A3.1.51 *Bank collapse in the Bassia diffusa-Sarcocornia perennis Saltmarsh community on Transect 25, adjacent to the Cerebos Saltworks on 2005, on the Berg River Estuary in 2005.*

APPENDIX 3.2

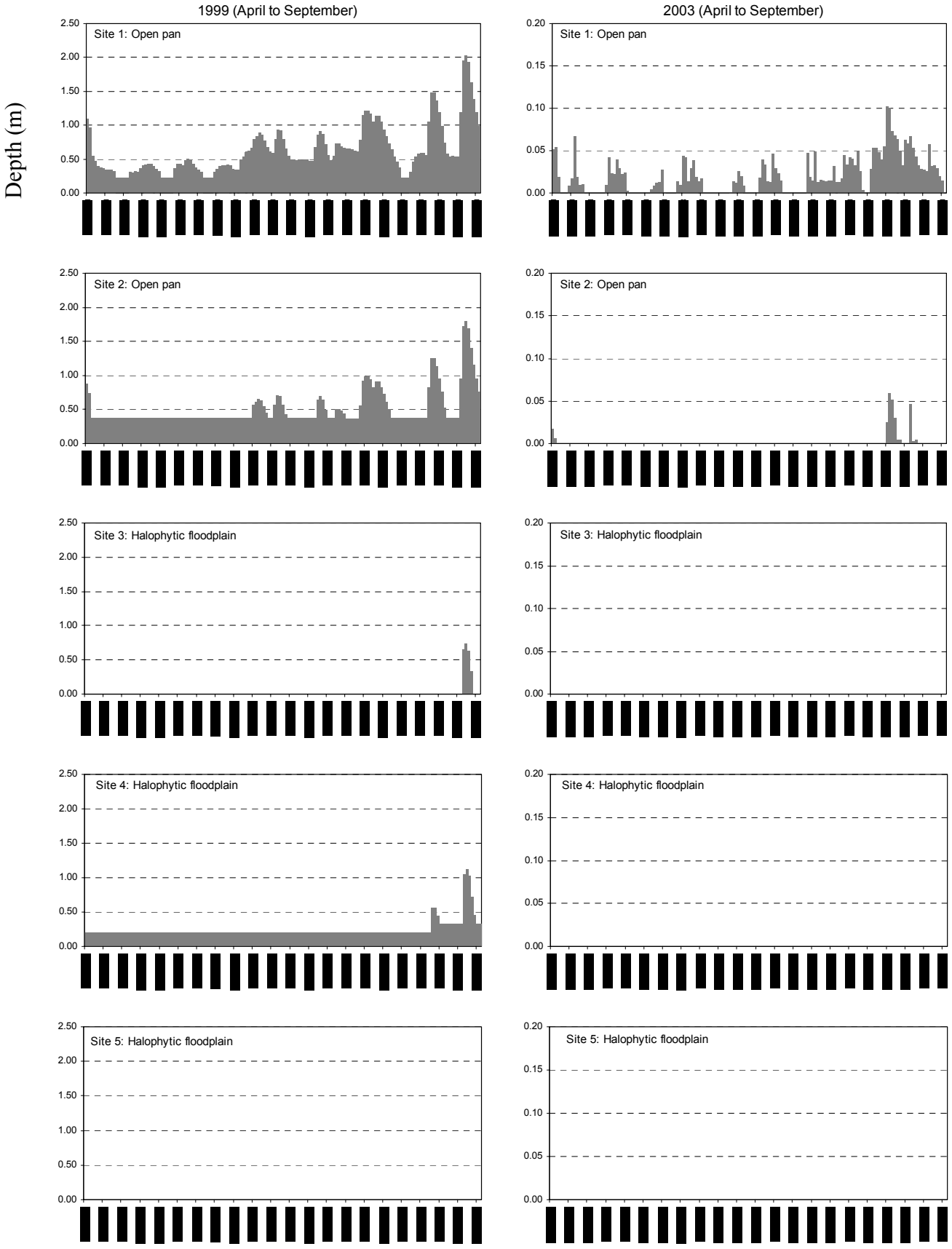
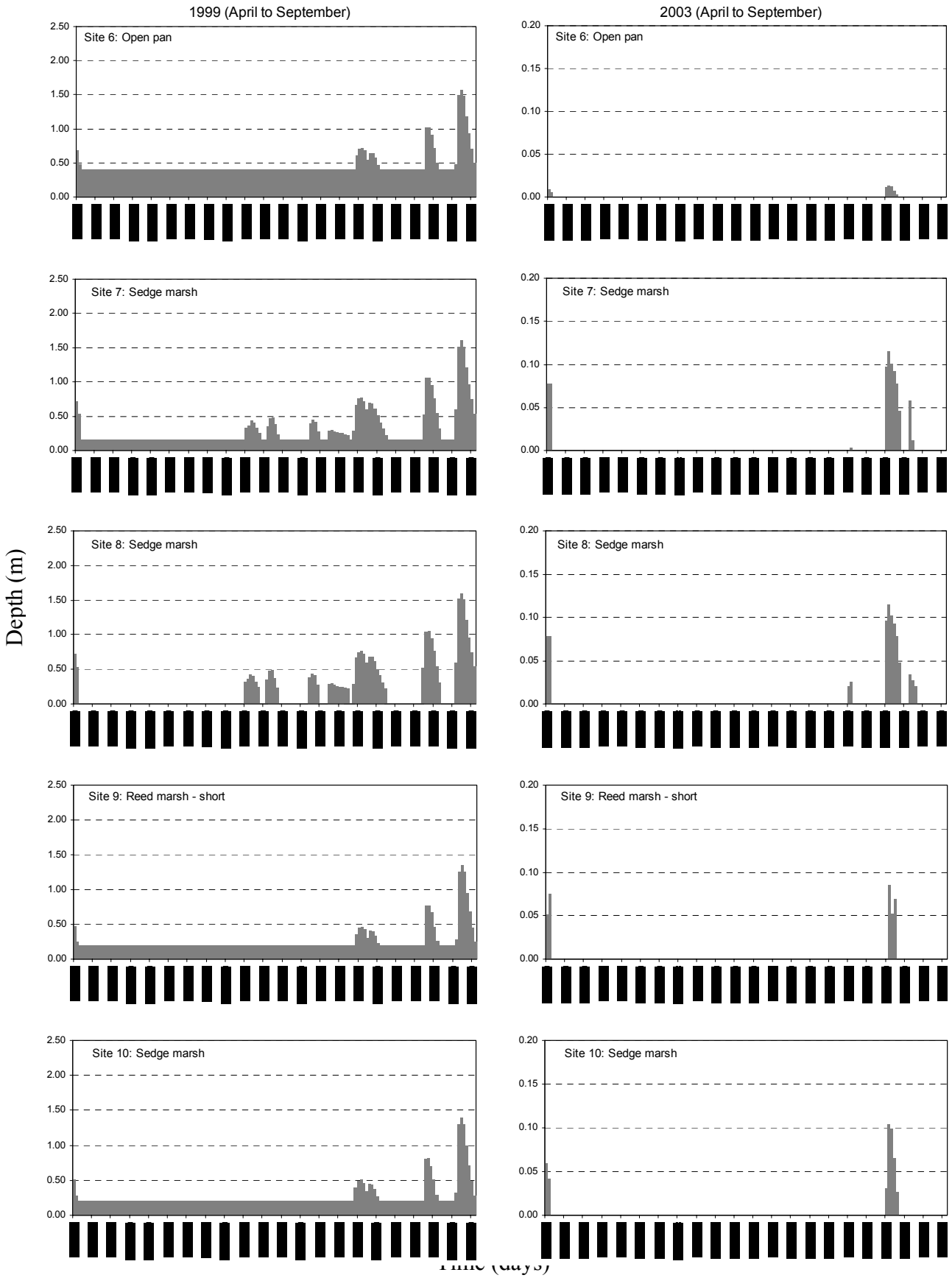
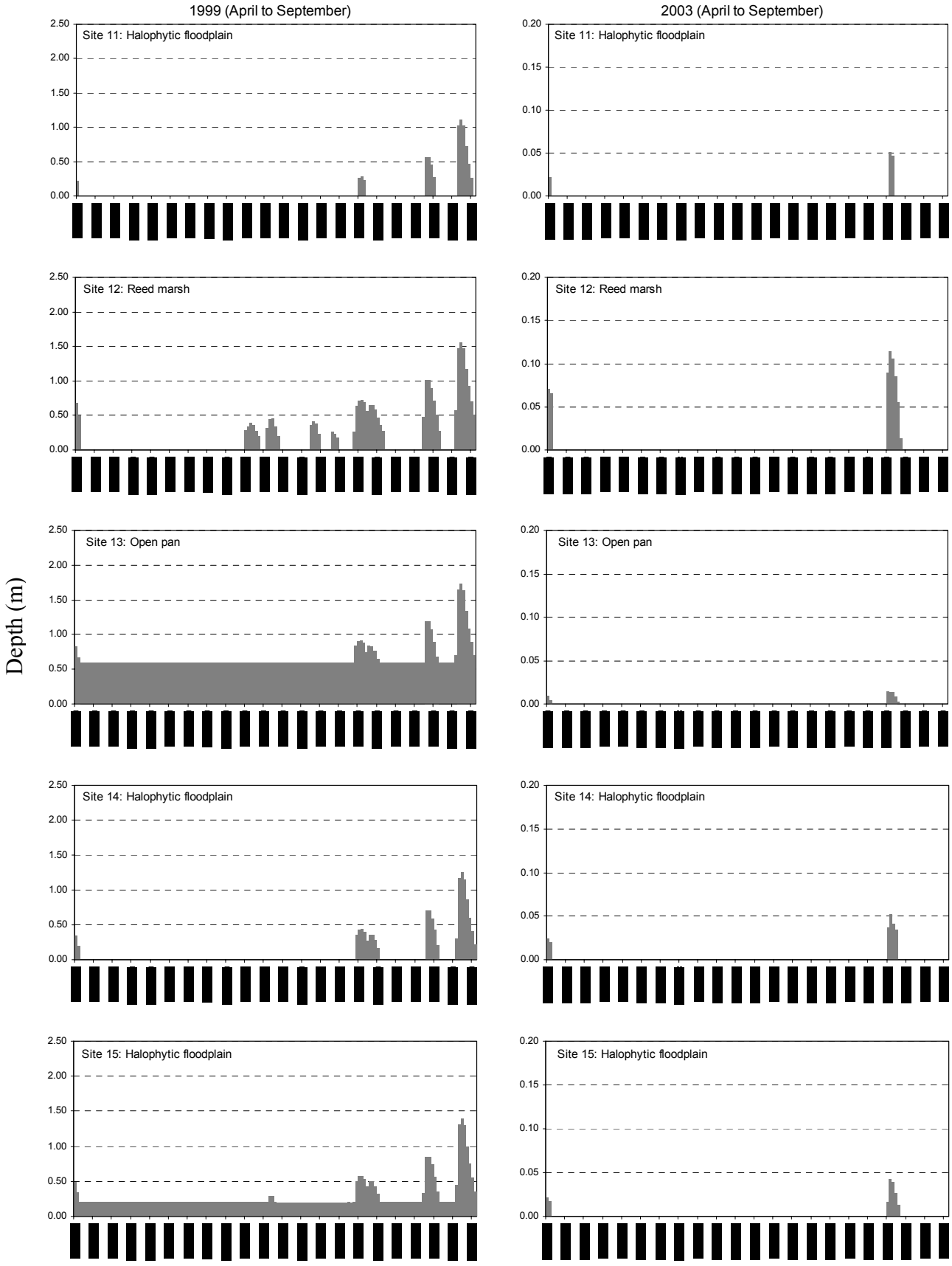
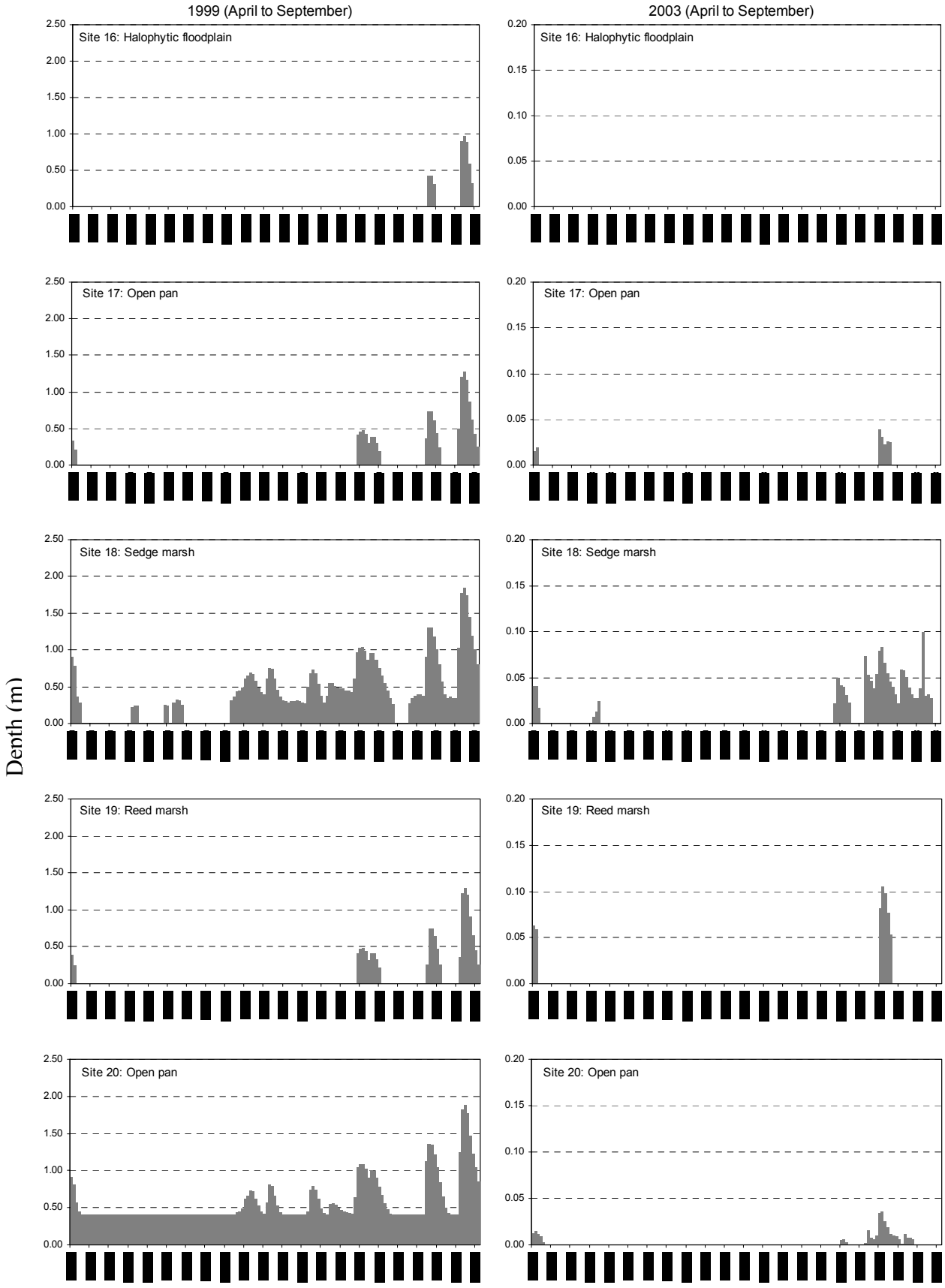
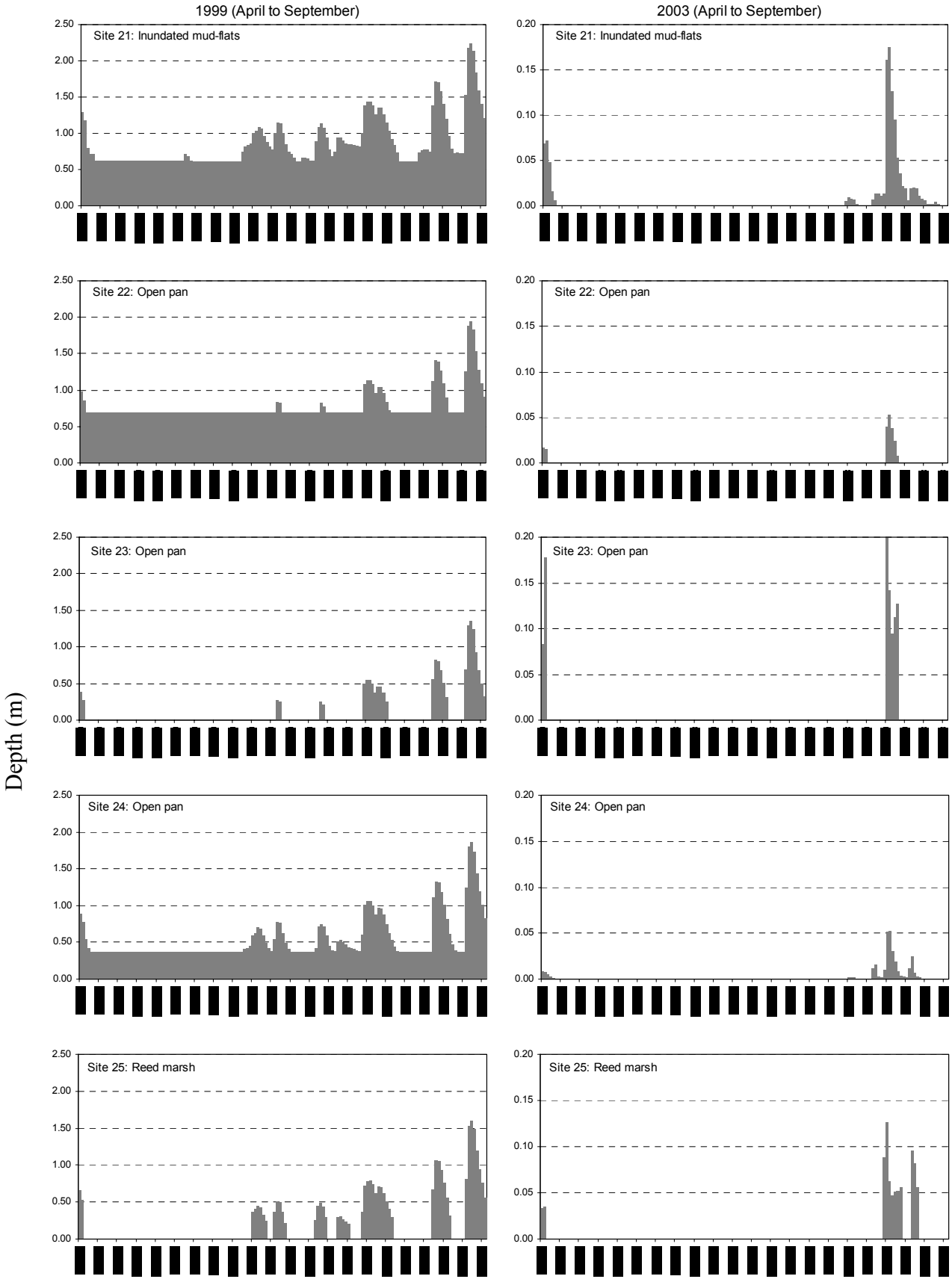


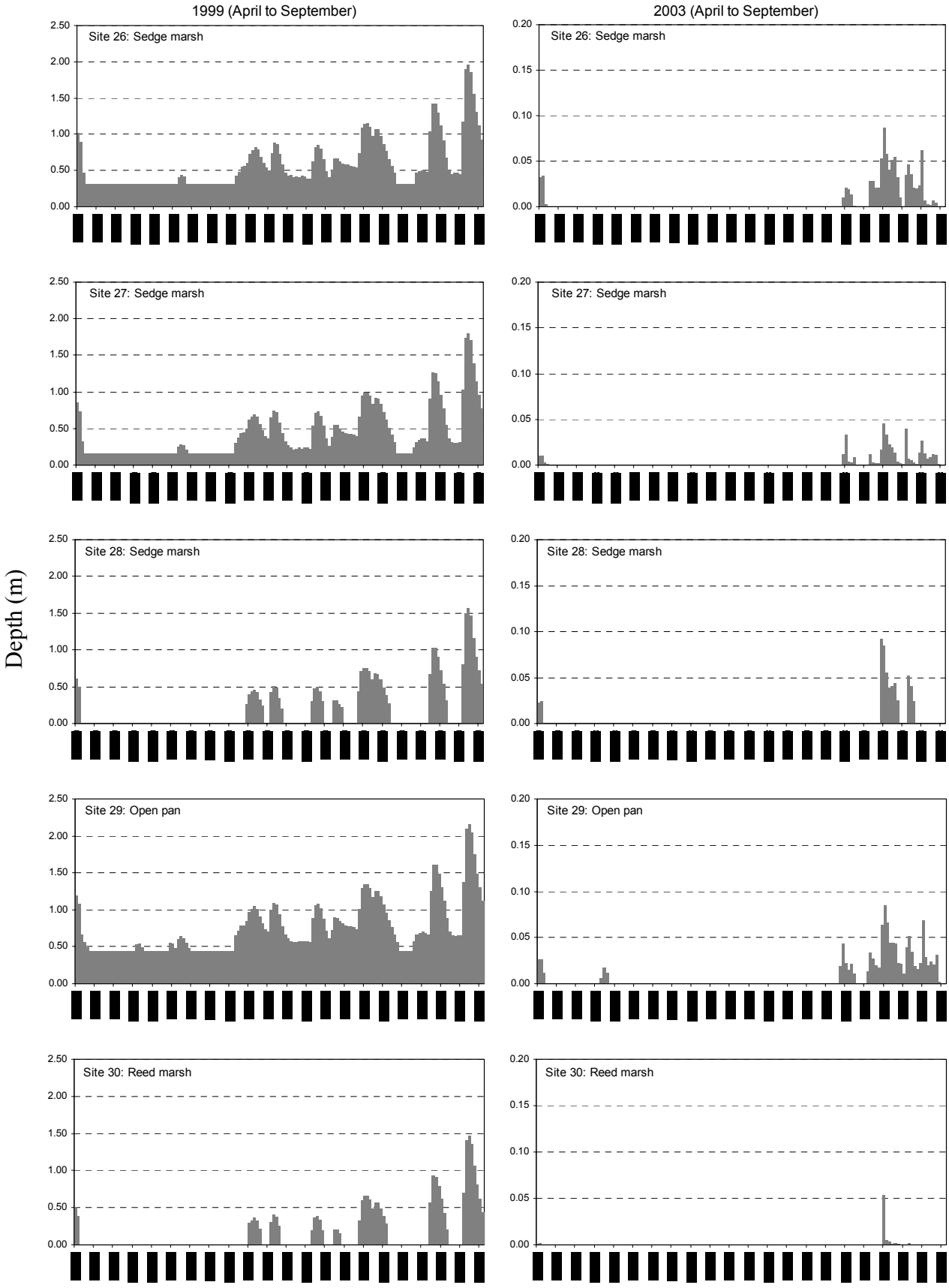
Figure A3.2.1 Inundation graphs for 100 selected points in Berg River Estuary and Floodplain (see Figures 7.2—7.5 for location of points)

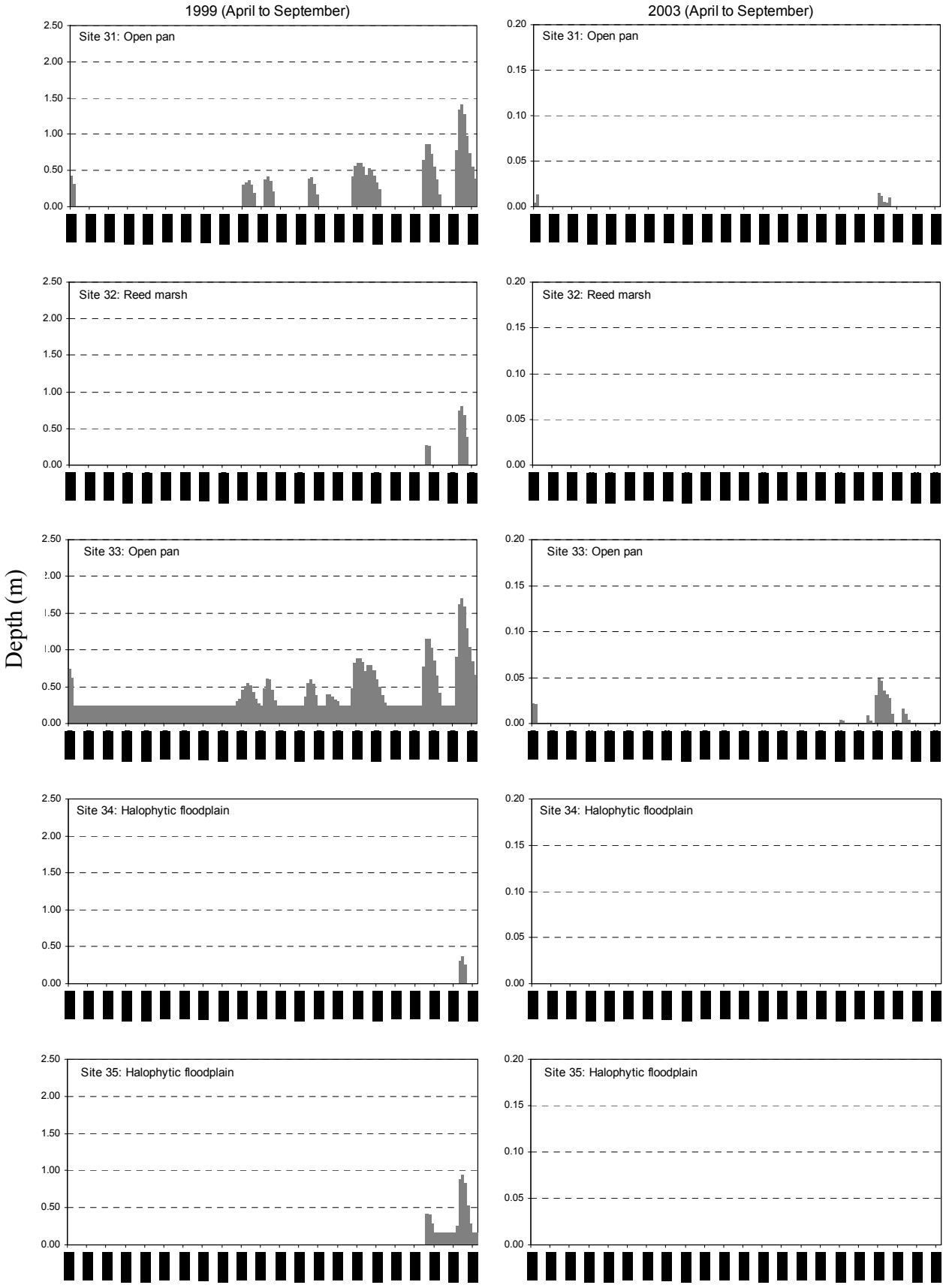

1999 (April to September)
2003 (April to September)
Site 6: Open pan
Site 7: Sedge marsh
Site 8: Sedge marsh
Site 9: Reed marsh - short
Site 10: Sedge marsh
Depth (m)
Time (days)

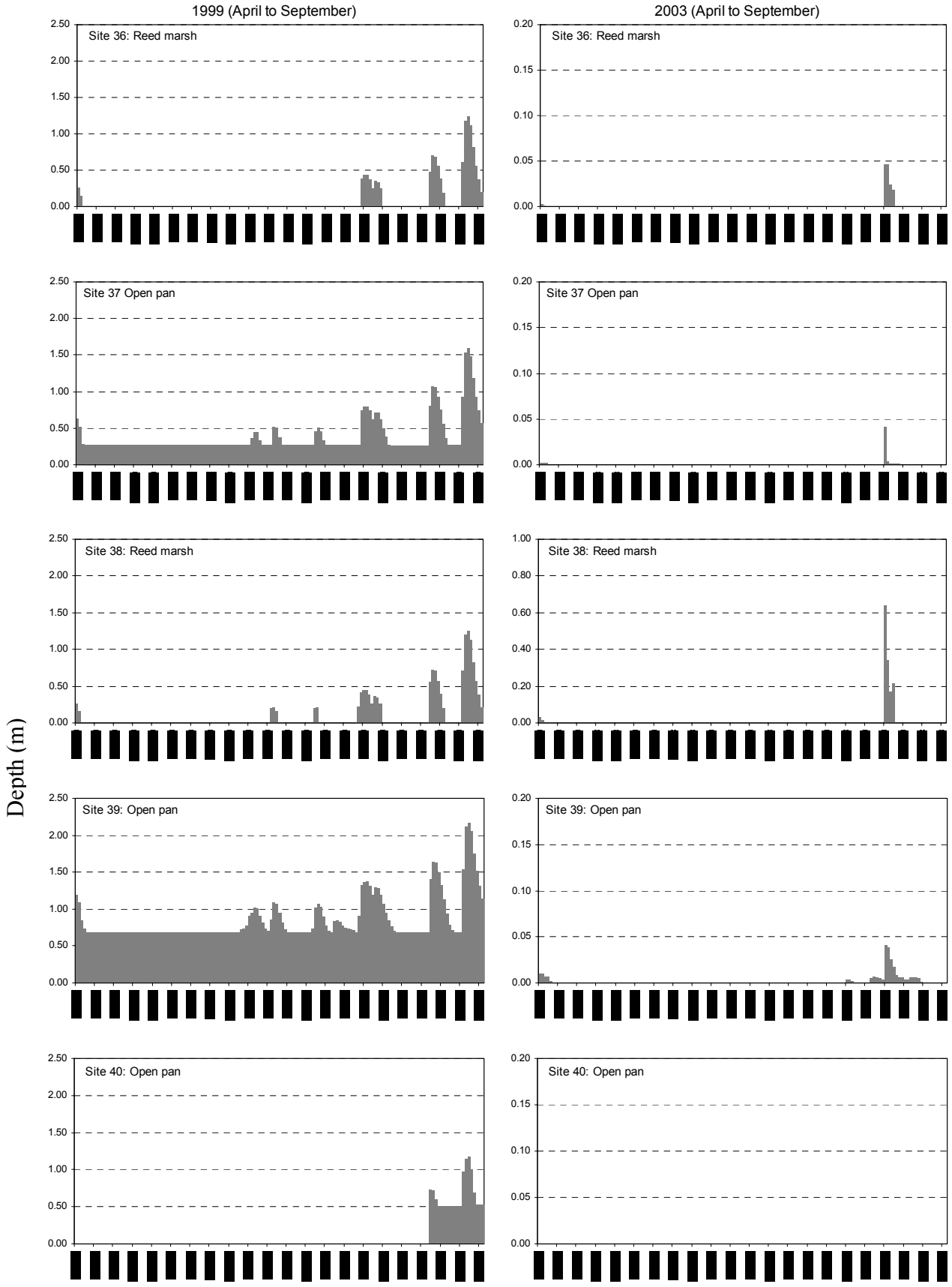

1999 (April to September)
2003 (April to September)
Site 11: Halophytic floodplain
Site 12: Reed marsh
Site 13: Open pan
Site 14: Halophytic floodplain
Site 15: Halophytic floodplain
Depth (m)
Time (days)


1999 (April to September)
2003 (April to September)
Site 16: Halophytic floodplain
Site 17: Open pan
Site 18: Sedge marsh
Site 19: Reed marsh
Site 20: Open pan
Depth (m)
Time (days)

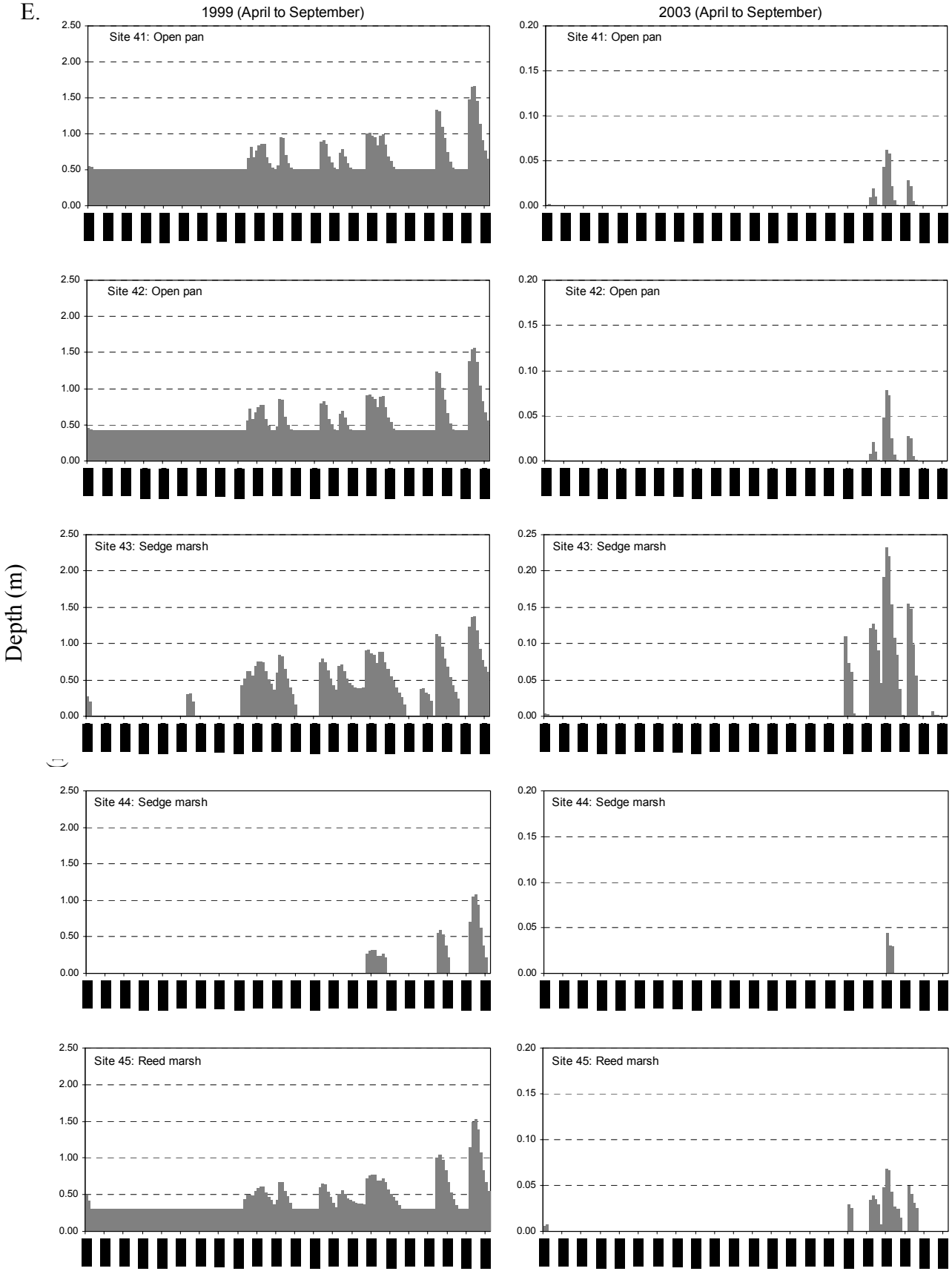

1999 (April to September)
2003 (April to September)
Site 21: Inundated mud-flats
Site 22: Open pan
Site 23: Open pan
Site 24: Open pan
Site 25: Reed marsh
Depth (m)
Time (days)

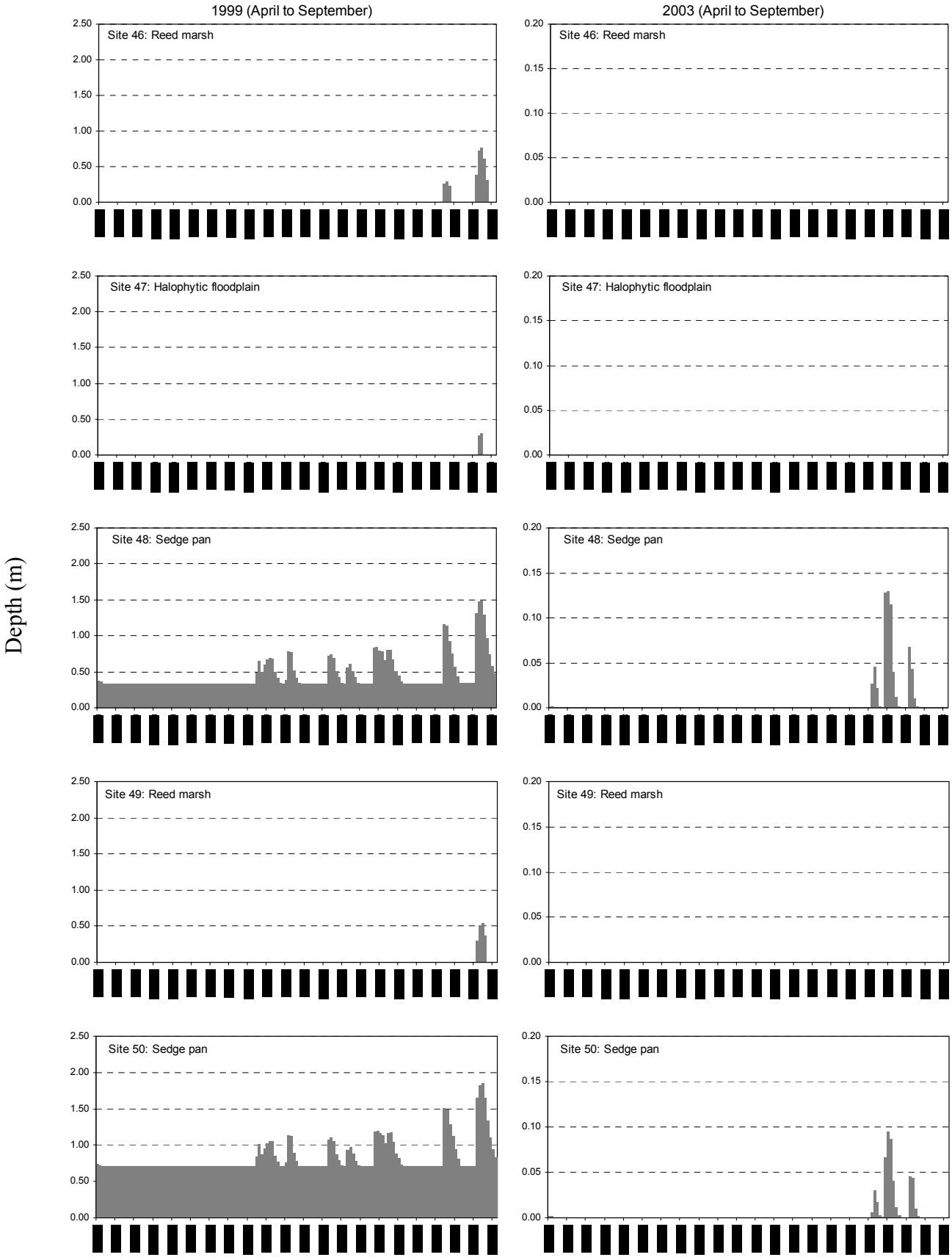

1999 (April to September)
2003 (April to September)
Site 26: Sedge marsh
Site 27: Sedge marsh
Site 28: Sedge marsh
Site 29: Open pan
Site 30: Reed marsh
Depth (m)
Time (days)

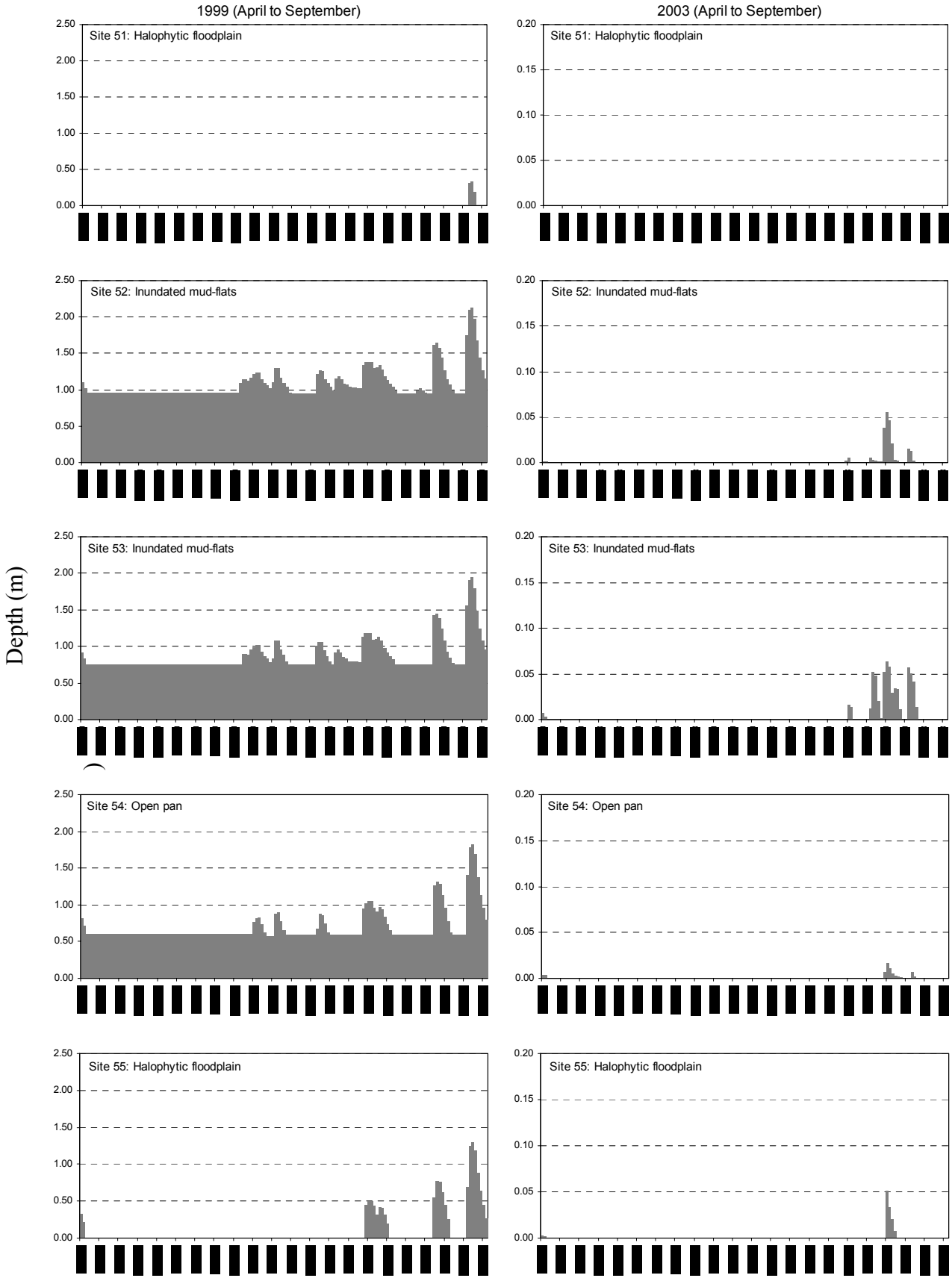

1999 (April to September)
2003 (April to September)
Site 31: Open pan
Site 32: Reed marsh
Site 33: Open pan
Site 34: Halophytic floodplain
Site 35: Halophytic floodplain
Depth (m)
Time (days)

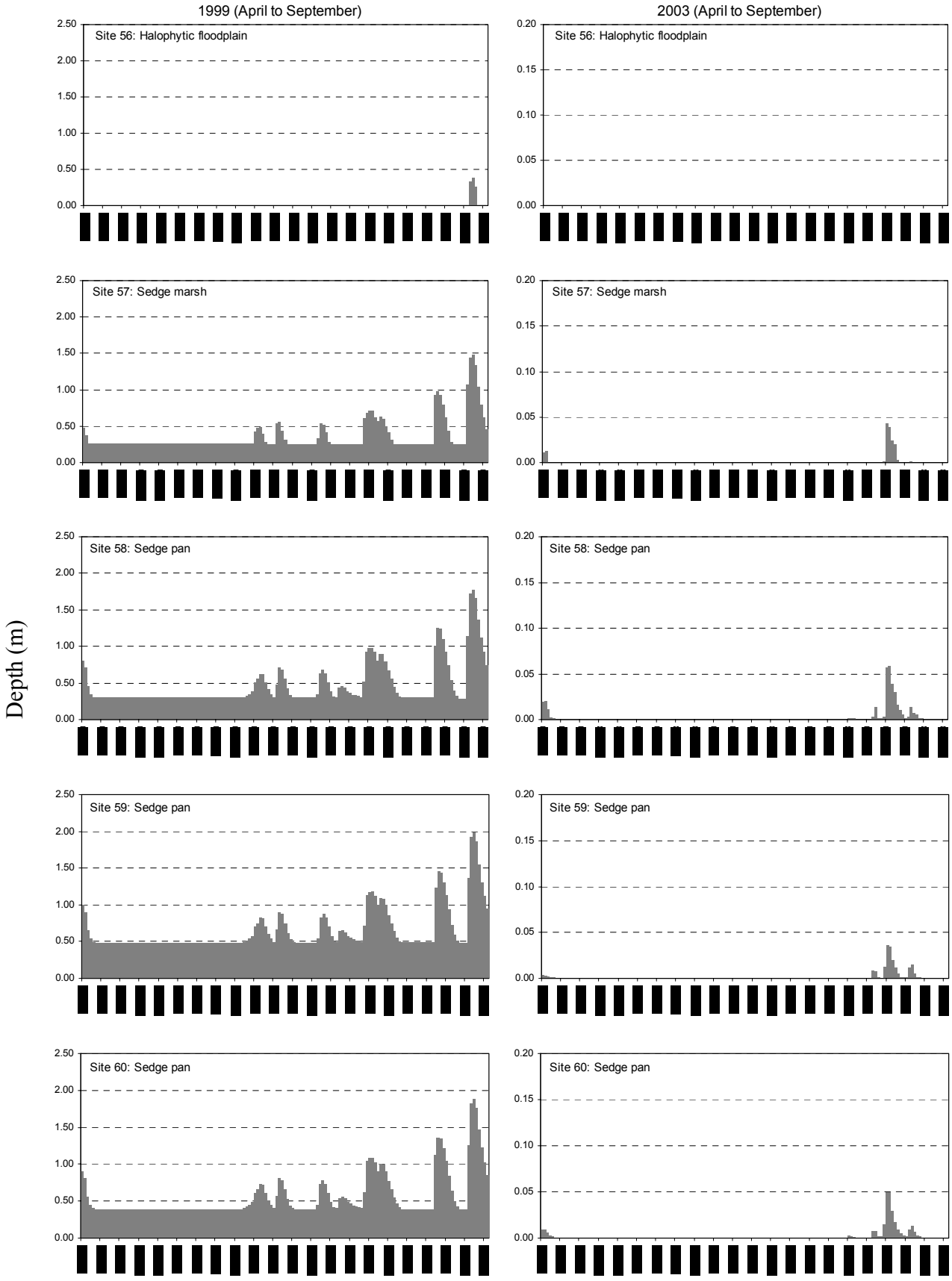

1999 (April to September)
2003 (April to September)
Site 36: Reed marsh
Site 37 Open pan
Site 38: Reed marsh
Site 39: Open pan
Site 40: Open pan
Depth (m)
Time (days)

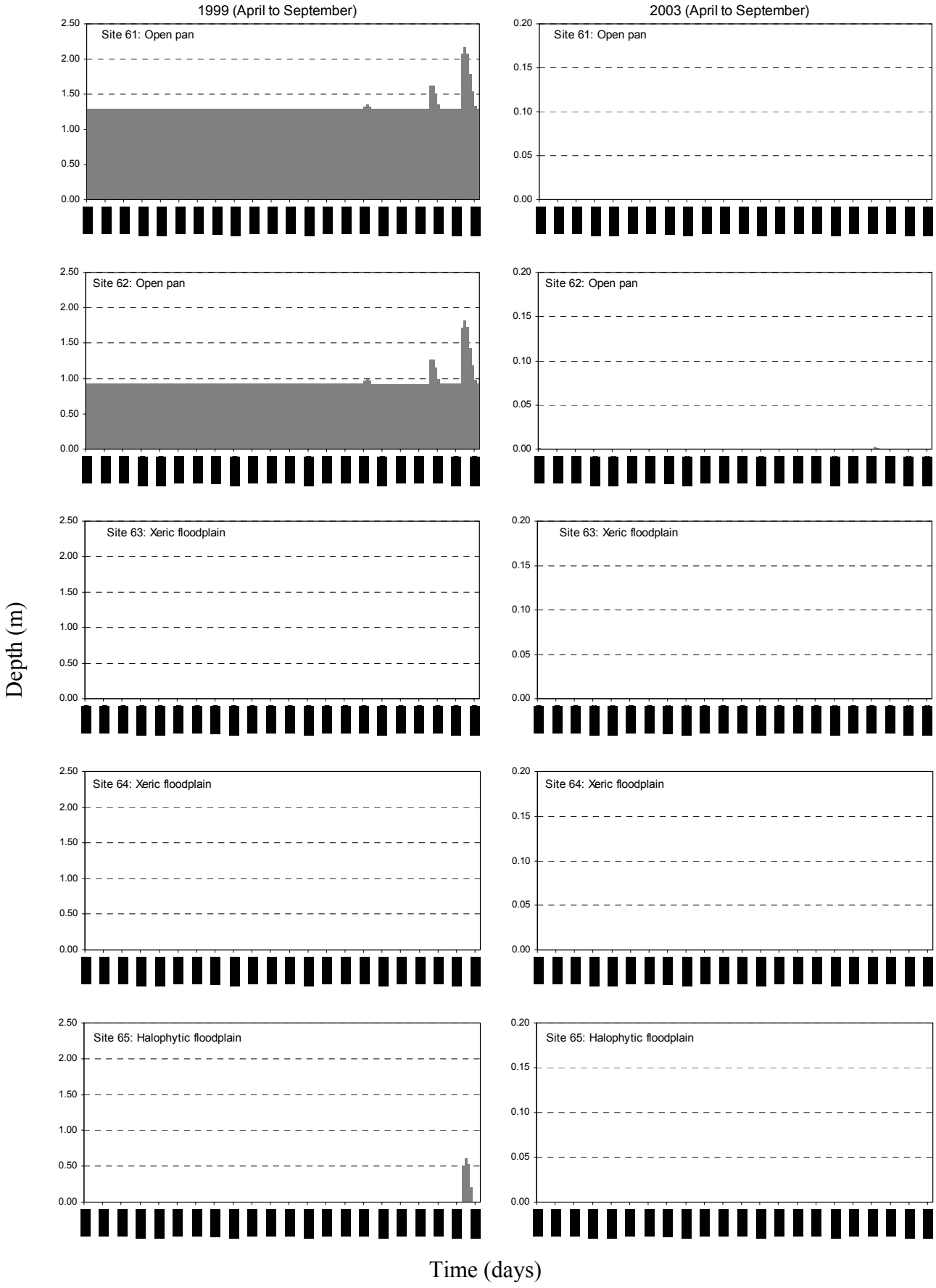
E.

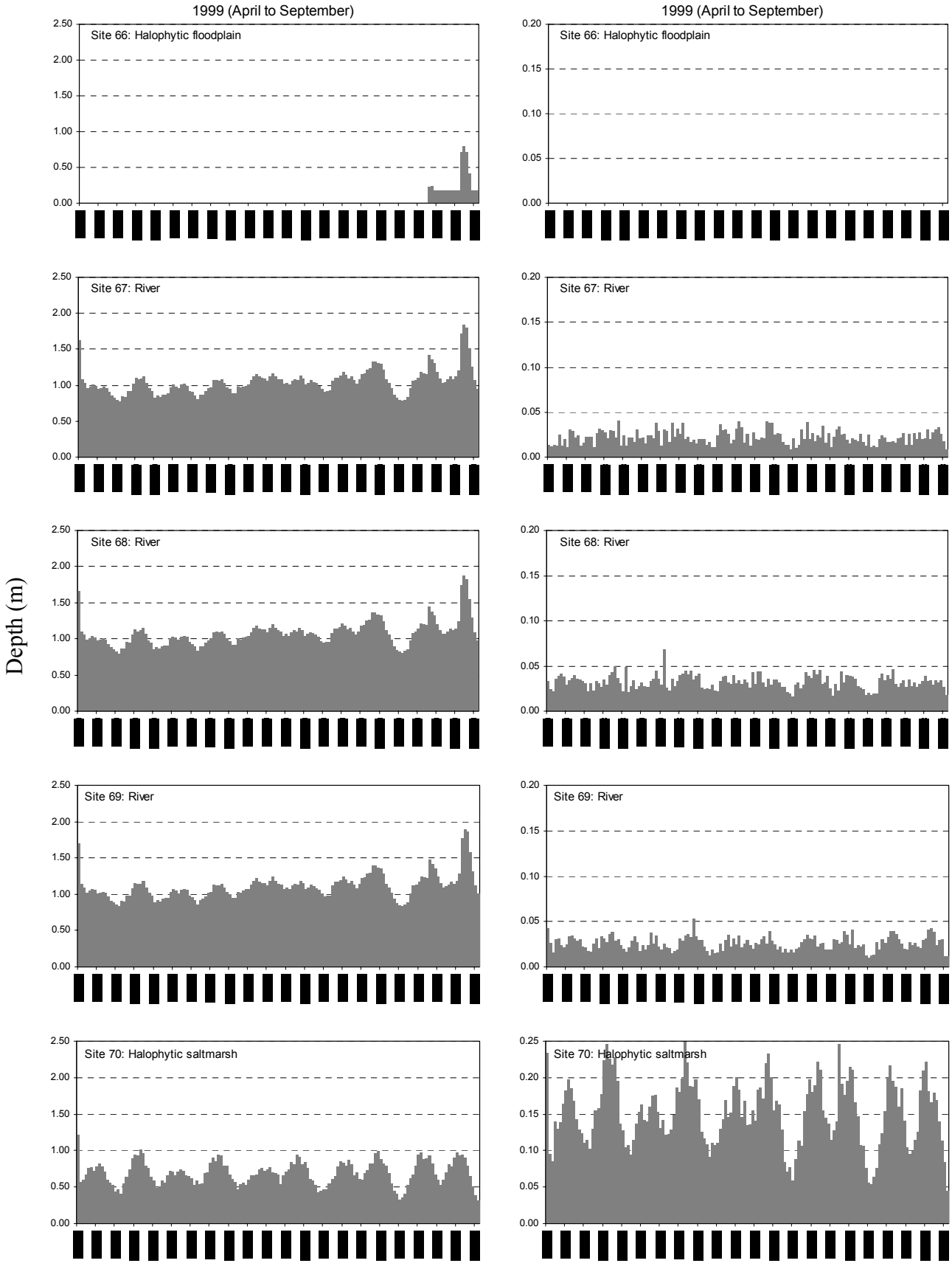

1999 (April to September)
2003 (April to September)
Site 41: Open pan
Site 42: Open pan
Site 43: Sedge marsh
Site 44: Sedge marsh
Site 45: Reed marsh
Depth (m)
Time (days)

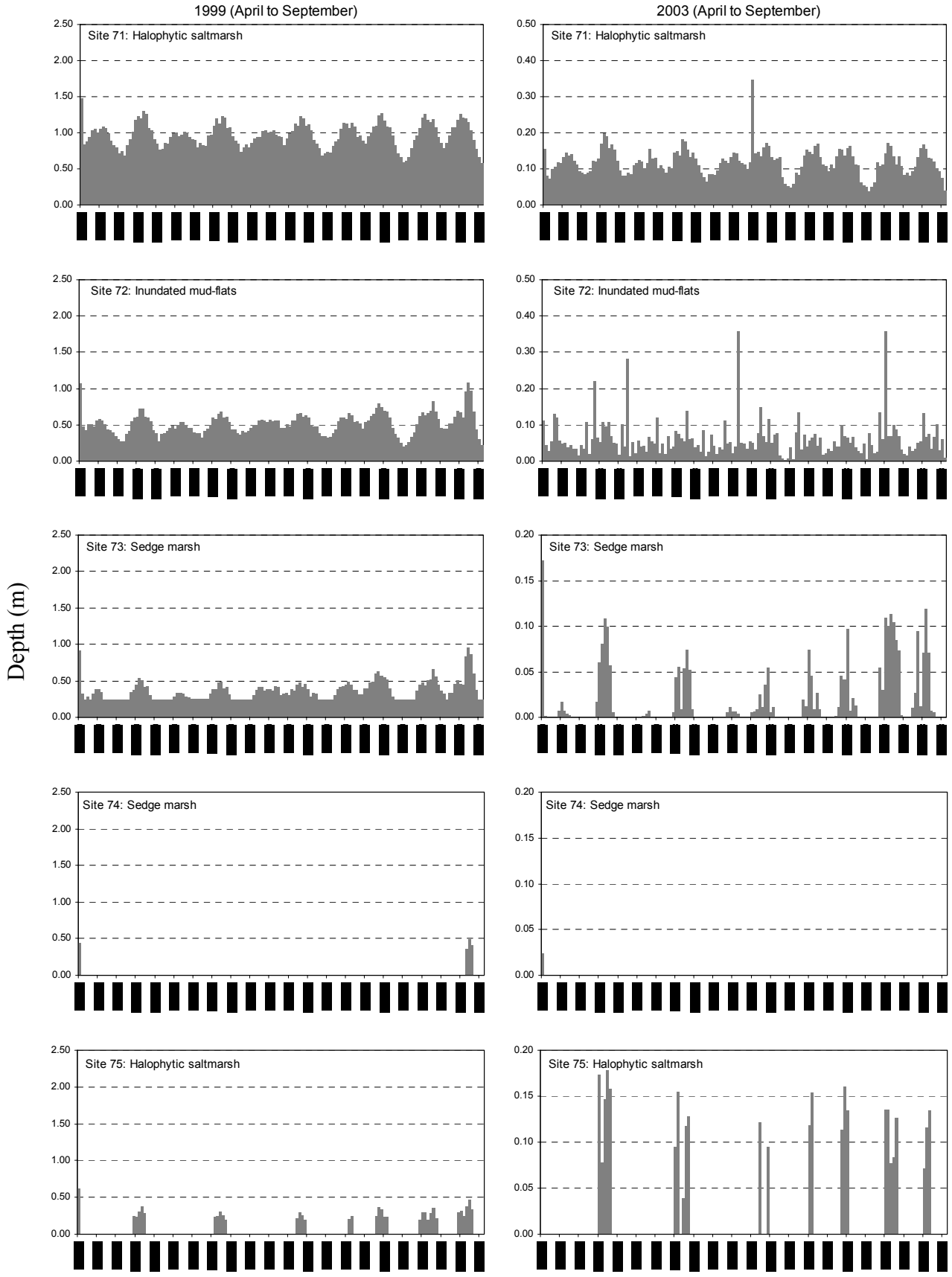

1999 (April to September)
2003 (April to September)
Site 46: Reed marsh
Site 47: Halophytic floodplain
Site 48: Sedge pan
Site 49: Reed marsh
Site 50: Sedge pan
Depth (m)
Time (days)

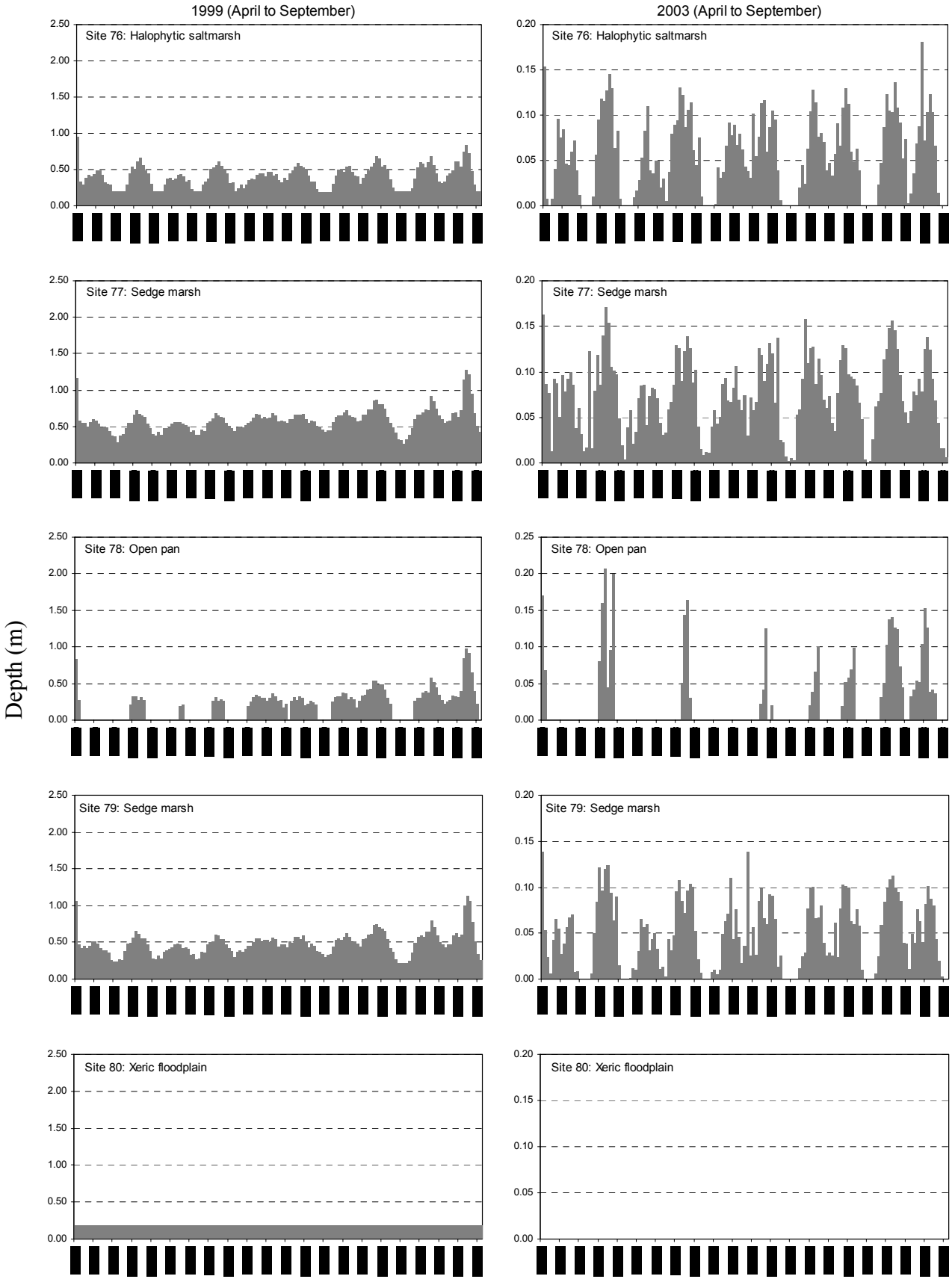

1999 (April to September)
2003 (April to September)
Site 51: Halophytic floodplain
Site 52: Inundated mud-flats
Site 53: Inundated mud-flats
Site 54: Open pan
Site 55: Halophytic floodplain
Depth (m)
Time (days)

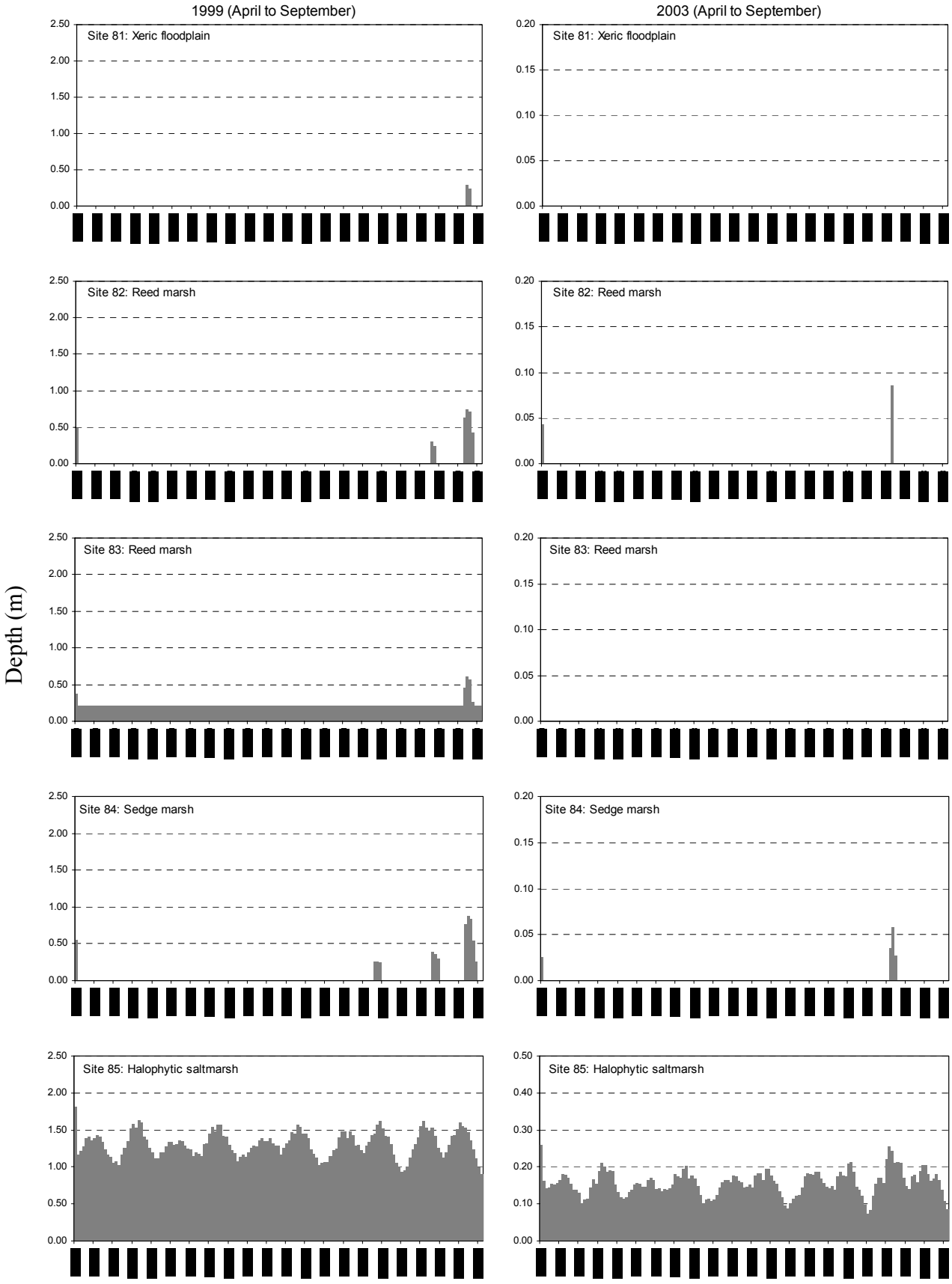

1999 (April to September)
2003 (April to September)
Site 56: Halophytic floodplain
Site 57: Sedge marsh
Site 58: Sedge pan
Site 59: Sedge pan
Site 60: Sedge pan
Depth (m)
Time (days)

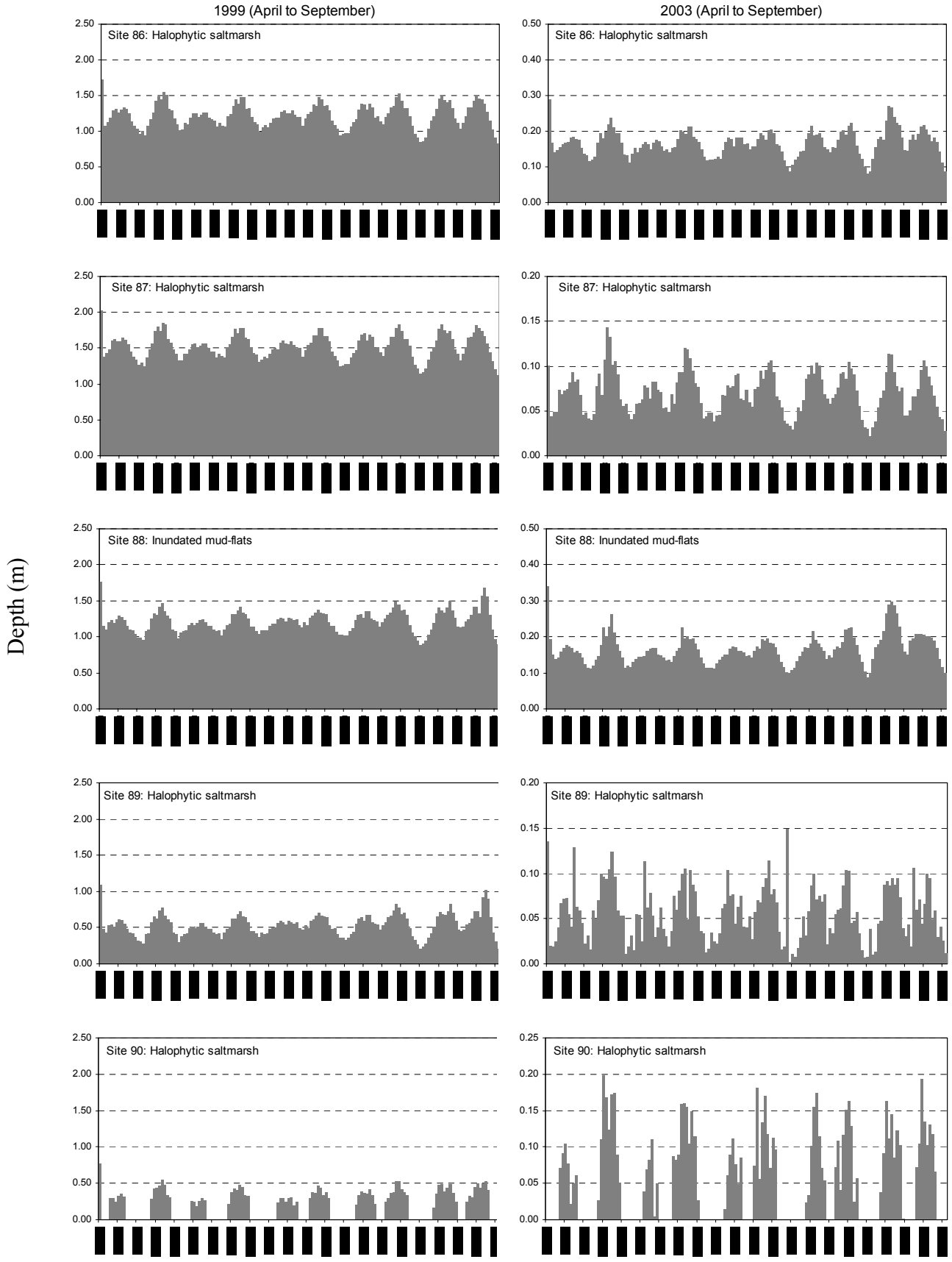

1999 (April to September)
2003 (April to September)
Site 61: Open pan
Site 62: Open pan
Site 63: Xeric floodplain
Site 64: Xeric floodplain
Site 65: Halophytic floodplain
Depth (m)
Time (days)

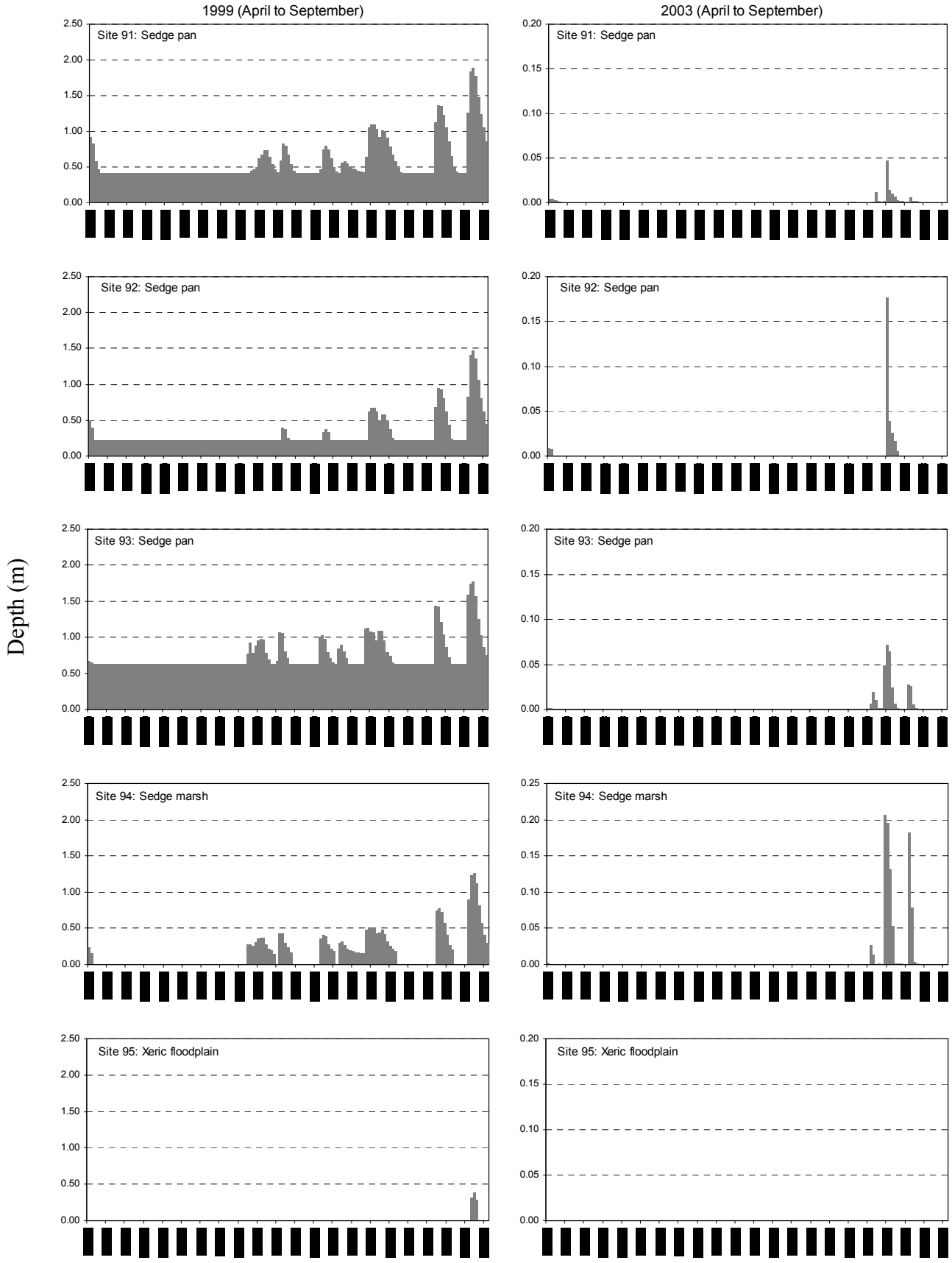

1999 (April to September)
Site 66: Halophytic floodplain
Site 67: River
Site 68: River
Site 69: River
Site 70: Halophytic saltmarsh
Depth (m)
Time (days)

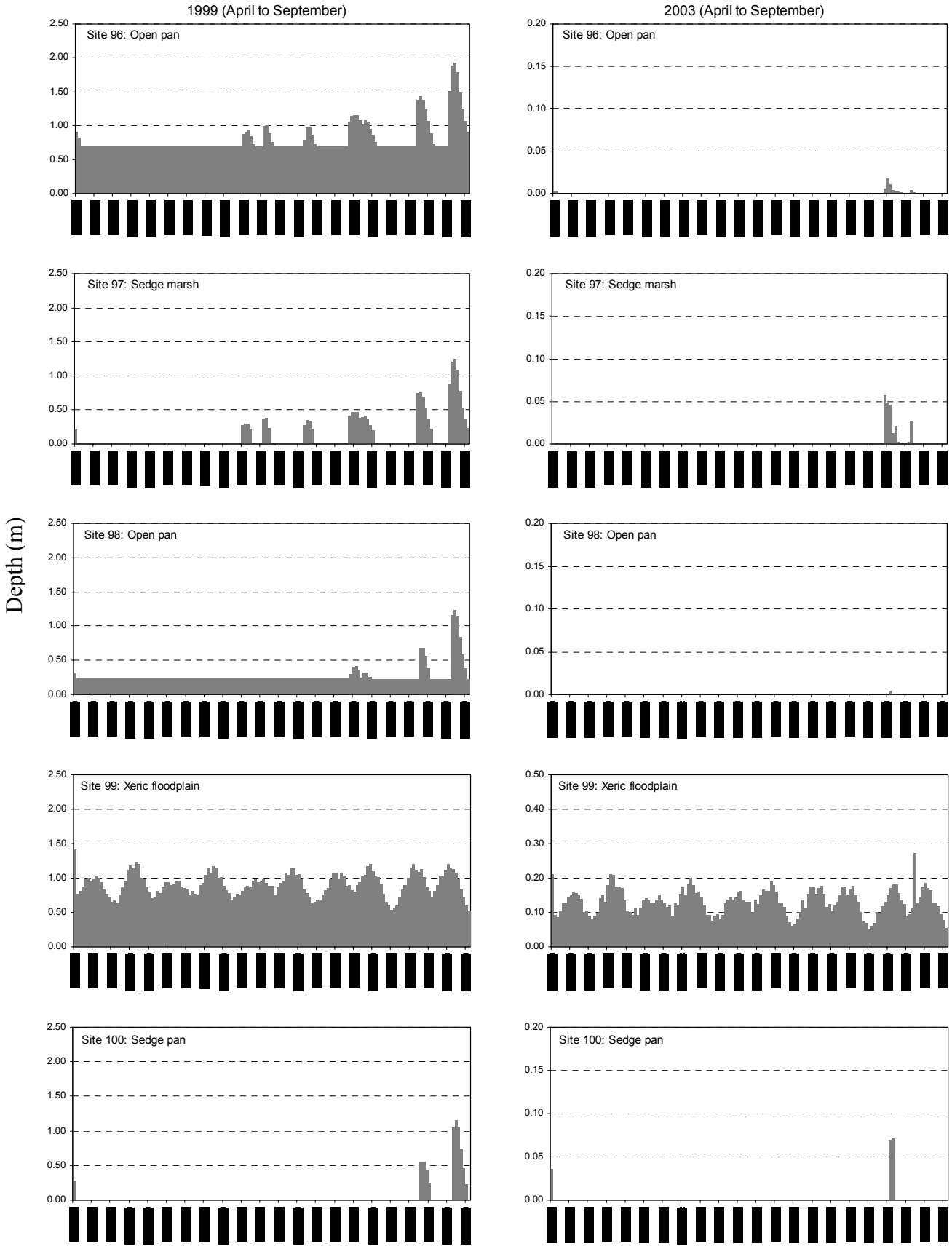

1999 (April to September)
2003 (April to September)
Site 71: Halophytic saltmarsh
Site 72: Inundated mud-flats
Site 73: Sedge marsh
Site 74: Sedge marsh
Site 75: Halophytic saltmarsh
Depth (m)
Time (days)


1999 (April to September)
2003 (April to September)
Site 76: Halophytic saltmarsh
Site 77: Sedge marsh
Site 78: Open pan
Site 79: Sedge marsh
Site 80: Xeric floodplain
Depth (m)
Time (days)


1999 (April to September)
2003 (April to September)
Site 81: Xeric floodplain
Site 82: Reed marsh
Site 83: Reed marsh
Site 84: Sedge marsh
Site 85: Halophytic saltmarsh
Depth (m)
Time (days)


1999 (April to September)
2003 (April to September)
Site 86: Halophytic saltmarsh
Site 87: Halophytic saltmarsh
Site 88: Inundated mud-flats
Site 89: Halophytic saltmarsh
Site 90: Halophytic saltmarsh
Depth (m)
Time (days)


1999 (April to September)
2003 (April to September)
Site 91: Sedge pan
Site 92: Sedge pan
Site 93: Sedge pan
Site 94: Sedge marsh
Site 95: Xeric floodplain
Depth (m)
Time (days)


1999 (April to September)
2003 (April to September)
Depth (m)
Site 96: Open pan
Site 97: Sedge marsh
Site 98: Open pan
Site 99: Xeric floodplain
Site 100: Sedge pan
0.00
0.50
1.00
1.50
2.00
2.50
0.05
0.10
0.15
0.20
0.30
0.40

APPENDIX 4

APPENDIX 4.1

ESTUARINE INVERTEBRATES:

ABIOTIC DATA

Time (days)

Table A4.1.1 Abiotic measurements recorded in February 2003 at 15 stations in the Great Berg estuary. Integrated values are the mean for all readings in the water column. Surface readings refer to the top 15 cm of the water column; bottom readings reflect conditions just above the substratum.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Salinity (integrated)	34.0	33.9	33.4	32.9	31.1	29.6	29.2	27.3	26.7	24.4	22.5	20.0	18.1	14.3	10.2
Salinity (surface)	34.0	33.9	33.4	32.7	30.7	29.6	28.9	27.2	26.6	23.7	20.1	19.4	16.9	10.6	6.7
Salinity (bottom)	34.0	33.9	33.4	33.0	31.4	29.6	29.5	27.3	26.8	24.8	25.4	20.7	18.8	15.9	13.8
Temperature (integrated °C)	18.1	18.5	19.7	20.4	22.3	23.0	23.1	23.1	23.5	24.0	24.1	24.1	24.4	24.7	24.7
Temperature (surface °C)	18.1	18.5	19.6	20.9	22.4	23.0	23.3	23.1	23.6	23.9	24.0	24.1	24.3	24.4	24.7
Temperature (bottom °C)	18.2	18.5	19.7	20.2	22.1	22.9	22.7	23.1	23.4	24.0	24.2	24.1	24.6	24.8	24.7
Conductivity (integrated)	44.8	45.1	45.6	45.8	45.2	43.9	43.4	40.8	40.5	37.6	35.1	31.4	29.0	23.5	17.0
Conductivity (surface)	44.8	45.1	45.6	45.9	44.9	43.9	43.2	40.8	40.4	36.5	31.6	30.6	27.2	17.8	11.7
Conductivity (bottom)	44.9	45.1	45.6	45.7	45.4	43.8	43.4	40.9	40.5	38.2	39.4	32.5	30.0	26.0	22.7
Depth (m)	2.5	3.5	2.5	3.0	2.5	3.0	3.0	2.0	3.5	2.0	3.5	2.5	2.5	4.0	3.0
pH (integrated)	7.4	7.4	7.4	7.4	7.5	7.5	7.5	7.5	7.5	7.6	7.6	7.6	7.6	7.6	7.7
Sediment - % mud (<0.065 mm)	36.9	10.2	5.7	9.3	10.0	7.6	5.4	14.6	16.3	76.7	77.4	82.6	9.9	0.6	2.1
Sediment - % sand (0.125 - 0.355 mm)	15.6	56.3	19.9	10.8	34.0	53.3	38.2	34.4	45.9	2.2	11.2	4.0	27.4	18.2	22.5
Sediment - % sand (0.355 - 1.00 mm)	9.1	20.9	44.6	13.8	24.3	9.4	41.4	12.7	20.9	2.4	2.6	0.8	51.7	74.4	65.9
Sediment organic matter (%)	4.8	1.8	1.7	2.4	1.7	2.6	2.5	2.1	2.8	14.1	5.6	6.4	1.8	0.6	0.9

Table A4.1.2 Abiotic measurements recorded in September 2003 at 15 stations in the Great Berg estuary. Integrated values are the mean for all readings in the water column. Surface readings refer to the top 15 cm of the water column; bottom readings reflect conditions just above the substratum.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Salinity (integrated)	55.6	38.8	19.1	4.1	1.9	1.3	1.1	0.9	0.9	0.9	0.8	0.9	0.9	0.9	0.9
Salinity (surface)	42.9	19.3	10.4	4.1	1.9	1.3	1.1	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Salinity (bottom)	65.1	61.1	25.1	4.2	1.9	1.3	1.1	0.9	0.9	0.9	0.8	0.9	0.9	0.9	0.9
Temperature (integrated °C)	15.9	16.0	16.4	16.6	17.0	17.0	17.0	17.0	16.8	16.8	17	17.8	17.4	17.4	17.6
Temperature (surface °C)	16.7	16.9	16.9	16.6	17.0	17.0	17.0	17.0	17.1	17.4	18.1	18.5	18.2	17.4	17.8
Temperature (bottom oC)	15.4	15.4	16.0	16.5	17.0	16.0	16.0	16.0	16.3	16.3	16.4	16.4	17.0	17.3	17.3
Conductivity (integrated)	65.6	48.0	25.4	6.2	3.0	2.8	1.8	1.5	1.5	1.4	1.4	1.5	1.6	1.6	1.5
Conductivity (surface)	53.5	26.1	14.9	6.2	3.0	2.1	1.8	1.6	1.5	1.4	1.4	1.5	1.6	1.6	1.5
Conductivity (bottom)	74.7	70.8	32.5	6.3	3.0	2.1	1.9	1.5	1.5	1.4	1.4	1.5	1.5	1.5	1.5
Oxygen (integrated mg/l)	4.1	4.1	5.0	7.2	7.4	7.2	7.1	7.5	7.9	7.8	8.2	8.2	8.9	8.3	9.1
Oxygen (surface mg/l)	4.6	5.5	6.1	7.2	6.9	6.9	6.9	7.3	8.0	7.9	8.9	8.8	9.8	7.7	9.3
Oxygen (bottom mg/l)	3.7	2.7	3.4	7.2	7.3	7.3	7.1	7.4	7.7	7.7	7.2	7.8	8.4	8.7	8.8
Oxygen (% saturation integrated)	59.1	51.5	54.4	76.0	74.6	74.0	73.0	77.0	82.1	82.5	85.2	84.5	92.5	86.1	95.8
Oxygen (% saturation surface)	62.0	63.5	66.0	76.0	72.3	70.0	72.0	76.0	83.2	81.2	92.4	91.2	97.3	79.2	96.5
Oxygen (% saturation bottom)	57.1	39.4	40.5	76.0	76.6	75.0	73.0	76.0	79.4	78.8	74.5	81.4	87.3	90.1	92.3
Depth (m)	1.5	2.0	2.8	1.5	1.0	4.5	3.0	3.5	2.3	3.0	2.2	2.0	1.3	2.3	1.5
pH (integrated)	7.9	7.9	7.8	7.8	7.9	7.8	7.8	7.8	7.8	7.9	8.1	8.5	8.2	8.2	8.2
Sediment organic matter (%)	6.6	1.8	1.6	1.3	1.5	1.1	1.1	3.0	4.7	7.8	3.5	7.6	3.3	1.8	4.7

Table A4.1.3 Abiotic measurements recorded in February 2004 at 15 stations in the Great Berg estuary. Integrated values are the mean for all readings in the water column. Surface readings refer to the top 15 cm of the water column; bottom readings reflect conditions just above the substratum.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Salinity (integrated)	34.1	33.3	32.4	31.9	29.9	27.1	23.5	19.1	14.0	15.3	11.1	7.3	1.7	0.0	0.0
Salinity (surface)	34.1	33.3	32.4	31.9	29.9	26.7	21.0	16.0	12.1	10.9	7.4	5.1	0.7	0.0	0.0
Salinity (bottom)	34.1	33.3	32.4	31.9	30.1	28.1	24.8	23.4	18.0	18.6	16.7	13.2	4.4	0.0	0.0
Temperature (integrated oC)	19.5	20.8	22.5	23.4	23.5	24.0	24.1	24.2	24.4	24.3	24.6	24.3	24.4	24.1	24.1
Temperature (surface oC)	19.5	20.8	22.5	23.4	23.5	24.0	24.1	24.2	24.4	24.4	25.1	24.3	24.6	24.5	24.1
Temperature (bottom oC)	19.0	20.8	22.5	23.4	23.4	24.1	24.1	24.2	24.4	24.2	24.3	24.5	24.5	23.9	23.9
Oxygen (integrated mg/l)	5.8	5.7	5.4	6.4	5.6	5.9									
Oxygen (bottom mg/l)	5.2	5.2	5.3	6.1	5.1	5.9									
Oxygen (% saturation integrated)	62.8	62.8	59.8	76.8	67.3	70.1									
Oxygen (% saturation bottom)	56.4	56.4	58.9	73.9	62.8	69.7									
Depth (m)	1.4	1.4	2.6	1.8	2.0	2.5	3.0	4.0	2.6	3.6	3.0	2.0	1.5	2.0	1.9
pH (integrated)	8.2	8.0	8.1	8.1	8.1	8.1	8.1	8.1	8.1	7.9	7.9	7.7	7.6	7.9	8.1
Sediment - % mud (<0.065 mm)	29.5	5.2	8.6	21.0	4.1	7.6	4.5	38.4	43.8	43.9	69.6	80.1	7.7	17.9	11.7
Sediment - % sand (0.125 - 0.355 mm)	28.6	15.2	16.1	18.6	41.6	3.3	43.0	3.2	15.7	4.3	11.4	2.8	84.9	70.0	26.3
Sediment - % sand (0.355 - 1.00 mm)	17.3	13.0	51.9	42.9	32.8	0.0	41.9	1.0	3.6	0.4	2.5	0.0	9.2	10.8	51.5
Sediment organic matter (%)	6.7	2.3	1.8	1.2	1.3	1.9	1.5	0.5	4.8	4.3	7.0	6.1	1.3	1.7	1.5

Table A4.1.4 Abiotic measurements recorded in April 2005 at 15 stations in the Great Berg estuary. Integrated values are the mean for all readings in the water column. Surface readings refer to the top 15 cm of the water column; bottom readings reflect conditions just above the substratum.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Salinity (integrated)	35.3	35.2	35.1	34.5	34.4	32.7	30.5	26.2	22.9	20.1	15.6	11.7	3.0	0.9	0.9
Salinity (surface)	35.2	35.2	35.1	34.5	34.4	32.6	30.1	26.0	21.6	17.7	10.8	7.0	1.8	0.9	0.9
Salinity (bottom)	35.3	35.2	35.1	34.5	34.4	32.7	30.9	26.4	24.0	22.4	19.3	18.2	4.6	0.9	0.9
Temperature (integrated °C)	15.8	16.4	16.7	17.1	17.6	18.3	18.7	19.0	18.9	19.2	19.0	19.2	18.2	18.3	18.2
Temperature (surface °C)	15.8	16.4	16.3	17.1	17.6	18.3	18.9	19.2	19.2	19.3	18.1	19.3	18.3	18.4	18.2
Temperature (bottom °C)	15.8	16.4	16.7	17.1	17.6	18.3	18.6	18.9	18.8	19.9	19.2	19.5	18.2	18.2	18.1
Oxygen (integrated mg/l)	2.8	2.8	2.4	3.9	4.4	5.1	5.7	5.7	6.0	6.2	6.7	6.3	7.2	7.5	7.5
Oxygen (bottom mg/l)	2.7	2.7	2.3	3.9	4.3	4.8	5.4	5.4	5.5	4.5	4.8	4.1	6.1	7.4	7.4
Oxygen (% saturation integrated)	34.8	35.9	30.1	49.2	56.0	65.3	72.7	71.3	74.1	76.0	80.2	73.1	77.8	80.7	79.6
Oxygen (% saturation bottom)	33.7	33.8	29.2	49.2	55.4	62.2	69.0	67.5	67.6	56.5	58.1	49.6	66.6	78.4	78.7
NTU (integrated)	21.5	18.3	19.0	6.9	9.1	4.1	0.9	0.0	2.5	5.9	18.4	65.7	127.0	126.8	107.0
NTU (surface)	22.0	13.2	7.1	5.2	8.9	2.3	0.2	0.0	0.0	1.5	30.5	74.0	99.4	118.9	99.4
NTU (bottom)	22.2	32.8	69.8	10.0	11.5	11.5	4.0	0.0	11.1	21.1	14.2	58.4	172.2	144.1	116.0
Depth (m)	1.0	3.0	3.6	1.5	3.0	5.0	3.5	5.0	3.0	3.4	2.5	2.8	1.5	2.4	2.4
pH (integrated)	7.0	7.1	7.1	7.2	7.2	7.3	7.1	7.0	7.0	7.1	7.1	7.0	7.1	7.1	7.0
Chlorophyll *a* (mg/l integrated)	2.0	1.6	1.5	1.9	2.1	3.7	4.7	5.0	8.4	11.5	23.4	22.7	17.9	13.4	14.4
Chlorophyll a (mg/l maximum)	2.2	2.3	1.9	2.1	2.4	7.2	9.3	5.4	10.6	20.0	33.9	34.1	19.1	14.7	15.1
Sediment - % mud (<0.065 mm)	92.3	5.9	7.0	12.9	13.4	8.2	6.9	17.8	35.9	79.4	90.9	6.4	37.5	23.9	9.0
Sediment - % sand (0.125 - 0.355 m	1.3	7.2	24.7	24.9	31.3	47.6	44.4	55.9	31.5	5.9	2.7	37.9	33.2	52.4	5.5
Sediment - % sand (0.355 - 1.00 mm	0.0	47.4	45.4	55.8	19.3	32.8	35.2	19.2	3.6	1.4	1.2	44.2	4.2	22.6	61.8
Sediment organic matter (%)	3	0.3	0.3	0.6	0.6	0.5	0.4	0.5	1.2	2.5	2.8	3.8	0.6	0.4	0.2

Table A4.1.5 Abiotic measurements recorded in July 2005 at 15 stations in the Great Berg estuary. Integrated values are the mean for all readings in the water column. Surface readings refer to the top 15 cm of the water column; bottom readings reflect conditions just above the substratum.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Salinity (integrated)	27.0	17.4	12.3	8.1	3.4	2.4	1.9	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5
Salinity (surface)	26.1	17.2	12.3	8.1	1.1	2.1	1.9	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Salinity (bottom)	29.3	18.1	12.3	8.1	3.9	2.9	1.9	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5
Temperature (integrated °C)	15.1	15.1	15.2	15.2	15.2	15.1	15.2	14.9	14.8	14.8	14.8	14.9	14.7	14.6	14.7
Temperature (surface °C)	15.2	15.1	15.2	15.2	15.2	15.1	15.2	14.9	14.8	14.8	14.8	15.0	14.7	14.6	14.7
Temperature (bottom °C)	14.9	15.1	15.2	15.2	15.1	15.1	15.2	14.9	14.8	14.8	14.8	14.8	14.7	14.6	14.7
Oxygen (integrated mg/l)	8.5	9.5													
Oxygen (bottom mg/l)	7.7	9.1													
Oxygen (% saturation integrated)	100.1	104.6													
Oxygen (% saturation bottom)	91.9	102.3													
NTU (integrated)	81.6	49.8	42.6	38.3	65.7	84.9	93.0	72.5	65.9	67.3	108.1	133.0	108.9	149.8	161.0
NTU (surface)	47.7	36.8	30.8	36.2	54.7	79.1	94.1	70.0	64.2	67.6	102.5	125.9	105.9	134.8	155.0
NTU (bottom)	145.7	67.8	50.1	39.5	101.3	92.2	96.5	75.0	72.3	67.7	114.5	138.9	113.1	164.0	168.9
Depth (m)	1.0	3.0	4.0	1.0	3.0	4.0	3.5	4.6	3.7	3.7	2.8	3.0	2.0	3.0	3.0
pH (integrated)	9.9	9.9	9.9	9.9	9.9	9.7	8.7	8.7	8.2	8.1	8.0	8.0	7.9	7.9	7.9
Chlorophyll *a* (mg/l integrated)	4.0	2.6	3.1	3.3	4.3	5.3	6.0	5.7	5.2	5.7	8.4	7.7	8.4	10.3	11.0
Chlorophyll a (mg/l maximum)	7.2	3.1	3.4	3.8	5.1	5.6	9.0	10.1	5.0	6.2	10.0	9.0	8.4	10.8	11.3
Sediment - % mud (<0.065 mm)	57.7	8.3	5.4	22.0	13.8	2.9	3.8	11.5	46.4	24.2	82.6	57.2	0.7	31.3	0.6
Sediment - % sand (0.125 - 0.355 mm)	5.3	46.6	22.9	11.9	42.5	37.2	44.2	44.8	24.9	14.4	4.2	6.7	18.5	11.8	12.2
Sediment - % sand (0.355 - 1.00 mm)	1.5	8.6	44.3	8.9	13.5	43.8	41.8	18.3	4.1	0.2	0.3	0.3	74.7	23.4	80.3
Sediment organic matter (%)	1.9	0.6	0.3	1	0.6	0.6	0.4	0.5	1.3	3.8	2.8	1.7	1.8	0.1	0.1

Table A4.1.6 Abiotic measurements recorded in November 2005 at 15 stations in the Great Berg estuary. Integrated values are the mean for all readings in the water column. Surface readings refer to the top 15 cm of the water column; bottom readings reflect conditions just above the substratum.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Salinity (integrated)	32.9	33.5	32.4	33.4	26.8	21.0	20.7	16.6	10.8	6.1	2.5	0.5	0.4	0.4	0.4
Salinity (surface)	32.9	33.5	32.4	33.4	26.8	21.0	18.5	16.9	10.4	6.1	2.0	0.5	0.4	0.4	0.4
Salinity (bottom)	32.9	33.5	32.4	33.4	26.8	21.0	23.7	16.9	11.3	6.2	3.5	0.5	0.4	0.4	0.4
Temperature (integrated °C)	18.0	16.3	18.3	16.4	21.4	22.4	22.3	23.4	23.3	22.9	22.9	23.0	23.4	23.1	23.3
Temperature (surface °C)	18.1	16.3	18.3	16.4	21.4	22.4	22.2	23.4	23.3	23.0	23.7	23.5	23.7	23.2	23.7
Temperature (bottom °C)	17.9	16.3	18.3	16.4	21.6	22.4	22.3	23.2	23.2	22.8	22.1	22.7	23.2	23.1	23.1
Oxygen (integrated mg/l)								8.3	8.3	9.1	10.0	9.3	4.1	3.9	5.3
Oxygen (bottom mg/l)								8.2	8.1	8.8	8.3	8.7	4.1	3.9	3.9
Oxygen (% saturation integrated)								106.8	104.2	110.1	118.0	108.1	47.8	45.9	64.0
Oxygen (% saturation bottom)								106.0	101.3	105.6	103.0	100.2	47.4	46.0	46.3
NTU (integrated)								36.6	23.8	78.9	128.4	257.6	297.0	268.0	168.8
NTU (surface)								20.0	26.0	57.1	129.0	225.0	271.2	214.9	8.0
NTU (bottom)								60.2	22.2	121.0	127.1	356.2	309.9	342.2	245.2
Depth (m)	1.5	2.0	1.0	2.0	3.5	1.5	2.0	4.0	2.0	4.0	3.0	3.0	1.0	2.0	3.0
pH (integrated)	8.2	8.0	8.0	7.7	7.6	7.5	7.5	7.5	7.5	7.4	7.4	7.3	7.2	7.1	7.1
Chlorophyll *a* (mg/l integrated)	0.3	0.5	0.4	0.4	0.4	0.4	1.0				8.1				6.1
Chlorophyll a (mg/l maximum)	0.3	0.7	0.4	0.5	0.5	0.5	1.7				8.1				8.6
Sediment - % mud (<0.065 mm)	21.1	13.0	15.4	6.4	6.4	28.1	20.2	8.2	28.7	15.5	50.3	80.3	11.2	14.6	21.0
Sediment - % sand (0.125 - 0.355 mm)	24.2	40.6	5.8	10.3	58.5	11.0	40.2	68.6	45.7	60.6	26.3	8.2	71.3	60.5	56.4
Sediment - % sand (0.355 - 1.00 mm)	0.5	44.4	0.1	2.0	0.4	0.2	0.4	17.5	0.5	3.9	0.7	0.3	9.2	24.4	0.2
Sediment organic matter (%)	2.3	0.6	2.8	1.5	1	3.1	2	0.6	2.7	1.1	3.9	3.4	0.9	1.1	2.7

Table A4.1.7 Abiotic measurements recorded in February 2006 at 15 stations in the Great Berg estuary. Integrated values are the mean for all readings in the water column. Surface readings refer to the top 15 cm of the water column; bottom readings reflect conditions just above the substratum.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Salinity (integrated)	36.8	36.0	35.8	35.5	34.5	33.1	31.4	26.1	22.8	19.6	16.2	13.4	8.4	4.5	1.6
Salinity (surface)	36.6	35.9	35.7	35.4	34.4	32.9	30.6	25.0	21.6	18.1	15.0	12.2	8.3	4.1	1.6
Salinity (bottom)	36.8	36.0	35.8	35.5	34.6	33.4	32.7	27.8	24.2	22.2	17.8	15.4	8.5	5.3	1.7
Temperature (integrated ^{o}C)	18.8	21.0	21.7	22.4	22.7	23.4	23.7	24.3	24.3	24.3	24.7	24.7	24.5	25.1	25.1
Temperature (surface ^{o}C)	18.8	21.0	21.8	22.4	22.8	23.4	24.1	24.6	24.1	24.1	24.5	24.3	24.6	25.1	25.1
Temperature (bottom ^{o}C)	18.8	20.9	21.7	22.4	22.6	23.5	23.2	24.0	24.5	24.9	24.9	25.4	24.3	25.1	25.1
Oxygen (integrated mg/l)	8.6	7.6	7.5	7.7	6.9	6.8	6.9	7.0	7.2	7.1	6.8	5.6	6.6	6.0	6.4
Oxygen (bottom mg/l)	7.9	7.0	7.3	7.5	6.6	6.4	6.3	6.2	6.5	5.7	6.0	2.2	6.3	5.3	6.1
Oxygen (% saturation integrated)	115.5	106.4	105.1	109.9	98.4	97.7	98.0	97.3	97.9	94.6	90.3	73.7	83.5	74.3	78.0
Oxygen (% saturation bottom)	105.7	96.3	102.7	106.7	92.9	92.8	88.6	85.7	89.3	78.0	80.3	34.4	79.6	66.3	75.1
NTU (integrated)	9.2	0.1	2.9	4.5	2.5	3.7	34.6	7.3	4.6	8.9	15.3	23.0	68.1	111.9	159.5
NTU (surface)	0.1	0.1	0.1	2.1	1.2	2.1	2.0	6.0	3.0	0.1	6.1	32.0	57.2	93.0	125.3
NTU (bottom)	36.5	0.1	17.4	13.4	6.9	4.1	194.8	53.1	14.6	48.1	59.9	17.2	90.3	148.6	278.1
Depth (m)	2.0	2.5	3.7	2.0	3.0	4.9	4.0	6.5	3.0	3.5	3.0	3.5	2.0	3.0	3.0
Chlorophyll *a* (mg/l integrated)	3.0	2.9	2.9	3.1	8.5	10.6	11.4	11.5	10.8	8.1	5.4	5.7	14.1	12.8	20.4
Chlorophyll a (mg/l maximum)	6.8	3.7	3.3	4.0	8.9	12.0	13.3	12.5	14.8	11.4	5.7	7.5	14.8	13.4	23.9
Sediment - % mud (<0.065 mm)	45.4	1.7	5.2	1.7	7.5	2.5	6.0	18.5	18.5	67.8	70.5	95.9	70.3	6.0	12.1
Sediment - % sand (0.125 - 0.355 mm)	11.4	30.7	30.6	8.4	40.3	46.7	37.7	45.9	49.1	20.8	12.6	1.4	19.0	30.4	38.4
Sediment - % sand (0.355 - 1.00 mm)	3.8	59.3	37.0	63.8	34.4	24.9	44.1	8.3	2.9	0.1	0.6	0.1	0.1	59.5	46.2
Sediment organic matter (%)	5.1	0.8	1.2	0.6	1.2	1.1	0.6	2.7	2.7	7.3	7.1	6.3	5.8	1.6	1.4

APPENDIX 4.2

ESTUARINE INVERTEBRATES:

ZOOPLANKTON

Table A4.2.1 Composition and abundance (numbers m^{-3}) of zooplankton collected February 2003 at 15 stations in the Great Berg estuary.

Station	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Copepoda															
Acartia longipatella	0	671	15108	4238	3147	1961	3814	5967	544	0	0	0	0	0	0
Copepod parasitic sp. 1	580	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Copepod parasitic sp. 2	0	0	0	0	0	0	0	0	544	307	24	122	0	0	0
Copepod spp.	175	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Daphnia sp.	0	0	0	0	0	0	0	0	0	0	0	0	28647	494	80
Halicyclops sp.	0	37	0	103	3	93	426	1146	13151	4845	2682	796	136	16	0
Labidocera sp.	32	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pseudodiaptomus hessei	460	2607	2300	9290	13579	12143	18662	14394	24198	29009	29603	13786	7421	7585	4792
Mysidacea															
Mesopodopsis wooldridgei	73	4	5	3	3	4	6	42	222	20	0	0	0	0	0
Rhopalophthalmus terranatalis	0	0	0	5	3	13	14	8	32	20	7	0	0	0	0
Cumacea															
Cumacean spp	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0
Isopoda															
Anthurid sp.	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Exosphaeroma hylocoetes	17	4	3	8	43	16	8	3	3	0	0	0	0	0	0
Munna sheltoni	0	0	0	0	18	34	1	0	0	8	4	0	0	0	0
Paridotea ungulata	0	3	0	3	0	0	0	0	0	0	0	0	0	0	0
Amphipoda															
Corophium acherusicum	0	0	2	18	1	1	0	1	3	192	65	157	11	0	0
Grandidierella lutosa	0	0	0	3	3	0	0	1	0	0	0	0	0	0	0
Melita zeylanica	0	0	3	3	5	5	1	0	6	8	0	0	0	0	0
Neomacrodeutopus sp.	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Anomura															
Upogebia africana stage 1	3	4	0	0	0	0	0	0	0	0	0	0	0	0	0
Upogebia africana postlarvae	0	0	0	0	18	2	4	0	0	0	0	0	0	0	0
Brachyura															
Chiromantes eulimine larvae	0	0	0	86	0	0	0	0	0	0	0	0	0	0	0
Hymenosoma orbiculare larvae	48	199	156	40	25	11	0	0	0	0	0	0	0	0	0
Hymenosoma orbiculare	1	1	0	0	1	1	1	1	0	0	0	0	0	0	0
Zoea larvae	0	0	0	0	8	16	0	0	0	0	0	0	0	0	0
Insectivora															
Insect larvae	0	0	0	0	0	0	0	0	0	0	20	6	4	3	0
Chironomid larvae	0	0	0	0	0	0	0	3	0	0	24	6	7	0	0
Pisces															
Gilchristella aestuaria eggs	0	0	3	31	0	0	0	16	0	0	0	0	0	0	0
Gilchristella aestuaria larvae	0	0	0	0	0	16	4	332	682	284	125	30	11	7	11
Gobiid larvae	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0

Table A4.2.2. Composition and abundance (numbers m^{-3}) of zooplankton collected September 2003 at 15 stations in the Great Berg estuary.

Station	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Cnidaria															
Cubomedusae	0.3	0	0	3	0	0	0	0	0	0	0	0	0	0	0
Copepoda															
Acartia longipatella	0	53	65	1039	0	0	0	0	0	0	0	0	0	0	0
Copepod parasitic sp. 1	0	0	0	0	0	0	0	0	0	43	15	0	0	0	0
Copepod spp.	206	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Euterpina acutifrons	72	85	0	0	0	0	0	0	0	0	0	0	0	0	0
Halicyclops sp.	0	0	0	0	1373	266	0	0	262	43	0	0	0	0	0
Labidocera sp.	0	0	0.1	0	0	0	0	0	0	0	0	0	0	0	0
Oithona spp	0	190	0	0	0	0	0	0	0	0	0	0	0	0	0
Paracalanus sp	1284	1553	4188	1746	0	0	0	0	0	0	0	0	0	0	0
Pseudodiaptomus hessei	0	0	86	624	29412	9894	9938	2484	1310	1563	626	18	0	0	0
Saphiriella sp.	24	200	0	0	0	0	0	0	0	0	0	0	0	0	0
Mysidacea															
Mysidopsis major	2	4	2	0	0	0	0	0	0	0	0	0	0	0	0
Mesopodopsis wooldridgei	79	712	2	3	7	7	5	5	0	0	0	0	0	0	0
Rhopalophthalmus terranatalis	2	0	2	3	14	25	131	119	119	0	0	0	0	0	0
Cumacea															
Cumacean spp	4	0	2	0	0	0	0	0	0	0	0	0	0	0	0
Isopoda															
Exosphaeroma hylocoetes	0.5	0.3	20	4	113	39	63	5	6	0	0	0	0	0	0
Amphipoda															
Afrochiltonia capensis	0	0	0	0	0	0	0	0	0	0.2	6	0	0	0	0
Corophium acherusicum	0	0	0.1	0	7	3	0.1	0.1	0.2	0.7	31	0	0	0	0
Grandidierella lutosa	0.3	1	3	0	13	5	0	0	0	0	0	0	0	0	0
Lysianassa ceratina	0.4	0	0.5	0	0	0	0	0	0	0	0	0	0	0	0
Melita zeylanica	2	3	3	9	27	3	5	0	0	0.2	6	0	0	0	0
Paramoera capensis	2	7	0	0.5	0	0	0	0	0	0	0	0	0	0	0
Talorchestia sp.	0	43	0	0	0	0.1	0	0	0	0	0	0	0	0	0
Brachyura															
Hymenosoma orbiculare larvae	30	13	0	12	0	0	0	0	0	0	0	0	0	0	0
Hymenosoma orbiculare	2	7	29	6	47	36	5	11	6	0.2	0	0	0	0	0
Chaetognatha															
Sagitta sp	2	43	63	0	0	0	0	0	0	0	0	0	0	0	0
Insectivora															
Chironomid larvae	0	0	0	0	0	0	0	0.2	0	0.4	2	0	0	0	0

Table A4.2.3 Composition and abundance (numbers m^{-3}) of zooplankton collected February 2004 at 15 stations in the Great Berg estuary.

Station	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Polychaeta															
Polychaete larvae	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
Copepoda															
Acartia longipatella	0	0	4665	275	218	779	120	33	32	0	0	0	0	0	0
Copepod parasitic sp. 1	0	47	0	0	0	0	0	0	0	0	0	0	0	0	0
Copepod spp.	289	64	0	0	0	0	0	0	0	26	0	0	8	0	0
Daphnia sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	335	98
Halicyclops sp.	0	0	0	0	0	72	32	40	33	52	320	433	162	152	71
Pseudodiaptomus hessei	0	0	821	2041	3295	1886	3786	1695	5349	4173	4014	3372	1461	2449	650
Saphiriella sp.	1900	987	149	148	0	0	0	0	0	0	0	0	0	0	0
Mysidacea															
Mesopodopsis wooldridgei	34	2	1	0	0	2	2	0	4	2	2	13	0	0	0
Rhopalophthalmus terranatalis	0	0	0	0	1	23	31	124	80	108	157	58	1	0	0
Cumacea															
Cumacean spp	1	17	2	0	0	0	0	0	0	0	0	0	0	0	0
Iphinoe truncata	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Isopoda															
Exosphaeroma hylocoetes	4	10	1	10	12	10	1	7	4	8	1	0	0	0	0
Paridotea ungulata	10	17	1	6	1	1	0	0	0	0	0	0	0	0	0
Uromunna sheltoni	0	0	0	0	0	2	0	0	32	2	0	0	0	0	1
Amphipoda															
Corophium acherusicum	0	0	0.5	2	0	0	0	0	9	56	42	16	184	16	0
Grandidierella lutosa	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Melita zeylanica	0	0	0	1	2	1	2	4	1	0	0	0	0	0	0
Paramoera capensis	2	1	0.2	0	0	0	0	0	0	0	0	0	0	0	0
Decapoda															
Decapod larvae	5	10	0	6	0	0	0	0	0	0	0	0	0	0	0
Caridea															
Palaemon peringueyi post larvae	1	1	1	0	0.3	0	0	0	0	0	0	0	0	0	0
Anomura															
Upogebia africana stage 1	20	15	0	0	0	0	0	0	0	0	0	0	0	0	0
Upogebia africana postlarvae	0	0	0	6	0.5	2	3	9	0	0	0	0	0	0	0
Brachyura															
Hymenosoma orbiculare larvae	53	78	25	5	1	3	0	0	2	0	0	0	0	0	0
Hymenosoma orbiculare	0	0	0	0	0	0.5	0.5	2	0	1	0	0	0	0	0
Zoea larvae	0	47	51	23	19	0	0	0	0	0	0	0	0	0	0
Insectivora															
Insect larvae	0	0	0	0	0	0	0	0	0	0	0	0	37	3	1
Chironomid larvae	0	0	0	0	0	0	0	0	0	0	0	0	23	4	3
Pisces															
Gilchristella aestuaria larvae	0	0	0	0	0	2	6	4	9	30	6	11	12	0	0
Gobiid larvae	1	0	0	4	0	0	0	2	0	2	0	0	0	0	0
Pipefish juv.	0.1	0	0.3	3	0	0	0.5	0	0	0	0	0	0	0	0

Table A4.2.4 Composition and abundance (numbers m^{-3}) of zooplankton collected April 2005 at 15 stations in the Great Berg estuary.

Station	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Copepoda															
Acartia longipatella	0	0	0	0	155	546	527	73	100	0	0	0	0	0	0
Copepod spp.	302	407	184	1199	0	0	0	0	55	0	0	0	0	0	0
Daphnia sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30
Halicyclops sp.	0	0	0	0	0	0	0	0	0	0	0	0	274	43	14
Harpacticoid sp.	130	153	117	0	155	113	133	0	0	0	0	0	0	0	0
Oithona spp	0	167	0	0	0	88	0	0	0	0	0	0	0	0	0
Oncaea sp.	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Paracalanus sp	898	5908	1138	4768	155	45	0	0	0	0	0	0	0	0	0
Pseudodiaptomus hessei	0	0	37	29	271	3019	2697	3286	2646	2985	7444	8562	3933	2273	1963
Saphiriella sp.	141	28	382	205	77	0	0	0	0	0	0	0	0	0	0
Mysidacea															
Mysidopsis major	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0
Mesopodopsis wooldridgei	89	198	1243	76	1	2	0	0	0	0	0	3	0	0	0
Rhopalophthalmus terranatalis	0	0	0	0	0	2	25	6	250	81	267	78	2	0	0
Cumacea															
Cumacean spp	0	14	0	0	0	0	0	0	0	0	0	0	0	0	0
I*phinoe* sp.	0	6	0	0	1	0	0.1	0	0	0	0	0	0	0	0
Isopoda															
Exosphaeroma hylocoetes	0	0	0	2	16	25	16	5	28	14	17	4	0	0	0
Paridotea ungulata	0	0	0.1	2	1	5	0.2	0	0	0	0	0	0	0	0
Uromunna sheltoni	0	0	0	0	0	0	60	101	11	152	0	0	0	1	0
Amphipoda															
Corophium acherusicum	0	0	0	0	0	0	2	0	11	2	10	14	43	19	2
Grandidierella lutosa	0	0	6	0	1	0	0	0	0	0	0	0	0	0	0
Melita zeylanica	0	0	0	2	1	6	10	4	3	2	7	43	3	2	0
Paramoera capensis	1	6	0.1	0	0	0	0	0	0	0	0	0	0	0	0
Caridea															
Palaemon perengueyi	0.1	0.1	0.1	2	0	0	0	0	0	0	0	0	0	0	0
Anomura															
*Callianassa krauss*i juvs	0	0	0	0	0.1	0	0.6	0	0	0	0	0	0	0	0
Brachyura															
Hymenosoma orbiculare larvae	1655	122	50	48	0.1	95	133	4	11	9	7	0	0	0	0
Hymenosoma orbiculare	0	0.1	0	0	0.1	0	1	0.2	0	0	0	0	0	0	0
Insectivora															
Insect larvae	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0	0
Chironomid larvae	0	0	0	0	0	0	0	0	0	0	0	1	26	23	2
Pisces															
Gobiid larvae	6	0	0	4	0.1	35	1	0	0	0	7	0	2	0.1	0
Pipefish juv.	0.1	0	0	0.1	0.1	1	0	0	0	0	0	0	0	0	0

Table A4.2.5 Composition and abundance (numbers m^{-3}) of zooplankton collected July 2005 at 15 stations in the Great Berg estuary.

Station	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Copepoda															
Copepod spp.	615	522	192	32	1	6	0	14	29	0	29	30	74	229	127
Daphnia sp.	0	0	0	0	0	0	0	0	0	0	0	0	4	0	1
Halicyclops sp.	0	0	0	0	0	0	3	12	8	21	29	33	62	23	10
Oithona spp	738	202	168	0	0	0	0	0	0	0	0	0	0	0	0
Paracalanus sp	1135	222	675	183	0	0	0	0	0	0	0	0	0	0	0
Pseudodiaptomus hessei	0	0	0	15	5	66	49	344	62	78	201	268	203	205	0
Mysidacea															
Mesopodopsis wooldridgei	1490	2462	2803	21	0	0	0	0	0	0	0	0	0	0	0
Rhopalophthalmus terranatalis	61	20	31	14	0	0.1	0.1	0	0	0	0	0	0	0	0
Cumacea															
Cumacean spp	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Iphinoe sp.	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Isopoda															
Exosphaeroma hylocoetes	0	0	3	13	19	3	0.1	0	0	0	0	0	0	0	0
Amphipoda															
Corophium acherusicum	0	0	0	0	0	1	2	4	2	1	3	4	7	13	5
Grandidierella lutosa	0	0	0	3	0	4	0.2	0	0	0	0	0	0	0	0
Melita zeylanica	0	0	0	2	0.5	1	4	0.5	2	0	2	2	0.1	0	0
Decapoda															
Decapod larvae	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Caridea															
Palaemon peringueyi post larvae	0	0	0	0	0.5	0	0	0	0	0	0	0	0	0	0
Anomura															
Callianassa kraussi juvs	0	0	0	1	0	0	0.2	0	0	0	0	0	0	0	0
Brachyura															
Hymenosoma orbiculare larvae	586	503	81	3	2	11	0	0	0	0	0	0	0	0	0
Hymenosoma orbiculare	0.1	0.2	0.1	1	1	4	2	3	0	0	0	0	0	0	0
Insectivora															
Insect larvae	0	0	0	0	0	0	0	0	0	0.1	0	3	2	2	1
Chironomid larvae	0	0	0	0	0	0	2	0.1	0	0.1	0	4	1	7	5
Pisces															
Anguilla sp.	0.1	0.1	0.2	0.1	0	0	0	0	0	0	0	0	0	0	0
Gilchristella aestuaria larvae	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Gobiid larvae	5	0	0	0	0	0.1	0	0	0	0	0	0	0	0	0
Pipefish juv.	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table A4.2.6 Composition and abundance (numbers m^{-3}) of zooplankton collected November 2005 at 15 stations in the Great Berg estuary.

Station	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Polychaeta															
Polychaete larvae	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Copepoda															
Acartia longipatella	0	38	535	1612	1653	5804	5118	496	1047	0	0	0	0	0	0
Daphnia sp.	0	0	0	0	0	0	0	0	0	0	0	0	25	85	0
Halicyclops sp.	0	0	0	0	0	0	0	1	215	481	717	136	20	57	216
Harpacticoid sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	621
Oithona spp	31	19	0	0	0	0	0	0	0	0	0	0	0	0	0
Paracalanus sp	511	463	209	0	0	0	0	0	0	0	0	0	0	0	0
Pseudodiaptomus hessei	0	571	2355	7776	11674	50667	37001	3823	10169	17849	14156	2727	520	2386	3439
Saphiriella sp.	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mysidacea															
Mesopodopsis wooldridgei	6	0	0	4	0	7	8	4	15	19	0	0	0	0	0
Rhopalophthalmus terranatalis	0	0	0	0	0	7	8	5	10	12	25	0	0	0	0
Cumacea															
Cumacean spp	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Iphinoe sp.	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Isopoda															
Exosphaeroma hylocoetes	8	28	30	21	22	23	8	7	0	5	0	0	0	0	0
Amphipoda															
Corophium acherusicum	0	0	6	0	27	7	5	4	4	9	6	18	4	2	8
Grandidierella lutosa	0	28	58	229	6	15	4	0	0	0	0	0	0	0	0
Melita zeylanica	11	28	24	21	9	16	23	2	0	9	3	0	0	0	0
Paramoera capensis	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Caridea															
Palaemon peringueyi post larvae	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Anomura															
Upogebia africana stage 1 larvae	240	38	0	0	0	0	0	0	0	0	0	0	0	0	0
Callianassa kraussi juvs	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Brachyura															
Hymenosoma orbiculare larvae	129	92	25	25	28	13	8	0	0	0	0	0	0	0	0
Hymenosoma orbiculare	11	19	1	0	6	7	0	0	0.2	4	6	0	0	0	0
Insectivora															
Insect larvae	0	0	0	0	0	0	0	0	0	0	6	3	4	4	8
Chironomid larvae	0	0	0	0	0	0	0	0	0	0	3	8	4	4	3
Mollusca															
Bivalve spat	36	0	0	0	0	0	4	0	0	0	0	0	0	0	0
Gastropod spat	0	0	0	2603	0	5998	16507	385	798	1105	0	0	0	23	0
Pisces															
Gilchristella aestuaria eggs	8	19	134	131	86	26	25	33	4	4	0	8	0	0	0
Gilchristella aestuaria larvae	3	0	0	16	0	10	45	5	105	31	19	3	2	0	0
Gobiid larvae	14	0	0	21	14	10	16	2	8	9	21	0	0	0	0
Pipefish juv.	0.2	0	0	1	0	0.2	0	0	0	0	0	0	0	0	0

Table A4.2.7 Composition and abundance (numbers m^{-3}) of zooplankton collected February 2006 at 15 stations in the Great Berg estuary.

Station	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Copepoda															
Acartia longipatella	0	0	147	99	102	112	44	771	433	0	37	0	0	0.0	0.0
Copepod spp.	124	252	140	121	0	0	0	0	0	0	0	0	0	0.0	0.0
Daphnia sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	62.0	934.0
Halicyclops sp.	0	0	0	0	262	112	115	41	0	0	0	0	39	62.0	163.0
Oithona spp	166	310	0	0	0	0	0	0	0	0	0	0	0	0.0	0.0
Paracalanus sp	166	191	666	0	0	0	0	0	0	0	0	0	0	0.0	0.0
Pseudodiaptomus hessei	0	0	446	2698	26055	1637	861	8265	6313	16446	11152	12514	7702	4954.0	3629.0
Saphiriella sp.	387	443	446	1450	166	112	0	0	0	0	0	0	0	0.0	0.0
Mysidacea															
Mysidopsis major	3	2	0	0	0	0	0	0	0	0	0	0	0	0.0	0.0
Mesopodopsis wooldridgei	0	0	4	0	0	0	0	0	4	0	9	0	14	0.0	0.0
Rhopalophthalmus terranatalis	0	0	0	0	0	21	22	29	62	205	154	209	101	0.0	0.0
Cumacea															
Cumacean spp	9	6	7	0	0	0	0	0	0	0	0	0	0	0.0	0.0
Iphinoe sp.	5	7	19	0	0	4	2	0	0	0	0	0	0	0.0	0.0
Isopoda															
Exosphaeroma hylocoetes	0	6	10	98	256	6	10	24	20	35	0	0	0	0.0	0.0
Paridotea ungulata	0	0	0	0	2	2	0	0	0	0	0	0	0	0.0	0.0
Uromunna sheltoni	0	0	0	3	0	66	0	307	14	38	0	0	0	0.0	0.0
Amphipoda															
Corophium acherusicum	0	0	4	1	18	0	4	40	406	4529	2421	16	509	251.0	3.0
Grandidierella lutosa	0	4	0	0	0	0	2	0	0	0	0	0	0	0.0	0.0
Melita zeylanica	0	6	0	17	258	10	4	6	9	27	12	0	0	0.0	0.0
Paramoera capensis	0	0	4	1	0	0	0	0	0	0	0	0	0	0.0	0.0
Caridea															
Palaemon perengueyi	2	6	2	0	0.4	2	0	0	0	0	0	0	0	0.0	0.0
Anomura															
Upogebia africana stage 1 larvae	3	64	8	37	0	0	0	0	0	0	0	0	0	0.0	0.0
Callianassa kraussi juvs	0	0	0	0	0	0	4	20	0	0	0	0	0	0.0	0.0
Brachyura															
Hymenosoma orbiculare larvae	31	89	0	0	0	0	0	61	0	10	0	0	0	0.0	0.0
Hymenosoma orbiculare	3	7	19	49	326	24	20	2	11	9	3	0	0	0.0	0.0
Zoea larvae	0	0	0	0	0	0	0	4	0	0	0	0	0	0.0	0.0
Insectivora															
Insect larvae	0	0	0	0	0	0	0	0	0	0	0	0	3	0.0	2.0
Chironomid larvae	0	0	0	0	0	0	0	0	0	0	0	0	0	4.0	6.0
Pisces															
Gilchristella aestuaria eggs	0	0	0	0	0	0	0	0	4	0	0	0	0	0.0	0.0
Gilchristella aestuaria larvae	0	0	0	0	0	0	4	8	54	18	17	171	6	2.0	2.0
Gobiid larvae	3	2	4	1	1	2	4	29	4	27	3	0	0	0.0	0.0
Pipefish juv.	0	0	0.2	1	0	0	0.2	0	0	0	0	0	0	0.0	0.0

APPENDIX 4.3

ESTUARINE INVERTEBRATES:

HYPERBENTHOS

Table A4.3.1 Composition and abundance (numbers m^{-3}) of hyperbenthic organisms, collected February 2003 at 15 stations in the Great Berg estuary.

Station	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Mysidacea															
Mesopodopsis wooldridgei	0	703.5	1	0.1	1	3.5	2	6.5	37.5	49.5	0	0	0	0	0
Rhopalophthalmus terranatalis	0	0	0	0	0.5	0	0	0.5	7.5	17	0	0	0.1	0	0
Isopoda															
Exosphaeroma hylocoetes	0	0	0.5	0	0	0	0	0	0	0	0	0	0	0	0
Paridotea ungulata	0.4	0	1	0.5	0	0	0	0	0	0	0	0	0	0	0
Sphaeromid sp	0.1	0	0	0	0.5	0	0	0	0	0	0	0	0	0	0
Uromunna sheltoni	0	0	0	2.5	0	0	0	0	0	0	0	0	0	0	0
Amphipoda															
Corophium acherusicum	0	0	0	0	0.5	0	0.5	2	7	1.5	3	0.1	0	0.1	0
Grandidierella lignorum	0	0	0	0	1	0	0	0	0	3	1	0	0	0	0
Melita zeylanica	0	0	1	5	0.5	0.1	0.5	1	0	0	0	0	0	0	0
Caridea															
Palaemon peringueyi	10.5	0	1	4	0	0	0	0	0	0	0	0	0	0	0
Anomura															
Upogebia africana stage 1	0	13	0	0	0	0	0	0	0	0	0	0	0	0	0
Brachyura															
Chiromantes eulimine larvae	0	2.5	0	0	344	176.5	65	5	0	0	0	0	0	0	0
Hymenosoma orbiculare larvae	0	0	0	564.5	3.5	0	0	0	0	0	0	0	0	0	0
Hymenosoma orbiculare	0	0	0.5	0.5	0	0	0	0	0	0	0	0	0	0	0
Zoea larvae	0	0	0	68.5	0	0	0	0	0	0	0	0	0	0	0
Insectivora															
Insect larvae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.5
Pisces															
Brown goby	0	0	0	0.1	0	0	0	0	0	0	0	0	0	0	0
Gilchristella aestuaria eggs	0	0	0	0	0	0	0	6.5	0	0	0	0	0	0	0
Gilchristella aestuaria larvae	0	0	0	0	0	0	0.5	103	251	74.5	12	0.5	13	3	0
Gobiid larvae	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pipe fish	0	0	0	0.1	0.1	0	0	0	0	0	0	0	0	0	0

Table A4.3.2 Composition and abundance (numbers m^{-3}) of hyperbenthic organisms, collected September 2003 at 15 stations in the Great Berg estuary.

Station	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Mysidacea															
Mesopodopsis wooldridgei	256.5	3.5	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rhopalophthalmus terranatalis	53.5	0.1	8.5	12.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Amphipoda															
Corophium acherusicum	0.0	0.0	0.0	4.0	0.4	0.4	0.1	0.5	11.0	20.0	14.5	0.0	0.0	0.0	0.0
Cyathura estuaria	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Grandidierella lutosa	0.0	0.0	0.0	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Melita zeylanica	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Caridea															
Palaemon peringueyi	4.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Brachyura															
Hymenosoma orbiculare	0.1	0.1	0.0	0.0	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pisces															
Caffrogobius nudiceps	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mullet juv	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0
Syngnathus temminkii	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Psammogobius knysnaensis	0.1	0.0	0.0	0.1	0.1	0.1	0.1	0.3	0.0	0.3	0.7	0.0	0.0	0.0	0.0
Solea bleekeri	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table A4.3.3 Composition and abundance (numbers m^{-3}) of hyperbenthic organisms, collected February 2004 at 15 stations in the Great Berg estuary.

Station	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Mysidacea															
Gastrosaccus brevifissura	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mesopodopsis wooldridgei	3.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0	6.0	1.0	0.0	0.0	0.0
Rhopalophthalmus terranatalis	0.0	0.0	0.0	0.0	3.0	48.0	25.0	31.0	53.0	28.0	427.0	3.0	0.0	0.0	0.0
Cumacea															
Cumacean spp	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Isopoda															
Exosphaeroma hylocoetes	0.0	0.1	0.1	0.0	0.0	0.0	0.0	1.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0
Paridotea ungulata	0.6	0.1	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Uromunna sheltoni	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Amphipoda															
Corophium acherusicum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	1.0	2.0	0.0	0.0	0.0	0.0	0.0
Melita zeylanica	0.0	0.0	0.1	0.0	0.0	0.3	0.1	9.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Decapoda															
Decapod larvae	1.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Caridea															
Palaemon peringueyi	0.0	0.0	0.2	7.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Palaemon peringueyi larvae	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Anomura															
Upogebia africana stage 1	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Brachyura															
Hymenosoma orbiculare	0.0	0.0	0.0	0.5	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Insectivora															
Chironomid larvae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1
Pisces															
Caffrogobius nudiceps	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Gilchristella aestuaria larvae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	2.0	2.0	0.5	1.0	0.0	0.0
Syngnathus temminkii	0.0	0.0	0.2	0.2	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table A4.3.4 Composition and abundance (numbers m^{-3}) of hyperbenthic organisms, collected April 2005 at 15 stations in the Great Berg estuary.

Station	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Mysidacea															
Mesopodopsis wooldridgei	230.0	1.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.5	0.0	0.0	0.0	0.0
Rhopalophthalmus terranatalis	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1	137.0	14.0	8.0	329.0	2.0	0.0	0.0
Isopoda															
Exosphaeroma hylocoetes	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0
Paridotea ungulata	3.0	1.0	0.1	0.1	0.1	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Uromunna sheltoni	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	115.0	1.0	0.0	0.0	0.0	0.0
Amphipoda															
Corophium acherusicum	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.1	0.0	13.0	79.0	4.0	15.0	20.0	0.1
Grandidierella lutosa	5.0	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Melita zeylanica	0.0	0.0	0.0	0.0	1.0	0.3	0.0	0.0	0.0	5.0	0.0	0.0	0.0	0.0	0.0
Caridea															
Palaemon peringueyi	1.0	2.0	0.0	2.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Brachyura															
Hymenosoma orbiculare larvae	9.0	32.0	0.0	6.0	1.0	1.0	5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hymenosoma orbiculare	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.1	0.0	0.0	0.0	0.0
Insectivora															
Chironomid larvae	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0
Pisces															
Gilchristella aestuaria larvae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
Gobiid larvae	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Syngnathus temminkii	0.0	0.1	0.0	0.0	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table A4.3.5 Composition and abundance (numbers m^{-3}) of hyperbenthic organisms, collected July 2005 at 15 stations in the Great Berg estuary.

Station	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Mysidacea															
Mesopodopsis wooldridgei	0.0	2.0	0.1	0.3	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rhopalophthalmus terranatalis	189.0	11.0	4.0	2.0	5.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Isopoda															
Exosphaeroma hylocoetes	0.0	0.0	0.4	0.2	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Amphipoda															
Corophium acherusicum	0.0	0.0	0.0	0.0	0.4	0.0	0.4	0.0	0.0	0.1	0.0	0.0	0.3	0.0	0.1
Cyathura estuaria	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Grandidierella lutosa	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Melita zeylanica	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.0
Caridea															
Palaemon peringueyi larvae	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Brachyura															
Hymenosoma orbiculare	0.1	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Insectivora															
Insect larvae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.0	0.0
Chironomid larvae	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pisces															
Anguilla sp.	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Gilchristella aestuaria larvae	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Psammogobius knysnaensis	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.0	0.0	0.0	0.0

Table A4.3.6 Composition and abundance (numbers m^{-3}) of hyperbenthic organisms, collected November 2005 at 15 stations in the Great Berg estuary.

Station	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Mysidacea															
Mesopodopsis wooldridgei	17.0	14.0	1.0	0.0	0.0	0.0	0.0	0.0	1.0	2.0	0.0	0.0	0.0	0.0	0.0
Rhopalophthalmus terranatalis	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	5.0	2.0	104.0	5.0	0.0	0.0	0.0
Isopoda															
Exosphaeroma hylocoetes	0.0	0.1	2.0	1.0	0.0	3.0	0.0	1.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0
Paridotea ungulata	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Amphipoda															
Amaryllis sp.	1.0	0.3	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Corophium acherusicum	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	5.0	0.2	0.0	2.0	2.0	3.0	0.4
Grandidierella lutosa	0.0	0.0	3.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Melita zeylanica	0.0	0.0	2.0	2.0	0.0	0.0	3.0	1.0	0.0	0.0	0.0	0.0	0.1	2.0	0.1
Caridea															
Palaemon peringueyi	0.0	0.0	0.5	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Anomura															
Upogebia africana stage 1	9.0	43.0	15.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Brachyura															
Hymenosoma orbiculare	3.0	2.0	2.0	2.0	0.0	0.0	3.0	3.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0
Insectivora															
Insect larvae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	7.0	0.4
Chironomid larvae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.1	0.4	5.0	0.4
Pisces															
Gilchristella aestuaria eggs	0.0	0.0	0.0	0.0	0.0	6.0	3.0	1.0	2.0	0.0	0.0	1.0	0.0	0.0	0.0
Gilchristella aestuaria larvae	0.0	0.0	0.0	0.0	0.0	0.0	1.0	3.0	14.0	2.0	25.0	1.0	0.1	0.1	0.1
Gobiid larvae	0.0	2.0	1.0	0.0	1.0	7.0	36.0	1.0	9.0	3.0	35.0	0.0	0.0	0.0	0.0
Syngnathus temminkii	0.0	0.0	0.0	0.0	0.0	0.2	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Psammogobius knysnaensis	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0

Table A4.3.7 Composition and abundance (numbers m^{-3}) of hyperbenthic organisms, collected February 2006 at 15 stations in the Great Berg estuary.

Station	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Mysidacea															
Mesopodopsis wooldridgei	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.5	1.0	15.0	0.1	0.0
Rhopalophthalmus terranatalis	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	2.0	2.0	4.0	7.0	2.0	0.0	0.0
Cumacea															
Iphinoe sp.	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Isopoda															
Uromunna sheltoni	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0
Amphipoda															
Corophium acherusicum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	2.0	6.0	52.0	2.0	0.0	0.5	0.0
Cyathura estuaria	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Melita zeylanica	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Caridea															
Palaemon peringueyi	0.1	0.1	0.3	20.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Brachyura															
Hymenosoma orbiculare	0.1	0.0	0.0	0.4	0.1	0.4	0.0	0.0	0.3	0.0	1.0	0.0	0.0	0.0	0.0
Insectivora															
Insect larvae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.3	0.1
Chironomid larvae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.1	0.0
Pisces															
Caffrogobius nudiceps	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Gilchristella aestuaria larvae	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	3.0	14.0	3.0	1.0	2.0	0.1
Gobiid larvae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Syngnathus temminkii	0.0	0.0	0.1	0.2	0.0	0.4	0.1	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0

APPENDIX 4.4

ESTUARINE INVERTEBRATES:

SUBTIDAL BENTHOS

Table A4.4.1. Composition and abundance (numbers m-2) of benthic organisms collected February 2003 at 15 stations in the Great Berg estuary.

Station	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Polychaeta															
Boccardia sp.	0.0	0.0	0.0	8.3	308.3	158.3	0.0	100.0	25.0	0.0	0.0	0.0	0.0	0.0	0.0
Capitella capitata	2183.3	16.7	12.5	466.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ceratonereis erythraeensis	583.3	16.7	75.0	333.3	0.0	0.0	133.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ceratonereis keiskama	0.0	0.0	12.5	308.3	500.0	775.0	325.0	300.0	175.0	0.0	0.0	0.0	0.0	0.0	0.0
Chaetopterid sp.	0.0	8.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Desdemona ornata	0.0	0.0	0.0	83.3	4033.3	9875.0	441.7	0.0	33.3	0.0	0.0	0.0	0.0	0.0	0.0
Oligochaete sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	150.0	400.0	25.0	100.0	68.8	66.7
Orbinia angrapequensis	16.7	50.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Potamilla reniformis	0.0	0.0	1300.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Prionospio bocki (?)	0.0	0.0	0.0	0.0	0.0	25.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Prionospio pinnata	0.0	0.0	0.0	0.0	0.0	58.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Prionospio sp. 1	0.0	8.3	0.0	16.7	8.3	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Prionospio sexoculata	0.0	8.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Spionid sp.	0.0	0.0	0.0	0.0	0.0	83.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cumacea															
Cumacean sp. 1	8.3	8.3	12.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
I*phinoe* sp. 1	0.0	25.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Isopoda															
Anthurid sp.	0.0	0.0	875.0	275.0	741.7	758.3	450.0	25.0	8.3	0.0	0.0	0.0	0.0	0.0	0.0
Exosphaeroma hylocoetes	0.0	0.0	12.5	0.0	0.0	0.0	0.0	33.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Paridotea ungulata	33.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Amphipoda															
Amphipod sp. 1	16.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Amphipod sp 2.	0.0	0.0	0.0	0.0	41.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Corophium acherusicum	8.3	0.0	62.5	25.0	133.3	1300.0	533.3	84183.3	10750.0	16.7	0.0	0.0	0.0	0.0	0.0
Grandidierella chelata	0.0	8.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Grandidierella lignorum	0.0	0.0	0.0	0.0	0.0	8.3	0.0	8.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Grandidierella lutosa	108.3	75.0	2437.5	1150.0	341.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lysianassa sp.	75.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Neomicrodeutopus sp.	0.0	0.0	512.5	225.0	108.3	41.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Anomura															
Callianassa kraussi	0.0	466.7	225.0	33.3	666.7	433.3	25.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Upogebia africana	41.7	0.0	12.5	8.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Brachyura															
Hymenosoma orbiculare	8.3	16.7	0.0	8.3	0.0	8.3	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Thaumastoplax spiralis	0.0	0.0	37.5	0.0	58.3	41.7	16.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.3
Insectivora															
Chironomid larvae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.7	8.3	31.3	0.0	83.3	87.5	25.0

Table A4.4.2 Composition and abundance (numbers m^{-2}) of subtidal benthic organisms collected September 2003 at 15 stations in the Great Berg estuary.

Station	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Polychaeta															
Boccardia sp.	0	0	0	33.3	583.3	233.3	116.7	18.8	77.8	0	0	0	0	0	0
Capitella capitata	2211	522.2	0	0	0	0	0	0	0	0	0	0	0	0	0
Ceratonereis erythraeensis	38.9	0	33.3	94.4	0	0	0	0	0	0	0	0	0	0	0
Ceratonereis keiskama	0	0	0	211.1	544.4	783.3	416.7	556.3	727.8	138.9	0	0	0	0	0
Desdemona ornata	0	77.8	27.8	66.7	1461.1	1061.1	2816.7	31.3	0	0	0	0	0	0	0
Glycera tridactyla	0	5.6	0	0	0	0	0	0	0	0	0	0	0	0	0
Oligochaete sp.	0	0	0	0	0	0	0	12.5	5.6	211.1	316.7	838.9	250	388.9	272.2
Prionospio bocki	16.7	38.9	222.2	44.4	133.3	372.2	22.2	50	0	0	0	0	0	0	0
Prionospio sexoculata	0	44.4	0	0	0	0	0	0	0	0	0	0	0	0	0
Isopoda															
Anthurid sp.	0	0	1178	1250	2388.9	1572.2	2727.8	37.5	0	0	0	0	0	0	0
Cyathura estuaria	11.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Exosphaeroma hylocoetes	0	0	0	16.7	0	0	0	0	0	0	0	0	0	0	0
Amphipoda															
Corophium acherusicum	0	0	0	111.1	6727.8	8377.8	8516.7	4437.5	1744	100	0	0	0	0	0
Grandidierella lutosa	5.6	11.1	3494	3594.4	16.7	77.8	83.3	0	0	0	0	0	0	0	0
Melita zeylanica	0	0	0	0	0	0	5.6	0	0	0	0	0	0	0	0
Anomura															
Callianassa kraussi	0	0	0	0	16.7	22.2	5.6	0	0	0	0	0	0	0	0
Upogebia africana	16.7	16.7	16.7	0	0	0	0	0	0	0	0	0	0	0	0
Brachyura															
Hymenosoma orbiculare	55.6	16.7	27.8	27.8	44.4	105.6	27.8	0	0	0	0	0	0	0	0
Thaumastoplax spiralis	0	0	0	11.1	0	0	0	0	0	0	0	0	0	0	0
Insectivora															
Insect larvae	0	0	0	0	0	0	0	0	0	0	0	5.6	0	0	11.1
Chironomid larvae	5.6	16.7	22.2	333.3	5.6	27.8	5.6	56.3	16.7	11.1	33.3	5.6	0	11.1	0
Mollusca															
Bivalve spat	0	5.6	0	0	0	0	0	0	0	0	0	0	0	0	0
Pisces															
Solea bleekeri	0	5.6	0	0	0	0	0	0	0	0	0	0	0	0	0

Table A4.4.3. Composition and abundance (numbers m^{-2}) of subtidal benthic organisms collected February 2004 at 15 stations in the Great Berg estuary.

Station	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Polychaeta															
Boccardia sp.	0	0	0	12.5	6706.3	77.8	62.5	200	0	0	0	0	0	0	0
Capitella capitata	450	2466.7	200	531.3	2593.8	0	0	50	6138.9	0	0	0	0	0	0
Ceratonereis keiskama	222.2	5.6	0	25	4306.3	450	562.5	1988.9	1038.9	366.7	38.9	0	0	0	0
Desdemona ornata	0	194.4	66.7	0	806.3	5750	306.3	0	0	5727.8	0	0	0	0	0
Dorvillea sp.	0	0	0	31.3	0	0	0	0	0	0	0	0	0	0	0
Glycera tridactyla	5.6	0	11.1	0	0	0	0	0	0	0	0	0	0	0	0
Oligochaete sp.	0	0	0	0	0	0	0	0	0	0	505.6	133.3	155.6	116.7	72.2
Orbinia angrapequensis	16.7	44.4	11.1	0	0	0	0	0	0	0	0	0	0	0	0
Prionospio sexoculata	0	0	0	0	875	50	25	0	0	0	0	0	0	0	0
Isopoda															
Anthurid sp.	0	27.8	855.6	2212.5	2743.8	4300	1256.3	11.1	0	0	0	0	0	0	0
Exosphaeroma hylocoetes	0	0	11.1	0	0	0	0	0	0	0	0	0	0	0	0
Amphipoda															
Corophium acherusicum	0	0	0	6.3	0	105.6	25	5.6	33.3	19472.2	22.2	0	0	0	0
Grandidierella lutosa	0	16.7	372.2	818.8	16043.8	388.9	62.5	0	0	0	0	0	0	0	0
Melita zeylanica	0	11.1	0	6.3	0	0	0	0	0	0	0	0	0	0	0
Anomura															
Callianassa kraussi	0	11.1	0	37.5	43.8	972.2	81.3	0	0	0	0	0	0	0	0
Upogebia africana	394.4	0	61.1	0	0	0	0	0	0	0	0	0	0	0	0
Brachyura															
Hymenosoma orbiculare	5.6	5.6	5.6	0	12.5	11.1	0	0	0	0	0	0	0	0	0
Thaumastoplax spiralis	0	0	0	6.3	12.5	44.4	12.5	0	0	0	0	0	0	0	0
Insectivora															
Chironomid larvae	0	0	0	0	0	0	0	0	0	5.6	11.1	22.2	111.1	5.6	11.1
Mollusca															
Bivalve spat	5.6	11.1	0	0	0	0	0	0	0	0	0	0	0	0	0

Table A4.4.4. Composition and abundance (numbers m^{-2}) of subtidal benthic organisms collected April 2005 at 15 stations in the Great Berg estuary.

Station	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Polychaeta															
Boccardia sp.	0	0	0	16.7	505.6	0	0	5.6	472.2	1705.6	0	0	0	0	0.0
Capitella capitata	3022.2	0	127.8	266.7	27.8	11.1	0	0	8055.6	16150	1927.8	227.8	0	227.8	0.0
Ceratonereis erythraeensis	0	22.2	27.8	0	0	0	0	0	0	0	0	0	0	0	0.0
Ceratonereis keiskama	44.4	0	16.7	22.2	894.4	266.7	272.2	216.7	2561.1	14166.7	3533.3	683.3	516.7	0	0.0
Desdemona ornata	0	0	144.4	0	661.1	127.8	5.6	0	0	0	0	0	0	0	0.0
Oligochaete sp.	0	0	22.2	0	0	0	61.1	0	0	2266.7	566.7	0	288.9	1338.9	1688.9
Orbinia angrapequensis	0	0	16.7	0	0	0	0	0	0	0	0	0	0	0	0.0
Prionospio bocki	0	0	0	0	0	16.7	0	5.6	227.8	0	283.3	0	16.7	0	0.0
Prionospio sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	5.6	0	0.0
Prionospio sexoculata	455.6	16.7	500	55.6	983.3	22.2	0	0	0	0	0	0	0	0	0.0
Cumacea															
Iphinoe sp. 1	0	11.1	11.1	0	22.2	5.6	0	0	0	0	0	0	0	0	0.0
Isopoda															
Anthurid sp.	0	0	1077.8	2261.1	4983.3	1411.1	2483.3	1216.7	0	0	0	0	0	0	0.0
Exosphaeroma hylocoetes	0	0	5.6	44.4	483.3	50	27.8	0	0	0	0	0	0	0	0.0
Uromunna sheltoni	0	0	0	0	0	5.6	5.6	11.1	0	0	0	0	0	0	0.0
Amphipoda															
Corophium acherusicum	0	0	0	55.6	5333.3	19055.6	94.4	77.8	38.9	25783.3	3227.8	600	4772.2	5700	4405.6
Grandidierella lutosa	0	27.8	1777.8	2272.2	10372.2	66.7	16.7	0	0	0	0	0	0	0	0.0
Melita zeylanica	227.8	0	0	0	0	455.6	0	0	0	0	0	0	0	0	0.0
Paramoera capensis	16.7	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
Caridea															
Palaemon peringueyi	16.7	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
Anomura															
Callianassa kraussi	0	50	66.7	55.6	0	27.8	311.1	33.3	0	0	0	0	0	0	0.0
Brachyura															
Hymenosoma orbiculare	0	0	0	0	0	5.6	5.6	0	0	0	0	0	0	0	0.0
Thaumastoplax spiralis	0	0	0	5.6	0	11.1	0	0	0	0	0	0	0	0	0.0
Insectivora															
Chironomid larvae	0	0	0	0	0	0	0	0	0	0	0	1822.2	1055.6	711.1	411.1
Mollusca															
Bivalve spat	0	5.6	11.1	0	0	0	0	0	0	0	0	0	0	0	0.0
Tellina sp.	0	0	27.8	0	0	0	0	0	0	0	0	0	0	0	0.0

Table A4.4.5 Composition and abundance (numbers m^{-2}) of subtidal benthic organisms collected July 2005 at 15 stations in the Great Berg estuary.

Station	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Polychaeta															
Boccardia sp.	0	0	0	5.6	50	0	0	0	111.1	0	0	0	0	0	0
Capitella capitata	5322.2	355.6	11.1	5.6	0	0	0	0	0	0	0	0	0	0	0
Ceratonereis keiskama	283.3	11.1	5.6	177.8	88.9	305.6	366.7	661.1	1138.9	3061.1	2155.6	172.2	0	0	0
Desdemona ornata	0	55.6	133.3	200	5233.3	1222.2	1000	22.2	0	0	0	0	0	0	0
Glycera tridactyla	0	5.6	0	0	0	0	0	0	0	0	0	0	0	0	0
Mercierella enigmatica	0	0	0	0	0	55.6	0	0	0	0	0	0	0	22.2	0
Oligochaete sp.	861.1	16.7	0	0	0	0	0	0	0	0	0	5.6	172.2	11.1	27.8
Prionospio sexoculata	344.4	250	222.2	600	244.4	188.9	27.8	27.8	222.2	172.2	0	0	0	0	0
Cumacea															
Iphinoe sp. 1	0	11.1	5.6	0	0	0	0	0	0	0	0	0	0	0	0
Isopoda															
Anthurid sp.	0	0	161.1	555.6	4266.7	1461.1	4005.6	1244.4	0	0	0	0	0	5.6	0
Exosphaeroma hylocoetes	0	0	5.6	0	5.6	11.1	0	0	0	0	0	0	0	0	0
Amphipoda															
Corophium acherusicum	0	0	0	111.1	6800	21100	1522.2	1083.3	4005.6	4938.9	0	0	0	1338.9	72.2
Grandidierella lutosa	0	0	738.9	283.3	4255.6	1716.7	1572.2	72.2	0	0	0	0	0	0	0
Melita zeylanica	0	0	0	0	0	1666.7	0	0	0	0	0	0	0	0	0
Anomura															
Callianassa kraussi	0	0	11.1	0	0	0	5.6	0	0	0	0	0	0	0	0
Upogebia africana	0	38.9	11.1	0	0	0	0	0	0	0	0	0	0	0	0
Brachyura															
Hymenosoma orbiculare	0	0	5.6	33.3	50	22.2	0	0	0	0	0	0	0	0	0
Thaumastoplax spiralis	0	0	0	5.6	0	5.6	0	0	0	0	0	0	0	0	0
Insectivora															
Insect larvae	0	0	0	0	16.7	0	0	0	0	0	0	0	0	0	0
Chironomid larvae	0	5.6	5.6	55.6	0	5.6	5.6	0	0	0	111.1	0	0	5.6	5.6
Mollusca															
Bivalve spat	0	5.6	5.6	0	0	0	0	0	0	0	0	0	0	0	0

Table A4.4.6 Composition and abundance (numbers m^{-2}) of subtidal benthic organisms collected November 2005 at 15 stations in the Great Berg estuary.

Station	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Polychaeta															
Boccardia sp.	0	0	0	28.6	0	538.9	350	0	355.6	0	22.2	0	5.6	0	0
Capitella capitata	611.1	0	161.1	14.3	0	222.2	262.5	0	0	0	0	0	0	0	0
Ceratonereis erythraeensis	11.1	11.1	0	0	0	0	0	0	0	0	0	0	0	0	0
Ceratonereis keiskama	38.9	0	0	50	38.9	94.4	181.3	88.9	172.2	83.3	11.1	27.8	16.7	0	0
Desdemona ornata	0	0	5.6	0	0	494.4	788.9	850	2494.4	333.3	0	0	0	0	0
Glycera tridactyla	0	5.6	0	0	0	0	0	0	0	0	0	0	0	0	0
Oligochaete sp.	0	0	0	0	0	0	0	0	0	0	0	0	77.8	38.9	594.4
Orbinia angrapequensis	22.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Prionospio bocki	0	0	50	28.6	27.8	488.9	325	0	122.2	61.1	5.6	5.6	0	0	0
Prionospio sexoculata	5.6	0	44.4	7.1	11.1	94.4	0	0	0	0	0	0	0	0	0
Cumacea															
Iphinoe sp. 1	16.7	0	5.6	0	0	0	0	0	0	0	0	0	0	0	0
Isopoda															
Anthurid sp.	0	22.2	266.7	928.6	3466.7	2172.2	3418.8	2027.8	4333.3	1733.3	0	0	0	0	0
Exosphaeroma hylocoetes	0	0	11.1	7.1	5.6	0	81.3	194.4	0	0	0	0	0	0	0
Amphipoda															
Corophium acherusicum	0	0	0	142.9	0	4705.6	12743.8	31750	11216.7	6805.6	33.3	5.6	0	11.1	0
Grandidierella lutosa	0	211.1	4183.3	4750	7538.9	516.7	218.8	111.1	338.9	0	0	0	0	0	0
Melita zeylanica	0	0	0	0	0	0	0	27.8	0	0	0	0	0	0	0
Anomura															
Callianassa kraussi	5.6	255.6	0	0	94.4	0	31.3	22.2	0	0	0	0	0	0	0
Brachyura															
Hymenosoma orbiculare	5.6	55.6	27.8	21.4	111.1	172.2	181.3	227.8	38.9	50	0	0	0	0	0
Thaumastoplax spiralis	0	0	0	0	11.1	5.6	6.3	0	11.1	0	0	0	0	0	0
Insectivora															
Insect larvae	0	0	0	7.1	0	33.3	0	0	0	0	0	0	0	0	0
Chironomid larvae	0	0	27.8	0	0	61.1	6.3	0	127.8	433.3	183.3	177.8	894.4	755.6	44.4
Mollusca															
Bivalve spat	11.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table A4.4.7 Composition and abundance (numbers m^{-2}) of subtidal benthic organisms collected February 2006 at 15 stations in the Great Berg estuary.

Station	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Polychaeta															
Boccardia sp.	0	0	11.1	16.7	5.6	544.4	16.7	0	1344.4	561.1	0	0	0	0	0
Capitella capitata	0	0	188.9	516.7	0	0	0	0	12983.3	1122.2	0	450	0	0	0
Ceratonereis erythraeensis	16.7	0	0	177.8	0	0	0	22.2	0	0	0	0	0	0	0
Ceratonereis keiskama	0	0	0	0	194.4	488.9	422.2	477.8	944.4	133.3	122.2	5.6	0	0	0
Desdemona ornata	0	0	544.4	44.4	0	7472.2	2455.6	0	0	0	0	0	0	0	0
Glycera tridactyla	0	16.7	0	0	0	0	0	0	0	0	0	0	0	0	0
Nephthys capensis	0	5.6	0	0	0	0	0	0	0	0	0	0	0	0	0
Oligochaete sp.	0	0	94.4	0	0	0	0	0	0	0	0	583.3	27.8	322.2	233.3
Orbinia angrapequensis	83.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Prionospio bocki	0	0	0	0	0	0	111.1	0	0	0	0	0	0	0	0
Prionospio sexoculata	0	0	22.2	0	0	5.6	0	0	0	0	0	0	0	0	0
Cumacea															
Cumacean sp. 1	0	11.1	155.6	0	0	0	0	0	0	0	0	0	0	0	0
Iphinoe sp. 1	0	0	155.6	0	0	0	0	0	0	0	0	0	0	0	0
Isopoda															
Anthurid sp.	0	5.6	938.9	744.4	361.1	3816.7	2461.1	705.6	0	0	0	0	0	0	0
Uromunna sheltoni	0	0	0	11.1	0	0	0	0	0	0	0	0	0	0	0
Amphipoda															
Corophium acherusicum	0	0	0	0	11.1	572.2	205.6	238.9	1638.9	1244.4	2605.6	694.4	0	5.6	0
Grandidierella lutosa	0	283.3	1116.7	694.4	394.4	11.1	0	0	0	0	0	0	0	0	0
Melita zeylanica	0	0	0	33.3	0	0	0	0	0	0	0	0	0	0	0
Paramoera capensis	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Anomura															
Callianassa kraussi	11.1	155.6	38.9	50	866.7	305.6	883.3	5.6	0	0	0	0	0	0	0
Brachyura															
Hymenosoma orbiculare	5.6	16.7	61.1	27.8	5.6	11.1	50	0	0	0	0	0	0	0	0
Thaumastoplax spiralis	0	11.1	11.1	0	16.7	22.2	11.1	22.2	0	0	0	0	0	0	0
Insectivora															
Chironomid larvae	0	0	5.6	0	0	0	0	5.6	0	0	0	5.6	111.1	61.1	16.7

APPENDIX 4.5

ESTUARINE INVERTEBRATES:

INTERTIDAL BENTHOS

Table 4.5.1 Composition and abundance (numbers m^{-2}) of intertidal benthic organisms collected September 2003 at seven stations in the Great Berg estuary.

Station	KH1	KH2	KH3	KH4	FP1	FP2	FP3	FP4
Polychaeta								
Boccardia sp.	960	40	160	0	0	0	0	0
Capitella capitata	80	100	620	0	0	0	0	0
Ceratonereis erythraeensis	980	1140	3600	0	0	0	0	0
Ceratonereis keiskama	0	20	60	0	0	0	0	0
Namalycasatis sp.	0	0	0	336	0	0	0	0
Isopoda								
Anthurid sp.	20	60	0	0	0	0	0	0
Exosphaeroma hylocoetes	0	0	0	336	0	0	0	0
Amphipoda								
Corophium acherusicum	20	0	0	0	0	0	0	0
Grandidierella chelata	60	0	0	0	0	0	0	0
Grandidierella lutosa	400	160	20	0	0	0	0	0
Melita zeylanica	0	20	0	120	0	0	0	0
Talorchestia sp.	60	0	0	264	0	0	0	0
Anomura								
Upogebia africana	0	80	80	0	0	0	0	0
Brachyura								
Hymenosoma orbiculare	0	0	40	24	0	0	0	0
Insectivora								
Chironomid larvae	0	0	0	0	240	192	0	0
Mollusca								
Hydrobia sp.	0	40	0	0	0	0	0	0

Table 4.5.2 Composition and abundance (numbers m^{-2}) of intertidal benthic organisms collected February 2006 at four stations in the Great Berg estuary.

Station	KH1	KH2	KH3	KH4
Polychaeta				
Capitella capitata	7520.0	720.0	520.0	1464.0
Ceratonereis erythraeensis	8820.0	9160.0	3200.0	6504.0
Isopoda				
Cyathura estuaria	20.0	0.0	0.0	0.0
Exosphaeroma hylocoetes	0.0	0.0	140.0	0.0
Paridotea ungulata	0.0	0.0	80.0	0.0
Amphipoda				
Grandidierella lutosa	0.0	1280.0	15140.0	960.0
Caridea				
Palaemon peringueyi	40.0	0.0	0.0	0.0
Anomura				
Upogebia africana	0.0	620.0	60.0	0.0
Brachyura				
Hymenosoma orbiculare	0.0	620.0	80.0	0.0
Thaumastoplax spiralis	0.0	0.0	20.0	0.0
Insectivora				
Insect larvae	40.0	0.0	0.0	0.0
Mollusca				
Bivalve spat	820.0	0.0	0.0	0.0