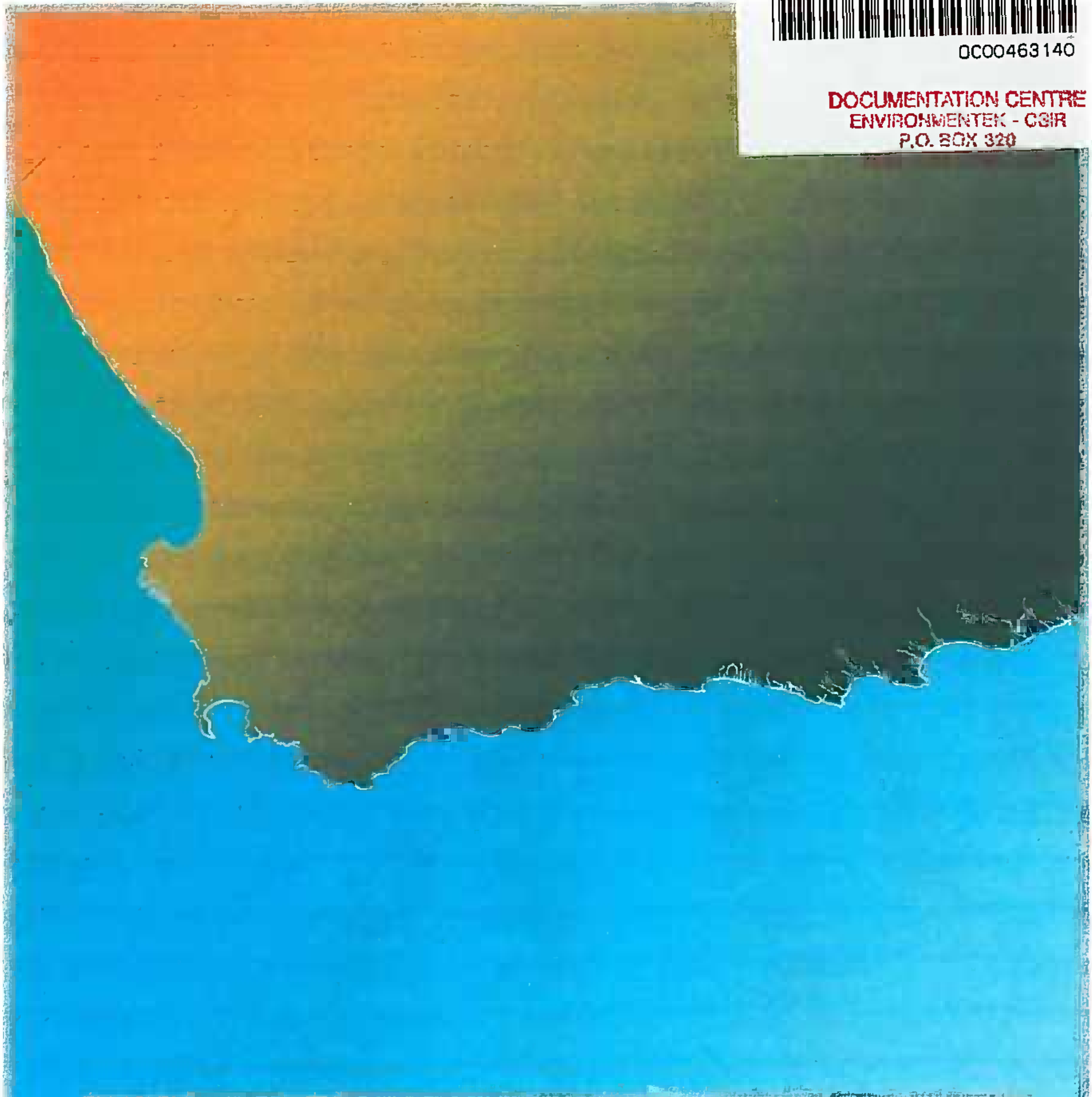

APPLICATION OF THE ESTUARINE HEALTH INDEX TO SOUTH AFRICA'S ESTUARIES, GROOT (Wes) - GREAT FISH

Technical Report

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Technical Report

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1. INTRODUCTION

Estuaries are one of the most important components of the South African coastal environment in terms of their abundance, biological importance and utilisation by man. A rapidly increasing coastal population is placing pressure on estuaries for residential, recreational and industrial uses. Changes in the catchments of rivers which flow into estuaries are also precipitating changes in the nature of estuaries which often act as receiving basins for catchment-generated waste. In short, estuaries are being impacted upon from both their immediate surroundings and from the coastal hinterland.

In order to effectively manage estuaries in the light of the pressures placed upon them both currently and in the past, it is necessary to have a fast and effective means of assessing their current state in relation to the undisturbed, or pristine state. Such a measure must be readily understood by the coastal planner, environmental manager or individual, who may not have the scientific background to assimilate a complex array of multidisciplinary environmental data. In this situation, measurement of the environmental health of an estuary using sound scientific principles, coupled with a simple index by which to convey the information effectively, becomes a necessity.

The Durban-based Catchment and Coastal Environmental Programme of the CSIR has developed the Estuarine Health Index which, based on a sound physical classification scheme, incorporates an index of biological health using fishes, a water quality suitability index and an aesthetic (naturalness) index. This research project has as its objectives the application of the Estuarine Health Index to each estuary in South Africa to construct a picture of the contemporary state of the estuarine environment. This will act as a baseline for any future monitoring and as a means of comparing the relative well-being of estuaries at present. Both aspects are vital for sound environmental management. This report deals with research undertaken on the southeast Cape coast estuaries in the year 1995-96.

Stated Work Plan for the Year

The work schedule for the year dealt with the estuaries on the southeast Cape coast from the Groot (Wes) to the Great Fish and involved completion of the following tasks:

1. A physical classification scheme for all the systems.
2. Ichthyofaunal surveys of all the systems.
3. Water quality surveys of all the systems.
4. Appraisal of the aesthetic state (degree of naturalness) of all the systems.
5. Application of the Biological Health Index to the estuaries.
6. Application of the Water Quality Index to the systems.

7. Application of the Aesthetic Health Index to the systems.
8. Application of the composite Estuarine Health Index

All of these objectives have been met and are discussed in the succeeding sections.

Based on the results of a survey of available information on the systems in this area by Whitfield (1995), it is worth noting that of the 29 systems included in his survey, the status of information on 17 (59%) of them was classified as "nil" (31%) or "poor" (28%). A further 4 (14%) systems were classified as having only "moderate" information. The available information for the remaining 8 systems was classed as "good" (17%) to "excellent" (10%). It is worth noting that these 8 systems are generally large systems which are tidal. The information gap regarding the smaller, more numerous estuaries, is striking.

2. PHYSICAL CLASSIFICATION

INTRODUCTION

Those environments that form where freshwater drainage systems reach the sea show wide variation in morphology and may form such features as lagoons, estuaries, coastal pans, river-mouths, deltas and bays to name but a few. In order to understand what type of feature one is considering, it is necessary to know something of its hydrology and geomorphology, for it is these that determine the type of environment that is produced. Naturally, many other factors actually influence and determine the geomorphology and hydrology and an understanding of their interactions will assist in defining these environments.

Why classify?

An introduction to the need for classification is necessary in order to place this in the context of the Estuarine Health Index. A vast amount of morphological variation is evident in those transitional fluvio-marine environments (including estuaries) which occur where a river discharges into the sea. The observed range of morphological variation may have little apparent order and the variety of forms necessitates classification as an aid to interpretation and understanding. No two environments are, strictly speaking, identical although some differ only in minor respects; others differ widely. The whole population of these environments is too heterogeneous to enable generalisations to be made and similarly, one cannot speak in terms of individual estuaries because they are far too numerous. To bring some order to the study of such a population it is essential to establish classes which subdivide the range of morphological variation. Such classes must group like individuals and separate them from unlike individuals and by so doing, reduce the number of entities to be comprehended. "Without classification one cannot hope to remember or manipulate the individuals or see relationships between them" (Van der Eyk *et al.*, 1969). Further, in the case of this research identification of estuaries with similar characteristics enables comparison of like with like.

To complicate the classification of such environments, many of the existing terms used in nomenclature are ambiguous or poorly defined and often mean different things to different people. For this reason it is necessary to provide a definition of each type of environment found in the study area. The most commonly applied definition in South Africa is that of Day (1980) who defined an estuary as " a partially enclosed coastal body of water which is either permanently or periodically open to the sea and within which there is a measurable variation of salinity due to the mixture of sea-water and freshwater derived from land drainage". Clearly there are some difficulties with such a definition, particularly around the need to specify a temporal aspect; is a system that opens once every 50 years really an estuary?; On what time scale does the variation in salinity have to be measured? It is hoped that one end result of the current investigations will be a more complete understanding of the nature of estuaries in South Africa.

How this classification was approached in the study area is considered below.

Classification procedure

In classifying the estuaries of a given stretch of coast a systematic approach must be taken. In this and previous studies the classification has followed six basic steps as follows:

1. What is the physical nature of inter-estuary variation in the region?
2. Do the estuaries lie within the same marine biogeographic region?
3. What factors contribute to inter-estuary variation in the region?
4. How are these factors inter-related?- can empirical data or logical arguments be presented to support such relationships?
5. Can the key controlling factors be quantified?
6. Does multivariate analysis of the accumulated data set adequately explain observed variation?

This is an iterative process in that further investigations of inter variable connections may be required in order to answer certain of the questions. When each of these steps has been successfully completed a dendogram is generated from which groups of estuaries who display closer intra-group similarity to inter-group similarity are identified. This approach does not imply that estuaries in a group are identical, but rather that they are more similar to other estuaries in the same group than they are to estuaries from other groups.

Physical variation among estuaries: regional trends

In the southeast Cape, beaches tend to be wide and dissipative as a result of high wave energy and fine grain size. These low gradient beaches tend to be associated with shallow outflow channels which are commonly unable to scour sufficiently deeply to induce regular tidal inflow and consequently river beds are graded to the elevation of the outflow channel, however, an additional consequence of such low beaches is the propensity for overwash to introduce sea water into back-barrier environments, even many of those which are closed. Only strong tidal currents are capable of sustaining semi-permanent inlets in such systems.

Sediment supply is a limiting factor in barrier development along a section of the study area between the Helpmekaars and Kaapsedrif outlets. In those rivers along this section which experience tidal flow, the absence of an adequate sediment supply has rendered barrier development incomplete and consequently river mouths are only partially blocked by an intertidally exposed section of the flood-tidal delta which is submerged at high tide. Observations indicate however that these features are sufficiently shallow to dissipate almost all of the incoming wave energy so that the lower reaches of the estuaries are characteristically calm.

According to Day (1981, p254) "the biota of the eastern and southern Cape is certainly warm-temperate". Whitfield (1994) considers the boundary between warm-temperate and cool-temperate to lie at Cape Point. He places the northern boundary between warm-temperate and subtropical at the Mbashee estuary (32°17'S; 28°54'E) in which both saltmarsh (warm-temperate) and mangrove (subtropical) vegetation occurs. South of the Mbashee upwelling events are fairly common while to the north they are rare or absent. On the basis of this evidence, no coastal biogeographic boundaries are therefore recognised in the area under discussion.

With the exception of the Bloukrans, all the rivers west of the Kromme had pH values less than 8. The inflowing streams are characterised by black, tannin-stained waters which are nutrient deficient and in which pH values are as low as 3.5 (Heydorn & Tinley, 1980, p34). Mixing with sea water has raised these values somewhat within the estuaries. Although the Kasuka and Rufane are also considered by Heydorn & Tinley (1980, p34), to be black water streams, their relatively higher pH values coupled with comparatively fresh water point to somewhat different characteristics at the time of sampling. Black water streams have been shown to have a distinctive fauna, (Noble & Hemens, 1978; Davies *et al.*, 1993) but whether this extends to the estuarine fauna is unclear.

A comparison of mean annual runoff and catchment area indicates that two trends exist in the study area (Figure 1). These may be separated geographically at the Kromme Estuary near Cape St Francis. This boundary is cited by Day (1981, p255) as the limit of the Tsitsikamma coastal sector in which mountain streams have good rainfall throughout the year. Heydorn & Tinley (1980, p27) show that this represents the approximate boundary between all-season rainfall on the Tsitsikamma sector and the bimodal rainfall regime east of Cape St Francis. The coastal belt west of Cape St Francis generally experiences between 400 and 500 mm of rainfall per year while the Tsitsikamma coastal sector receives between 700 and 1000 mm. Analysis of the NRIO (1987a; b) mean annual runoff and river catchment area data indicates an approximately tenfold increase in runoff for a given catchment area in the Tsitsikamma area compared to areas of lower rainfall east of Cape St Francis.

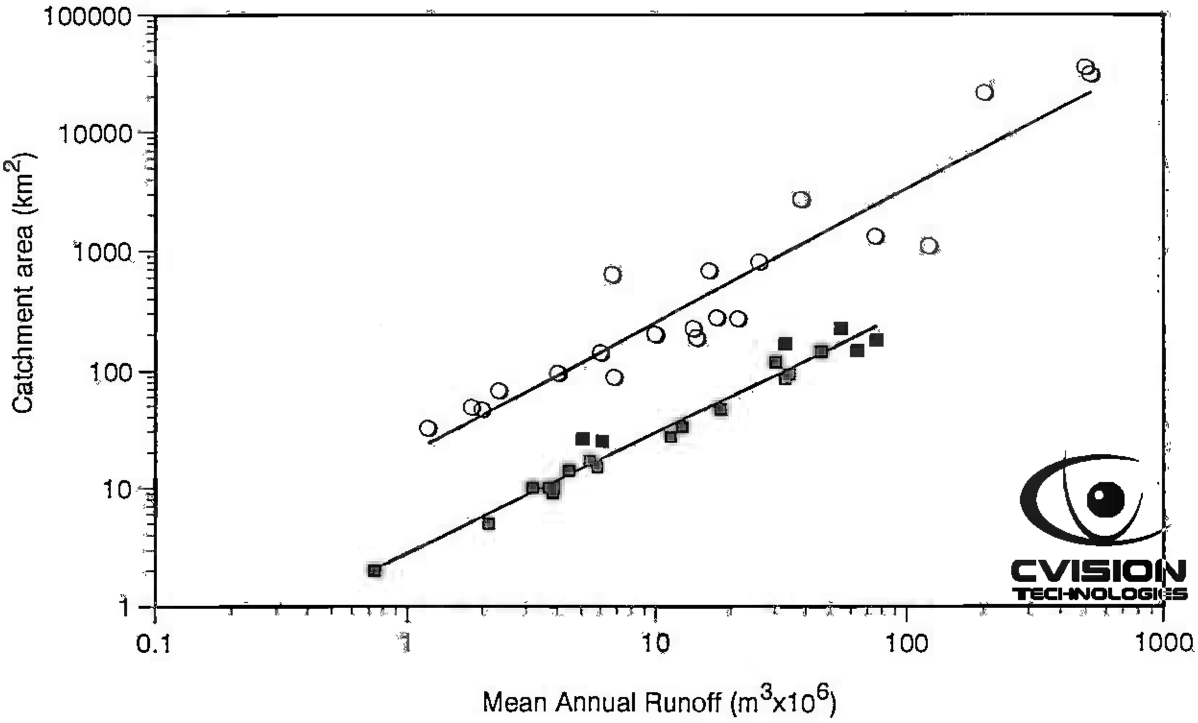


Figure 1. MAR (m^3x10^6) vs Catchment area (km^2) for rivers in the study area. Note the almost tenfold increase in runoff for rivers in the Tsitsikamma sector (■) compared to those in the Algoa sector (○). The Kromme River marks the transition between the two regions (data from NRIO, 1987a,b).

Reddering & Esterhuysen (1984) noted that the mud content of fluvially-derived sediment in eastern Cape estuaries exerted a strong control on channel morphology, the sandy sediments of mud-depleted rivers being characterised by wide intertidal flats (principally the flood-tidal delta sediments unlike Natal where sand-rich sediments produce braiding in the river-dominated estuaries) whereas mud-rich rivers produced confined channels with limited intertidal areas. The extent of flood-tidal deposition (admittedly potentially controlled by channel width) is the true determinant of intertidal exposure in the eastern Cape. Several estuaries (e.g. Gamtoos, Sundays) have large flood-tidal deltas within laterally confined channels and thus do contain fairly extensive intertidal areas.

In the analysis of the estuaries under consideration the following factors were used in a multivariate analysis to identify groupings of estuaries with similar characteristics. Maximum salinity, % mouth open, barrier length, average floodplain width, channel width, flow at mouth when open, MAR.

MAR was used in preference to catchment area since two distinct rainfall regimes had been identified with a tenfold increase in runoff in the Tsitsikamma section compared to the eastern Cape sector. By using MAR, estuaries within each sector could therefore be compared on the same basis.

RESULTS

Several river mouths were eliminated from the classification on the basis of demonstrably non-estuarine characteristics or on account of their very small areal extent (the latter approach following Whitfield, 1995). Those systems eliminated were all located in the Tsitsikamma coastal sector. The Helpmekaars, Bruglaagte, Langbos, Sanddrif, Eerste and Klipdrif (Wes) all have a waterfall or series of waterfalls at, or very close to the coast such that the extent of marine influence on them is minimal. The Kaapsedrif has a waterfall approximately 200 m from the sea and comprises a small stream which has a stream bed composed of boulders and sand. The Kleinbos, which is an unbarred inlet 5-10 m wide, is similar in appearance to the Storms River but was excluded on the basis of its small size as were the Klip, Witels, Geelhoutbos and Boskloof for the same reason. The Klip is a small stream like the Witels and Boskloof with a stream bed composed of boulders and sand, while the Geelhoutbos is similar with a sandy bed.

The classification procedure indicated that several distinctive groupings of estuaries existed in which members exhibited similar characteristics. The groups identified are as follows:

Group 1. **Storms, Elandsbos, Elands, Bloukrans, Lottering, Groot (Oos).**

These systems are all located on the Tsitsikamma coast and are confined between steep, resistant valley sides. With the exception of the Storms River, which has no depositional barrier, each has an intertidally exposed barrier which is typically overflowed along most of its length during normal high tides. The valley beds are characterised by coarse-grained fluvial sediments (boulders, gravel) or by bedrock. The peculiar combination of unimpeded marine tidal inflow at high tide, with high (low pH water) fluvial discharge during low tide identifies this group as distinctive. Although barriers are intertidally exposed, even at high tide they effect almost complete attenuation of incident wave energy and thus provide calm water environments on this high wave energy coastline. Even at the non-barred Storms river mouth nearshore bottom topography is such that wave energy penetrating the river mouth is negligible under even moderate storm conditions. A study by Huizinga (1994) is one of the few reports dealing with aspects of the hydrology of these systems and it is based on aerial photographic analysis of the Elands and Groot (Oos) systems.

The peculiar combination of regularly alternating marine and freshwater conditions and unusual substrate type renders these systems unique in the study area. The lack of supratidal barriers may be attributed to a general lack of marine sediment in the Tsitsikamma area. This is further attested to by the presence of boulder beaches composed of rock derived from erosion of surrounding country rock. The submerged barriers which are in fact flood-tidal deltas present an intertidal environment which is largely composed of clean sand and is largely unvegetated, probably as a result of its high mobility.

These systems are similar to the Steenbras in False Bay (unique on that stretch of coast, Harrison *et al.*, 1994) and to the Sout, Kaaimans, Maalgate and Gwaing (members of type 4A of Harrison *et al.*, 1995)

Group 2. **Slang, Maitland, Rufane, Klipdrif Oos, Bakens.**

These small estuaries are typically closed to the sea and are dominated by fresh water. Although there is a distinct gradient in size, they are similar in terms of their narrow floodplains, dominance of outflow when open, shallow water and in the presence of typically fresh water vegetation in their estuarine areas. They typically comprise a shallow water body confined behind a dissipative (broad and low) beach barrier and receive marine inputs principally via barrier overwash. When they open they drain and water levels are lowered. They generally close soon after opening. Several of these systems are perched on top of beach sediments in interdune depressions at the coast. This suggests an important groundwater role in maintaining surface water in such systems. Little research has been undertaken on these systems and consequently their dynamics are little understood.

Group 3. **Van Stadens, Tsitsikamma, Kabeljous, Groot (Wes), Boknes, Riet, Kasuka, Oos-Kleinemond, Wes-Kleinemond, Papkuils.**

This group of estuaries is characterised by temporarily open mouths (normally mouths are present for <10% of the year), predominantly fresh to slightly brackish water conditions (0-10‰) and extensive shallow water areas separated from the sea by a broad dissipative beach across which periodic overwash introduces sea water which enhances salinities within the systems. Several of these systems (Groot (Wes), Boknes) have extensive fluvial deltas in their upper reaches which may point to an advanced evolutionary stage in which tidal prism reduction through fluvial deposition has caused a reduction in tidal current competence. Alternatively, and more probably due to the relatively low MAR values for these systems, they are river-dominated systems in which either sediment supply or geological setting has caused an elevated bed position such that tidal prisms are naturally small and the systems were never (at least historically) much more affected by marine inflow than they are at present. When open these systems experience a fall in water level as water drains seaward; tidal inflow is limited and is insufficient to generate the tidal currents required to maintain permanent inlets against wave-induced sediment transport. Such a situation was documented in the Kleinemond (West and East) estuaries by Badenhorst (1988) although a report in Day (1981) suggests the estuaries may remain tidal for over a month after river-induced breaching.

Physically these systems differ from Group 2 in terms of size and possibly in terms of frequency of surface channels to the sea (although present data is insufficient to confirm the latter possibility). The estuaries of Group 3 are bigger, are slightly more frequently in contact with the sea, have longer barriers and (probably through increased length of the overwashing front) have slightly higher salinity than those of Group 2. Consequently the extent of available habitat is increased even though it may not be markedly materially different in type from that present in those estuaries of Group 2.

Prolonged closure in these systems leads to relative stability in water level which might be expected to vary according to variations in river inflow and evaporation rates. Only during breaching are larger water level variations likely to occur and these are likely to be near instantaneous lowering of water level, followed by limited tidal action and then closure accompanied by a gradual rise in water level.

Research on the geomorphology and hydrology of the estuaries of this group is somewhat limited but Fromme (1986) studied the Boknes and Kasuka and drew attention to some similarities. The main difference noted was in terms of the position of the estuary mouth in relation to mobile aeolian dunes which was considered to have enabled more frequent breaching of the Boknes due to its position upwind of a dunefield. The Boknes was found to drain following breaching and although limited tidal conditions were established after breaching these were of short duration. It was also inferred that periodic river floods removed accumulated sediment from the lower reaches of the Boknes.

Marine sedimentation within such systems is limited since only limited tidal inflow occurs even when the systems breach. Fromme & Badenhorst (1987) and Reddering & Esterhuysen (1984), however, describe marine sediment in the Kabeljous which is consistent with an origin through barrier overwashing, while other estuaries in this group (e.g. Kasuka - Fromme, 1986) may accumulate marine sediment through aeolian deposition.

Although in the dendrogram the Papkuils is at the boundary between Groups 3 and 4, it was placed in this group because of its closer mean annual runoff to the Wes-Kleinemond than to the Bushmans, its two nearest neighbours in the analysis. Due to its severe physical disruption, the original form of the Papkuils was not able to be determined without recourse to historical sources but even its name is suggestive of prolonged closure and a tendency toward fresh water conditions.

Group 4. **Bushmans, Kariega, Kowie, Sundays, Kromme, Great Fish, Gamtoos, Swartkops.**

These systems were difficult to separate from each other in the classification procedure even though individually they exhibit clear morphological characteristics. Rather, the classification yielded a dendogram which suggested these systems formed a continuum, largely on the basis of size. As a group these estuaries may be defined as follows.

They are semi-permanently in contact with the sea and experience regular tidal inflow and outflow which is sufficient to maintain a tidal inlet. Consequently flood-tidal deposits are present to a greater or lesser extent in each of these systems. In several of these systems which have been better studied clear flood-dominance may be demonstrated in the tidal inlet currents (e.g. Kromme - Reddering & Esterhuysen, 1983). The importance of such flood-tidal deltas is in the provision of sandy intertidal habitats, particularly for the burrowing (mainly invertebrate) infauna. River floods which periodically erode the non-cohesive sands of the flood-tidal deltas and cause episodic deepening followed by re-establishment of the flood-tidal delta have been noted in some of these systems (Reddering & Esterhuysen, 1983).

The free connection with the open sea and strong reversing tidal currents, permit both active and passive migration of biotic elements and enable the maintenance of 'typical' estuarine salinity and water level fluctuations. Extensive sandy intertidal areas and salt marshes which occur within these systems comprise important habitats for the estuarine biota and typify these ecosystems.

One physiographic source of intra-group variation is in terms of size which is best illustrated by comparison of the two end-members of this group, the Swartkops and the Bushmans. Although both are permanently open and contain water of up to fully marine salinity, the Swartkops has a markedly longer barrier, wider floodplain, greater freshwater discharge and larger inlet than the Bushmans. It is interesting to note in this regard that Fromme (1986) noted that although the Kariega was about half the size of the Bushmans estuary the two showed great resemblance in terms of its geology, morphology, hydrology and hydraulics.

In addition, Reddering & Esterhuysen (1981; 1984) have drawn attention to the fact that rivers draining mud-yielding catchments in the eastern Cape tend to have narrower, channels due to the cohesive nature of the river banks. This serves to reduce intertidally exposed areas in such estuaries which include, in the study area, the Gamtoos, Great Fish and Sundays estuaries. Fluvial sediments in other systems such as the Kromme have lower mud content and thus more extensive intertidal areas due in part to a greater area in which to accumulate sandy flood-tidal sediments. This phenomena is somewhat reduced in mud-rich estuaries by the presence of coast-parallel channel sections or by the upstream extent of flood-tidal sediments.

Some intra-group variation is also induced by the relative strength of tidal and fluvial currents. Although not well documented there is strong evidence from several estuaries (e.g. Great Fish - Reddering & Esterhuysen, 1982; Kariega - Fromme, 1986) of a clear dominance of fluvial flow over tidal inflow, although the regular and persistent presence of even limited tidal currents is considered sufficient to warrant direct comparisons between these systems at this stage. In other systems, such as the Bushmans and Kariega tidal flow is dominant (Day, 1981; Fromme, 1986).

Estuaries within the group that have mud-rich, strong flowing rivers are characterised by floodplains which are elevated above the normal range of high tides and are thus characterised by fully terrestrial vegetation. Such a situation may be ascribed to overbank deposition during successive river floods which gradually raises the floodplain level. Observations in the Swartkops, supplemented by a accounts in Day (1981) show that it contains a wide floodplain that is, in contrast, largely filled with saltmarsh. The flood-tidal delta is confined to the lower 1500 m of the estuary and the arrangement of tidal channels within the salt marsh are suggestive of dissipation of incoming tidal energy within these channels. The presence of salt marsh in this system might be ascribed either to (i) a less advanced evolutionary stage, whereby flood-associated overbank deposition has not yet raised the salt marsh to fully supratidal levels or (ii) a stronger influence of tidal currents over fluvial currents, or (iii) a combination of the two factors.

There is probably scope for subdivision of this group into those systems with extensive intertidal areas and those without. This variation is likely to result from variations in catchment geology (which determine mud content of river-derived sediment) and differences in the relative strength of freshwater and marine current dominance (which determine the capacity of the system to deposit and maintain a flood-tidal delta).

Outliers

Two apparent outliers were present among the estuaries studied. These were the Koega and Seekoei.

The Koega, was separated from all other estuaries at a high level of similarity. It was apparently identified as unique as a result of its hypersaline characteristics. Although the system is highly altered and information on its former state lacking, water in the lower reaches below the salt pans was hypersaline. The high probability of overwashing (numerous overwash channels were present on the barrier, with distinct overwash lagoons formed on the beach in interdune hollows) would have introduced seawater into the unaltered system and while this may have potentially rendered the system periodically hypersaline during low river flow periods in its natural state, the relatively large catchment area >600 km^2 and associated freshwater runoff probably mitigated against prolonged hypersalinity. Excepting its altered salinity characteristics this system resembles those estuaries in Group 3 and may have had similar characteristics in its unaltered state. Further research is required to verify such a possibility.

The Seekoei, although highly altered through the presence of a causeway sat more closely with Groups 3 and 4 from both of which it was distinguished, probably in terms of its unique combination of typically closed conditions and high salinity. Descriptions of the pre-impoundment phase suggest the Seekoei may have operated much as a Group 3 estuary under natural conditions. Indeed, Fromme & Badenhorst (1987) point to similarities between the Seekoei and Kabeljous, one of the estuaries presently in this group. Under natural conditions the Seekoei had an ephemeral inlet and drained to a certain extent when breached. The level of water maintained in the system was controlled by a rock outcrop in the mouth position (Esterhuysen, 1982).

3. BIOLOGICAL HEALTH

INTRODUCTION

It is generally agreed that measuring only the physical and chemical attributes of an aquatic system does not provide the sole assessment of the health of that system (Roux *et al.*, 1993). Biological communities, by integrating the effect of changes across a wide array of environmental factors (chemical, physical and biological), are good indicators of ecosystem health (Karr *et al.*, 1986; Roux *et al.*, 1993). Furthermore, the concept of biological community health is useful within the broader management context because in general, the idea of healthy ecosystems is readily comprehended and widely accepted by the public. The monitoring of biological communities also has a number of advantages over other assessment techniques in that it can be relatively inexpensive, particularly when compared with the cost of comprehensive chemical assessments. Biological communities may also be the only practical means of evaluating certain impacts which are difficult to measure, for instance diffuse source impacts or habitat degradation (Roux *et al.*, 1993).

A critical element of biological community health is the characterisation of the biological communities inhabiting the waters under consideration. Since it is not financially or technically feasible to evaluate all the organisms in an entire ecosystem at all times, careful consideration must be given to the selection of the community components used to assess biological health (EPA, 1990). Many groups of organisms have been proposed as indicators of ecosystem health and although no single group is favoured by the majority of biologists, it appears that fish and macroinvertebrates have received most attention (Roux *et al.*, 1993). Karr *et al.* (1986) maintain that more informed and less costly decisions are possible when fish are used as the primary taxon in biological monitoring.

Fish are typically present even in the smallest systems and in all but the most polluted waters (Karr *et al.*, 1986). Compared to invertebrates, fish are relatively easy to identify and most samples can be identified and sorted in the field. In most cases, no time-consuming laboratory work is required. Invertebrates on the other hand, are often difficult and time-consuming to identify and sort; technicians may require more specialised taxonomic expertise (Karr, 1981; Karr *et al.*, 1986). Fish integrate adverse effects of complex and varied stresses on other components of the ecosystem, such as habitat and macroinvertebrates, by virtue of their dependence on those components for reproduction, survival and growth (Karr, 1981; Karr *et al.*, 1986; Fausch *et al.*, 1990). Because fish often range considerable distances, they have the potential to integrate diverse aspects of relatively large-scale habitats (Karr *et al.*, 1986). As fish are comparatively long-lived, they provide a long-term record of environmental stress (Karr *et al.*, 1986, Fausch *et al.*, 1990). Fish communities can also be used to evaluate societal costs of degradation more directly than other taxa because their economic and aesthetic values are widely recognised (Fausch *et al.*, 1990). The public in general are more likely to relate to information about the condition of the fish community than data on invertebrates (Karr *et al.*, 1986). Finally, fish are a valuable natural resource that should be monitored for their own sake (Karr *et al.*, 1986).

The use of fish as biological monitors is, of course, not without difficulties. Among these are the selective nature of sampling gear for certain sites and for certain sizes and species of fishes, the mobility of fishes on seasonal and diel time scales, and the number of technicians needed for field sampling. Nevertheless, the same problems are associated with the use of other taxa (Karr *et al.*, 1986).

Ramm (1988) developed the Community Degradation Index which compares the fish species assemblage present within an aquatic system to the assemblage that would exist in the absence of or prior to degradation. The approach assumes that the major differences between the potential species assemblage and the present assemblage are due to habitat degradation (Ramm, 1988) and has been applied to some South African estuaries on the Natal coast (Ramm, 1990). The Community Degradation Index measures the degree of dissimilarity (degradation) between the potential fish species assemblage and the actual species assemblage (Ramm, 1988). Since we are primarily concerned with a measure of community health, the Community Degradation Index was modified to incorporate a measure of the degree of similarity between the potential fish species assemblage and the actual species assemblage to produce the Biological Health Index.

IMPLEMENTATION OF THE BIOLOGICAL HEALTH INDEX

Physical Classification

To view biological data in context, reference or baseline conditions are needed against which data from assemblages in degraded environments can be compared (EPA, 1990; Fausch *et al.*, 1990; Roux *et al.*, 1993). The biologist cannot evaluate biological condition effectively by any method without first addressing the question, "What should fish communities look like in this ecoregion?" (Fausch *et al.*, 1990). Reference conditions are usually determined by establishing the normal range of community components such as species richness, presence or absence of taxa and distribution of trophic groups in the most unimpaired waters representative of the areas or regions under consideration (EPA, 1990).

Reference conditions can be site-specific, which requires the availability of comparable habitat of both the reference location and the assessment area within the same waterbody (EPA, 1990). This approach is best for systems with a strong directional flow such as in streams and rivers (the upstream-downstream approach). A site-specific reference condition is difficult to establish if most of the water body is impacted by pollution, modifications to the channel, shoreline, or bottom substrate are extensive and habitat characteristics differ significantly between possible reference locations and the sample site (EPA, 1990). Some of the limitations of site-specific reference conditions can be overcome by using regional reference conditions that are based on the assumption that surface waters integrate the character of the land they drain. Regions of ecological similarity are based on hydrological, climatic, geological, or other relevant geographical variables that influence the nature of the biota present (EPA, 1990).

In applying the Biological Health Index to South African estuaries, we classified the estuaries into groups of similar systems based upon a variety of physical-geological factors (see previous section). The resulting groupings were then regarded as analogous to regions of ecological similarity.

Reference ichthyofaunal species assemblages

Of a total of 142 species of indigenous fish associated southern African estuaries, 101 (71%) are either completely or partially dependent on estuaries for their existence (Whitfield, 1994). Whitfield (1994) has grouped South Africa's estuaries into three biogeographical regions. Subtropical estuaries extend along the east coast from 26°S to the Mbashee estuary (32°17'S; 28°54'E); warm-temperate systems extend south from the Mbashee to Cape Point (34°22'S; 18°30'E); and cool-temperate systems extend northwards from Cape Point to beyond Walvis Bay (22°59'S; 14°31'E).

The highest estuarine fish diversity occurs in the subtropical region and of 133 species associated with estuaries in this region, a total of 93 (70%) have a strong association with estuaries (Whitfield, 1994). As one moves around the South African coast from the subtropical east coast to the cool-temperate west coast, estuarine fish diversity declines (Wallace & van der Elst, 1975, Day *et al.*, 1981; Whitfield *et al.*, 1989). Some 70 estuary-associated species occur in warm-temperate estuaries of which, 53 (76%) are either completely or partially dependent on estuaries for their existence (Whitfield, 1994). Twenty five species of fishes are associated with the estuaries on the cool-temperate west coast and 21 (84%) of these may be regarded as having a relatively strong association with systems in this region (Whitfield, 1994). The decline in estuarine fish diversity from the subtropical east coast to around the Cape to the Atlantic west coast is linked to the subtraction in the distribution of tropical and subtropical species which form the bulk of southern African estuarine ichthyofauna.

Because the expectations for a fish species assemblage vary with system type and regional zoogeography, a considerable investment of time is required to define expectation criteria and to collect, collate, and interpret data from various systems (Karr *et al.*, 1986). As a first approximation at a potential fish species assemblage, we used the data collected during a recent survey of the systems as well as available records of fishes reported in the estuaries comprising each physical group. The species lists were then pooled to produce a composite list for each physical group. The fishes in each composite species list were then classified according to whether they were species which breed in estuaries (estuarine), euryhaline marine species which breed at sea with the juveniles showing varying degrees of dependence on estuaries (estuarine-dependent), marine species which are not dependent on estuaries (marine), and freshwater species whose penetration into estuaries is determined primarily by salinity tolerance (freshwater). The estuary-association classification of the fishes followed that described by Whitfield (1994) and included the geographical occurrence of the various species in southern African estuaries.

The composite list for each group of systems was then adjusted firstly by removing all species not usually associated with the biogeographical region under consideration. The estuaries in the study area, from the Groot (Wes) to the Great Fish, all fell within the warm-temperate region described by Whitfield (1994). The composite species lists were then further adjusted by removing all stenohaline freshwater species, all marine species and all exotic species. The resulting fish species lists were then used as the reference species assemblage representative of the physical group of estuaries under consideration. We recognise that there are potential errors in this somewhat subjective method in producing a reference ichthyofaunal species assemblage for a group of estuaries. Many factors exist which may determine the presence or absence of specific faunal groups within a given environment. Failure to account for all of these factors in the development of a reference list of species will introduce errors of inclusion and or exclusion however, no individual or group of experts can hope to create an expected species assemblage without the risk of such errors.

Ichthyofauna of the estuaries

A critical element in determining the biological health of an ecosystem is the characterisation of biological communities inhabiting the system. Biological surveys provide the only direct method for measuring the structure and function of an aquatic community (EPA, 1990). All biological index methods require that the entire fish community is representatively sampled and that sampling is carefully conducted to ensure accurate measurement of the fish community (Fausch *et al.*, 1990). Sampling effectiveness varies according to the species of fish being sampled, their size, visibility in the water, flow conditions, habitat structure and a variety of other environmental factors (Karr *et al.*, 1986). In spite of the care given to sampling design and sampling procedures, biologists must exercise judgement to ensure that a sample is representative (Karr *et al.*, 1986).

The fish community of the estuaries from the Groot (Wes) to the Great Fish was sampled during the period September 1995 to November 1995. Each system was, where possible, sampled using a 30 m x 1.7 m x 15 mm bar mesh seine net fitted with a 5 mm bar mesh purse and a fleet of gill nets. Each gill net comprised three 45 mm, 75 mm and 100 mm stretch mesh monofilament panels producing a net with a range of mesh sizes. Beach seining is a common method for assessing abundance and species composition of littoral zone fish communities and has been used widely in freshwater, marine and estuarine studies. Seining combines several advantages over other assessment techniques in that the gear is simple and easy to deploy, a large area can be sampled and since sampling is active, should in principle, capture all species equally (Pierce *et al.*, 1990). Gill nets, made of panels of different mesh sizes, are standard gears used by researchers for sampling fish populations in estuarine waters and are effective for collecting large, mobile specimens in deeper waters (Marais, 1985; Hayes, 1989). Sampling was generally carried out in the lower, middle and upper reaches of each system and usually continued until no new species were collected. A number of systems within the study area however, could not be sampled primarily due to their inaccessibility and/or their small size.

The fish species collected in each estuary were treated in a similar fashion to the potential species lists where, after classifying the species according to Whitfield (1994), all species not usually associated with the biogeographical region under consideration (warm-temperate) were removed, and all stenohaline freshwater species, stenohaline inshore marine species and all exotic species were also removed. The resultant ichthyofaunal species assemblage was then considered as representative of the current faunal status of each estuary.

The Biological Health Index

The biological health of the estuaries on the Cape coast from the Groot (Wes) to the Great Fish was then calculated using the Biological Health Index:

$$BHI = 10 (J)[Ln (P)/Ln (P_{max})]$$

where: J = the number of species in the system ÷ the number of species in the reference community; P = the potential species richness (number of species) of each reference community and P_{max} = the maximum potential species richness from all the reference communities. The index ranges from 0 (poor) to 10 (good).

RESULTS & CONCLUSIONS

A total of 43 systems were located in the study area from the Groot (Wes) to the Great Fish and were classified into four groups based on a variety of physical-geological factors (see previous section). A number of systems however were eliminated from the classification due to their very small size or non-estuarine characteristics. These were the Helpmekaars, Klip, Witels, Geelhoutbos, Kleinbos, Bruglaagte, Langbos, Sanddrif, Eerste, Klipdrif (Wes), Boskloof and Kaapsedrif systems.

The Bloukrans, Lottering, Elandsbos, Storms, Elands and Groot (Oos) are all estuaries on the Tsitsikamma coast which are characterised by steep-sided, narrow bedrock valleys, intertidally exposed barriers which permit full tidal exchange at high tide and black water of low pH supplied by inflowing streams. In all cases, wave energy is dissipated at the mouth area such that calm conditions characterise the estuarine areas. Salinity is highly variable depending on the state of the tide and may vary from fully marine to fresh at the mouth.

The Klipdrif (Oos), Slang, Maitland, Bakens and Rufane formed a group of small shallow sandy systems which are typically closed to the sea for extended periods and which, when they open, form shallow drainage channels for river water with minimal tidal inflow. The principal source of marine water input is via barrier overwash, which coupled with periodic surface flow provides connection with the sea. All these estuaries are fronted by broad, low, dissipative barriers.

The Groot (Wes), Tsitsikamma, Seekoei, Kabeljous, Van Stadens, Papkuils, Koega, Boknes, Kasuka, Riet, West-Kleinemond and Oos-Kleinemond comprised a group of moderately sized estuaries that are characterised by temporarily open mouths, fresh to brackish water and shallow water areas separated from the sea by a broad dissipative beach across which overwash periodically introduces seawater into the back-barrier area.

The Kromme, Gamtoos, Swartkops, Sundays, Bushmans, Kariega, Kowie and Great Fish were classified as a group of estuaries which are characterised by near-permanent tidal inlets maintained by reversing tidal currents and regular tidal variation in water level.

The biological health, based on the fish species community, of the 31 estuaries classified from the Groot (Wes) to the Great Fish are presented in Table 1. The Biological Health Index ranged from a maximum of 6.4 for the Kasuka to a minimum of 0.0 for the Papkuils. The distribution of the Biological Health Index values was bimodal with four systems at the low end having index values below 1.3. Eight systems had index values from 1.3 to 2.6. Four systems had index values from 2.6 to 3.9. A further eight systems had index values from 3.9 to 5.2 and the remaining seven systems had biological index values above 5.2.

Since the primary objective of the Biological Health Index is to produce a picture of the comparative health of a group of estuaries, the *absolute* index values are not as significant as the *relative* comparisons among systems (Ramm, 1988; 1990). Karr *et al.* (1986) highlights the importance of professional judgement in the interpretation of index scores and the Biological Health Index is no exception. Management decisions based on index methods must be made with the guidance of a fish biologist familiar with the index and with the local fish fauna of the region (Karr *et al.*, 1986).

On comparing the relative index values it is possible to tentatively classify the estuaries according to their biological health as follows:

BHI Interval	Number	Percent	Rating
BHI < 1.3	4	13%	poor
1.3 ≤ BHI < 2.6	8	26%	moderately poor
2.6 ≤ BHI < 3.9	4	13%	moderate
3.9 ≤ BHI < 5.2	8	26%	moderately good
BHI > 5.2	7	23%	good

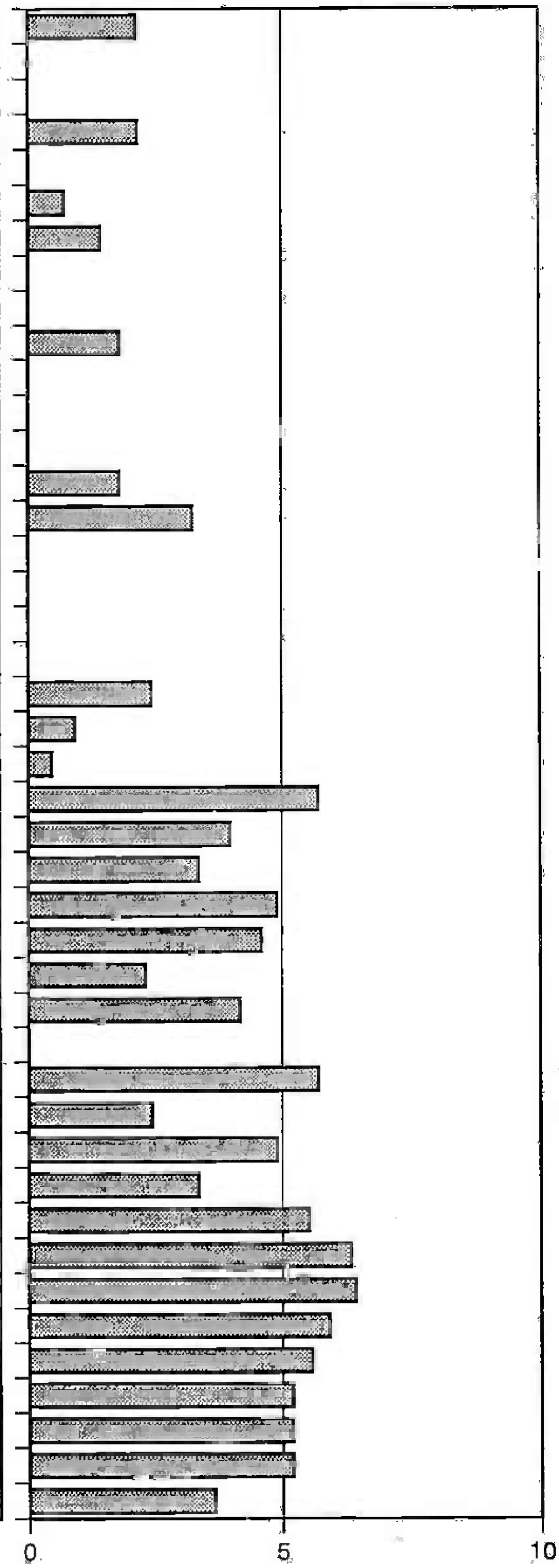
The results of the Biological Health Index revealed that the systems which fell within the Tsitsikamma coastal sector, with the exception of the Groot (Oos), were relatively poor to moderately poor in terms of their fish species assemblages. This may be a result of the limited habitat availability offered by these systems or the low nutrient status of these blackwater (low pH) systems or a combination of factors.

In the remainder of the study area, the majority of the systems were rated moderately good to good. Those systems which were rated poor to moderately poor is probably a result of habitat degradation where the Koega has been converted into a saltworks and the Papkuils has been reduced to an industrial canal (Whitfield, 1995). It is interesting to note that the Bakens, which has also been dramatically altered, was rated as being in a moderately good condition. This is most likely due to the fact that the system flows into the Port Elizabeth Harbour, which in itself offers a sheltered environment for estuarine-associated fish species. The fish assemblage recorded in the Bakens is therefore probably an extension of the harbour fish community rather than that of the estuary itself.

As with all index methods, the Biological Health Index a tool that aids in the interpretation of complex biological data and as a result some information is lost in the process of preparing the index and detail is sacrificed for perspective (Ramm, 1988). Biological information should be manager and even public friendly and in a format which is a compromise between information richness and ecological information richness (Roux *et al.*, 1993). The Biological Health Index, which is based on a sound ecological and mathematical basis, is a useful tool for giving a simple and effective measure of the overall biological health of any estuary or group of estuaries along any particular stretch of coastline.

Table 1. Biological Health Index values for estuaries on the southeastern Cape coast, Groot (Wes) - Great Fish.

	BHI
Groot (Wes)	2.1
Helpmekaars	
Klip	
Bloukrans	2.2
Witels	
Lottering	0.7
Elandsbos	1.4
Geelhoutbos	
Kleinbos	
Storms	1.8
Bruglaagte	
Langbos	
Sanddrif	
Elands	1.8
Groot (Oos)	3.3
Eerste	
Klipdrif (Wes)	
Boskloof	
Kaapsedrif	
Tsitsikamma	2.5
Klipdrif (Oos)	0.9
Slang	0.5
Kromme	5.7
Seekoei	4.0
Kabeljous	3.4
Gamtoos	4.9
Van Stadens	4.6
Maitland	2.3
Bakens	4.2
Papkuils	0.0
Swartkops	5.7
Koega	2.5
Sundays	4.9
Boknes	3.4
Bushmans	5.5
Kariega	6.3
Kasuka	6.4
Kowie	5.9
Rufane	5.6
Riet	5.2
Wes-Kleinemond	5.2
Oos-Kleinemond	5.2
Great Fish	3.7



4. WATER QUALITY

INTRODUCTION

It is a well known principle in ecology that the nature of the biological community in an estuary is largely determined by a multiplicity of factors in its physical-chemical environment. This is why we have utilised the fish assemblage structure as a measure of the health of estuaries. The biotic community structure serves as an integrated measure of health, responding to wide-spread long-term conditions and changes.

However, it is important to remember that water quality can change significantly over short periods of time. These episodic events may not be reflected in the fish community structure, as fish are largely mobile and may temporarily accommodate or avoid periods of water quality deterioration. In addition, biotic change will lag physical-chemical changes, and hence the water quality characteristics may foreshadow long term trends. For example, the presence of increasing concentrations of nutrients may indicate future eutrophication with all of its attendant problems. Finally, there are some water quality characteristics which are of great importance to man which are not reflected by fish community structure. The suitability of estuaries for contact recreation is just one such example.

Background

The use of indices to condense and summarise large volumes of water quality data has increasingly gained acceptance in the last decade. This has come about largely because of a practical need to compare the overall water quality at many different locations. What is necessary in this respect is a simple, objective, consistent, and reproducible numeric scale on which to represent water quality information.

There are four principal steps involved in the development of most water quality indices. These include:

- selecting the set of water quality variables (indicators) of concern
- developing rating curves for comparing indicators on a common scale
- weighting the indicators based on their relative importance to overall water quality
- formulating and computing the overall water quality index

Dunnette (1979), House (1989), Moore (1991), and others have thoroughly discussed and described these steps and the theory behind constructing water quality indices.

In brief, Dunnette (1979) recommended that variables of concern to water quality should be selected from five commonly recognised impairment categories including: (1) oxygen status, (2) eutrophication, (3) health aspects, (4) physical characteristics, and (5) dissolved substances. It should be noted that these recommendations were based on perceived requirements of freshwater and not marine or estuarine systems. House (1989) conducted a review of the many different index formulations in the literature and concluded that the modified arithmetic weighted mean (Stojda & Dojlido, 1983), or Solway modified weighted sum (Couillard & Lefebvre, 1985), provides the best results for general water quality indexing. Moore (1991) further concluded that this was the most suitable formulation for a general water quality index in the South African context.

This formulation was considered to be most applicable by Moore (1991) because:

- it is sensitive to changes in water quality variables throughout their range
- it lacks bias to either good or poor water quality
- it includes weighting factors as all variables of concern are not equally important indicators of water quality
- it is relatively easy to compute on a routine basis

Where the index takes on the range 0 - 100, this formulation can be expressed as:

$$\frac{1}{100}\left(\sum_{i=1}^{n} q_i w_i\right)^2 \qquad (1)$$

and	n	=	number of variables of concern
	q_i	=	the water quality rating value of the ith variable
	w_i	=	the weighting of the ith variable

The water quality rating value (q) for each variable (i) is determined from a rating curve which relates the observed concentration to a corresponding rating value between 0 and 100. In this manner, all variables are assigned rating values based on comparable scales (House, 1989).

WATER QUALITY SURVEYS

We investigated the possibility of applying our Water Quality Index to the estuaries in the study area using existing data. After a thorough review and evaluation of the available data we came to the conclusion that existing data were not suitable for our purpose. In order to obtain a meaningful synoptic comparison of the existing water quality in South African estuaries, it is necessary to have available a set of data which is internally consistent. This requires that all data should be collected from comparable locations in the systems, using similar techniques, and within as narrow a time window as practical. The mouth condition of each system should be noted, and where salinity layering is observed, surface and bottom samples must be collected.

To obtain such a set of internally consistent data, we conducted water quality surveys of 35 estuaries from the Groot (Wes) to the Great Fish during the period 26 July to 12 August 1995. Water samples and associated physical-chemical measurements were obtained from one to five sites within each system from the mouth area to the head area. Where water depth was greater than 50 cm and/or salinity layering strong, samples and measurements were obtained at approximately 25 cm below the surface and 25 cm above the bottom. The following data were obtained for each site:

- mouth condition
- time
- depth
- secchi depth
- salinity
- temperature
- turbidity
- dissolved oxygen
- conductivity
- oxygen absorbed
- total ammonia
- *E. coli*
- nitrate nitrogen
- orthophosphate
- chlorophyll-*a*
- pH

Water quality measurements of temperature, turbidity, dissolved oxygen, pH, salinity and conductivity were taken *in situ* using a Horiba U-10 Water Quality Checker. Water samples were taken using generally accepted procedures and analyses were conducted within 24 hours of sample collection. Total ammonia, nitrate nitrogen and orthophosphate were determined using the Merck Spectroquant analysis system together with a Merck SQ118 photometer. Bacteriological water quality (*E. coli*) was determined following the South African Bureau of Standards method 221 together with an ELE Paqualab system for microbiological water analysis. Oxygen absorbed was determined by titration in accordance with the South African Bureau of Standards method 220. Chlorophyll-*a* was determined using a modification of the spectrophotometric method recommended by the Hydrological Research Institute (Sartory, 1982). All equipment and methods were verified prior to the field surveys by running quality control experiments of the field equipment and methods against standard laboratory equipment and methods.

DEVELOPMENT OF THE WATER QUALITY INDEX

Selection of Variables of Concern

As noted earlier, Dunnette (1979) recommended that variables of concern to water quality should be selected from five commonly recognised impairment categories including: (1) oxygen status, (2) eutrophication, (3) health aspects, (4) physical characteristics, and (5) dissolved substances. While the importance of all five of these categories is evident for freshwater systems, the meaning of (4) and (5) in terms of estuarine water quality needs to be carefully considered.

Due to the dynamic nature of estuarine water masses under "normal" conditions, physical characteristics and dissolved substances content of estuarine water are highly variable. pH and turbidity are strongly controlled by the mixing of marine and fresh water. Given the buffering capacity of sea water, the pH of river water entering an estuary will be driven toward 8. Thus, the pH of estuarine water will often increase toward the mouth, and an average value for the estuary probably has little utility in general. Its importance, however, as an indicator of ionic equilibria (for example in evaluating the potential for ammonia toxicity, etc.) should be recognised.

The water quality significance of turbidity or suspended solids in estuarine water is largely unknown. The turbidity of the river water entering estuaries is probably more closely related to the nature of the catchment geology and geomorphology than to other factors. Furthermore, as this more turbid water encounters the intruding sea water a zone of maximum turbidity will often develop within the estuary. Again, this has very little bearing on overall estuarine water quality.

The major source of dissolved substances in estuaries is the intruding sea water; hence measurement of total dissolved solids (salinity) is a much more important indicator of the extent of sea water mixing than water quality impairment. In fact, it is the brackish nature of estuarine water that makes this habitat unique.

As a consequence of the above we have revised the five impairment categories recommended by Dunnette (1979) into three categories which we feel to be of primary importance to water quality in estuaries. These three categories, their seven associated variables of concern, and reason for inclusion are listed below:

Categories, variables of concern, and their basis for inclusion in index.

CATEGORY	VARIABLES	BASIS FOR INCLUSION
(1) suitability for Aquatic Life	Dissolved Oxygen	essential to aquatic faunal metabolism
	Oxygen Absorbed	measure of organic loading
	unionised Ammonia	toxicity to aquatic fauna
(2) suitability for Human Contact	*E. coli*	presumptive evidence for human pathogens
(3) Trophic Status	Nitrate Nitrogen	aquatic plant growth stimulant
	Ortho Phosphate	aquatic plant growth stimulant
	Chlorophyll-*a*	indicator of algal growth

Development of rating curves

In order to standardise the concentrations of the variables of concern, rating curves were developed. These curves have been developed in consultation with a variety of organisations and individuals including the Department of Water Affairs, University of Natal, consulting firms and CSIR. Where possible, we utilised rating curves which had been developed by other investigators. The rating curves for Chlorophyll-*a*, dissolved oxygen, and *E. coli* were taken directly from the curves developed by Moore (1991) in conjunction with the South African Department of Water Affairs.

The rating curve for oxygen absorbed (OA) was adapted from the biochemical oxygen demand (BOD) rating curve developed by Smith (1990). Observations of the relationship between BOD and OA in several Natal estuaries have suggested that there is a loose correlation between the two. In general the OA values have been approximately 2-3 times the BOD concentrations. As an approximation, we have appropriately adjusted Smith's (1990) BOD rating curve by this factor.

The rating curves for ammonia and nitrate were developed from data provided by the Department of Water Affairs. pH measurements were used to correct our data for total ammonia to unionised ammonia. The phosphate rating curve was developed by reviewing the literature on the relationships between water quality and known concentrations of ortho-phosphate. Australian standards for aquatic systems were also used for development of the phosphate curve.

Variable weighting

In order to arrive at a relative weighting of the seven water quality variables we have weighted the three categories approximately equally. We thus weighted AQUATIC LIFE at 35%, TROPHIC STATUS at 35%, and HUMAN CONTACT at 30%. The slightly lower rating of the human contact category was used since this entire weight would be accorded to the one variable *E. coli*. This kept the individual weighting for *E. coli* within the range of weights assigned to *E. coli* by the respondents in the study by Moore (1991). The breakdown of weights assigned to each of the water quality variables of concern is shown below:

Relative weights provisionally assigned to variables of concern

CATEGORY	VARIABLES	BASIS FOR INCLUSION	WEIGHT
(1) suitability for Aquatic Life	Dissolved Oxygen	essential to aquatic fauna	0.20
	Oxygen Absorbed	measure of organic loading	0.05
	Ammonia Nitrogen	toxicity to aquatic fauna	0.10
			0.35
(2) suitability for Human Contact	*E. coli*	presumptive evidence for human pathogens	**0.30**
(3) Trophic Status	Nitrate Nitrogen	aquatic plant growth stimulant	0.10
	Ortho Phosphate	aquatic plant growth stimulant	0.15
	Chlorophyll-*a*	indicator of algal growth	0.10
			0.35

Formulating and computing the water quality index

We have formulated and computed the Water Quality Index for those southeast Cape systems from the Groot (Wes) to the Great Fish using the rating curves and variable weightings described above and based on equation (1). The final index values were then rescaled between 0-10 to provide comparability with the range of the Biological Health Index.

In order to provide a single water quality index value for each estuary, the average surface and average bottom concentrations for each water quality variable were first calculated across the sites in each system. Then the following protocol for each water quality variable of concern was applied.

For dissolved oxygen (DO) a surface-weighted water column value was calculated. The DO concentrations were first converted to percent saturation's and then surface values given twice the weight of the bottom DO saturation values. The rating curve was then applied to this single surface-weighted percent saturation value to obtain a subindex value for DO for the estuary.

For *E. coli*, oxygen absorbed (OA), and chlorophyll-*a*, surface values alone were used with the respective rating curves to obtain a subindex value for each variable in each system.

For ammonia, nitrate and phosphate, the higher of the surface or bottom average value was used with the respective rating curve to obtain the appropriate subindex value.

RESULTS AND CONCLUSIONS

The results of applying the formulation described in equation (1) to the water quality variables of concern using the protocol outlined above are summarised in Table 2. The overall Water Quality Index (on a scale of 0-10) is presented for each estuary, as well as a breakdown of the overall index by its three water quality subcategories (aquatic life, human contact, trophic status). Seven systems, situated in the Tsitsikamma National Park area, were not sampled due to access problems.

For the 35 estuaries surveyed, the Water Quality Index ranged from a low of 0.4 for the Papkuils to a high of 8.8 (Bloukrans and Elandsbos). The distribution of the water quality index values was bimodal with two impacted systems (Papkuils and Klipdrif (Wes)) standing out at the low end (index values less than 2.0) and were classified as in "very poor" condition. The remaining 33 systems formed an upwards skewed distribution with index values ranging from 4.6 to 8.8. Six systems had indices above 8.0 and were classified as in "very good" condition. The remaining 27 systems, were classified as either "moderate" (4-6) , or "good" (6-8).

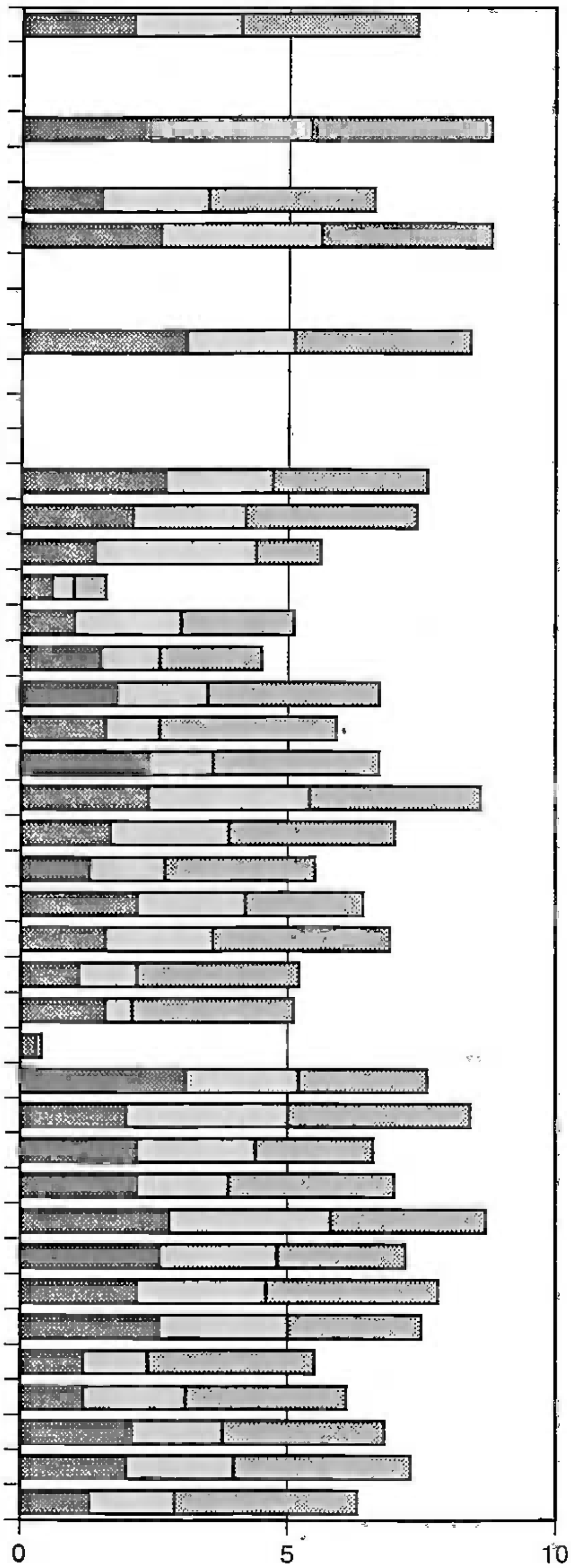
The results of the survey clearly illustrate the utility of the water quality index for succinctly identifying the relative health of southeastern Cape estuaries with respect to their water quality. Furthermore the usefulness of the index is further highlighted when one compares systems with similar index values. The Slang and Tsitsikamma for example, both have Water Quality Index values of 6.7 (good), however relative to the Slang, the major water quality impairment in the Tsitsikamma was in its suitability for aquatic life, while in the case of the Slang the most significant impairment was in the suitability for human contact.

While the synoptic data collected over the period of our surveys is admittedly limited to one period, it is the only consistent data set of its kind which has been collected nearly simultaneously for South African estuaries. The management applications of this kind of synoptic sampling effort are readily evident when the results are focused via the index approach we have developed.

We have constructed the rating curves and weighting factors for the variables of concern based upon the previous work of Moore (1991) and House (1989). We have also obtained valuable input from a variety of investigators and agencies which has strengthened the validity of the Water Quality Index as an integral component of the composite Estuarine Health Index.

Table 2. Water Quality Index values for estuaries on the southeastern Cape coast, Groot (Wes) - Great Fish.

	Aquatic Life	Human Contact	Trophic Status
Groot (Wes)	2.1	2.0	3.3
Helpmekaars			
Klip			
Bloukrans	2.4	3.0	3.4
Witels			
Lottering	1.5	2.0	3.1
Elandsbos	2.6	3.0	3.2
Geelhoutbos			
Kleinbos			
Storms	3.1	2.0	3.3
Bruglaagte			
Langbos			
Sanddrif			
Elands	2.7	2.0	2.9
Groot (Oos)	2.1	2.1	3.2
Eerste	1.4	3.0	1.2
Klipdrif (Wes)	0.6	0.4	0.6
Boskloof	1.0	2.0	2.1
Kaapsedrif	1.5	1.1	1.9
Tsitsikamma	1.8	1.7	3.2
Klipdrif (Oos)	1.6	1.0	3.3
Slang	2.4	1.2	3.1
Kromme	2.4	3.0	3.2
Seekoei	1.7	2.2	3.1
Kabeljous	1.3	1.4	2.8
Gamtoos	2.2	2.0	2.2
Van Stadens	1.6	2.0	3.3
Maitland	1.1	1.1	3.0
Bakens	1.6	0.5	3.0
Papkuils	0.3	0.0	0.1
Swartkops	3.1	2.1	2.4
Koega	2.0	3.0	3.4
Sundays	2.2	2.2	2.2
Boknes	2.2	1.7	3.1
Bushmans	2.8	3.0	2.9
Kariega	2.6	2.2	2.4
Kasuka	2.2	2.4	3.2
Kowie	2.6	2.4	2.5
Rufane	1.2	1.2	3.1
Riet	1.2	1.9	3.0
Wes-Kleinemond	2.1	1.7	3.0
Oos-Kleinemond	2.0	2.0	3.3
Great Fish	1.3	1.6	3.4



5. AESTHETIC PARAMETERS

INTRODUCTION

The appearance of an estuary contributes to its perceived environmental health, particularly in terms of its utilisation by man. Reimold *et al.* (1980) in a rare assessment of the aesthetic value of estuaries, noted that an aesthetic appreciation of wetlands is essentially a sensual one, in that vision, hearing, smell, touch and taste senses are stimulated. Certain uses (e.g. industrial or commercial development) change the appearance of an estuary and in so doing impair its suitability for other potential uses (e.g. nature conservation/recreation/tourism). The perception of the best possible appearance of an area will vary from one individual to another and from members of one socio-economic or cultural group to another. Thus the measurement of aesthetic health of estuaries and other wetlands is largely subjective (Reimold *et al.*, 1980). This problem centres on what an individual perceives the ideal state of an estuary to be.

In order to eliminate this problem and introduce a more objective method of assessment the ideal state of each estuarine area was defined as its pristine, unimpaired state. In other words the measure employed is of the degree of "naturalness" of the estuary, based on the premise that man cannot improve upon nature. It is intended that the information presented in this section of the index will be of use in planning the utilisation of estuarine areas: those which are unspoilt might, for example, be retained for nature conservation; those with little disturbance might be suitable for recreation, as long as water quality is sufficient for that purpose; estuaries which are heavily impacted visually by industrial development are unlikely to be of much use in encouraging tourists to the area.

DEVELOPMENT OF THE AESTHETIC HEALTH INDEX

The basic premise of the Aesthetic Health Index is that an estuary which is totally unimpacted by man, reflecting a maximum degree of "naturalness", is in a perfect or pristine state - and deviation from this state is indicative of degradation. A number of parameters contribute to the aesthetic health of an estuary and it is in the selection and assignment of a relative value to each parameter that subjectivity is involved. During the development of the index, a survey of 25 coastal zone managers and planners was undertaken to identify and determine the relative importance of the various criteria which contribute to the naturalness an estuary (Cooper, 1993). These inputs were used in the refinement of the index. The parameters, which accommodate most of the aesthetic impacts on an estuary were considered to be floodplain landuse, the degree to which the channel margins were natural, the appearance of the floodplain surrounds, the presence of various types of bridges, the presence of dams and weirs, the degree to which the mouth of a system is artificially stabilised, the amount of litter and rubble present, the degree to which the system is used by man, the presence of invasive and exotic vegetation, the presence of algal blooms and/or aquatic nuisance plants, the turbidity of the water, the presence of odours, the presence of air pollution and the nature and extent of any noise.

Each parameter was given a percent weighting from which points were deducted according to the type and degree of impairment.

Floodplain Landuse

One of the main parameters measured related to the floodplain landuse. This involved an estimation of the percentage of the floodplain given over to natural vegetation, agriculture, industrial and commercial development, recreational development and housing. Of these, the largest impacts were assigned to industrial development and informal housing, followed by commercial development and recreation. These were in turn followed by formal housing and then agriculture. The category "floodplain landuse" had a weighting of 25%.

Shoreline Status

The shoreline status was assessed by estimating the extent to which the shoreline was natural, the extent to which it consisted of solid structures such as fill, walls and gabbions, the extent to which it was grassed or landscaped, and the extent to which it was stabilised and vegetated. This category had a weighting of 15%. The greatest impacts were assigned to the extent to which the shoreline comprised solid structures, followed by grassed and landscaped and stabilised and vegetated.

Floodplain Surrounds

The overall aspect of an estuary was assessed by estimating the degree to which the *floodplain surrounds* were either natural, under agriculture, used for industrial and commercial purposes, recreational development and housing. The largest impact was assigned to industrial development and informal housing, followed by commercial development and recreation. These were in turn followed by formal housing and then agriculture. This category had a weighting of 15%.

Bridges

Bridges crossing an estuary were initially assessed as to whether they were high or low and whether they had embankments, and points were deducted according to the number and type of bridges. High bridges were not considered to have as large an impact as low bridges or bridges with embankments. This category had a weighting of 6%.

Dams & Weirs

The category "dams and weirs" was assigned a weighting of 6%. Points were deducted according to the type and number of structures present.

Mouth Stabilised

In this category, a weighting of 6% was allocated and points were deducted according to the extent to which the mouth an estuary was stabilised.

Litter & Rubble

The parameter "litter and rubble" incorporated the degree to which an estuary was impacted by litter and dumping. This category had a weighting of 6% and points were deducted according to the severity of the impact.

Human Usage

The category "human usage" was assigned a weighting of 4%. Points were deducted according to the degree of usage and ranged from heavy and persistent (such as commercial fishing activities) to light and intermittent (such as occasional bathing and picnicking).

Invasive & Exotic Vegetation

Points were deducted from a total weighting of 2%, according to the occurrence of invasive and exotic vegetation present.

Aquatic Nuisance Plants

The category "aquatic nuisance plants" included the evaluation of the degree to which the estuary was affected by algal blooms and aquatic macrophytes such as water hyacinth (*Eichornia*) and water lettuce (*Pistia*). From an allocated weighting of 3%, points were deducted according to the severity of the impact.

Turbidity

This category was allocated a weighting of 3% and points were deducted according to whether the water in an estuary was very turbid, moderately turbid or slightly turbid.

Odours

For this category, points were deducted from a total weighting of 3% according to whether odours were strong and persistent, strong but not persistent or moderately strong.

Air Pollution

Air pollution was assigned a weighting of 3% and points were deducted according to the severity of the problem. This ranged from strong and persistent factory emissions to isolated fires and smoke.

Noise

This category was assigned a weighting of 3%. Points were deducted according to the severity of the impact and ranged from loud and persistent to weak and intermittent.

An information-gathering sheet was designed which could be completed in the field while sampling. It should be noted here that the assessments were essentially conducted on the ground from some vantage point such as a bridge and were limited to only the area visible from that point. Assessments, particularly for the larger estuaries, were therefore generally limited to the lower reaches of these systems. The measurement of aesthetic health began with a perfect score of 100% from which, points were deducted according to the type and degree of impairment. The final index values were then rescaled between 0-10 to provide comparability with the range of the biological and water quality indices. Thus a severely impacted estuary would have a value tending toward 0 and a near pristine estuary would tend toward 10.

RESULTS & CONCLUSIONS

The results of the Aesthetic Health Index calculated for each estuary are presented in Table 3 and ranged from 1.42 for the Bakens to 9.89 for the Elands and Groot (Oos) systems. A number of systems within the Tsitsikamma National Park were not assessed due to access problems. These included the Helpmekaars, Klip, Witels, Geelhoutbos, Kleinbos, Bruglaagte, Langbos and Sanddrif systems.

The distribution of the Aesthetic Health Index values and their relative ratings is presented below:

AHI Interval	Number	Percent	Rating
AHI < 2.6	2	6%	very poor
2.6 ≤ AHI < 5.1	2	6%	poor
5.1 ≤ AHI < 6.3	1	3%	moderately poor
6.3 ≤ AHI < 8.8	8	23%	moderate
AHI > 8.8	22	63%	good

The distribution of the Aesthetic Health Index values was skewed with 22 (63%) systems having values above 8.8 and were classed as good. Eight systems (23%) had index values from 6.3 to 8.8 and were considered moderate. One system (3%) had an index value of between 5.1 and 6.3 and was rated moderately poor. Two systems (6%) had index values below 2.6 (very poor) and two systems (6%) had index values between 2.6 and 5.1 (poor).

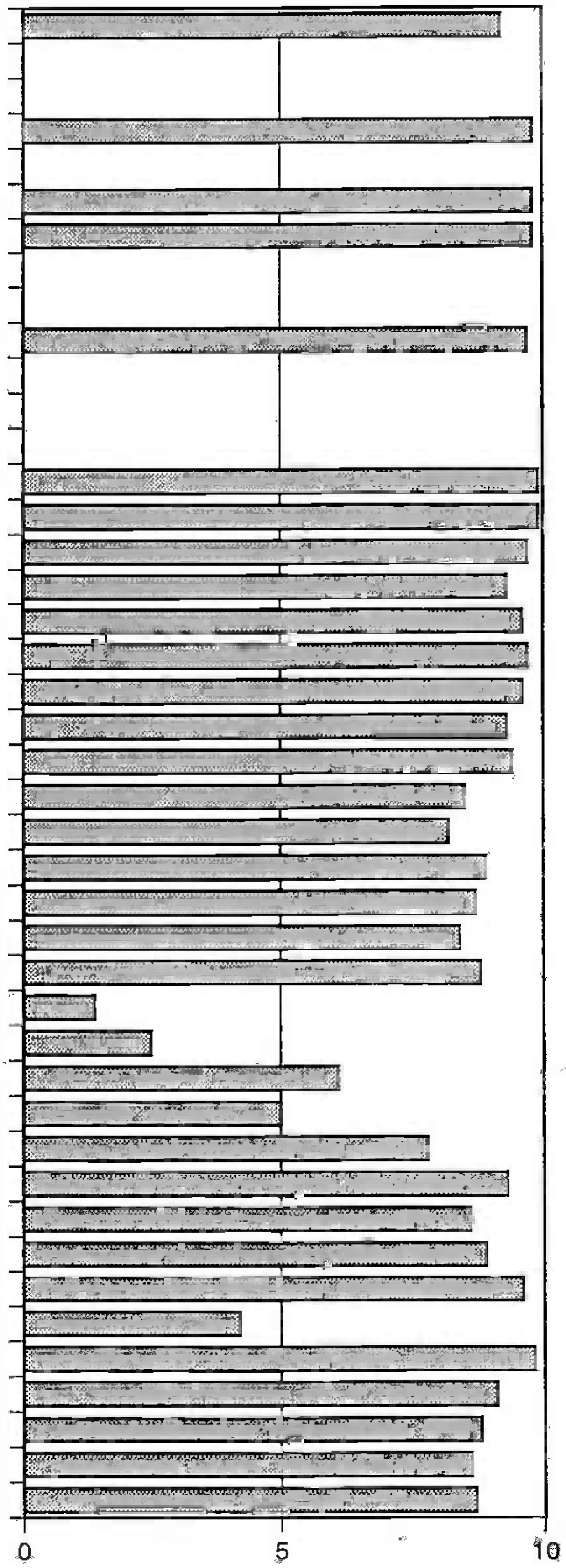
The vast majority of the aesthetically good systems either fell within the Tsitsikamma National Park which is administered by the National Parks Board or were situated in private farmlands where access was limited. The two lowest scoring systems, the Bakens (1.4) and the Papkuils (2.5) are both situated in the city of Port Elizabeth and have effectively been transformed into stormwater and effluent culverts. The Swartkops (6.1), which flows past the city of Port Elizabeth was rated as being in a moderately poor condition aesthetically. The Koega, which has been converted into a saltworks, was also rated poor with a score of 5.0.

The low score for the Kowie estuary (4.2) is due to the fact that only the lower reaches of the system, which flows through the town of Port Alfred, was assessed. Most of the upper reaches of the Kowie falls within nature reserves which are administered by East Cape Nature Conservation. The Aesthetic Health Index however still provides a relative measure of the degree of "naturalness" of a group of systems. The Bushmans, Kariega and Kowie systems were all assessed in a similar fashion where only the lower reaches were considered. It is clear from the results that the Kowie, which runs through Port Alfred is the most developed system. The Bushmans (8.6 - moderate) whose mouth area is bordered by Boesmansriviermond town on the eastern bank and Kenton-on-sea town on the west bank is the next most developed followed by the Kariega estuary (8.9 - good) whose mouth is only bordered by Kenton-on-sea town in the east.

Aesthetic parameters are commonly recognised as an important aspect of the environment. For example, Heydorn & Tinley (1980) observed "...coast resorts...are dependent on <u>pristine scenery</u> and undamaged resources" Few quantitative measurements have, however, been undertaken worldwide. The Aesthetic Health Index represents one of the first indices to be developed by a multidisciplinary team of scientists, which holistically and validly measures the aesthetics of an estuarine environment. It can be applied uniformly and offers a standard or baseline upon which aesthetic evaluations can be made in an objective manner. It may be used for (a) site specific, 'one-off', and local monitoring and management evaluations, and/or (b) regional, national, and international comparative evaluations. For these reasons the index is a unique and valuable tool for the management and monitoring of estuarine health.

Table 3. Aesthetic Health Index values for estuaries on the southeastern Cape coast, Groot (Wes) - Great Fish.

	AHI
Groot (Wes)	9.2
Helpmekaars	
Klip	
Bloukrans	9.8
Witels	
Lottering	9.8
Elandsbos	9.8
Geelhoutbos	
Kleinbos	
Storms	9.7
Bruglaagte	
Langbos	
Sanddrif	
Elands	9.9
Groot (Oos)	9.9
Eerste	9.7
Klipdrif (Wes)	9.3
Boskloof	9.6
Kaapsedrif	9.7
Tsitsikamma	9.6
Klipdrif (Oos)	9.3
Slang	9.4
Kromme	8.5
Seekoei	8.2
Kabelious	8.9
Gamtoos	8.7
Van Stadens	8.4
Maitland	8.8
Bakens	1.4
Papkuils	2.5
Swartkops	6.1
Koega	5
Sundays	7.8
Boknes	9.3
Bushmans	8.6
Kariega	8.9
Kasuka	9.6
Kowie	4.2
Rufane	9.8
Riet	9.1
Wes-Kleinemond	8.8
Oos-Kleinemond	8.6
Great Fish	8.7



6. COMPOSITE ESTUARINE HEALTH INDEX

INTRODUCTION

An evaluation of any coastal resource ideally requires a multidisciplinary approach, incorporating physical, biological and chemical aspects as well as socio-economic factors. The gathering of this information, its interpretation, and the communication of these results typically take the form of technical or scientific reports. The planner or end-user must then assimilate this information and determine its relevance before developing or implementing management plans.

The Estuarine Health Index, developed here, is specifically designed to provide a simple but effective method of communicating technical information to those end-users who typically do not have any scientific background. It condenses complex physical, biological and water quality data into an easily understood and readily comprehended index format. In addition to this scientific information, the index also incorporates an aesthetic (degree of naturalness) component which is important in the evaluation of any natural resource.

DEVELOPMENT OF THE COMPOSITE ESTUARINE HEALTH INDEX

The composite health index presented in Table 4 represents the integrated biological health, water quality condition and aesthetic state of the estuaries on the southeast Cape coast from the Groot (Wes) to the Great Fish. At this stage, equal rating has been given to each parameter, and the composite index is consequently simply the sum of the three components. It thus ranges from 0 (poor) to 30 (good).

RESULTS AND CONCLUSIONS

No biological sampling was undertaken in the Helpmekaars, Klip, Witels, Geelhoutbos, Kleinbos, Bruglaagte, Langbos, Sanddrif, Eerste, Klipdrif (Wes), Boskloof and Kaapsedrif systems. The Helpmekaars, Klip, Witels, Geelhoutbos, Kleinbos, Bruglaagte, Langbos and Sanddrif systems were also not assessed for water quality or aesthetic state.

Excluding the above systems, the Estuarine Health Index (EHI) for the 31 remaining estuaries ranged from 2.9 for the Papkuils to 23.8 for the Kasuka. The distribution of these 31 Estuarine Health Index scores was skewed with two systems sitting at the low end. One system had an EHI of 2.9 (very poor) and one system had an EHI value of 10.7 (poor). The distribution of the remaining systems was as follows: Seven systems fell within the range

15.4 to 18.6. Eighteen systems had index scores between 18.6 and 21.7 and four systems had index values above 21.7.

Using these cut-off points it is thus possible to tentatively classify the estuaries according to their EHIs as follows:

EHI Interval	Number	Percent	Rating
EHI < 9.2	1	3%	very poor
9.2 ≤ EHI < 15.4	1	3%	poor
15.4 ≤ EHI < 18.6	7	23%	moderate
18.6 ≤ EHI < 21.7	18	58%	moderately good
EHI > 21.7	4	13%	good

The Estuarine Health Index allows one to assess the potential resource value of a particular stretch of coastline. Systems which are biologically and aesthetically healthy may be set aside for recreation or conservation while those systems with good water quality may be utilised for contact recreation.

The ease of reference to the amount of information contained in the Estuarine Health Index, which would normally have to be gleaned from a wide variety of sources, will be of assistance in planning the utilisation of South Africa's estuaries and in the formulation of a comprehensive coastal zone management plan.

Finally, it should be restated that the results of a summary of available information on the systems in this area (Whitfield, 1995), showed that of the 29 systems included in Whitfield's survey, 59% of them was classified as "nil" (31%) or "poor" (28%), 14% were classified as having only "moderate" information, 17% were classed as "good" and 10% were classed as "excellent".

As a result of our surveys in the past year, information is now available on almost all of these systems. The information was collected in a short timespan and provides previously unavailable baseline information against which future studies can be planned and compared.

In addition to provision of indices of health of the systems for coastal zone planning purposes, the major achievements of the survey may be summarised as follows:

- baseline data on each system;

- recognition of the range of transitional fluvio-marine environments in the southeast Cape region;

- fish community data for each system;

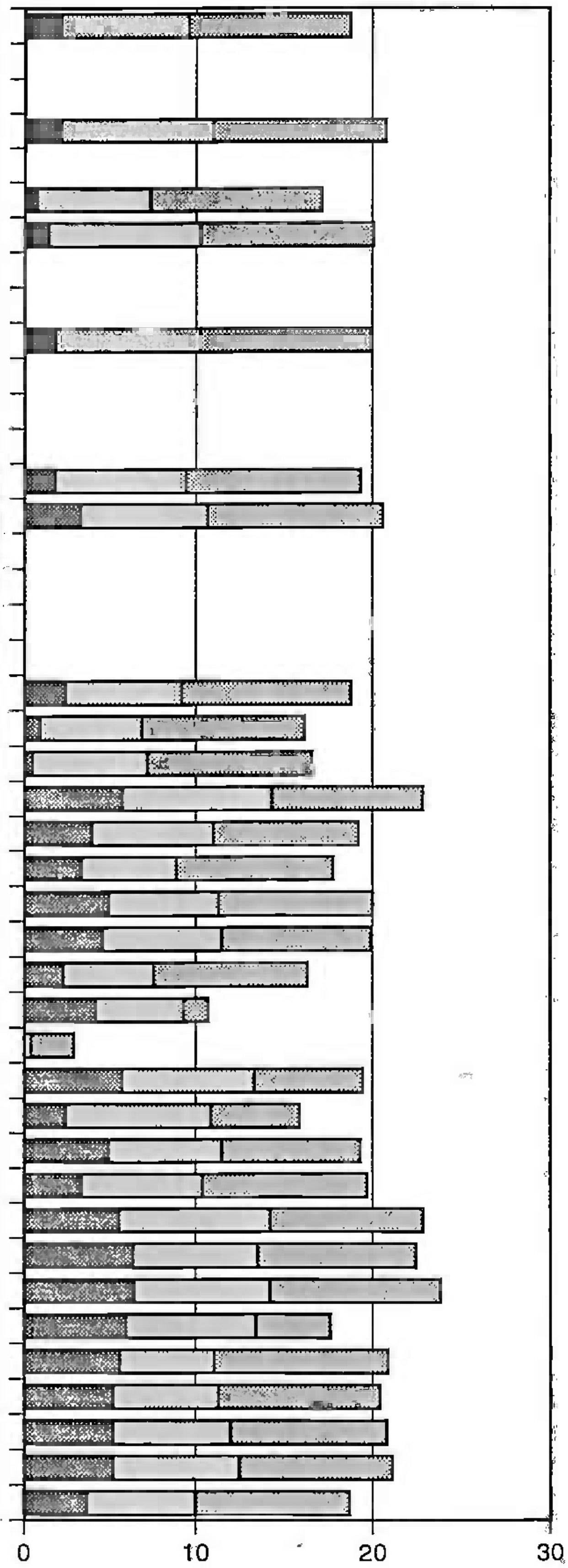
- comparable water quality data for each system.

- assessment of aesthetic status of each system.

It is hoped that this will not only provide an essential management tool but will also stimulate further research into these coastal systems.

Table 4. Composite Estuarine Health Index values for estuaries on the southeastern Cape coast, Groot (Wes) - Great Fish.

	BHI	WQI	AHI
Groot (Wes)	2.1	7.4	9.2
Helpmekaars			
Klip			
Bloukrans	2.2	8.8	9.8
Witels			
Lottering	0.7	6.6	9.8
Elandsbos	1.4	8.8	9.8
Geelhoutbos			
Kleinbos			
Storms	1.8	8.4	9.7
Bruglaagte			
Langbos			
Sanddrif			
Elands	1.8	7.6	9.9
Groot (Oos)	3.3	7.4	9.9
Eerste			
Klipdrif (Wes)			
Boskloof			
Kaapsedrif			
Tsitsikamma	2.5	6.7	9.6
Klipdrif (Oos)	0.9	5.9	9.3
Slang	0.5	6.7	9.4
Kromme	5.7	8.6	8.5
Seekoei	4.0	7.0	8.2
Kabeljous	3.4	5.5	8.9
Gamtoos	4.9	6.4	8.7
Van Stadens	4.6	6.9	8.4
Maitland	2.3	5.2	8.8
Bakens	4.2	5.1	1.4
Papkuils	0.0	0.4	2.5
Swartkops	5.7	7.6	6.1
Koega	2.5	8.4	5.0
Sundays	4.9	6.6	7.8
Boknes	3.4	7.0	9.3
Bushmans	5.5	8.7	8.6
Kariega	6.3	7.2	8.9
Kasuka	6.4	7.8	9.6
Kowie	5.9	7.5	4.2
Rufane	5.6	5.5	9.8
Riet	5.2	6.1	9.1
Wes-Kleinemond	5.2	6.8	8.8
Oos-Kleinemond	5.2	7.3	8.6
Great Fish	3.7	6.3	8.7



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