



**DEVELOPMENT OF CRITERIA FOR THE
DESIGN OF FISHWAYS FOR SOUTH AFRICAN
RIVERS AND ESTUARIES**

**R Heath • A Bok • PSO Fouche •
WK Mastebroek • AT Forbes**

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Water Research Commission



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EXECUTIVE SUMMARY

INTRODUCTION

There has been a worldwide increase in interest and research effort over the last 15 to 20 years on promoting free passage of aquatic organisms in rivers, as part of the wider goal to restore and conserve aquatic ecosystems. There is an increased appreciation of the necessity of both adults and juveniles for a variety of species to undertake longitudinal movements in rivers as part of their life history.

The presence of existing barriers to migration in rivers (weirs, dams, road bridges, causeways, etc) is considered to be a major factor responsible for the reduction in numbers and range of many migratory fish and invertebrate species throughout South Africa. Most indigenous fish species in this country carry out annual migrations within river systems for a number of reasons such as, to optimise feeding, to promote dispersal, to avoid unfavourable conditions and to enhance reproductive success. Impassable fabricated barriers to migration are partly responsible for the threatened status of a number of Red Data species in southern Africa.

There are about 100 indigenous freshwater fish species in South Africa, including both the subtropical Zambebian and temperate ichthyofauna. The majority of these freshwater species undertake migrations for purposes of feeding, spawning, dispersion, and colonization after droughts or for other environmental purposes. Many of these larger species (e.g. *Labeobarbus*, *Barbus*, *Clarias*) are well known for undertaking spectacular spawning migrations after rains in summer. However, as our knowledge of fish habitat requirements increases, there is a growing body of evidence indicating that many fish species migrate various distances both upstream and downstream into more favourable habitats, as both adults and juveniles, at various times of the year, for a variety of reasons.

CURRENT SOUTH AFRICAN FISHWAY INITIATIVES

The Water Research Commission (WRC) has a fishway research programme that has to date sponsored four projects dealing with fishways in South Africa. These projects are:

- Guidelines for the planning, design and operation of fishways in South Africa Bok *et al.*, (2004, WRC Project No. K5/1270).
- Discharge measurements at natural controls in Western Cape Rivers. Barnard and Rooseboom, 2004 (WRC Report No. 1270/1/04).
- Development of Criteria for the Design of Fishways for South African Rivers and Estuaries - this project.
- Research on facilitating free passage of migratory biota in South African waters with a view to producing guidelines for the planning and design on fishways in South Africa (2003 – 2007, WRC Project No. K5/1409).

Due to the overlaps of these projects it was agreed by the project steering committee that the end product of the WRC fishway programme would be a book titled: “*Guidelines for the*

planning, design and operation of fishways in South Africa". This will be the final product of project K5/1409.

SITUATION ASSESSMENT OF FISHWAYS IN SOUTH AFRICA

The design limitations of earlier fishways has resulted in a renewed research effort to develop designs for non-salmonid species by both hydraulic engineers and fish biologists in many countries around the world. This research has resulted in much-improved fishway designs that successfully pass a wide variety of fish and other aquatic migratory species.

Until recently, very limited research funding has been available in South Africa to investigate fishway facilities designed to cater for indigenous species under local environmental conditions. The situation assessment attempts to outline the "state of the art" regarding fishway provision in South Africa. Aspects discussed include:

- the extent of the problem of man-made barriers blocking fish passage,
- the provision of fishways in South Africa to date,
- enabling legislation,
- the effectiveness of these existing fishways,
- appropriate fishway designs that appear suitable for South African conditions and deserve further research, and
- recent advances in fishway designs elsewhere in the world that could be applied in South Africa.

Due to the favourable reports worldwide regarding the success of "standard" Vertical-slot fishways in passing a variety of fish species, both large and small, and in rivers with similar hydrology, this design is thought to hold great promise for South Africa. Fine-tuning of Vertical-slot type fishway designs for South African conditions is therefore considered a high priority and on-going research is being sponsored by WRC.

Preliminary findings indicate that South African species can negotiate velocities and turbulence levels greater than those recommended in similar work overseas. If these findings are correct then they will allow the construction of steeper and shorter Vertical-slot fishways, which will result in substantial savings on construction costs.

DEVELOPMENT OF AN INVENTORY OF EXISTING FISHWAYS IN SOUTH AFRICA

As there was a lack of readily available information on instream barriers in South African rivers, an annotated inventory of all fishways in South Africa was developed. There are a total of approximately 57 fishways in South Africa, of which about 42 are functional to some degree. Considering the functional fishways, the most common type is the Pool and Weir (32) and then the vertical slot (8). One rock ramp and one pre-barrage fishway have also been constructed. However, both the Pool and Weir and the Vertical-slot fishways constructed in South Africa have major differences compared to the typical designs from Europe or North America. A detailed assessment of the current fishways in South Africa is given in this report.

MONITORING OF FISHWAYS

There is a paucity of quantitative data on the performance of existing fishways in South Africa, particularly information identifying the designs that are more successful in allowing the passage of the full range of target species. In addition, little is known of the swimming ability or the migratory behaviour of indigenous southern African fish species.

A carefully designed fishway monitoring programmes on selected functional fishways will make a valuable contribution to the current fishway knowledge in South Africa. Not only, will the information allow the effectiveness of the monitored individual fishways to be improved, but also this data should facilitate the development of fishway designs suitable for the hydrological conditions and migratory species found in this country. Furthermore, the standardisation of sampling methods and data collection sheets will enable the results to be captured on a centralised database (such as being developed on the fishway website <http://www.fishways.co.za>). The accessibility of the data will greatly assist with further design development and refinements. Fishway monitoring should therefore be designed to provide data on both the effectiveness of the fishway in terms of the internal hydraulics at various flows, as well as data on the migratory behaviour and swimming ability of the migrants.

In order to further determine the applicability of fishway designs, two fishways in South Africa were monitored as part of this project, namely Lake Nhlabane and Xikundu fishways.

Detailed monitoring procedures were developed for both the Lake Nhlabane and Xikundu fishways. These include the equipment to be used, the techniques used to collect the data as well as a standardised set of data sheets. The results of these monitoring programmes have resulted in the development of a standardised generic monitoring programme for fishways in South Africa.

NHLABANE FISHWAY MONITORING

Richards Bay Minerals (RBM) has built a fishway that links Lake Nhlabane with the Nhlabane estuary. This Pool and Weir fishway with a sloping baffle is state of the art and has been constructed so as to allow many variables to be altered (such as flow rate and water depth). This fishway can also be adjusted for the flow requirements of invertebrates such as crabs and prawns. An initial one-year monitoring programme on the fishway was undertaken in order to assess the effectiveness of the fishway. This one-year programme answered some of the questions but was too short a programme to determine the effects of seasonality and breeding migrations. A further year of monitoring was funded by the WRC as part of this project.

The Nhlabane fishway was found to allow for the successful passage of fish over a size range of at least 10 to 310 mm TL. The fishway design is thought to be partly responsible for the upper size limit of upstream fish migrants, but caters well for small and juvenile specimens that are more likely to move between the estuary and upstream freshwater habitat. The design of the fishway caters well for fish within this size range at water flow volumes of between 1 and 40 l/s and even as high as 90 l/s. Fishway water volume affected the numbers, by affecting the location of the entrance by migrants, but not size classes of upstream migrants. Optimum flow down the fishway is regarded as around 20 to 40 l/s.

The fishway exits in the lake operate at a range of lake levels, allowing upstream migrants entry into the freshwater habitat. Several mugilids - possibly *Myxus capensis* - of approximately 200 to 300 mm total length were observed in the shallows immediately upstream of the weir in the lake. As no mugilids of this size were recorded in the fishway, this strongly indicates that fish are successfully negotiating the fishway and exiting and surviving in the lake.

The timed-run experiment, although not conclusive, indicated that the design of the fishway is such that migrants can negotiate the entire length of the fishway in a remarkably short time. This is significant as it confirms that fish do not accumulate at points in the fishway, and suggests that fish do not exit the fishway unduly exhausted or stressed.

XIKUNDU FISHWAY MONITORING

Xikundu Weir, approximately 40 km downstream of the Nandoni Dam on the Luvuvhu River in the Limpopo Province had a fishway designed and built specifically for the aquatic biota in the river. This fishway is a pool and weir design incorporating a standard horizontal weir with staggered notches.

The experiences of the fish biologists and ecologists of the project team working in conjunction with DWAF engineers used the design criteria and process suggested by Bok *et al.*, (2004) to construct the Xikundu fishway on the Luvuvhu River. This fishway was completed in mid 2003. The fishway at Xikundu is a typical pool-type fishway with notched baffles.

The Xikundu fishway was monitored to determine the effectiveness of this fishway design. From this monitoring programme, it can be deduced that the design of the Xikundu fishway allows for effective movement of fish through the fishway. Twenty of a possible 28 species were able to locate and enter the fishway. This clearly indicates that the entrance to the fishway is well placed and accessible. A significant number of these species, namely fifteen were collected in the top and lower pools of the fishway, which indicates that the hydraulic characteristics within the fishway allowed for movement through the fishway. These characteristics include suitable resting areas with minimized flow and velocity and connections between the pools where the height difference and water velocity allow movement of all the size groups of the different species. The characteristics exist as a result of the specific design of the fishway and it can be concluded that the design of the fishway is suitable for the fish encountered in the river reach.

Of the eleven species broadly classified as migratory, eight were collected in the fishway. The fact that Tigerfish had been collected upstream of the fishway for the first time in many years while it had been collected on a regular basis downstream in the KNP may also be an indication that they had utilized the fishway.

PRELIMINARY DESIGN AND MONITORING REFINEMENT

The results of these two monitoring programmes were used to assess the suitability of the fishways designs. Furthermore, the monitoring was designed to gain further knowledge of the fish movement patterns and assist in the development of a set of design criteria for fishways that can be implemented nationally by DWAF on weirs and dams in South African rivers and estuaries.

Due to the overlap of the study of fishways in the WRC projects, the results developed on the design criteria of fishways (Bok *et al.*, 2005) were not duplicated in this report but rather assessed during the monitoring programmes of Nhlabane and Xikundu fishways. The results of all these South Africa fishway studies will be used and incorporated into each of the WRC reports. All these studies have the same common goal of producing a definitive guideline book of **how to design, monitor and maintain fishways for South African conditions**.

The hydraulic design of fishways is discussed and examples of these are related to South African conditions (Bok *et al.*, 2005). The basic hydraulic theory and design criteria is given as well as the advantages and disadvantages of various types of fishways.

In summary, the recommendations of Bok *et al.*, (2005), with regards to design guidelines for fishways are as follows:

- The fishway designs currently being used in South Africa are only a few of the possibilities.
- A proper and appropriate design can only be made once the needs of the fish species to be catered for are known.
- The hydrology of the river needs to be considered before the fishway is designed to take into account the specific migratory requirements of the fish (when they need to move)
- It is important to remember that fish have to migrate during high flows and that the designs such as Vertical-slot fishways will be preferred.
- From the examples used it is clear that it is often possible to design a cheap Pool and Weir type fishway for small fish migrating in small rivers with long periods of low flow at which the water level at the barrier remains relatively constant.
- In large rivers where the flow level varies the Vertical-slot type of fishway is recommended.
- The combination of Pool and Weir and a Vertical-slot fishway by providing a sloping sill in the slot has a high potential for South African river.

The design criteria principles described above were used in the development of both the Nhlabane and Xikundu fishways. The Nhlabane fishway is a modified Pool and Weir fishway with 98 pools arranged in a folded-staircase type design giving a total length of 47 m. The Xikundu fishway is a Pool and Weir with deep pools also arranged in a folded-staircase type design. The results of the monitoring programme undertaken on both these fishways will be used in the further refinement of South African fishway design criteria (WRC project K5/1409) and used to develop field and laboratory tests to determine fish movement patterns under different flows and fishway designs.

RECOMMENDATIONS FOR FURTHER WORK

It is recognised internationally that the three most important research topics on fishways are:

- assessing the relative swimming abilities and behavioural characteristics of indigenous migrating fishes with respect to fishways;
- assessing the relative performance of different fishway types;
- entrance and exit conditions adjacent to fishways (including tidal conditions).

It is significant that the WRC fishway research programmes (initiated in 2001 and continuing until 2007), includes projects that are aimed at determining the above mentioned research topics.

The most promising fishway designs for South African conditions, as indicated by both local and overseas studies, have been identified in this report. It is important that these designs are selected and thoroughly tested, modified and fine-tuned for local species and conditions. Further trials, using portable model fishways, under both laboratory and field conditions will be conducted.

Also included in the continued WRC fishway programme are the following aspects, which will further refine our local knowledge, enabling us to develop a set of guidelines for optimum fishway design criteria:

- a centralised database on fishways, design, fish catches (fishway website, <http://www.fishways.co.za/>). The accessibility and ongoing population of this data will greatly assist with further design development and refinements.
- protocols developed by Bok *et al.*, (2004) for fishway requirements and importance in South African rivers will be further tested and refined.
- further testing of fishway designs in different regions of the county using portable fishways . The results of these fishway studies will enable design modifications and a recommended design per situation. The design modifications will then be implemented and retested both in the field and laboratory (both at Rhodes and Johannesburg Universities).
- the swimming abilities and behavioural characteristics of a selected number of key indigenous migrating fish will be tested in environmentally stable conditions (controlled light and water temperature as well as within an array of chosen fishway designs.
- ongoing liaison with DWAF design engineers, consultants and international experts needs to take place through a series of workshops.

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Dr SA Mitchell	Water Research Commission (Chairman)
Ms MM Barnard	University of Stellenbosch
Mr J Geringer	Department of Water Affairs & Forestry
Prof A Rooseboom	University of Stellenbosch
Dr J Rossouw	University of Stellenbosch
Prof P Skelton	South African Institute for Aquatic Biodiversity
Dr A Deacon	SA National Parks Scientific Services
Dr HH du Preez	Rand Water Analytical Services
Mr D Fischer	Richards Bay Minerals
Dr P Wessels	Department of Water Affairs & Forestry
Dr N Demetriades	Marine and Estuarine Research
Prof Ben van der Waal	University of Venda
Dr J Cambray	Albany Museum
Mr D Impson	Cape Nature Conservation

PROJECT TEAM

The following people worked on the project:

- Dr Ralph Heath (Pulles Howard & de Lange Inc) – Project Manager
- Dr Anton Bok (Anton Bok and Associates)
- Professor Ticky Forbes (Marine and Estuarine Research)
- Dr Nicky Demetriades (Marine and Estuarine Research)
- Mr Walter Mastebroek (Marine and Estuarine Research)
- Mr Paul Fouche (University of Venda)
- Mr PM Radzilani (University of Venda)
- Mr HE Munzhelele (University of Venda)
- Mr Ray Jones (Richards Bay Minerals)

Richards Bay Minerals is thanked for enabling us to continue monitoring the Nhlabane fishway.

DEVELOPMENT OF CRITERIA FOR THE DESIGN OF FISHWAY FOR SOUTH AFRICAN RIVERS AND ESTUARIES

1. INTRODUCTION

The presence of existing barriers to migration in rivers (weirs, dams, road bridges, causeways, etc) is considered to be a major factor responsible for the reduction in numbers and range of many migratory fish and invertebrate species throughout South Africa. Most indigenous fish species in this country carry out annual migrations within river systems for a number of reasons such as to optimise feeding, to promote dispersal, avoid unfavourable conditions and to enhance reproductive success. Impassable man-made barriers to migration are partly responsible for the threatened status of a number of Red Data species in southern Africa according to Paul Skelton (personal communication).

The harmful effect of barriers to migration is particularly severe in coastal rivers where a number of catadromous species need to migrate from their marine or estuarine spawning grounds into freshwater reaches of rivers for feeding purposes. As these fish migrate upstream as small juveniles, even low barriers of less than a meter can be impassable. Catadromous species include the threatened freshwater mullet (*Myxus capensis*), four species of freshwater eels and at least five species of freshwater prawns and crabs (Anton Bok, personal communication). In addition, there are over 20 species of marine or estuarine fishes that frequently enter freshwater in these coastal regions, even though this movement does not involve a major portion on the population. These migratory species, (particularly the eels, mullet and prawns) present a valuable resource (food, angling) and play a valuable role in the ecology of the coastal river systems.

There is presently a paucity of readily available information on instream barriers in South African rivers. Even though impoundments (weirs and dams) require registration in terms of the National Water Act (Act 36 of 1998) the exact locality of them is not available due to the process of registration still taking place. Furthermore, the principles of the National Water Act (Act 36 of 1998) endorse Integrated Water Resource Management (IWRM) on a catchment scale. One of the guiding principles is the determination of the Reserve for ecological and human needs. This has resulted in the Department of Water Affairs and Forestry (DWA), as part of the Reserve process, determining the instream flow requirements (IFR or Ecological Water Requirements - EWR) of many of our rivers. The Reserve process for the aquatic ecosystem requires an expert knowledge of fish flow requirements (how much and when per species of indigenous fish). The current knowledge of the requirements of the aquatic organisms has increased over the past decade enabling us to get a closer approximation of the Reserve determination.

Richards Bay Minerals (RBM) has built a fishway that links Lake Nhlabane with the Nhlabane estuary that has been operational for five years. This fishway is state of the art and has been constructed so as to allow many variables to be altered such as flow rate and water depth. This fishway can also be adjusted for the flow requirements of invertebrates such as crabs and prawns. RBM and the University of Natal monitored this fishway for one year in order to attempt to answer the question as to whether the fishway works or not? This initial one-year programme answered some of the questions but was too short a programme to determine the effects of seasonality and breeding migrations. As part of this Water Research Commission (WRC) funded project the monitoring programme at Lake Nhlabane was

extended for another year. This extension was to gain further knowledge of the fish movement patterns and further assist in the development of a set of design criteria for fishways that can be implemented nationally by DWAF on weirs and dams in South African rivers and estuaries.

Furthermore Xikundu Weir, approximately 40 km downstream of the Nandoni Dam on the Luvuvhu River in the Limpopo Province has had a fishway designed and built specifically for the aquatic biota in the river. The Xikundu weir, which is approximately 6 m high, was monitored as part of this WRC project by the University of Venda to determine the effectiveness of this fishway design. The results of these two monitoring programmes were to assess the suitability of the fishways designs. These findings will be used to assist engineers at DWAF, academic institutions and consultants in their further development of design criteria for South African fishways.

This project has progressed through a collaborative and consultative process with leading South African fish experts, ecologists, hydraulics engineers and hydrologists who have given up their time to participate in a series of workshops. Their guidance and expertise have been used to refine the project plan and methods used.

2. CURRENT SOUTH AFRICAN FISHWAY INITIATIVES

The WRC has taken the initiative to fund a research programme on the **development of criteria for design of fishways for South African conditions**. This research programme is specifically designed to enable DWAF to determine if a fishway is required and if required what is the most effective design (in terms of costs and maximum aquatic biota movement).

This current project cannot be seen in isolation and needs to be seen as a contribution to the overall WRC fishway programme.

The WRC funded projects that have inputs into the delivery of the final product are indicated below including the project title, project number, period of funding, lead research organization and expected deliverable:

Guidelines for the planning, design and operation of fishways in South Africa.

University of Stellenbosch and Anton Bok & Associates (2001- 2005) (WRC Project No. K5/1270) – Bok *et al.*, 2004.

- Introduction
- Summary of protocols
- Biological background to necessity protocol
- Background to priority rating protocol
- Biological constraints on fishway design
- Site specific considerations
- Design guidelines
- Monitoring and operational management
- References

Development of Criteria for the Design of Fishways for South African Rivers and Estuaries

Pulles Howard & de Lange (2002 – 2005) (WRC Project No. K5/1310) – this project

- Literature review
- Situation assessment
- Nlabane sampling
- Sampling prototype
- Test sampling program - Xikundu
- Revised sampling protocol
- Preliminary design criteria – from field assessments

Research on facilitating free passage of migratory biota in South African waters with a view to producing guidelines for the planning and design on fishways in South Africa

Pulles Howard & de Lange consortium (2003 – 2007) (WRC Project No. K5/1409)

- GIS data base
- Protocols for ranking & need for fishway
- Database on swimming & migratory behaviour
- Laboratory studies – swimming, species

- Field studies - swimming, species
- Hydraulics field studies
- Hydraulic laboratory studies

The objectives of the above project are:

- Quantify extent of problem relating to the blocking of free passage of migratory biota in South African rivers;
- Develop an assessment method/protocol around the provision of fishways for use in EIA and RDM determinations;
- Develop an understanding of biological/physiological requirements of fish for successful fishway implementation; and
- Develop/review fishway designs that are suitable for different species and river systems

The final product of the WRC fishway funding will be a book entitled “**Guidelines for the planning and design of fishways in South Africa**” with the following chapters:

1. Introduction
2. Biological Factors
3. Hydrological and Hydraulic Considerations
4. Planning Considerations
5. Types of fishways suited to South African Rivers
6. Design Guidelines
7. Provision and Construction Protocols
8. Operation Monitoring and Maintenance

The WRC has further funded a project “Discharge measurements at natural controls in Western Cape Rivers (Barnard and Rooseboom, 2004, WRC Report No. 1270/1/04). This project, although not directly related in fishways, has given a good indication that natural control measures can be used for accurate measurement of flows. In future these types of flow measurements could be used in place of gauging weirs, which would reduce the need for the building of fishways.

3. SITUATION ASSESSMENT OF FISHWAYS IN SOUTH AFRICA

3.1 INTRODUCTION

There has been a worldwide increase in interest and research effort over the last 15 to 20 years on promoting free passage of aquatic organisms in rivers, as part of the wider goal to restore and conserve aquatic ecosystems. There is an increased appreciation of the necessity of both adults and juveniles of a variety of species to undertake longitudinal movements in rivers as part of their life history. The earlier fishways designed to cater for strong-swimming adult salmonids were found to be ineffective for passing juveniles or smaller fish species.

The design limitations of these earlier fishways has resulted in a renewed research effort to develop designs for non-salmonid species by both hydraulic engineers and fish biologists in many countries around the world. This research has resulted in much-improved fishway designs that successfully pass a wide variety of fish and other aquatic migratory species.

Until recently, very limited research funding has been available in South Africa to investigate fishway facilities designed to cater for indigenous species under local environmental conditions. This section attempts to outline the “state of the art” regarding fishway provision in South Africa. Aspects discussed include:

- the extent of the problem of man-made barriers blocking fish passage,
- the provision of fishways in South Africa to date,
- the effectiveness of these existing fishways,
- appropriate fishway designs that appear suitable for South African conditions and deserve further research, and
- recent advances in fishway designs elsewhere in the world that could be applied in South Africa.

The main aim of this chapter is to give an overview of the state of the art relating to the provision of fishways in South Africa and, by assessing advances in fishway design overseas, help focus the ongoing research effort on appropriate fishway designs and associated data requirements.

3.2 MIGRATORY BIOTA IN SOUTH AFRICA

3.2.1 Fish Species

3.2.1.1 Primary Freshwater Fishes

Number of migratory species

There are about 100 freshwater fish (indigenous) species in South Africa, including both the subtropical Zambebian and temperate ichthyofauna (Skelton, 1993). The majority of these primary freshwater species undertake migrations for feeding, spawning, dispersion, and colonization after droughts or for other environmental purposes i.e. entering warmer downstream reaches as winter approaches. Many of these larger species (e.g. *Labeobarbus*, *Clarias*) are well known for undertaking spectacular spawning migrations *en masse* after rains in summer. However, as our knowledge of fish habitat requirements increases, there is a growing body of evidence indicating that many fish species migrate various distances both

upstream and downstream into more favourable habitats, as both adults and juveniles, at various times of the year, for a variety of reasons.

Timing of migrations

The extent, timing and reasons for these non-spawning migrations, particularly by juveniles and sub-adults, are not well known and require further research. Recent studies in Australia, for example, have found that (contrary to popular belief) most indigenous fish migrate as juveniles (Mallen-Cooper, 1997; Stuart, 1997), and often at low river flows and not only as adults during floods or high flows.

Size of migrating fish

Although information from South African rivers is limited, there is evidence that the migratory behaviour of local indigenous primary freshwater fish is similar to that in Australia, i.e. with both juveniles and adult fish undergoing migrations. Examples include:

- Monitoring studies on the Kanniedood Weir Fishway on the Shingwedsi River in the Kruger National Park (KNP), showed that a high proportion of the fish (90%) captured migrating up the fishway were sub-adults or small adult fish of under 100mm in length (Olivier, 1994).
- Monitoring data from the Neusberg Fishway near Kakamas on the Orange River, found that the most numerous fish species using the fishway were sub-adult (50 to 59 mm in length) three spot barb, *Barbus trimaculatus* (Benade *et al.*, 1995).
- Recent field trials (November 2004) using a model Vertical-slot fishway placed at a gauging weir blocking fish migrations in the Sabie River in the Kruger National Park (Kotze *et al.*, 2004), found that the majority of fish actively migrating were sub-adults or small adult fish less than 100mm in length. Of the 12 fish species found migrating in the Sabie River at this time, the adults of only 2 species (*Clarias gariepinus* and *Labeo rosae*) appeared to be actively migrating.

The need for fishways designed for primary freshwater fishes to cater for both large and small fish and also to operate effectively at both high and low river flows, has not received sufficient attention in South Africa. If indeed necessary, this will have significant implications regarding fishway design and operation, as well as costs. Further research on these aspects of fish migration in South Africa, particularly in inland rivers, is therefore of crucial importance for any successful fishway programme.

3.2.1.2 Diadromous Fishes

In addition to these primary freshwater species, there are at least 24 marine and estuarine fish species that are known to migrate (mainly as post-larvae and juveniles) into freshwater zones of rivers along the south and east coasts of South Africa (Bruton *et al.*, 1988). These diadromous species spend varying amounts of time in freshwater habitats in the lower river reaches, which serve mainly as secondary nursery areas.

Only the four species of freshwater eels (*Anguillidae*) and possibly the freshwater mullet *Myxus capensis* (Bok, 1983) have an obligatory freshwater phase in their life cycle, i.e. are truly catadromous (migrate downstream as adults to breed at sea and then migrate upstream as post-larvae and juveniles). The other marine and estuarine species that migrate between fresh and estuarine reaches displayed varying degrees of dependence on freshwater habitats.

The more common diadromous species that are expected to use fishways located on south and east coast rivers in South Africa, are listed by Bok *et al.*, (2004).

Of significance to the designs of fishways in these coastal rivers, is that these diadromous fish can be as small as 20 to 30 mm in length when migrating upstream and are thus relatively weak swimmers. In addition, they appear to migrate upstream during both high and low river flows. These migratory characteristics have a major influence on fishway design in these coastal rivers, as discussed further below.

3.2.2 Macrocrustacea

There are at least nine species of macrocrustacea (freshwater prawns and crabs) that are known to migrate between the sea or estuary and freshwater reaches of rivers along the south and east coast of South Africa (Bickerton, 1989; Bok *et al.*, 2004). The freshwater prawns need to migrate into brackish water with a salinity of at least 8 parts per thousand for successful larval development. The adults and juveniles then migrate back into freshwater feeding areas to complete their life cycle. Thus if movement between fresh and estuarine habitats are blocked by a barrier to migration, these macrocrustacea can be exterminated from the river in question.

These species have limited swimming ability and tend to avoid strong currents usually associated with most formal fishway designs. However, prawns and crabs have the ability to pass over barriers to migration by leaving the water and crawling up sloping surfaces in the splash zone on the edge of the flow (Bok, 2001), providing the surface is rough and wet. Fishways designed to pass macrocrustacea will thus have to take these migratory characteristics into consideration.

3.3 EXISTING LEGISLATION

Environmental legislation has recently been promulgated in South Africa that adequately protects riverine ecosystems from man-induced impacts. If correctly and strictly applied, this new legislation should ensure that appropriate mitigation (e.g. fishway provision) is taken when instream barriers to fish migration are constructed. This legislation includes:

3.3.1 The Environment Conservation Act, 1989 (No. 73 of 1989)

In terms of Regulations (Section 21, Schedule 1, No.1 (j) published in Government Gazette No. 18261, 5 September 1997, in terms of the Environment Conservation Act, 1989 (ECA), appropriate environmental investigations (EIA's) are mandatory before approval for the "*construction or upgrading of dams, levees or weirs affecting the flow of a river*" will be given by the relevant authority. Thus, approval for the construction of any potential instream barrier can be made conditional to the provision of a successful fishway.

It should be noted that the National Environmental Management Act (Act 107 of 1998) is presently being amended and provided with new regulations and will replace the ECA in the near future. However, the requirement stipulating that appropriate mitigation should be taken (e.g. fishway provision), before approval for any instream barrier construction is granted, will remain in force.

3.3.2 National Water Act, 1998 (Act No. 36 of 1998)

In the National Water Act (NWA), use of water is no longer limited to consumptive use, such as the abstraction of water, but includes non-consumptive activities that may have an impact on the resource quality. These “water uses”, which require authorisation (usually in the form of a licence) are given in Section 21 of the NWA, and include:

- Section 21 (a): storing water;
- Section 21 (c): impeding or diverting the flow of water in a watercourse;
- Section 21 (i): altering the bed, banks, course or characteristics of a watercourse.

Thus, in terms of the NWA, the erection of any instream structure within a watercourse, which could theoretically impede fish passage, such as bridges, causeways, weirs, dams, etc., is listed as a water use, and would require a licence. If the proposed structure or “alteration” of the watercourse could impede aquatic biota migration, the granting of the permit should be conditional on providing free passage of aquatic biota past the potential man-made barrier.

In addition to the above authorisations, there are also control measures for a dam with a safety risk, which is defined as any dam which can contain more than 50 000m² of water and which has a vertical wall height of more than 5 metres, or which has been declared as a dam with a safety risk. A dam safety licence is required from DWAF before any such dam with a safety risk may be constructed or altered.

The intention of the legislation in the NWA in relation to fish movement is apparent in the Government Gazette No. 20526, 8 October 1999, which states in Schedule 1 (THE TAKING OF WATER FROM A RESOURCE AND THE STORAGE OF WATER, SECTION 21 (A) AND 1 (B)) under paragraphs 1.9 (3): “*Where water is stored in a watercourse, the registered user must take reasonable measures to ensure that the movement of aquatic species is not prevented, including those species which normally migrate through the watercourse*”.

3.3.3 National Environmental Management: Biodiversity Bill

This bill provides for the conservation of South Africa’s biodiversity, especially threatened and protected species, within the framework of the National Environmental Management Act (NEMA), 1998. Thus all listed threatened or protected migratory fish species will be afforded additional protection in terms of any “restricted activity” which may impact negatively on the population, such as the construction of a barrier to migration.

Therefore, in terms of the Environment Conservation Act, 1989 the National Water Act, 1998, and the National Environmental Management: Biodiversity Bill, legislation exists to enforce the provision of fishways on any instream structure that threatens to impede the free passage of migratory aquatic biota present.

3.4 BARRIERS TO MIGRATION

As discussed above, legislation prior to 1998 did not require environmental impacts to be undertaken when constructing instream barriers. As a result, mitigation measures such as the construction of fishways to ensure free passage of migratory aquatic biota were seldom undertaken. Almost 15 years ago it was estimated that South Africa had in excess of 5 000 registered weirs and dams with a wall height of over 5 m and a capacity in excess of 50 000

m³, as well as approximately 1 150 gauging structures, diversion and storage weirs (Rowlston, 1990).

The above estimate does not include the enormous number of unregistered smaller weirs constructed by riparian landowners and local authorities for farming purposes or domestic consumption, thought to run into tens of thousands. Many of these existing instream structures are known to completely or partially block the natural migration of South Africa's riverine aquatic biota and are considered to be a major contributing factor to the threatened status of many of the indigenous fish species (e.g. Bok, 1983; Skelton, 1993; Skelton, 1998).

In spite of the well-documented negative impacts of instream barriers on aquatic migratory species in South Africa, there has been very little effort to date to establish an inventory of such barriers on a catchment basis, or to prioritise them in terms of their ecological impact and hence mitigation requirements.

3.5 FISHWAYS IN SOUTH AFRICA

3.5.1 General Outline

There is an extensive international literature on fishway designs, including in-depth studies on their internal hydraulics (for reviews see Beach, 1984; Bell, 1986; Rowlston, 1990; Clay, 1995; FAO/DVWK, 2002; Larinier *et al.*, 2002). Only designs of existing "successful" fishways in South Africa or designs considered applicable to the South African situation will be discussed in this report.

The most common fishway designs include: a) Pool and Weir; b) Vertical-slot; c) Rock-ramp and d) Bypass channel. An additional fishway design of common use in Europe and North America, the Denil type fishway, is not considered in this report as it is designed for strong-swimming adult fish and has proved unsuitable for smaller, non-salmonid fish in Australia (Mallen-Cooper, 1994a; Mallen-Cooper, 1997).

An annotated inventory of all fishways in South Africa is in given Appendix A. There are a total of approximately 57 fishways in South Africa, of which a total of 42 are considered functional to some degree (Appendix A). As can be seen, the most common type is the Pool and Weir (32) and then the vertical slot (8). In addition, one rock ramp fishway and one pre barrage type fishway have been constructed. However, both the pool and weir and the vertical slot fishways constructed in South Africa have major design modifications compared to the typical designs from Europe or North America. These differences are discussed in some detail in this report.

3.5.2 Pool and Weir Fishways

This fishway type consists essentially of a sloping, usually rectangular channel, which is divided into a series of pools by the construction of weir walls across the full width of the channel. The weir crests can be notched and also low-level orifices can be incorporated in the weir walls. Variations in channel slope and the dimensions of the pools are obvious design features that influence the internal hydraulics within the fishway.

The first fishways constructed in South Africa were of the Pool and Weir type, based on northern hemisphere concepts, and did take into account the swimming behaviour and ability

of indigenous species. These early fishways were designed to cater for fast-swimming adult salmonids and typically had water velocities of about 2.0 to 2.5 m/s and steps of about 30 cm between pools (Mallen-Cooper, 1994a). In retrospect, these early fishways provide an unfortunate example of the dangers inherent in blindly applying foreign technology without determining whether it is appropriate for local conditions. Significant modifications to the standard northern hemisphere Pool and Weir design are apparent in the more recently constructed fishways in South Africa. Of particular importance regarding the Pool and Weir fishways in South Africa is the variation in the design of the baffles, the slope of the channel, the size of the pools and the height difference between pools.

Available fishway monitoring data in South Africa has shown the following Pool and Weir fishway designs to be effective or partially successful and therefore warrant further development.

3.5.2.1 Pool and Weir Fishway with Notched Weir

In the Kruger National Park (KNP) nearly all the formal-type fishways are of the Pool and Weir design, with notched weirs (Appendix A). The one exception is the Engelhardt Dam fishway, which is a Pool and Weir fishway with sub-merged orifices. Information from monitoring programmes incorporating capture and observations of migrating fish, has determined the most successful fishway designs in the KNP (Deacon *et al.* 1995; Deacon, *pers. comm.*, October 2001).

This has allowed the development of a recommended “generic” Pool and Weir fishway design for weirs in the KNP. These dimensions and design features are typified in a fishway constructed by the KNP Technical Services Division, on the Kanniedood Dam on the Shingwedsi River, which was completed in April 1992 (see Plates 3.1 and 3.2). A detailed description of this fishway is given in Olivier (1994).

These typical design features include:

- the weir walls are 150 mm thick and typically have staggered notches;
- the notches are approximately 500 mm wide at the top (upstream end), sloping to 300 mm at the bottom;



Plate 3.1: View looking upstream at the Kanniedood fishway on the Shingwedzi River in the KNP during low flow conditions.



Plate 3.2: Close-up view of weir notch in the Kanniedood fishway, KNP during low-flow conditions.

- there is maximum height difference between pools of 300 mm – i.e. between consecutive crest levels in notches in the weirs (or between the weir crests if no notches);
- the downstream surface of the notches are sloped at about 45% (1:2) to ensure an adherent nappe (no air between water and downstream face of notch or baffle);
- the water level in the pools at low flow is at the lower edge of the upstream notch (i.e. fish do not have to jump clear of the water to move upstream);
- the side-walls extend about 600 to 1000 mm above the low flow water level to prevent fish from jumping out and to contain high flows through the fishway;
- the gradient of the fishway varies between about 10% (1:10) to 7% (1:14);
- calculated velocities through critical areas in the fishway (through notches) should be less than about 2 m/s (preferably <1.8 m/s) at the recommended flows.

The Kanniedood fishway was intensively monitored over three 24-hour periods in February and December 1993 and January 1994 (Olivier, 1994). The effectiveness of this fishway design is clearly apparent, as over 18 species (n = 2395 fish) were caught in the fishway over the three 24 hour sampling periods.

In spite of relatively high-calculated water velocities in the fishway at the time of sampling, which was estimated at between 1.8 and 2.1 meters per second, a high proportion (90%) of the fish captured in the fishway were small fish of under 100 mm in length. For example, of the total of 675 Mozambique tilapia (*Oreochromis mossambicus*) captured during this monitoring, 91% were smaller than 50 mm and 76% in the 20 to 40 mm size class. As this species reaches over 400 mm (Skelton, 1993), these results again emphasize that fishways should be designed to pass not only adult fish (as is often the case), but weaker-swimming juveniles as well.

The Kanniedood fishway data are of particular value as they show the maximum swimming ability of some indigenous fish species. *O. mossambicus* of 40 mm in length were found to negotiate water velocities of about 2 m/s, or 50 BL/s (BL = burst lengths). This is higher than that reported in studies overseas, where experimental data on burst swimming speeds indicate maximum burst swimming speeds of up to about 20 to 25 BL/s for small fish (Mallen-Cooper, 1992). The ability of small fish to negotiate the ca. 2 m/s velocities through the notches in the Kanniedood fishway may be because this extreme swimming effort is required for less than one second and that slow-flowing water in the large pools allow ample rest.

However, these preliminary data indicate that not all fish that enter the Kanniedood fishway reach the top (Olivier, 1994), i.e. the fish may not ascend “without undue stress”. In order to accurately assess the effectiveness of the Kanniedood fishway (or any other fishway), it will be necessary to determine the proportion of fish entering the downstream end of the fishway that can swim up the entire fishway without undue stress.

A hydraulic determination, comparing the full horizontal width of a Pool and Weir fishway with a notched weir design, was undertaken by Bok *et al.*, (2004). This study shows that the notch in the weir wall greatly reduces turbulence at low flows and provided much easier conditions for small fish to negotiate the fishway, as all the flow is concentrated in the notch and low values of turbulence prevailed in the pools. In addition, by providing the notch in the weir, the range of heads under which the fishway will operate efficiently in terms of turbulence levels in the pools, is greatly increased.

3.5.2.2 Pool and Weir Fishway with Sloping Weir

This fishway design was specifically developed to enable the fry and juveniles of marine-spawning fish such as mullet (*Mugilidae*), as well as climbing species such as eels and macrocrustacea, to migrate over weirs into the freshwater reaches of east coast rivers of southern Africa (Bok, 1995). This objective has been achieved at a number of fishways on weirs in rivers on the southeast coast of South Africa (Bok, 1995; 1998 and 2000).

Design features of the Pool and Weir fishway with sloping weir

The design follows that of a standard Pool and Weir fishway without notches and has the following features (Figure 3.1, Plates 3.3 and 3.4):

- The sloping rectangular channel is divided into a series of pools by weirs constructed across the full width of the channel, with the significant, unique feature being the design of the weirs;
- The weirs are relatively thick (100 to 200mm) and have a forward slope of about 1:2 on the down-stream side of the crest to ensure that the water does not fall in an arch between pools, i.e. ensures an adherent nappe;
- The water levels in the pools at low flow are at the lower edge of the sloping crest of the upstream weir. This allows small fish to swim or wriggle up in shallow water over the weir rather than jump into the pool above (Plates 3.3 and 3.4);
- Most importantly, the weirs are set at an angle to the sidewalls (in elevation). The recommended cross slope of 1:4 results in a range of water depths over the weir and ensures that fish of different sizes can choose the preferred depth (and current speed) when passing over the weir to the pool upstream;
- A further significant feature of this weir design is that (for the desired range of water flows down the fishway) a broad, gently sloping wetted area on the water's edge (splash-zone) is formed on the weir. This is the area (which should be roughened to improve purchase) is preferred by eels and macrocrustacea for climbing or crawling up to the next pool;
- The fishway channel has a recommended slope of about 1:10, although even steeper slopes may be possible if discharge volumes and hence turbulence can be reduced.

- The height difference between pools can vary depending of the size of the migratory species, but is about 80 to 100 mm for fishways near the coast, in order to cater for catadromous fish as small as 20 to 25mm, which migrate into freshwater from estuaries.

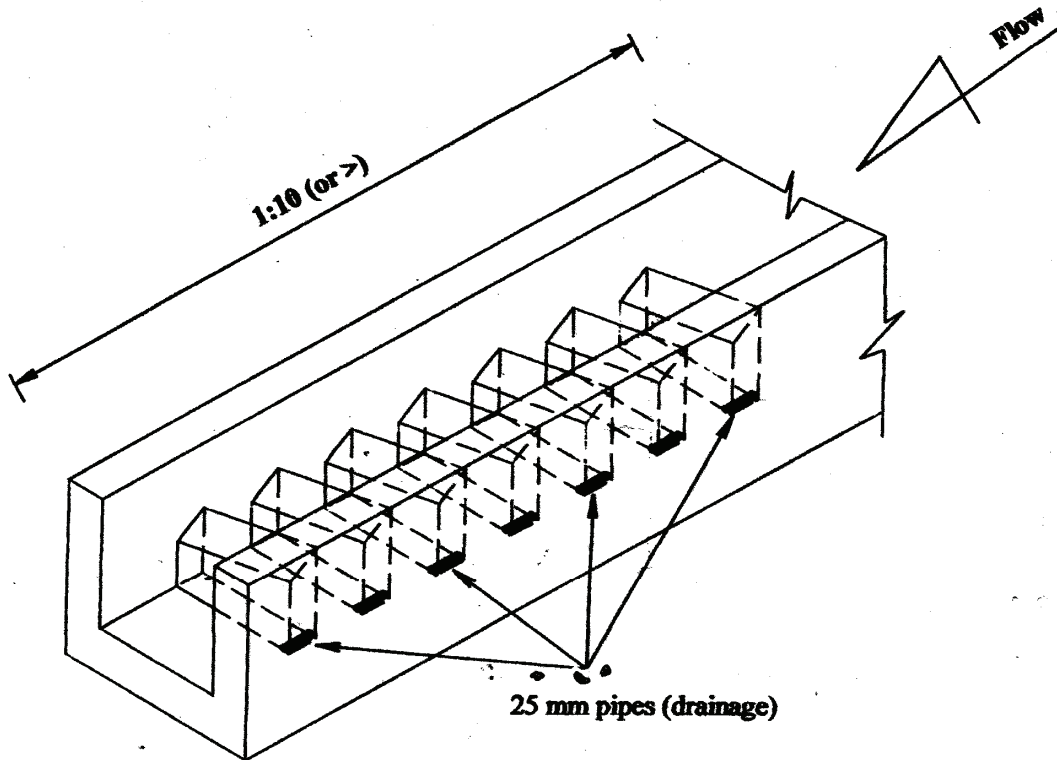


Figure 3.1: Sketch of generalised Pool and Weir fishway with sloping weir.

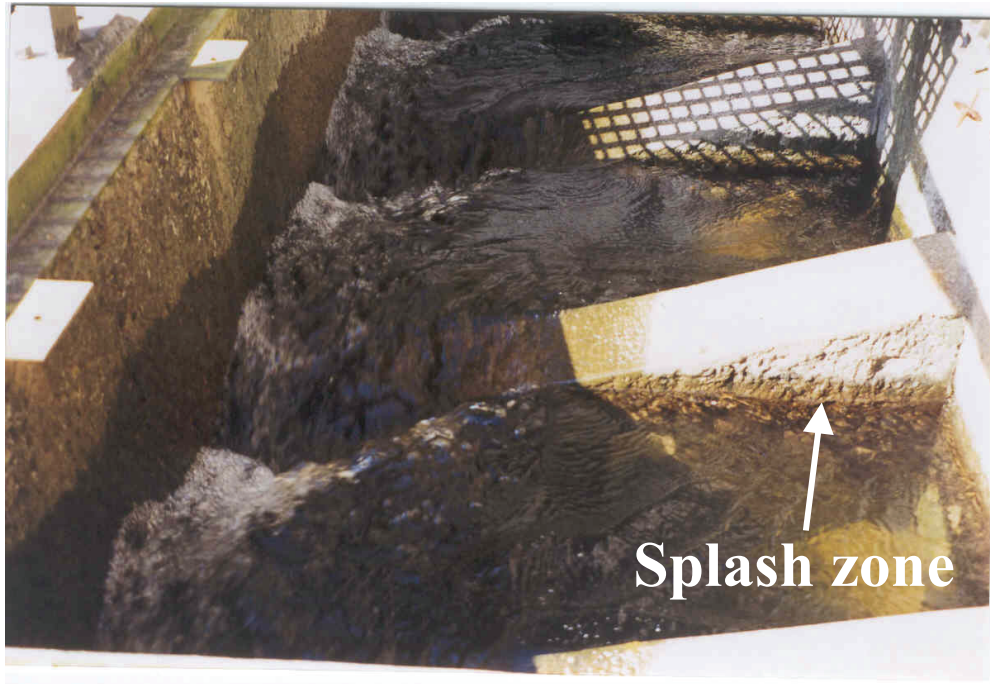


Plate 3.3: Water flow over the weir of the Nhlabane Pool and Weir fishway, showing the sloping weir with variable passage depth and wetted “splash-zone” for eels and macroinvertebrates.

The sloping baffle design ensures a range of depths and current velocities between pools, in addition to a wide, gently sloping splash-zone and is a relatively unusual feature in most formal fishways. The variable passage depth over the weirs ensures that it is effective in passing both small fish (15mm in length), as well as climbing biota, such as small eels (elvers) and macrocrustaceans. A formal fishway design that can successfully pass climbing species that prefer to leave the water and migrate in the splash zone, as well as very small “normal” swimming species, has not been reported in the literature.

Monitoring data for Pool and Weir fishways with sloping weir

An intensive monitoring study on a sloping weir (or variable-passage depth) Pool and Weir fishway built in 1998 by Richards Bay Minerals on a 6.25m barrier weir separating the Nhlabane estuary and lake in northern KwaZulu-Natal, has given very promising results (Bok, 2000; Mastenbroek, 2003, Chapter 7). This 74m long fishway has successfully allowed passage of over 23 species of fish of various sizes, from as small as 10mm in length and is also used by a variety of climbing crabs and prawns. A further advantage of this particular fishway is that it can operate successfully for small fish (<50 mm) at very low flows (5 – 10 l/s) found during the dry season, when these fish often migrate.

However, the appropriate design parameters of this fishway type that ensures the optimum hydraulic conditions within the fishway at various flows have yet to be studied under controlled conditions. Such hydraulic studies on model fishways will allow the development of the most cost-effective, as well as most successful design parameters for this fishway type, for specific target species found in various regions in South Africa.

Disadvantages

The above sloping weir Pool and Weir fishway design, however, operates effectively over a very narrow range of headwater levels. This can be a serious drawback in South African rivers with their highly variable flows, and may exclude its use at some sites.

3.5.3 Vertical-slot Fishways

3.5.3.1 General Description

Vertical-slot fishways have the same basic design as Pool and Weir fishways, except that the weir walls do not extend the full width of the channel. The water flows between each pool through a slot, which normally extends the full depth of each pool. The weir walls may have single or double slots, but in South Africa, where only 10 Vertical-slot (or near-Vertical-slot) fishways have been built to date only the single slot design has been used (Appendix A).

It is important to note that Australia has recently gone through the same process regarding developing suitable fishway designs for indigenous fish species, as is happening in South Africa at present. About a decade ago, the Australians began an assessment of the effectiveness of existing fishways and the development of designs suitable for Australian fish and rivers (Mallen-Cooper, 1994b). After much research, they found that the Vertical-slot design was by far the most effective design to pass the diverse migratory fish fauna of the sub-tropical and tropical rivers, which also have a large seasonal variation in river flows (Stuart, 1997; Mallen-Cooper, 1997).

However, most vertical slot fishway designs are thought to have a serious shortcoming, as they are not known to pass crawling eels and macro-crustaceans. In addition, the Australian designs are usually large structures and built with gentle gradients (>1:15), which means they are relatively long and expensive to construct.

3.5.3.2 Neusberg Weir Vertical-slot Fishway, Orange River

Although 10 Vertical-slot type fishways are listed in the inventory of fishways in South Africa (Appendix A), there is only one near “standard” Vertical-slot fishway design, namely on the Orange River at the 7.4m high Neusberg Weir. Built in 1994, this large structure is 54m long, has pools of 2.9 x 1.0 x 2.5 m, a slope of 1:10 and is designed to take flows of up to 1.24 m³/s and depths at the inflow of over 2 m. Details of the design as well as the results of hydraulic modelling studies on this fishway can be found in Van der Merwe *et al.*, (1991). These data are used in the present assessment as the completed fishway itself has yet to be accurately hydraulically rated. The predicted (and measured) current speeds through the slots in the model studies were found to vary between 1.8 to 2.4 m/s and were constant regardless of the volume of water flowing through the fishway, i.e. water depth through slots.

During a monitoring project in January and February 1994, a total of 48 fish comprising 3 fish species were captured (Benade *et al.*, 1994). The majority of the smallest species caught, the three spot barb *Barbus trimaculatus*, were in the 50 to 99 mm size class. These data again indicate that small (50 mm) fish can swim short distances against current speeds of about 2 m/s or 40 BL/s. In addition, a large proportion of the migrating fish were sub-adults, as three spot barb attain a maximum length of 150 mm (Skelton, 1993). These data again indicate that fishways in South African rivers should not be designed to only cater for adult fish undergoing spawning migrations, as has often been accepted in the past. In practical terms

this means that even in inland river reaches beyond the range of juvenile catadromous species, fishways should cater for fish as small as 40 mm, which have relatively low maximum swimming speeds.

3.5.3.3 Pool and Slot Type Vertical-Slot Fishways

A number of “Pool and Slot” Vertical-slot fishways have recently been built on DWAF gauging weirs in the KNP, for example at Riverside weir and Ten Bosch weir on the Crocodile River (see plates 3.4 and 3.5) and the Lower Sabie gauging weir (Appendix A). A similar design has been used for a fishway on the Waterpoort gauging weir on the Sand River, Inkomati system.



Plate 3.4: View of most downstream slot of the “Pool and Slot” Ten Bosch fishway on the Crocodile River in the KNP, during low stream-flow conditions (no flow through fishway).



Plate 3.5: Close-up of “Pool and Slot” baffle at Riverside Weir fishway in the KNP under low flow conditions.

- These fishways have a number of unusual design features that are not normally associated with Vertical-slot fishways. These include:
- The invert (or retention) level of the slots are about 500 to 600 mm above the floor level of the downstream pool;
- The floor of each slot slopes downstream at about 45% to ensure an adherent nappe (no air between water and downstream face of notch or baffle) at low flows;
- There is maximum height difference between pools of 250 – 300 mm – i.e. between consecutive invert levels in slots in the weirs.

The above fishways are thus a combination of the Vertical-slot and Pool and Weir design and are therefore termed “Pool and Slot” fishways. In the KNP, these fishways are designed to operate effectively over the very wide range of flows found in these rivers during the summer months. At low flows the sill controls the flow and the fishway tends to act as a notched Pool and Weir fishway. When the flows increase and the water levels in the pool below the weir drowns out the flow over the weir, the fishway starts acting more like a vertical-slot fishway. At high discharges, the slot and the fishway functions control the flow down the fishway as a vertical-slot fishway.

In theory, these pool dimensions should ensure that average velocities in the pools are between 0.7 m/s and 1.2 m/s when between 1.0 and 1.5 m of water is flowing through the slots between pools (Pieter Wessels, DWAF, *pers. comm.*, October 2001). These features can be seen in the Plates 3.4 and 3.5.

The effectiveness of these so-called “Pool and Slot” fishways has yet to be determined under natural migratory flow conditions. However, in some instances it is probable that the anticipated high turbulence levels in the relatively small pools (in relation to the slot width and hence discharges) will hinder fish passage.

3.5.3.4 General Conclusions

Due to the favourable reports world-wide regarding the success of “standard” Vertical-slot fishways in passing a variety of fish species, both large and small, and in rivers with similar hydrology (see review in text below), this design is thought to hold great promise for South Africa. Fine-tuning of Vertical-slot type fishway designs for South African conditions is therefore considered a high priority and is being researched on-going WRC sponsored fishway studies.

Recent trials using indigenous fish species in small model Vertical-slot fishways have been undertaken as part of an on-going WRC research project (K5/1409). Initial results from this work appear very promising (Kotze *et al.*, 2004; Bok *et al.*, 2005). Preliminary findings indicate that South African species can negotiate velocities and turbulence levels greater than those recommended in similar work overseas. If these findings are correct then they will allow the construction of steeper and shorter Vertical-slot fishways, which will result in substantial savings on construction costs.

3.6 RECENT TRENDS IN FISHWAY DESIGN WORLDWIDE

3.6.1 Bypass Channels

Nearly all the formal fishway designs have disadvantages and very seldom provide passage for all migratory aquatic fauna under all conditions. The recent emphasis on promoting the free passage of migratory fauna worldwide has shown a clear preference for more natural alternatives for fish barrier mitigation, where feasible. These include “nature-like” bypass channels, which consist of low-gradient rocky channels that mimic the natural rapids and riffles found in the particular river. In addition to allowing the free passage of a variety of aquatic organisms, they also provide important flowing-water habitats and are often integrated into river restoration programmes.

Bypass channels are designed specifically to suit the characteristics of the site and can vary greatly in size and gradient, but generally are not steeper than 1:20 or 1:30. Site-specific factors influencing design include the size and nature of the barrier, topography and geology of the site, target migratory species, hydrology, form of the stream channel, etc. These structures can thus vary from gently meandering artificial streams with slopes of 1:1000, to roughened rock channels or rock-ramps with implanted boulders with 1:20 gradients.

Reviews and reports on bypass channels in both Europe (Jungwirth, *et al.*, 1998; Larinier *et al.*, 2002; FAO/DVWK, 2002) and Australia (Berghuis *et al.*, 1997; Harris, 1997; Keller and Peterken, 2001), show that these structures have been successfully applied to provide passage for a wide variety of species at a range of river flows. The design concept of bypass channels (and rock-ramps) provides the range of water depths and flow velocities naturally occurring in that particular river and which can thus be exploited by the migratory biota present.

Bypass channels or rock-ramps in some form are now by far the preferred option worldwide on all low barriers (up to about 4m), provided the site is suitable (White *et al.*, 2001). Detailed descriptions of the designs of the various types of bypass channels in Europe and Australia are given in the recent workshops and reviews referred to above, and will not be discussed in this report.

To date, only one bypass channel or rock-ramp has been built in South Africa, at the lower Sabie road bridge weir on the Sabie River in the Kruger National Park, (Plate 3.6) (Appendix A). Although no monitoring data are available to the author, anecdotal evidence from observations by fish scientists indicate that this rock-ramp fishway should be very effective in passing both large and small fish at a range of river flows.



Plate 3.6: Lower Sabie bridge Rock-ramp fishway at commissioning in October 2001.

3.6.2 Vertical-slot Fishways

The Vertical-slot design appears to be rapidly becoming the most preferred “formal” fishway type for non-salmonids in many countries. Field trials, as well as hydraulic model studies to fine-tune the design parameters of this fishway, have been undertaken in Australia (Mallen-Cooper, 1994a; Mallen-Cooper, 1994b; Berghuis *et al.*, 1997; Stuart, 1997), in North America (Clay, 1995) and Europe (Larinier, 2002; DVWK/FAO, 2002). Hydraulic model studies in Europe have allowed the development of a standard design in which the geometry of the baffles and cross walls are standardised and where all the design parameters are expressed as a function of the width of the slot (Larinier, 2002).

Extensive laboratory, as well as field trials, in Queensland, Australia has confirmed the suitability of Vertical-slot fishways in passing both large and small indigenous fish over a range of river flows in sub-tropical and tropical rivers (Stuart, 1997; Mallen-Cooper, 1997). The Vertical-slot design has now been adapted as the preferred formal fishway design for indigenous fish in Queensland, Australia (Beitz, 2001), with existing Pool and Weir fishways even being “upgraded” to this design. As the velocity and turbulence remain very stable regardless of the water levels in this fishway, the Vertical-slot design is considered particularly suitable for rivers with a wide range of flows, as found in South African and Australian rivers.

In a recent extensive world-wide survey of fishway experts regarding their preferences for fishway types, the Australian experts were firmly in favour of Vertical-slot fishways at barriers below 4m high, while both fish locks and fish elevators were favoured at 7m high barriers (White *et al.*, 2001).

Interestingly, the 75 overseas (mainly from Europe and North America) fishway experts surveyed in this study, strongly favoured the Vertical-slot design (before fish locks/elevators) even at 7m high barriers. This difference in preference is thought to be related to construction costs. In Australia, Vertical-slot fishways tend to be expensive, as they are built with a relatively gentle slope of about 1:20 compared to northern hemisphere designs of about 1:10 (White *et al.*, 2001).

It is clearly apparent from this worldwide survey of fishway experts, however, that there is a widespread and distinct preference for the Vertical-slot fishway design for a wide range of indigenous fish species.

However, as with most formal fishways, there are also negative features associated with the Vertical-slot design. These include:

- Vertical-slot fishways, even those in the coastal rivers in Australia designed for small, weak-swimming catadromous species, appear unable to pass climbing fauna, such as macrobrachium prawns, juvenile crabs (*Varuna litterata*) or elvers of long-finned eels (Stuart, 1997). This appears related to the absence of a gently sloping splash zone on the edge of the main flow to cater for the climbing behaviour of these species.
- These fishways normally require relatively large volumes of water to operate effectively. For example, Mallen-Cooper (1997) states that a “small” Vertical-slot fishway with a 15 cm slot width on a 1:30 slope will require 12 Ml per day (or 138l/sec) to operate effectively.

These two potentially problematic aspects of vertical slot fishways require further investigation under local conditions. In this regard, initial trials in South Africa with small vertical slot fishways with a slot width of only 60mm, and specifically designed for small fish under about 200mm, found that they can effectively pass fish at discharges of 5 to 15 l/sec at slopes of 1:10 and even steeper (Bok *et al.*, 2005).

It is apparent that additional research on the suitability of Vertical-slot designs for South African migratory species will be required before all aspects of these designs can be accepted in this country.

3.7 THE WAY FORWARD

3.7.1 Guidelines for Fishway Provision

The on-going research programmes on fishways in South Africa, sponsored by the WRC, are aimed at developing guidelines for the provision of fishways suitable for the wide variety of migratory aquatic species found within the various climatic and hydrological regions of the country. A preliminary report has been published, entitled: “*Guidelines for the planning, design and operation of fishways in South Africa: First Edition*” (Bok, *et al.*, 2004) and is an initial product stemming from these on-going projects.

3.7.2 Identifying Priorities

In addition to developing suitable fishway designs for placement on instream barriers, it is also important to quantify the extent to which natural migrations in rivers have been blocked by man-made structures. Preliminary protocols have been developed to assess the need for a fishway at any instream structure, as well as to quantify the impact of the barrier on migratory species present (Bok *et al.*, 2004). These protocols will enable priority sites for the provision of fishways to be identified and the limited available funding to be spent optimally.

The inventory as discussed in Chapter 4 and Appendix A of existing South African fishways at instream barriers to fish movement on a catchment basis, highlights the paucity of fishways in this country in relation to the number of instream barriers. It is important that an inventory of barriers to fish movement in priority catchments be undertaken. To ensure that the limited funding for fishway construction is spent wisely, it is essential to prioritise these barriers in terms of their ecological impact. A national inventory of barriers to migration will allow these high priority barriers to be identified and a cost-effective fishway strategy developed. The database structure for this inventory is presently under development and can be seen on the following website: <http://www.fishways.co.za/>.

It is interesting to note that the recent world-wide survey of fishway experts mentioned above (White *et al.*, 2001), gave (in order of priority) the three most important research topics on fishways as:

- Assessing the relative swimming abilities and behavioural characteristics of indigenous migrating fishes with respect to fishways;
- Assessing the relative performance of different fishway types;
- Entrance and exit conditions adjacent to fishways (including tidal conditions).

It is significant that the various WRC fishway research programmes, initiated in 2001 and continuing until 2007, includes projects that are aimed at:

- assessing the effectiveness of existing hydraulically-rated fishways of various designs in passing indigenous fish under various flow regimes, and
- field trials using model fishway prototypes at barriers to natural fish migration in rivers, as well as trials using model fishways under controlled laboratory conditions.

It is apparent that these WRC research projects should be designed to provide answers relating to the three priority research topics given above. The most promising fishway designs for South African conditions, as indicated by both local and overseas studies, have been identified in this report. It is important that prototype model fishways of these selected designs are thoroughly tested and then modified and fine-tuned for local species and conditions in these proposed field and laboratory trials.

4. DEVELOPMENT OF AN INVENTORY OF EXISTING FISHWAYS IN SOUTH AFRICA

The existing knowledge base on South African fishways was extended by obtaining information from DWAF, regional provincial ecologists and follow-up inspections of fishways known to be the planning stages or under construction. (Appendix A). This data has been geo-referenced and plotted in Arc View 3.1 (Figure 4.1). A collection of photographs of each fishway that can be linked with the GIS and database has also been collected. The results of this database are currently being published on the web and can be accessed on <http://www.fishways.co.za/>. The final results of this inventory will be available when the WRC project K5/1409 is complete in 2007.

The most common fishway design in South Africa is the Pool and Weir and a notched Pool and Weir with a total of 46 fishways with this design. There are a total of 10 Vertical-slots and Vertical-slots with pools (Appendix A).

As can be seen from Appendix A there are 18 fishways for which we do not currently have accurate coordinates. The precise position of these fishways needs to be determined in order to complete Figure 4.1.

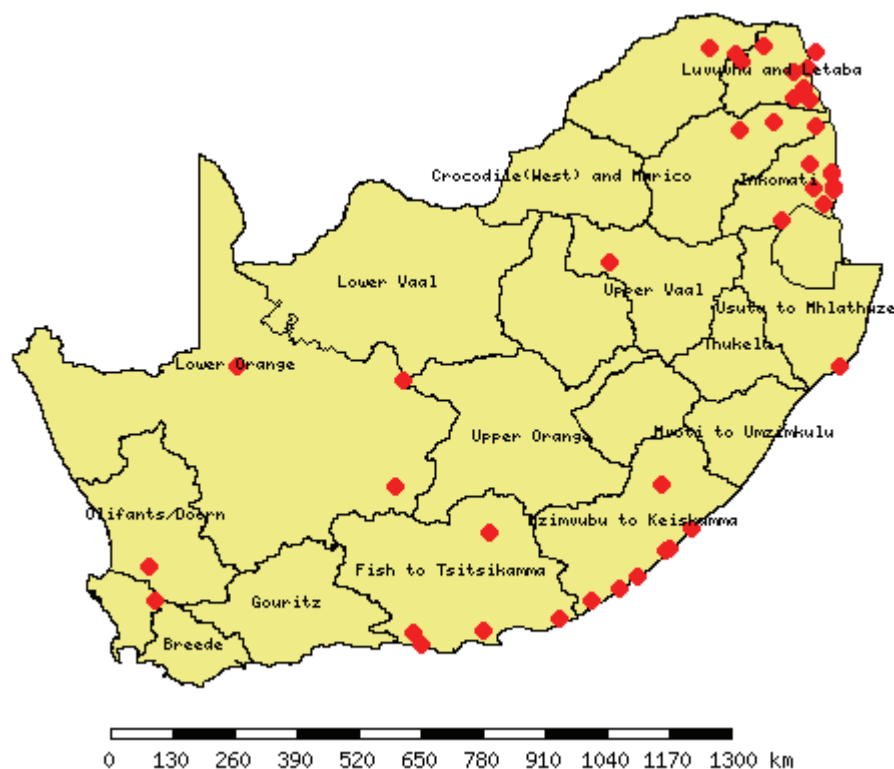


Figure 4.1: Location of fishways in South Africa per Water Management Area.

5. MONITORING OF FISHWAYS

This chapter has been abridged from Bok *et al.*, (2004). The principles as described in this chapter have been used and adapted for the fishway monitoring that took place at both Nhlabane (Chapter 7) and Xikundu fishways (Chapter 9).

The majority of fishway assessments in South Africa in the past have simply involved catching and recording the fish at the upstream end of the fishway. The monitoring was mainly conducted during daylight hours for periods of less than a week. Although useful, these data have limited value in really assessing the effectiveness of the fishway being studied.

There is a lack of quantitative data on the performance of existing fishways in South Africa, particularly information on designs that successfully allow the passage of the full range of target species. Furthermore, little is known of the swimming ability or the migratory behaviour of indigenous southern African fish species. In order to supply this information carefully designed fishway monitoring programmes on existing fishways in South Africa is required.

Fishway monitoring should therefore be designed to provide data on both the effectiveness of the fishway in terms of the internal hydraulics at various flows, as well as data on the migratory behaviour and swimming ability of all migrants that move up the river (including prawns, crabs and eels).

To determine fishway performance, information is required on the number and size composition of fish species, which were migrating but could not find the fishway entrance, as well as the fish, which entered the fishway but were unable to reach the top. Additionally environmental parameters (abiotic and biotic) need to be monitored to determine what stimulates fish migrations, which should be over months rather than weeks. It is apparent that carefully planned monitoring programs and more sophisticated monitoring methods are required to assess the effectiveness of fishways in South Africa in order to improve their design and to optimise their management.

Details of the monitoring procedures to be used and the techniques and equipment used to collect the data will naturally vary from site to site, but a generic fishway-monitoring programme should attempt to answer the questions posed below.

5.1 KEY QUESTIONS FOR A FISHWAY MONITORING PROTOCOL

5.1.1 Biological/Ecological Parameters

- What species, size and numbers of fish successfully pass through the fishway?
- What species, size and numbers of fish attempt to use the fishway (i.e. are actively migrating and enter the downstream end of the fishway)?
- What species, size and numbers of fish actively migrating are blocked by the barrier in question and what proportion actually enter the fishway?
- Why are the fish migrating? Reasons could include sexual reproduction, colonization/dispersion, feeding, over-wintering, etc.

5.1.2 Physical Parameters

- Do the water discharge rates (i.e. water volumes) down the fishway impact on successful use of the fishway by the different species, or size of fish?
- How does the internal hydraulics in the fishway (current speed, turbulence and depths in critical areas) change at the various discharges?
- How does the discharge down the fishway vary with changes in stream flow in the main river channel?
- At what levels of stream-flow or stages of the flood hydrograph do peak migrations in the river take place?
- Do peak migrations in the river correspond to peak movement through the fishway – i.e. is the fishway effective at river flows when peak fish migrations occur?
- When (time of day/night, season) do migrations of the various species occur?
- How does water quality (temperature, conductivity, pH, turbidity) impact on fish migration?
- What other environmental cues (barometric pressure, air temperature, wind, phase of the moon, tidal cycle, etc.) appear to influence fish migration?
- Are there physical constraints downstream that could impact on fish migration at the fishway site, such as natural or man-made barriers, closed estuary mouth, etc.

5.2 DATA COLLECTION

The techniques and equipment used to collect the data required will vary depending on conditions at the site. The data collection equipment and procedures suggested below should therefore be used as a guide and adapted as the need arises. All data collected during each session should be accurately recorded on field data sheets. Examples of data sheets used for the Nhlabane and Xikundu fishway monitoring programmes are given in Appendices D, E, F, G and H.

5.2.1 Fish Capture

Fish capture methods, as well as equipment required, will vary depending on the physical constraints at the site and type of fishway. Care should be taken to ensure that traps placed in the fishway do not interfere significantly with the internal hydraulics of the fishway.

The following equipment should be used where appropriate:

- Funnel trap nets. These should be designed to fit snugly into the fishway pools. Funnel placement should be aimed at capturing fish moving both upstream and downstream. These traps should be sufficiently large and include areas of slow-flowing water so that the fish can be held without injury or stress for long periods and can be easily removed alive for identification and measuring. Ideally, a funnel trap for the fishway exit (upstream end) as well as for the downstream end (most downstream pool) should be constructed to allow paired sampling to take place. In natural-type fishways, wing-nets on the side of the traps may be necessary to guide the migrating fish into the funnel trap.
- Stop nets. A sufficient number of stop nets (at least 4) consisting of fine-meshed netting attached to a solid (normally rectangular) frame that fits tightly in the fishway channel will allow sections of the fishway to be partitioned off. Placement of the nets

will enable the fish present in each section (e.g. top, middle and bottom) to be captured and analysed separately in order to detect the presence of bottlenecks in the fishway.

- Dip nets. Their size should match the internal dimensions of the fishway channel or pools to ensure effective operation.
- Other fishing equipment. The standard range of fish capture methods and equipment should be used for sampling both in the fishway and in the river downstream of the barrier, depending on the conditions. This could include electro-fishing apparatus (fish-shocker); seine nets, throw nets, fyke-nets and fish-traps. Destructive sampling should only be used if the above methods do not work.

5.2.2 Sampling Downstream (and Upstream) of the Fishway

It is important to establish what species and size range are present downstream of the barrier weir that could potentially use the fishway. In addition, the species and size range that actively migrate and are blocked by the barrier weir should be determined, as this may differ from that found in the fishway. In some cases, the species and population structure of migratory species upstream of the fishway should be established (as was the case in Nhlabane when the fishway created a barrier between a salt water estuary and a freshwater lake, Chapter 7).

Downstream

The full range of habitats present below the fishway should be sampled for fish. To achieve this, a variety of catch methods should be used to ensure that all species, as well as all size classes, are sampled using throw nets, dip nets, gill nets, seine nets, or traps. Sampling frequency will depend on river conditions (e.g. flow levels), and whether fish are actively migrating through the fishway. When fish are actively migrating and the fishway itself is being intensively monitored, a sampling frequency of up to once a day with a seine net (throw-net/fish shocker) at the fishway entrance, in order to catch fish attempting to enter the fishway, is suggested.

5.2.3 Sampling in the fishway

Upstream migrants which have successfully negotiated the fishway should be captured by means of funnel traps placed at the exit of the fishway (upstream). In long fishways, a trap could be placed within the fishway (e.g. at the halfway stage or first bend or resting pool in fishway), as was the case for Nhlabane fishway (Chapter 7). A trap should also be placed at the bottom of the fishway to catch all migrants that enter the fishway. Comparative catch data from these localities should indicate whether some species or size classes enter the lower part of the fishway, but have difficulties negotiating the entire structure.

Bottlenecks in fishway

Various sections of the fishway should be blocked off with stop nets and sampled with dip nets or a fish shocker at high, medium and low flows. Accumulation of fish at any point will indicate whether there are any bottlenecks within the fishway when operating at various flows.

Downstream migrants

A two-way trap could be installed half-way up (or bottom of) the fishway to capture fish moving both up and down the fishway. Large-scale use of the fishway for downstream migration is usually not anticipated, as studies elsewhere have shown that downstream migration usually takes place over the weir crest when it overtops during high water levels.

5.2.4 Data Collected from Fish

Details of each fish should be recorded, including:

- date, time period and locality captured,
- species, and
- length and sexual condition/gonadal maturity (as collected at Xikundu fishway, Chapter 8).

5.2.5 Fish tagging or marking

Fish tagging or marking is only feasible if an intensive, long-term study is intended. Fish captured swimming upstream in the fishway or at the exit of the fishway should be tagged or fin-clipped and returned unharmed upstream of the weir. Fish captured swimming downstream in the fishway or captured in the river downstream of the fishway should be tagged and released below the weir. Any recaptures will enable subsequent downstream or upstream migration of these fish to be detected.

5.2.6 Abiotic Data

The following water quality data from the fishway (and in some instances, in the river or tailwater pool downstream of the fishway, as well in the headwater pool) should be recorded during each monitoring session, e.g. once or twice (dusk and dawn) daily and more often if the water conditions change rapidly (e.g. during floods):

- temperature - maximum and minimum
- conductivity (or TDS)
- turbidity

Additional parameters such as pH and dissolved oxygen could also be measured.

Further data recorded during each monitoring session should include:

- headwater and tailwater levels at the barrier,
- water flow volumes (or water depths) spilling over the weir crest, and/or via attraction water outlet, if applicable),
- water volumes down fishway (including any auxiliary water),
- weather conditions (rain, cloud cover, air-temperature, wind speed and direction, barometric pressure),
- time of day/night (phase of moon).

5.2.7 Other observations

Observations of additional factors that may possibly influence fish migration or that may be of value in understanding fish migration should be recorded for each monitoring session, such as:

- presence of predators such as birds, otters, etc.;
- unusual migratory behaviour, (e.g. crawling or leaping activity) or accumulations of fish at the entrance, exit or in sections of the fishway;
- changes in water flow down fishway during session due to regulation of inlet sluices, manipulation of attraction or auxiliary water, rise or drop in river flow, changes in water quality, etc.

5.3 MONITORING PERIOD AND FREQUENCY

Ideally, monitoring during the first few years after construction of the fishway should take place over the entire period of the year during which fish movement is likely to take place and when the fishway is operational, i.e. when there is water flowing down the fishway. This monitoring frequency was undertaken for both the Xikundu and Nhlabane fishways (Chapters 7 and 8). After commissioning of the fishway, an initial monitoring period of at least one month during the peak migratory period will be required to assess its effectiveness and to fine-tune its operation.

5.3.1 Long-term, low-intensity monitoring

Ideally, low-intensity fishway monitoring should take place continuously during the entire period during which the fishway is operational. The level of intensity will naturally depend on available staff and funding, as well as numbers of fish moving through the fishway at the time.

Sampling Frequency

Clearing and resetting of traps within the fishway should take place at least once (preferably twice, at dawn and dusk) every 24 hours.

Data Recorded

The standard data listed in the fishway monitoring field data sheet should be completed (Appendices D, E, F, G and H). The minimum information required would be the number and the size range of each species, with preferably the size of a representative sub-sample of each species measured individually. Water quality data could be obtained (or extrapolated) from existing water quality monitoring programmes. A subsample of the collection should be lodged at a suitable museum (e.g. Albany Museum).

5.3.2 Intensive, Short-term Monitoring

Intensive monitoring should ideally take place during periods of peak migration, usually thought to occur after rainfall events in spring and summer and/or during and immediately after floods and freshets. At this time as much information as possible on fish movements and related abiotic factors, should be collected.

Sampling Frequency

Clearing of traps within the fishway should take place every 4 to 8 hours, depending on the numbers off fish migrating through the fishway. Sampling at dawn and dusk will allow diurnal migratory peaks to be determined. Variable water quality data such as water temperature, conductivity and turbidity should be obtained 2 to 3 times a day (dawn, midday and dusk) if found to change significantly. Other abiotic parameters should be measured once a day unless conditions are obviously fluctuating (e.g. during floods).

Data Recorded

This should include detailed water quality data and other abiotic data and measurements from the fish caught, as set out in the fish monitoring field data form. Fish could be tagged and released as described above, if a long-term programme is envisaged.

Paired Sampling: During the period of active migration it is important to assess the effectiveness of the fishway by means of paired sampling. The objective is to compare the fish that located and entered the fishway (bottom sample) to an independent sample of fish that located, entered and successfully passed through the full length of the fishway (top sample). To achieve this, a funnel trap should be placed at the top of the fishway for 24 hours, followed by a funnel trap placed at the bottom of the fishway for 24 hours. This should be done on consecutive days to provide paired samples for comparison.

Stop Nets: During this period of intense migration, the use of the stop nets to divide the fishway into top, middle and bottom sections as described above should be undertaken in order to find if any bottle-necks are present.

Additional information on fishway operation (depths of water over baffles and flow volumes and velocities within the fishway) should be measured. If a relationship between water depths over the baffles, discharge down the fishway and current velocities has been established, only water depths need be measured for each sampling session.

5.4 SUPPORTING STUDIES

Where feasible, hydraulic studies of the fishway should be undertaken to supplement the fish migration monitoring data. This will allow information on the hydraulic conditions within the fishway (current velocities at critical areas, turbulence, etc.) at various discharges in the fishway to be correlated with the swimming performance of the fish found using the fishway at these times. These hydraulic data can be obtained theoretically, via model studies under controlled conditions in the lab or measurements taken in the fishway in the field during the monitoring programme.

The information gathered during the monitoring should allow for a operational management and maintenance plan to be put into place for the fishway. This should include the release of optimal discharges down the fishway, providing additional protection to the migrants from predation, placement of debris deflectors, manual removal of debris and/or sediment from the fishway, attraction or auxiliary water flow requirements, etc.

5.5 FURTHER REFINEMENTS

In order to refine the monitoring programmes at fishways the principles discussed in this chapter were used in both the Nhlabane and Xikundu fishways. The findings from these monitoring programmes can be used for further fishway monitoring programmes in South Africa.

6. FISHWAY MONITORING PROGRAMME - NHLABANE

The Nhlabane coastal lake – estuary system in northern KwaZulu-Natal is situated approximately 30 km north of Richards Bay; In 1976 construction of a 4 m weir *ca.* 3 km from the mouth was initiated by Richards Bay Minerals (RBM) in order to provide a source of freshwater for their dune mining operations. The weir/barrage split the system into two distinct environments, namely salt water and freshwater. The weir was subsequently raised by 0.75 m to 4.75 m above mean sea level (AMSL) in 1984.

Intensive monitoring of the Nhlabane fishway (Plate 6.1) was undertaken 5 days a month from January to December 2001 (Mastenbroek, 2003). The aim of this monitoring programme was to determine if the fishway design enables fish and crustaceans to move freely from the estuary to the lake. The method used to determine this was as follows:

- Monitor the efficiency of the Nhlabane fishway in terms of the movement of fish and crustaceans up the fishway.
- Determine the range of flows occurring when fish move up the fishway.
- Determine the seasonal migration movements up the fishway.
- Compare the species of fish above and below the fishway with those found in the fishway.

6.1 SAMPLING PROGRAMME LESSONS (2001)

Intensive monitoring of the Nhlabane fishway (Figure 1) was undertaken by Walter Mastenbroek (M.Sc student at UD) for about 5 days a month from January to December 2001, giving a total sampling time over the 12 month monitoring period of 573 hours (Mastenbroek, 2003). Fishway monitoring involved placing fish traps (Figure 2) at various points in the fishway, which were cleared every 3 hours during the day, while overnight traps were set at sunset and cleared at sunrise. In addition, a low-intensity fishway monitoring programme was conducted by Mr Ray Jones of RBM, who once a day in the morning about 3 or 4 times a week, cleared and reset traps placed in the upper section of the fishway. A summary of important findings from this monitoring programme, which have implications for fishway management, are summarised below (Bok, 2002; Mastenbroek, 2003):

- The fishway design was found to be highly effective and facilitated the passage over the weir of both small and large fish (from 10 mm to 320 mm in length) over a variety of flows (5 to 80 l/s).
- The design readily accommodates the crawling/climbing behaviour of important upstream migrants, such as crab megalopa (*Varuna litterata*) and freshwater prawns (*Macrobrachium*);
- Peak upstream migration of small fish from the estuary to the lake through the fishway occurred from October to January, although migration took place all year round;
- Larger numbers of fish were found to migrate up the fishway soon after the estuary had closed, during periods of elevated water levels in the estuary and when a longitudinal salinity gradient had been established;

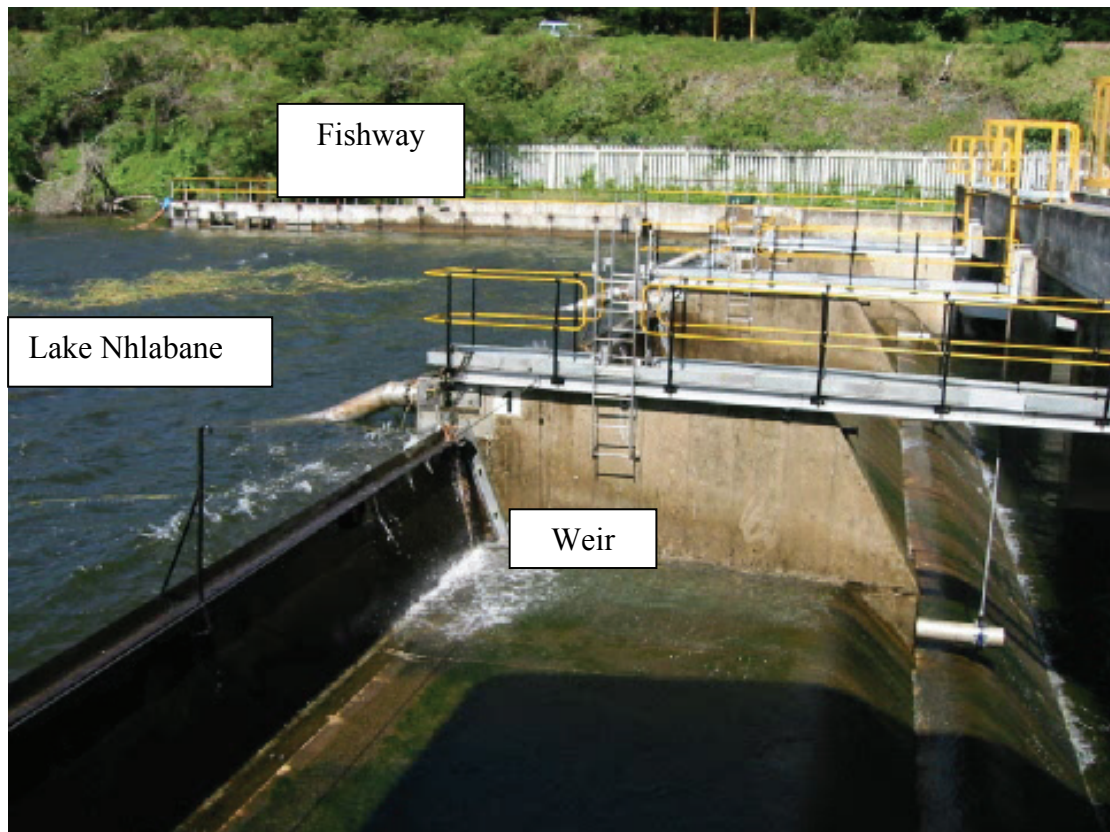


Plate 6.1: View of Nhlabane weir in the foreground and the fishway in the background.

- There is some evidence of fish recruiting into the estuary from the sea during overtopping of the sand-berm at the mouth during high tides, although quantitative data are not available;
- Fish were absent from the fishway during and shortly after the weir-gates had opened, possibly due to high current speeds and turbulence below the weir, making it difficult for fish to locate the fishway entrance under these conditions;
- The increased number of fish migrating upstream through the fishway at high flows (80 l/s and greater) in the fishway was probably because fish can more easily find the fishway entrance under these conditions;
- During the study period, of the 1 238 fish comprising 22 species captured migrating upstream, 40% were freshwater mullet (*Myxus capensis*) and 45% were Mozambique tilapia (*Oreochromis mossambicus*);
- Fish migrated upstream through the fishway during the day at almost twice the rate compared to numbers migrating at night;

6.2 REVISED SAMPLING PROGRAMME

Taking cognisance of the requirements of this project and RBM a new sampling programme was developed for the Nhlabane fishway (Chapter 7). Furthermore, the monitoring programme requirements suggested in Chapter 5 were also applied. The adapted monitoring programme for Nhlabane fishway incorporated an intensive monitoring phase in the season when it is expected that the main migration will occur (including the estuary, fishway and lake) and an ongoing low level weekly monitoring which will be used as an early warning system to detect migratory movements.



Figure 6.1: Schematic of Nhlabane Fishway Monitoring Programme

6.2.1 Sampling coordination

It is important that the roles and responsibilities of the fishway monitoring is clearly defined at the onset. In the case of the Nhlabane fishway Marine and Estuarine Research (MER) coordinated all sampling and requirements with RBM.

RBM personnel sampled twice weekly. This sampling was used as an “early warning system”. If more than 50 fish are collected in a day moving into the fishway them RBM set the fish traps the next day for verification of movement. If more than 50 fish are recorded for a second day running them MER were contacted. MER, would then if at all possible, sample according to their sampling methodology in order to catch the migratory movement.

6.2.2 Frequency

MER undertake intensive sampling at least once a month for 4 days at a time. The intensity of the sampling was typically higher in the months October to March (as indicated by Bok, 2002; Mastenbroek, 2003) as well as depending on the estuary mouth being open. RBM monitored the fishway twice a week (set traps on a Monday and Thursday) and placed the traps in the upper section of the fishway for 6 to 8 hours at a time.

RBM’s personnel undertook this routine twice-weekly sampling. During the months April to September 2003 the fishway will be sampled intensively every 6 weeks, or as determined by consistently high fish numbers.

6.2.3 Seasonality

The intensity of the sampling (Bok, 2002; Mastenbroek, 2003) determined higher migration in the months October to March. This migration was further complicated by when the estuary mouth was open. During the months April to September the fishway was sampled intensively every 6 weeks.



Plate 6.2: An example of a fish trap used in the fishway.

6.2.4 Data sheets

Standardised sets of monitoring data sheet were developed for the sampling programme as per Chapter 5 recommendations (see Appendices D and E).

6.2.5 Data collation

The sampling results were collated into a database (Access and Excel) for archiving and making interpretation easier

6.2.6 Reporting

Three monthly reports were produced (Chapter 7).

6.2.7 Verification

The South African Institute of Aquatic Biodiversity were sent reference samples for species identification verification. Specimens were sub-sampled and stored in 5% formalin before being sent for identification verification.

6.2.8 Possible additions to sampling programme

Additional information on fish catches was collected from various sources. These included:

- Locals who have fishing permits for Lake Nhlabane
- A concurrent Nhlabane estuary sampling programme
- Historical fish catches of Lake Nhlabane undertaken for RBM by CRUZ.

- The Mzingazi salt water barrier was to be sampled to determine what biota is moving in and out of a permanently open estuary.
- The RBM weather station data.

6.3 FISHWAY FLOW VERIFICATION

Arrangements were made for the Hydrology Division of DWAF to undertake a detailed rating study of the fishway and to install the necessary water level monitoring equipment in the fishway. This would enable a continuous record of discharge in the fishway to be obtained.

7. NHLABANE FISHWAY MONITORING

7.1 INTRODUCTION

The Nhlabane coastal lake – estuary system (28° 40' S., 32° 16' E) in northern KwaZulu-Natal is situated approximately 30 km north of Richards Bay (Whitfield, 2000). It is the only estuary along the 60 km stretch of coast between Richards Bay and the St. Lucia/Mfolozi complex. Described by Begg (1978) as “one of the most unspoilt and least known systems in Natal”, it existed in its natural state until 1976. In this natural state the system consisted of a channel *ca.* 3.5 km long linked to two shallow lakes up to 1 km wide with a total area of 120 ha (Begg, 1978).

During 1976 a 4 m weir was constructed, *ca.* 3 km from the mouth was built by Richards Bay Minerals (RBM) in order to provide a source of freshwater for their dune mining operations. The barrage reduced the area of the estuary from 120 to 17 ha, splitting the system into two distinct environments (Begg, 1978). The weir was subsequently raised by 0.75 m to 4.75 m above mean sea level (AMSL) in 1984 (Bok, 1997). In 1998 the weir was raised by a further 1.5 m to 6.25 m AMSL to cater for increased water demands arising from an expansion of mining activities. While this increase in height of the weir had little effect on the extent of the estuary, *i.e.* that area downstream of the barrage, the effect on the system above the weir was to increase the water surface area from *ca.* 100 ha prior to impoundment to *ca.* 1 270 ha at full supply level and the depth from *ca.* 1.5 m to a maximum of 5-6 m. The effect on the nature of the water, as recognized and recorded by Begg (1978), was to convert a low salinity, “brackish” estuarine type condition to a fresh water environment. It is significant that his pre-barrage data were obtained in the mid 1970’s, a relatively wet period. It could be expected, therefore, that salinities in the upper reaches of the Nhlabane system would have been at low levels due to higher runoff. Under drier conditions it is possible that salinities in the upper reaches could have been higher and the contrast he noted was therefore not as great as might have been found during such drier periods.

Investigations of the fish fauna of the Nhlabane estuary during the 90’s (Cyrus and Wepener, 1997; Forbes and Demetriades, 2000) all indicated that this lower part of the system constituted an important nursery area for marine fish species with juveniles wholly or partially dependent on estuarine nursery grounds. It is reasonable to assume that these species, many of which have remarkable tolerance of low salinities, particularly in the relatively warm conditions of northern KwaZulu-Natal, would in the past have utilised the upper regions of the system. Begg (1978) refers to records of tarpon, *Megalops cyprinoids*, and flathead mullet, *Mugil cephalus*, collected by netting in 1958. Cyrus (2001) argued that the weir and sluice gates have blocked the natural migration routes of at least 18 species of fish and five species of macro-invertebrates. It can be assumed that species that habitually move through estuaries into freshwater conditions would be most strongly affected. One of these species, which occurs in the Nhlabane estuary, is the catadromous freshwater mullet, *Myxus capensis*, which has declined drastically in Eastern Cape rivers due to in-channel barriers (Bok, 1983; 1997).

Despite statements in Begg (1978) which record that RBM “were advised (by the then Natal Parks Board) that a fishway around the barrage would serve no purpose” the weir has been largely responsible for the Nhlabane being given the ecological status of Class E/D. This category describes a system which is *seriously to largely modified* (Bok, 2001) and in which loss of natural habitat, biota and basic ecosystem functioning have been large to extensive.

According to an Estuarine Flow Requirement study commissioned by the Department of Water Affairs and Forestry, construction of an effective, functional fishway on the weir, which would allow for the movement of migratory fish, eels and macro-invertebrates between the lake and estuary, could mitigate some of this impact and change the classification to a Class C, or moderately modified estuary (Viljoen and Wepener, 1998).

As a result the second raising of the weir in 1998 incorporated a pool-and-weir fishway intended to create flow conditions to accommodate swimming as well as climbing and crawling behaviour of migratory fish, eels and macro-invertebrates occurring in the Nhlabane system (Bok, 2000). The fishway was designed primarily to cater for upstream migrations as downstream movement normally takes place during flood events or periods of overtopping (Bok, 1983).

Very few quantitative data are available on the use or significance of fishways at the upper tidal limits of estuaries in South Africa and no such information was available for KwaZulu-Natal. This study was intended to provide information on the species, numbers and sizes of the individuals using the fishway in relation to environmental variables such as seasonality, day/night, mouth condition and particularly water volumes and current velocities. The latter was particularly relevant because of the compromise required between the role of the dam as a water storage mechanism and the requirement for an adequate flow down the fishway to optimise its function as a route for migratory species.

7.2 METHODOLOGY

7.2.1 The Fishway

The Nhlabane fishway (Plates 7.1, 7.2 and 7.3) is a modified pool-and-weir fishway with 98 pools arranged in a folded-staircase type design giving a total length of 47 m (Appendix B). The first section of the fishway (pool 1 to 80) has a slope of 1:12, while the remaining section is set at a slope of 1:10. Pools in the fishway are approximately 500 mm long between baffles and 900 mm wide (Plate 7.4). Water depth in the pools is at least 450 mm depending on water flow down the fishway. All pools are covered with removable steel gratings to provide migrating biota protection from human and other predators, as well as preventing debris from falling into the pools and obstructing water flow and migration.

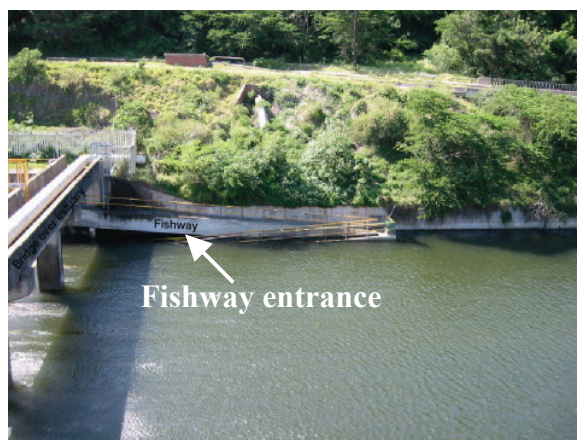


Plate 7.1: Fishway entrance immediately downstream of the weir at high estuary water level .

The "variable passage-depth" baffles or weirs between pools in the fishway are approximately 100 mm thick and have a forward slope *i.e.* facing against the water flow. This ensures that water does not fall in an arch between pools and allows for the movement of small fish in the shallow water over the baffle, without having to jump to the next pool. These baffles are also set at an angle to the sidewalls, with a height difference of approximately 250 mm between sides. This creates a range of water depths and current speeds over the baffle to allow for the different sizes and swimming abilities of migrating organisms. Within the optimal range of water flows down the fishway, a wide splash-zone with a gentle slope is formed on the baffles between pools, which can be used by climbing or crawling species such as eels and macro-invertebrates. In addition, the inside surfaces of the fishway are rough, thereby increasing friction and reducing water velocities near the bottom and sides (Bok, 1997).

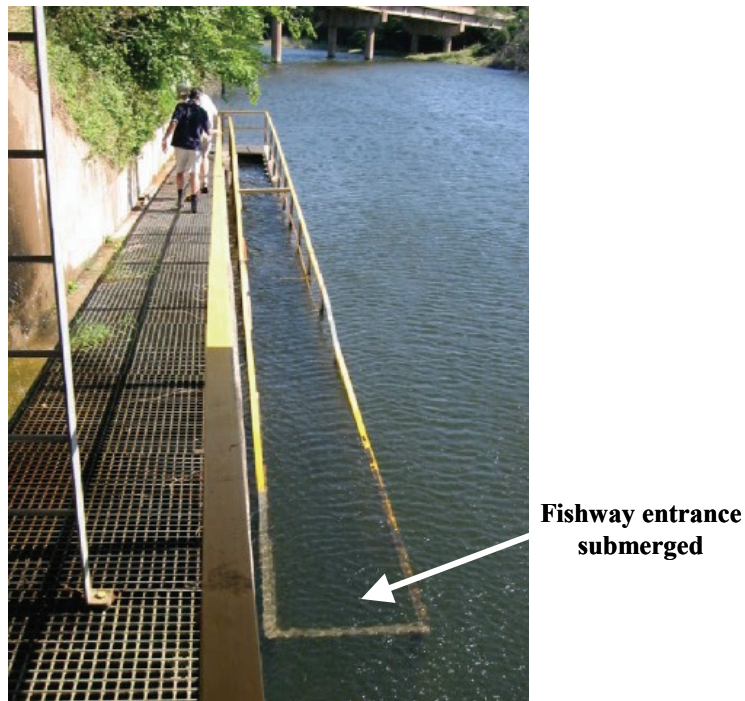


Plate 7.2: Fishway entrance as seen from the weir.



Plate 7.3: Upstream view of Nhlabane weir and fishway exit during low lake level. Arrows indicate positions of exposed exit ports/inlet sluices.



Plate 7.4: Grating removed to show pools and baffles inside Nhlabane Fishway.

The fishway is situated on the eastern bank of the estuary with the entrance, *i.e.* the downstream end, situated approximately 1 m from the base of the weir. The folded-staircase design of the fishway allows the entrance to operate under fluctuating tailwater pool (estuary) levels, with the exact position of entry shifting with rising and falling tailwater levels. An attraction water pipe with a regulating valve has an outlet situated near the fishway entrance, allowing for an increased flow of freshwater separate from the fishway to attract fish to the general area of the entrance and to the side of the estuary where the fishway is situated. An auxiliary water pipe is also positioned so as to release set amounts of water into the fishway in the first downstream pool at the entrance to the fishway. This auxiliary water may be particularly important to attract fish to the entrance of the fishway when the volume of water flowing down the fishway is small compared with water flowing over the barrier, or when the fishway is operating at below full supply level (Bok, 1997). Water flow from the attraction and auxiliary water pipes is less than 90° to the flow direction of the water discharging from

the fishway to avoid disorientation of fish and to guide fish into the fishway (Mallen-Cooper and Harris, 1992).

The fishway exit in Lake Nhlabane consists of a series of 11 exit ports set at different heights along the fishway. The different heights of these exit ports allows water to flow down the fishway and ensures effective functioning of the fishway at fluctuating headwater (lake) levels of between 4.65 m AMSL (Bok, 2001) and 6.00 m AMSL or full supply level. This lower operating level is consistent with the "Maintenance Minimum Level" of 4.5 m AMSL recommended by the Department of Water Affairs and Forestry (DWAF) for Lake Nhlabane (Bok, 2001). Exit ports can be opened or closed individually by means of manually operated inlet sluices to adjust the water volume flowing down the fishway. The fishway exit is situated far enough from the weir crest in an area of low water flow to ensure that tired upstream migrants exiting the fishway are not swept back downstream (Bok, 1997). During periods of extended drought when the lake water level drops below the minimum level for effective functioning of the fishway, water can be pumped from the lake into the fishway to facilitate and maintain upstream movement. In this case a mechanism to flush or move migratory biota from the fishway into the lake is required.

Monitoring of the Nhlabane fishway involved monthly sampling from January to December 2001; monitoring was resumed in October 2002 and carried out monthly from December 2002 to April 2003. Sampling intervals were then extended to six weeks over winter and the fishway was monitored in June, July and September 2003. Each sampling period lasted between three and six days, during which all migrating fish and macro-crustaceans in the fishway were trapped, identified, measured and returned alive upstream or downstream of the weir, depending on the direction of movement of the specimen when trapped. At the same time a suite of abiotic parameters were measured (See Appendices D and E for field data sheets). Water salinity measurements were made by means of a hand refractometer, with bottom water samples collected with a weighted bottle and rope at a position near the fishway entrance in the estuary. Water temperature measurements were made by means of a thermometer fixed to the inside of the fishway in pool number 81. Estuary and lake water levels were obtained from RBM's automatic water level monitoring system on Nhlabane.

Water flow volume was measured as depth of water over the baffle between chambers 80 and 81 (Appendix C), using a flat metal ruler against the fishway wall on the lowest part of the baffle. This depth was converted into a water flow measurement from a water depth *vs.* flow volume graph (Institute of Water Pollution Control, 1973). The measurements of water depth over baffle and corresponding water flow volumes are shown in Appendix C. Water flow down the fishway varied naturally with short-term (daily or hourly) fluctuations in lake water level, usually as a result of windy conditions or heavy rainfall in the lake catchment area. Water flow volumes were also altered by opening or closing the fishway water inlet sluices in the lake, releasing greater or lesser volumes of water down the fishway. This was done in order to allow sampling in the fishway at various flow rates. Water flow alterations were made before the start of a sampling session and flow rates recorded at each trap clearing. The effect of water flow down attraction / auxiliary water pipes was not tested as these pipes were damaged during a flood shortly before the onset of the monitoring programme and not repaired during the study period. Fish identifications followed Skelton (1993) and Smith and Heemstra (1991). All fish were classified according to their Estuarine Dependency Category (EDC) after Whitfield (1998), as follows:

Estuarine Dependence Categories Describing Fish Utilisation Of South African Estuaries (Whitfield, 1998).

Description of Categories

I	Estuarine species that breed in southern African estuaries. Further subdivided into: Ia. Resident species that have not been recorded spawning in marine or freshwater environments. Ib. Resident species that also have marine or freshwater breeding populations.
II	Euryhaline marine species that usually breed at sea with the juveniles showing varying degrees of dependence on southern African estuaries. Further subdivided into: IIa. Juveniles dependent on estuaries as nursery areas. IIb. Juveniles occur mainly in estuaries, but are also found at sea. IIc. Juveniles occur in estuaries but are more abundant at sea.
III	Marine species that occur in estuaries in small numbers but are not dependent on these systems.
IV	Freshwater species, whose penetration into estuaries is determined primarily by salinity tolerance. This category includes some species which may breed in both freshwater and estuarine systems
V	Catadromous species that use estuaries as transit routes between the marine and freshwater environments but may also occupy estuaries in certain regions. Further subdivided into: Va. Obligate catadromous species that require a freshwater phase in their development. Vb. Facultative catadromous species which do not require a freshwater phase in their development

Traps in the fishway (Plates 7.5 and 7.6) consisted of stainless steel frames covered with fine meshed 'shade cloth' and were in the shape of box-shaped funnel traps or blocknets designed to fit inside pools in the fishway. Each sampling session involved either a funnel trap placed in pool number 36 or 81 in the fishway (Appendix B), or a blocknet fitted to the baffle between pools 81 and 82, or between pools 82 and 83. Fish and macro-invertebrates were sampled in these two parts of the fishway to ascertain whether individual species or particular size classes could negotiate the entire length of the fishway, as well as to establish if there were any accumulations of fish due to faulty design or operation. Funnel traps caught migratory biota moving either in an upstream or downstream direction depending on the direction in which the traps were facing, while blocknets prevented fish and macro-invertebrates from migrating further up and down the fishway and caused an accumulation of migrants in the pool immediately upstream or downstream of the blocknet. After a recorded length of time, another blocknet was placed on the baffle either upstream or downstream of the first blocknet, allowing migrants trapped inside the pool to be netted out by means of a scoop-net. Funnel traps were set and cleared at recorded times, allowing all migrants in the fishway over a known period of time to be sampled. Each sampling session lasted three hours, allowing several consecutive sampling sessions to be done during daytime. For logistical reasons some sampling sessions varied from one to nine hours, while night-time sessions lasted from sunset to sunrise. In effect therefore, fishway migrants were recorded on a 24-hour basis during the sampling periods. Other factors possibly influencing fish migration, such as the presence of predators or accumulations of fish at the entrance / exit, were also noted during each sampling session.



Plate 7.5: Funnel trap (A) and block nets (B) in pool 82 in fishway showing position of block nets and use of scoop net to clear trap.

Fish and macro-invertebrate specimens were not collected from Lake Nhlabane, due primarily to a lack of field assistants and a suitable boat. The extensive lake area and densely vegetated banks also made the lake difficult to net effectively and made the chances of recapture of upstream migrants very small. Due to similar logistical constraints, collection of specimens in the estuary was irregular and opportunistic. The purpose of sampling in the estuary was not to generate an accurate description of the estuarine fish and macro-invertebrate community, but rather to gain as much knowledge as possible regarding the presence of potential migrants in the estuary immediately downstream of the weir during periods of sampling in the fishway.

Collection methods included seine-netting with a 25 m seine net fitted with a 5 mm bar mesh purse, cast-netting with a 1.8 m diameter monofilament cast-net and line-fishing. Small baited invertebrate traps were also used. Due to the nature of this part of the estuary, with steep banks and dense fringing vegetation, sampling in the estuary, with the exception of line fishing, was only possible at low estuary levels. Gill nets were available during the last three months of the data collection period and were used to sample fish in the estuary. Two-gill nets, consisting of three monofilament panels each (3 m long and 1.7 m deep) with stretch mesh size of 45, 75 and 100 mm each were placed in three locations in the estuary:

- at the fishway entrance,
- in a deep pool 30 m downstream from the weir and
- in the area of the old dredger crossing approximately 1 km downstream of the weir.

Sampling in the estuary took place during daylight hours and seine netting was limited to the area under the road bridge approximately 100 m downstream of the weir. Cast netting and line fishing were limited to the area immediately downstream of the weir. All specimens

collected in the estuary were identified, using Skelton (1993) and Smith and Heemstra (1991), measured and, where possible, returned to the water alive.

All data were recorded on field data sheets (Appendices D and E) and later in a Microsoft Access database for analysis, with analyses done using Microsoft Excel.

7.2.2 Fishway Timed-Run Experiment

At 15h30 on 11 / 12 / 2002, a blocknet was placed in the fishway between pools 35 and 36 (bend near fishway entrance in estuary - Appendix B), to prevent fish from entering the fishway. At 06h25 on 12 / 12 / 2002, approximately 15 hours after blocking off the fishway entrance, the blocknet between pools 35 and 36 was lifted and immediately replaced by a funnel trap in pool 36. At the same time, a blocknet was placed in the middle of the fishway, between pools 82 and 83 (Appendix B). Between 06h30 and 06h40 pools 81 and 82 were checked for the presence of fish by means of a scoop-net. All pools downstream of these pools to the funnel trap were also visually inspected to ensure no fish were present in the fishway. At 06h40 the funnel trap in pool 36 was lifted and replaced by a blocknet between pool 35 and 36. Two *Monodactylus falciformis* of 40 mm TL and one *Myxus capensis* of 48 mm TL were removed from the funnel trap and placed in pool 36 (immediately upstream of the blocknet) at approximately 06h45. At 06h50 pool 82 was checked for the presence of these two specimens by means of a scoop-net.

7.3 RESULTS

7.3.1 Physical Conditions in the Estuary

Estuary water levels during the monitoring period ranged from a minimum of 1.06 m to a maximum of 3.7 m AMSL, while levels in Lake Nhlabane remained between 5 m and 5.95 m AMSL. Open mouth conditions were accompanied by low estuarine water levels and freshwater conditions at the fishway entrance although a range of salinities from zero to 17 parts per thousand (ppt) respectively was recorded at the fishway entrance during the study period; the lake was consistent at zero ppt. Fishway water temperatures varied seasonally from 15.5°C to 28°C (Figure 7.1). Estuary mouth open conditions occurred only during 6.5 % of total upstream sampling time, with such conditions recorded during sampling in February, July and November 2001. During the second sampling period from October 2002 to September 2003, the mouth opened once from the 29th June to 1st July 2003. During November 2002 the natural sandbar, blocking the estuary mouth was artificially built up to avoid oil from the *Jolly Rubino* shipwreck from entering the estuary.

7.3.2 Biota

During the monitoring period from January 2001 to September 2003, a total of 2265 fish and macro-invertebrate specimens were recorded migrating upstream during 929 hours of sampling.

7.3.2.1 Macro-Invertebrates

A total of 307 macro-invertebrate specimens were recorded migrating upstream through the fishway; these consisted of 303 megalopae of the crab *Varuna litterata* and four *Macrobrachium* spp. prawns.

The *V. litterata* megalopae were all between one and three mm TL and were recorded in the middle of the fishway during three consecutive trap sessions (one midday, one late afternoon and one night trap) in May 2001, at flow rates of 2.75 to 4.25 l/s. Fishway water temperature at the time ranged from 21 to 22°C; salinity at the fishway entrance was 3 ppt and the estuary water level at 2.1 m AMSL.

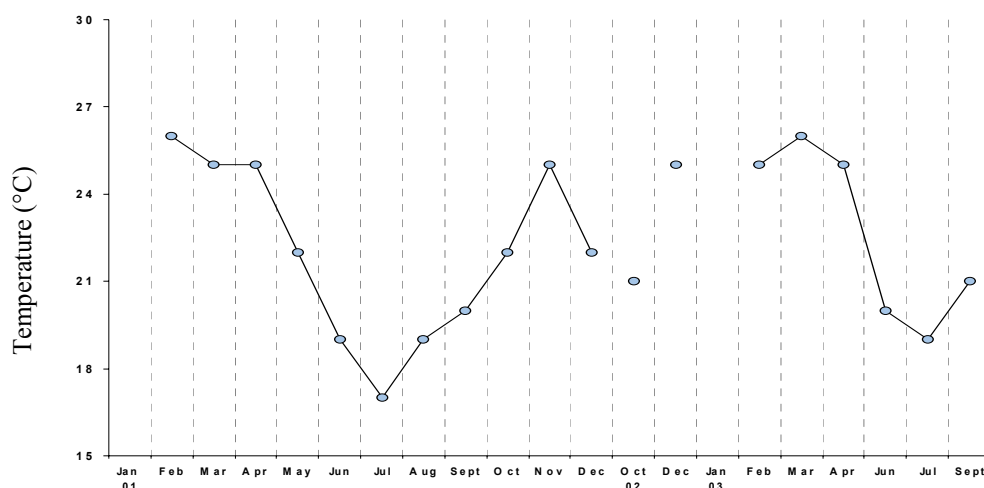


Figure 7.1: Average monthly water temperature in the Nhlabane fishway during the sampling period. No data available for the period January to September 2002.

The *Macrobrachium* prawns recorded were all less than 23 mm carapace length and were recorded during two trap sessions in the middle of the fishway; one night trap in January and one late afternoon in February 2001. Water flow rates in the fishway during these sessions were 12 and 1 l/s, with estuary water levels at 2.8 and 1.3 m AMSL respectively. The water temperature in the fishway was 26°C. No estuary water salinity measurements were available.

7.3.2.2 Ichthyofauna

Downstream migrants consisted of 51 fishes of six species sampled during 51 hours of sampling (Table 7.1). Upstream migrants consisted of 1 958 individuals of 23 species sampled during 929 hours of monitoring. *Oreochromis mossambicus* and *Myxus capensis* were the dominant species, contributing 42.5 % and 39.0 % respectively (Table 7. 2).

Table 7.1: Total species and numbers of fish recorded moving downstream through the Nhlabane fishway between January and September 2003. Estuarine dependency categories (Whitfield, 1998) for each fish species are also shown (n = 51 h).

Species	Common Name	Number	EDC
<i>Pseudocrenilabrus philander</i>	Southern mouthbrooder	18	IV
<i>Oreochromis mossambicus</i>	Mozambique tilapia	17	IV; E*
<i>Myxus capensis</i>	freshwater mullet	10	Vb; E*
<i>Glossogobius callidus</i>	river goby	4	Ib, E*
<i>Glossogobius giurus</i>	tank goby	1	IV
<i>Tilapia sparmanii</i>	banded tilapia	1	IV

*E - endemic to southern Africa (Whitfield, 1998).

Table 7.2: Total species and numbers of fish recorded moving upstream through the Nhlabane fishway during the period January 2001 to September 2003. Estuarine dependency categories (Whitfield, 1998) for each fish species are also shown (n = 929 hr).

Species	Number	Size Range (TL in mm)	EDC
<i>Oreochromis mossambicus</i>	832	10 – 300	IV; E*
<i>Myxus capensis</i>	763	10 – 130	Vb; E*
<i>Monodactylus falciformis</i>	229	26 – 95	IIa
<i>Glossogobius callidus / giurus</i>	32	20 – 165	Ib; E*/ IV
<i>Gilchristella aestuaria</i>	23	20 – 35	Ia; E*
<i>Eleotris melanosoma</i>	13	21 – 83	Ia
unknown larvae	12	15	N/A
<i>Caranx sexfasciatus</i>	10	60 – 85	IIb
<i>Acanthopagrus berda</i>	7	137 - 196	IIa
<i>Mugil cephalus</i>	6	29 – 35	IIa
<i>Awaous aeneofuscus</i>	4	50 – 224	IV
<i>Pseudocrenilabrus philander</i>	4	30 – 81	IV
<i>Ambassis productus</i>	3	73 – 160	Ia
<i>Hypseleotris dayi</i>	3	25 – 33	IV; E*
<i>Redigobius dewaali</i>	3	32 – 38	Ib; E*
<i>Aplocheilichthys katangae</i>	2	26 – 30	IV
<i>Caranx ignobilis</i>	2	70 – 80	IIb
<i>Eleotris fusca</i>	2	40 – 43	Ia
<i>Anguilla marmorata</i>	1	750	Va
<i>Anguilla</i> spp.	1	75	N/A
<i>Barbus viviparus</i>	1	40	IV
<i>Rhabdosargus holubi</i>	1	98	IIa; E*
<i>Tilapia sparmanii</i>	1	108	IV

*E - endemic to southern Africa (Whitfield, 1998)

Upstream migrants ranged in size from 10 to 300 mm TL, with one specimen of 750 mm TL recorded (Table 7.2). *O. mossambicus* ranged in size from 10 to 300 mm TL, with the majority (26.6 %) between 115 and 125 mm TL. *M. capensis* ranged between 10 and 130 mm TL, with the majority (43.5 %) between 45 and 55 mm TL.

Average total numbers of upstream migrants per hour peaked during January, October and November 2001, December 2002 and January 2003. Numbers of the dominant migrant species, *O. mossambicus* and *M. capensis* were highest during January and November 2001, and November 2001 and December 2003 respectively (Figure 7.2).

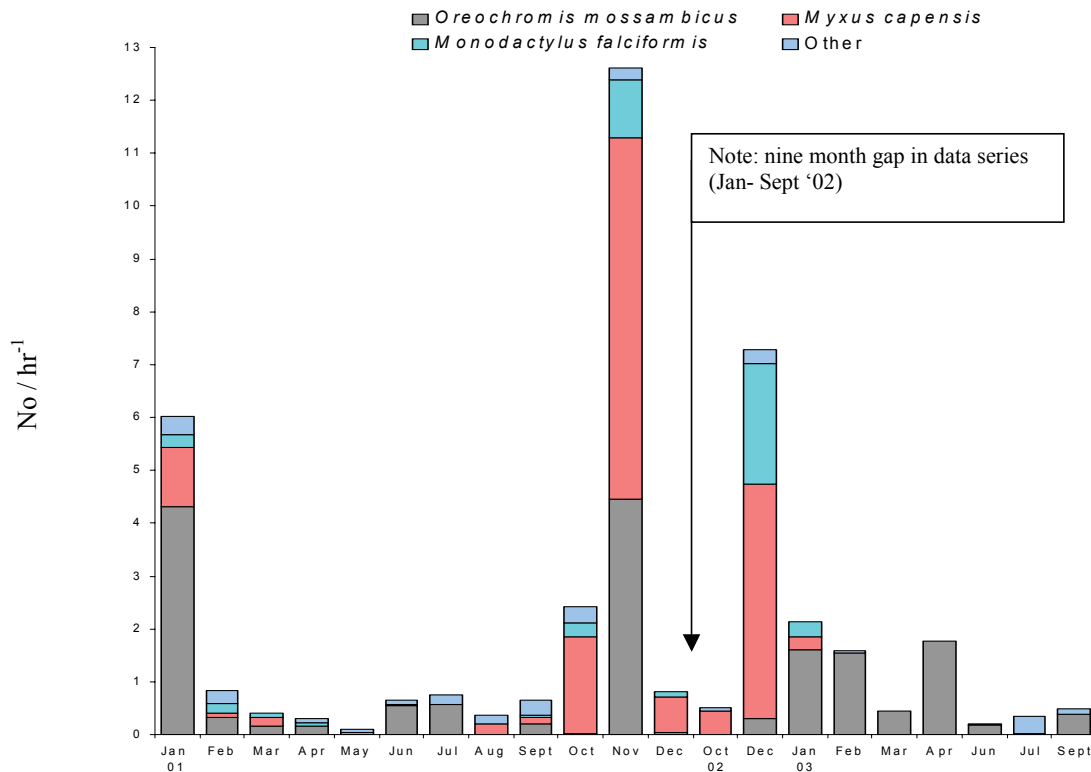


Figure 7.2: Numbers of fish recorded migrating upstream through the Nhlabane fishway per hour during the sampling period from January – December 2001 and October 2002 - September 2003 (n = 929 hr).

The average hourly number of upstream migrants was almost five times higher between sunrise and sunset than between sunset and sunrise (Figure 7.3). The average hourly number of fish recorded migrating upstream was highest at estuary water levels of 2.2 to 2.4 m AMSL (Figure 7.4), while most migrants were recorded when the salinity at the fishway entrance was 2 ppt (Figure 7.5).

Numbers of *O. mossambicus*, *M. capensis*, *M. falciformis* as well as all other upstream migrants combined were highest at flows of 20.1 to 40 l/s (Figure 7.6). Flow rate preferences in the resident *O. mossambicus* appeared to change with size (Figure 7.7). Smaller fish of *ca.* 60 mm were more common in flows of <10 l/s while larger individuals of *ca.* 120 mm or more were more common at flow rates of 10-40 l/s. The migratory moony *M. falciformis* showed relatively little preference and while rare at flows <5 l/s occurred consistently over the range from 5-40 l/s. The freshwater mullet, *M. capensis*, showed a strong preference for faster flows and was four to five times more abundant at flows of 10-40 l/s than rates <10 l/s.

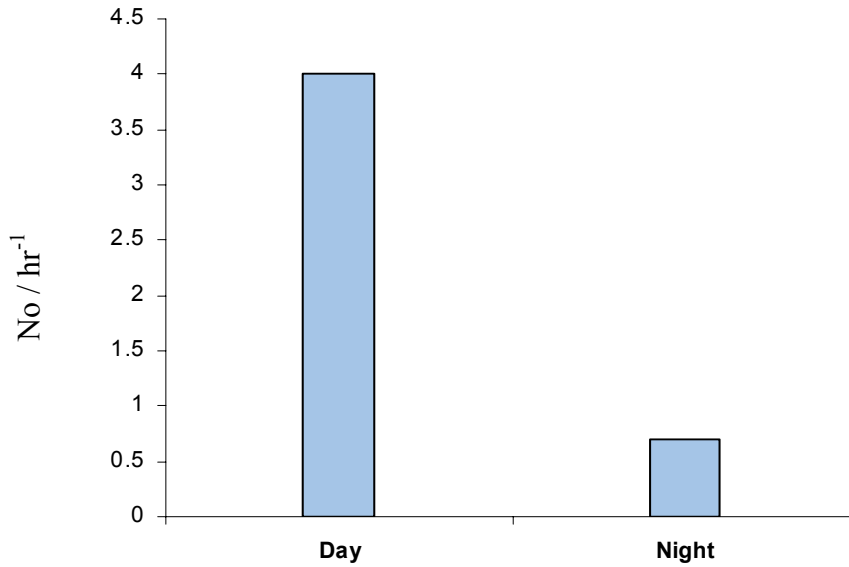


Figure 7.3: Number of fish recorded migrating upstream per hour through the Nhlabane fishway during daylight hours (n = 395 h) and night-time (n = 534 h) during the sampling period from January –December 2001 and October 2002 - September 2003

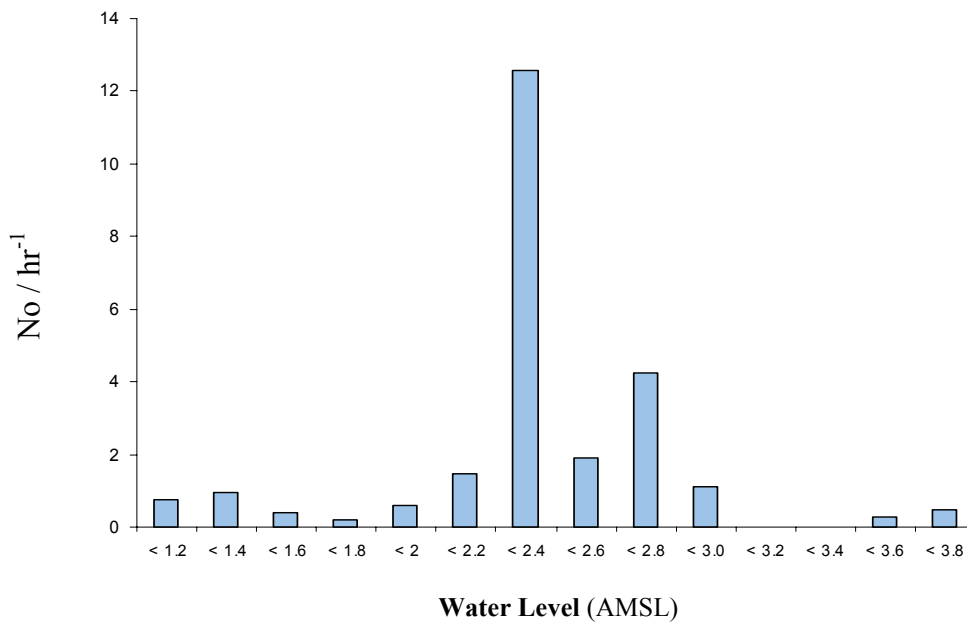


Figure 7.4: Number of fish recorded migrating upstream per hour through the Nhlabane fishway at estuary water levels of 1.0 - 1.2 (n = 80 h), 1.21 - 1.4 (n = 27 h), 1.41 - 1.6 (n = 38 h), 1.61 - 1.8 (n = 14 h), 1.81 - 2.0 (n = 12 h), 2.01 - 2.2 (n = 103 h), 2.21 - 2.4 (n = 57 h), 2.41 - 2.6 (n = 123 h), 2.61 - 2.8 (n = 108 h), 2.81 - 3.0 (n = 216 h), 3.01 - 3.2 (n = 3 h), 3.21 - 3.4 (n = 0 h), 3.41 - 3.6 (n = 100 h) and 3.61 - 3.8 (n = 48 h) m AMSL during the sampling period from January –December 2001 and October 2002 - September 2003.

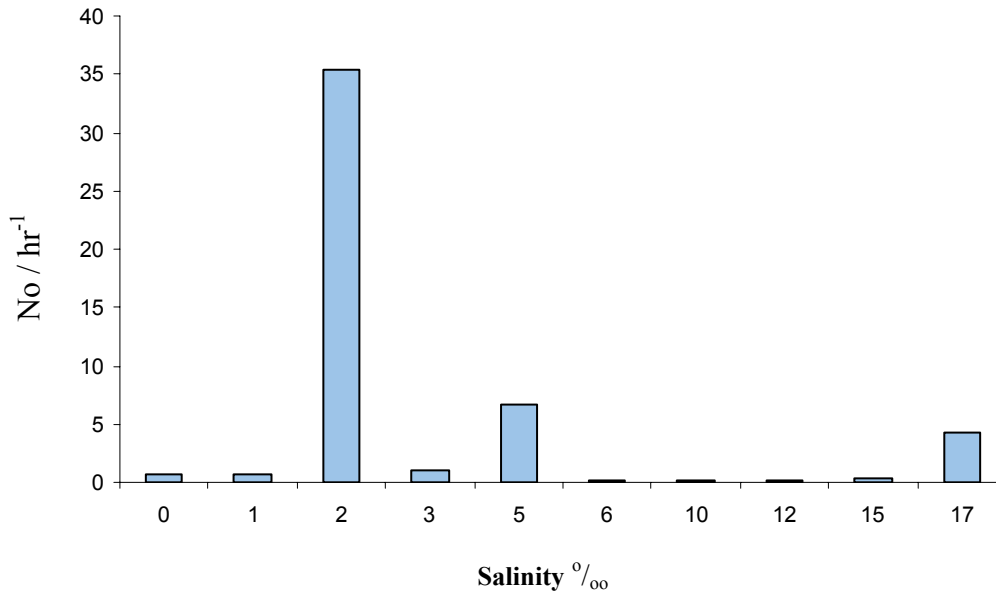


Figure 7.5: Number of fish recorded migrating upstream per hour through the Nhlabane fishway at estuary salinities of zero (n = 311 h), one (n = 84 h), two (n = 3 h), three (n = 100 h), five (n = 59 h), six (n = 23 h), 10 (n = 6 h), 12 (n = 11 h), 15 (n = 24 h) and 17 (n = 21 h) ‰, January –December 2001 and October 2002 - September 2003.

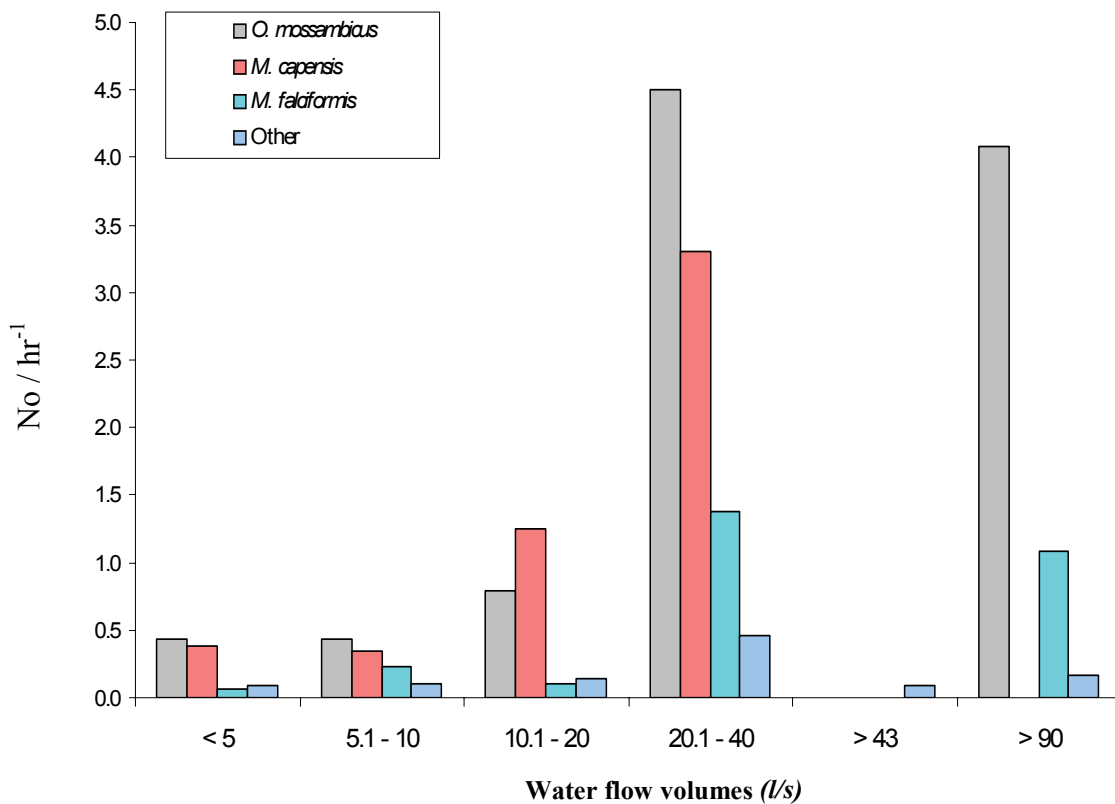


Figure 7.6: Number of fish recorded migrating upstream per hour through the fishway at water flow volumes of less than five (n = 286 h), five to 10 (n = 305 h), 10 to 20 (n = 239 h), 20 to 40 (n = 75 h), > 40 n = 12 h and >90 l/s n = 12 h).

7.3.2.3 Fishway timed-run experiment

Preliminary observations on one *M. falciformis* of 40 mm TL and one *M. capensis* of 48 mm TL indicated that they had traversed the fishway in less than 10 minutes.

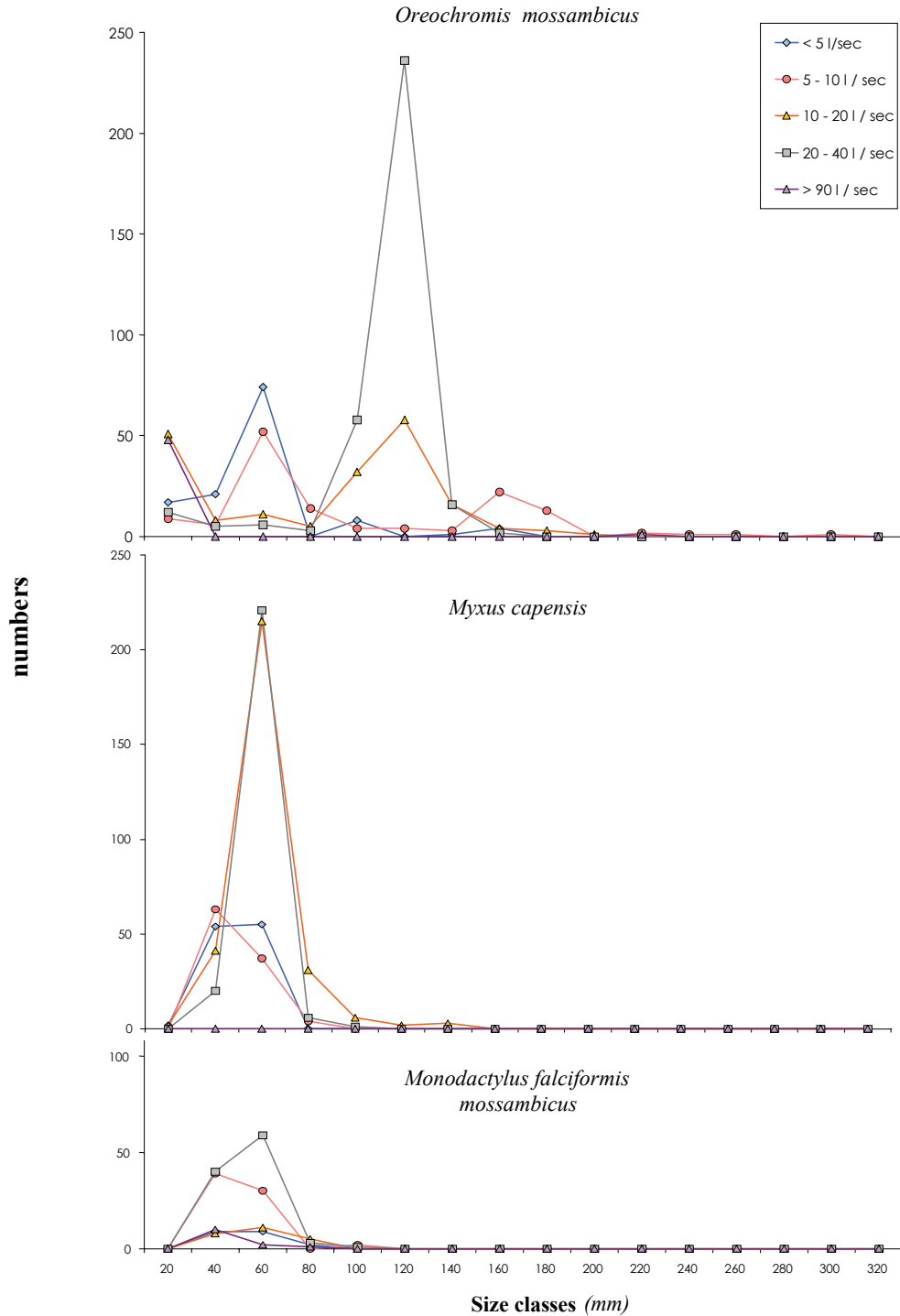


Figure 7.7: Abundance of the size classes of the three most common species in the Nhlabane fishway at different flow rates (< 5 l/s n = 286 h; 5-10 l/s n = 305 h; 10-20 l/s n = 239 h; 20-40 l/s n = 75 h; 43 (n = 12 h) and 90 l/s (n = 12 h) during the sampling period from January 2001 to September 2003.

Table 7.3: Species list and size ranges of fish recorded in the Nhlabane estuary during the sampling period from January 2001 to September 2003 (n = 93 h).

Species	Sample Method	Size range (TL in mm)
<i>Myxus capensis</i>	Gill-net	180 – 400
<i>Liza alata</i>	Gill-net	250 – 650
<i>Mugil cephalus</i>	Gill-net	250 – 265
<i>Liza macrolepis</i>	Gill-net	190 – 230
<i>Acanthopagrus berda</i>	Gill-net	240 – 340
<i>Gerres</i> spp.	Gill-net	175
<i>Oreochromis mossambicus</i>	Gill-net	300
<i>Rhabdosargus thorpei</i>	Gill-net	140
<i>Chanos chanos</i>	Gill-net	520
<i>Acanthopagrus berda</i>	Hook and line	160 – 450
<i>Monodactylus falciformis</i>	Hook and line	90 – 110
<i>Megalops cyprinoides</i>	Hook and line	250 – 300
<i>Ambassis</i> spp.	Hook and line	60 – 70
<i>Clarias gariepinus</i>	Hook and line	600 – 850
<i>Oreochromis mossambicus</i>	Hook and line	260
<i>Caranx sexfasciatus</i>	Hook and line	350
<i>Therapon jarbua</i>	Hook and line	175
<i>Ambassis productus</i>	2 m minnow seine net	22 – 51
<i>Myxus capensis</i>	2 m minnow seine net	23 – 34
<i>Rhabdosargus</i> spp.	2 m minnow seine net	18
<i>Monodactylus falciformis</i>	1.8 m cast net	83 – 91
<i>Oreochromis mossambicus</i>	1.8 m cast net	160 – 165
<i>Acanthopagrus berda</i>	1.8 m cast net	230
<i>Gilchristella aestuaria</i>	Hand-held scoop-net	20 – 50
<i>Myxus capensis</i>	Hand-held scoop-net	50 – 52
<i>Pseudocrenilabrus philander</i>	10 m bag seine net	30 – 50
<i>Myxus capensis</i>	70 m bag seine net	250

7.4 DISCUSSION

7.4.1 Macro-Invertebrates

During the sampling period, only 303 *Varuna litterata* megalopae and four *Macrobrachium* spp. prawns were recorded migrating upstream through the fishway. Adult *V. litterata* crabs were present in the lake, estuary and fishway year-round, but were utilizing the fishway as a habitat rather than actively migrating (Bok, 2000). Similarly, large numbers of *Caridina nilotica* (freshwater prawns) were present in the fishway throughout the study period, but were similarly utilizing the fishway as a habitat rather than a migratory route.

The *Macrobrachium* spp. prawns as well as the *V. litterata* megalopae were sampled at low water flows and two of the prawns were collected at night. The *V. litterata* megalopae were all sampled in the fishway during a mass migration lasting approximately three to four days in May 2001. It therefore appears as if migration of these macro-invertebrate species occurs mainly under low water flow conditions when these organisms can make optimum use of the wetted splash zone on the baffles between pools. This wetted splash zone, which was flooded at flow volumes greater than approximately 40 l/s, provides a rough surface to accommodate the climbing behaviour of migrating crab larvae and prawns, as well as areas of shallow water and low current velocity. The crabs and prawns recorded also showed a tendency to migrate

between sunset and sunrise and at high water temperatures, or specific times of the year. More sampling is however needed to confirm the migratory habits of these species. The presence of prawns and crabs in the fishway does indicate that the design and operation of the fishway is such that these species can utilise the fishway successfully.

Cyrus *et al.* (1996) found three *Macrobrachium* species, *M. equidens*, *M. rude* and *M. lepidactylus* as well as two *Palaemon* species, *P. concinnus* and *P. debilis* in the Nhlabane system. These freshwater prawns migrate into brackish water with salinity of at least 8 ppt for successful breeding and larval development. Adults and juveniles then migrate back into freshwater to complete the lifecycle. If migration of these adults and juveniles between freshwater feeding and estuarine breeding areas is prevented, localised extinction of these species is possible (Bickerton, 1989). The general absence of these prawns in the fishway is possibly partly explained by the ability of both prawns and crabs to crawl up the splash zone of the sloping wall of the weir (Bok, 1997). During the mass migration of *V. litterata* megalopae recorded in the fishway in the present study, large numbers of megalopae were also observed crawling up wet splash zones on the weir. Ropes hung in these splash zones from the top of the weir into the estuary, for the benefit of these organisms, provided further rough surface for many of the megalopae to successfully negotiate the weir. This ability of crabs and prawns to negotiate the weir (Bok, 1997) is supported by the fact that populations of freshwater prawns were found by Cyrus *et al.* (1996) in the estuary 15 years after construction of the weir. The movement of prawns and crabs between the estuary and lake over the weir is however thought to occur in limited numbers. The low numbers of prawns recorded in the fishway could therefore indicate that the weir has played a role in reducing the number of *Macrobrachium* and *Palaemon* prawns in the system.

7.4.2 Ichthyofauna

7.4.2.1 Downstream migration

As downstream movement of aquatic migratory biota normally takes place during flood events when water moves from the lake to the estuary, downstream migration of fish and macro-invertebrates through the fishway was not intensively monitored. Adult catadromous fish, such as *Myxus capensis*, are also known to swim downstream in the mainstream flow spilling over the crests of weirs (Bok, 1983). The water depth at the base of the Nhlabane weir is also regarded as sufficient to ensure that fish swimming over the crest can survive the fall (Bok, 1997). In addition, the dimensions of the Nhlabane fishway are such that, should downstream migrants enter the fishway, these could easily pass through (Bok, 1997). A total of six fish species was recorded moving downstream through the fishway during the limited amount of sampling time (Table 7.1). With the exception of *M. capensis* and *Glossogobius callidus*, all were freshwater species probably utilizing the fishway as a habitat safe from large aquatic and avian predators.

7.4.2.2 Numbers and sizes

The three most abundant species recorded migrating upstream were *O. mossambicus*, *M. capensis*, and *M. falciformis*, contributing 42.5%, 39% and 11.7% respectively to the total number of fish sampled (Table 7.2). *M. capensis* is a Red Data species (Skelton, 1993; Bok, 1997) endemic to southern Africa and classified by Whitfield (1998) as a facultative catadromous species that moves from marine to freshwater environments through estuaries. *O. mossambicus*, also endemic to southern Africa, is a common freshwater species that can

tolerate salinities from zero to 100 ppt and breeds in freshwater as well as estuaries (Whitfield, 1998). *M. falciformis* is a euryhaline marine species which breeds at sea but has juveniles dependent on estuaries (Whitfield, 1998). The three most abundant fish species recorded by the Coastal Research Unit of Zululand (CRUZ) during 1992 to 1997 in the Nhlabane estuary were *O. mossambicus* (38 %), *Ambassis productus* (18 %) and *M. capensis* (10 %, Viljoen and Wepener, 1998). Marine and Estuarine Research (MER) found the most abundant fish species to be *A. productus* (20 %), *M. capensis* (14 %) and *O. mossambicus* (13 %) (Forbes and Demetriades, 2000). *A. productus* has not yet been recorded spawning in freshwater or marine environments and is known to breed in estuaries only (Whitfield, 1998). The reasons for the low number of *A. productus* recorded in the fishway during the present study (Table 7.2) are unclear but could be due to a possible non-migratory habit as this species was recorded in the estuary during the present study (Table 7.3). The reason for the absence of *Anguilla* spp. glass eel or elvers in the fishway and estuary also remains unclear, as these highly migratory eels were expected to utilise the fishway, particularly during the spring and summer months (Harris and Cyrus, 1995; Bok, 1997).

In total, 64 species of fish were recorded in the Nhlabane estuary during studies from 1992 to the present (Table 7.5); of these, 23 species were recorded in the fishway during the present study. A further seven species were recorded in the estuary but not the fishway during the present study. Four species, viz. *Redigobius dewaali*, *Barbus viviparus*, *Hypseleotris dayi* and *Anguilla marmorata* not recorded in the Nhlabane estuary by the CRUZ, Council for Scientific and Industrial Research (CSIR) or MER were recorded migrating upstream in the fishway during the present study (Table 7.5).

Very little data are available on the use of fishways at the tidal limit of estuaries in southern Africa. During a brief monitoring period of the Nhlabane fishway from 22 to 25 September 1999, Bok (2000) recorded a total of 193 fish of nine species migrating upstream during 72 hours of sampling. All nine species recorded were also found during the present study. Numbers and size ranges of these species are shown in Table 7.4. In a similar study on a pool-and-weir fishway 21 km upstream of the mouth at the tidal limit of the Kowie river estuary in the Eastern Cape, Bok and Cambray (1995) recorded four species migrating upstream during January and February 1995. A total of 1 011 fish was recorded in the fishway and in a trap at the fishway exit during the study period, comprising 58 % Mugilidae, mainly *Myxus capensis* and *Mugil cephalus*, 41% *Monodactylus falciformis* and 1% *Glossogobius callidus* (Bok and Cambray, 1995). A pool-and-weir fishway on a tidal barrier on a coastal sub-tropical river in south-eastern Queensland, Australia proved ineffective for passage of the diverse fauna within that system, particularly for large fish. This fishway was reconstructed to a modified Vertical-slot fishway with lowered water velocities and turbulence, and monitored over a period of 17 months. During this time, 34 fish species were recorded in the fishway, with a total of 52 000 fish at a maximum rate of 4 500 fish per day (Stuart and Berghuis, 1999).

The comparatively low numbers and species of fish recorded migrating through the Nhlabane fishway during the present study are more likely a reflection of the estuarine fish community rather than fishway design or operation. Extensive monitoring of the Nhlabane system was beyond the scope of this study, and proved difficult due to logistical constraints, but it is possible that the sluice-gate operation on the Nhlabane weir during the sampling in 2001 had a negative effect on the fish community of the estuary. From January to December 2001, sluice gates opened on average one to two times per month, with approximately 30 - 50 cumecs of water flowing from the lake into the estuary from one sluice gate. Sluice gates

remained open for periods of between 8 and 24 hours (Jones, 2001, *pers. comm*). Relatively high rainfall in the Lake Nhlabane catchment area during 2001 also contributed to more water being released from the lake more often.

It was found that the high water volumes released from the open sluice gates rapidly lowered the estuarine water salinity to zero and also caused the estuary mouth to breach resulting in low estuary water levels. The effect of a low estuary water level and low salinity, combined with a scouring effect of the water released from the sluices was a possible cause of the absence of fish in the fishway during and shortly after periods of gate opening events. Harrison (1998) and Forbes and Demetriades (2000) noted that physical disturbance of estuary bottom sediments by freshwater input from Lake Nhlabane caused a decrease in the total numbers of benthic organisms. Benthic samples from the Nhlabane estuary also indicated fewer species and numbers of benthic organisms in the estuary at the time of the 2001 fishway monitoring study period than before (L Vivier, *pers. comm.*, 2001). This is in keeping with the fact that 17 of the 25 estuarine dependent marine fish species recorded in the Nhlabane estuary from 1992 to 1997 (Table 7.5) and not recorded in the fishway or estuary during the present study, are regarded as benthic feeders (Smith and Heemstra, 1991; Skelton, 1993). During their studies on the Nhlabane estuary, Viljoen and Wepener (1998) recorded 17 % freshwater species out of the total species composition, while Harrison (1998) recorded 19 % and Forbes and Demetriades (2000) 20 % (Table 7.5). In comparison, 41 % of the total number of fish species recorded during the present study were freshwater species, while none of the eight non-estuarine dependent marine species previously recorded in the estuary (Table 5) was recorded. In addition, two of the four fish species recorded migrating upstream through the fishway and not previously recorded in the Nhlabane estuary, *B. viviparus* and *H. dayi*, are regarded as freshwater species (Skelton, 1993; Whitfield, 1998).

These results suggest a change in the species composition and numbers of fishes in the estuarine fish community, similar to the change in fish species composition recorded by Vivier *et al.* (1998) in the estuary from 1992 to 1995. This change in species composition was attributed to low salinity conditions and lack of contact with the marine environment. Similar low salinity conditions prevailed during the present study due to freshwater flooding through the sluice gate operation and/or increased freshwater input through underground seepage at the time of the study. The operation of the sluice gates at the time of the study is also thought to have altered the estuary mouth dynamics such that the mouth was only open to the sea for short periods of a few days instead of weeks. In the absence of a slowly declining flow of water after flood-type sluice-opening events, wave action and longshore drift rapidly built up the sandbar blocking the estuary mouth, resulting in reduced marine input. In addition, although sluice gate operation was altered during the 2002/2003 sampling period (by slightly lowering sluice gates) low rainfall during this period resulted in few mouth open events and a lack of contact with the marine environment. The consequent impact on the species composition and numbers of fish in the estuary is reflected in the relatively low number of upstream migrants recorded in the fishway during this study.

Table 7.4: Fish species, numbers and sizes recorded migrating upstream during 72 hours of monitoring in the Nhlabane fishway by Bok (2000) over the period 22 to 25 September 1999.

Species	Number	Size Range (FL, mm)
<i>Monodactylus falciformis</i>	135	23 - 49
<i>Eleotris fusca</i>	19	34 - 76
<i>Hypseleotris dayi</i>	4	57 - 65
<i>Myxus capensis</i>	12	23 - 73
<i>Glossogobius giurus</i>	4	37 - 60
<i>Glossogobius callidus</i>	1	58
<i>Pseudocrenilabrus philander</i>	3	62 - 68
<i>Aplocheilichthys katangae</i>	2	45 - 48
<i>Oreochromis mossambicus</i>	1	65

Table 7.5: Fish species recorded in the Nhlabane estuary from 1992 to 1999, and in the present study up to September 2003; estuarine dependence category (EDC) after Whitfield (1998).

Species	EDC	CRUZ	CSIR	MER	Present study
<i>Ambassis productus</i>	Ia				Fishway
<i>Eleotris fusca</i>	Ia				Fishway
<i>Eleotris melanosoma</i>	Ia				Fishway
<i>Gilchristella aestuaria</i>	Ia				Fishway
<i>Ambassis gymnocephalus</i>	Ib				
<i>Ambassis natalensis</i>	Ib				
<i>Croilia mossambica</i>	Ib				
<i>Glossogobius callidus</i>	Ib				Fishway
<i>Hippichthys heptagonus</i>	Ib				
<i>Redigobius dewaali</i>	Ib				Fishway
<i>Silhouettea sibayi</i>	Ib				
<i>Acanthopagrus berda</i>	IIa				Fishway; Estuary
<i>Argyrosomus japonicus</i>	IIa				
<i>Elops machnata</i>	IIa				
<i>Liza macrolepis</i>	IIa				Estuary
<i>Monodactylus falciformis</i>	IIa				Fishway
<i>Mugil cephalus</i>	IIa				Fishway; Estuary
<i>Pomadasy commersonii</i>	IIa				
<i>Rhabdosargus holubi</i>	IIa				Fishway
<i>Terapon jarbua</i>	IIa				Estuary
<i>Valamugil cunnesius</i>	IIa				
<i>Valamugil robustus</i>	IIa				
<i>Caranx ignobilis</i>	IIb				Fishway
<i>Caranx sexfasciatus</i>	IIb				Fishway; Estuary
<i>Gerres acinaces</i>	IIb				
<i>Gerres filamentosus</i>	IIb				
<i>Gerres methuenii</i>	IIb				
<i>Leiognathus equula</i>	IIb				
<i>Liza alata</i>	IIb				Estuary
<i>Liza dumerilii</i>	IIb				
<i>Liza tricuspidens</i>	IIb				

Table 7.5 (Continued)

Species	EDC	CRUZ	CSIR	MER	Present study
<i>Monodactylus argenteus</i>	IIb				
<i>Rhabdosargus sarba</i>	IIb				
<i>Rhabdosargus thorpei</i>	IIb				
<i>Solea bleekeri</i>	IIb				
<i>Sphyaena sp.</i>	IIb				
<i>Caranx papuensis</i>	IIc				
<i>Chanos chanos</i>	IIc				Estuary
<i>Lutjanus argentimaculatus</i>	IIc				Estuary
<i>Pomatomus saltatrix</i>	IIc				
<i>Valamugil buchanani</i>	IIc				
<i>Valamugil seheli</i>	IIc				
<i>Amblyrhynchotes honckenii</i>	III				
<i>Arothron immaculatus</i>	III				
<i>Caranx sem</i>	III				
<i>Kuhlia rupestris</i>	III				
<i>Otolithes ruber</i>	III				
<i>Pomadasys olivaceum</i>	III				
<i>Trachinus bailonnii</i>	III				
<i>Trachinotus botla</i>	III				
<i>Aplocheilichthys katangae</i>	IV				Fishway
<i>Awaous aeneofuscus</i>	IV				Fishway
<i>Barbus paludinosus</i>	IV				
<i>Barbus viviparus</i>	IV				Fishway
<i>Clarias gariepinus</i>	IV				Estuary
<i>Glossogobius giuris</i>	IV				Fishway
<i>Hypseleotris dayi</i>	IV				Fishway
<i>Oreochromis mossambicus</i>	IV				Fishway; Estuary
<i>Pseudocrenilabrus philander</i>	IV				Fishway; Estuary
<i>Tilapia rendalli</i>	IV				
<i>Tilapia sparmanii</i>	IV				Fishway
<i>Anguilla marmorata</i>	Va				Fishway
<i>Megalops cyprinoides</i>	Vb				Estuary
<i>Myxus capensis</i>	Vb				Fishway; Estuary
Total number of species:		48	37	40	29

Fish migrating upstream through the fishway varied in size from 9 to 750 mm TL (Figure 7.2). The largest specimen was a 750 mm TL *A. marmorata*, with the second largest specimen measuring 300 mm TL (Table 7.2). The size frequencies of *O. mossambicus* and *M. capensis* recorded in the fishway were similar to those found by Harrison (1998) in the estuary in 1997 but larger specimens of *M. capensis* were found in the estuary (Table 3) than in the fishway. Similarly, results for the second and third most common upstream migrants, *M. capensis* and *M. falciformis*, which mature respectively at 190 mm (male) and 230 mm SL (female) (Bok, 1983), and 140 mm SL (van der Elst, 1988), indicated that mainly juveniles of these species were migrating upstream.

Although extensive monitoring of the estuary was not done, it was evident that larger specimens of *Caranx sexfasciatus*, *Acanthopagrus berda*, *M. cephalus*, *Chanos chanos*, *Clarias gariepinus*, *Liza alata*, *Liza macrolepis* and *Megalops cyprinoides* were present in the estuary but not in the fishway (Table 7.3). With the longest distance between baffles

separating pools in the first half of the fishway being 500 mm, the fishway design suggests an upper size limit for upstream 'typical' fish migrants of less than 500 mm TL. Results confirm this upper size limit as, apart from the single 750 mm TL eel specimen that has a body shape more conducive to dealing with the relatively confined space inside the fishway, no fish larger than 310 mm TL was recorded migrating upstream in the fishway. This design limitation is not thought to have a significant negative impact on the functioning of the fishway, as it is designed to cater mainly for the small juvenile migrants moving between the estuary and upstream freshwater habitats (Bok, 1997). In addition, it is possible that larger specimens (> 300 mm TL) are not as effectively recorded in the fishway with the sampling techniques used (funnel traps and block nets), particularly in the case of blocknets where larger fish were observed to be more likely to return downstream when faced with this barrier within the fishway. Larger fish are also thought not to have a strong upstream migratory urge (Bok, 1997). Large fish, particularly the rare diamond mullet *L. alata*, were often observed in the estuary at the fishway entrance or against the weir, often for up to three to four days at a time but never entering the fishway. Larger fish were also observed to appear more wary around the fishway entrance and it may partly be a behavioural response precluding such fish from freely entering the fishway. A combination of fishway design, sampling technique, non-migratory urge and behavioural response may therefore have combined to produce the low number of larger fish specimens recorded in the fishway.

Bok and Cambray (1995), during a monitoring period on a fishway at the tidal limit of the Kowie River in the Eastern Cape, recorded that *M. capensis* smaller than about 45 mm TL were unable to negotiate the fishway, with juvenile *M. capensis* of around 30 to 40 mm TL the most numerous size class below the fishway. Similarly, *M. falciformis* smaller than 35 mm TL were unable to use the fishway. This exclusion of smaller fish was due to the high water velocities and turbulence in the fishway, coupled with a relatively steep gradient and lack of areas of low water velocities.

In contrast to the above, small specimens of *O. mossambicus*, *M. capensis* and *M. falciformis* of 10 to 20 mm TL were commonly found in the middle to upper section of the Nhlabane fishway. Small specimens of *M. capensis* were also often observed freely entering and moving up the fishway from the estuary in small shoals. Bok (2000) recorded an overall size range of 23 - 76 mm Fork Length in the Nhlabane fishway in September 1999, also indicating the suitability of the fishway for upstream migration of small fish. This suitability is largely due to the relatively gentle slopes of the Nhlabane fishway, which reduce water velocities and turbulence, as well as the sloping baffles between pools creating areas of low water velocity. The position of the fishway entrance near the barrier (weir) is also vital as migratory biotas usually accumulate in this area and many previous fishways in South Africa have failed because the entrance was located too far downstream from the barrier (Bok, 1990). Upstream migratory fish normally also migrate in or near the edges of the main water flow, particularly on the edge of the flow in the case of small fish avoiding high water velocities and turbulence (Bok, 1997). In the Nhlabane estuary, this area of migration is against the banks of the estuary, where the fishway entrance is situated, thereby allowing small fish to locate the entrance more easily. It therefore appears that the Nhlabane fishway allows for the successful passage of small fish and macro-invertebrates, although it appears less suitable for larger individuals.

7.4.2.3 Seasonality

Recorded upstream migrations through the Nhlabane fishway peaked during January, October and November 2001, December 2002 as well as January 2003 (Figure 7.2). Migration through the fishway therefore appeared to coincide with the peak spring/summer recruitment period for most estuarine fish species (Whitfield, 1998; Wallace and Van der Elst, 1975; Kok and Whitfield, 1986; Harrison, 1998), as well as with periods of warmest water temperatures in the fishway (Figure 7.1).

Numbers of *O. mossambicus* in the fishway were highest during January and November 2001, although peak abundance in the estuary was recorded during June and September by Harrison (1998) during sampling in 1997. Upstream migration of *M. capensis* peaked in November 2001 and December 2003 (Figure 7.2). The peak recruitment period for *M. capensis* in KwaZulu-Natal estuaries is from August to December (Wallace and van der Elst, 1975; Blaber, 1987), indicating that this species migrates up the fishway shortly after recruitment into the estuary. Harrison (1998) recorded a peak abundance of *M. capensis* in the Nhlabane estuary during March and September to December of 1997. Peaks of upstream migration therefore appear to be a seasonal effect of recruitment and presence of fish in the estuary.

7.4.2.4 Day / night migration

Average numbers of fish migrating upstream per hour through the fishway during the day were almost five times those at night (Figure 7.3). A similar trend was found by Kotze *et al.* (1998) in fishways on freshwater systems in the Kruger National Park, where capture rates were much higher during daytime than at night. A study on the Kowie River also indicated that the majority of all migrating species used the fishway during daylight hours (Bok and Cambray 1995).

Intensive sampling between sunset and sunrise was limited due to security factors, but it is possible that less movement through the fishway occurred at night due to the presence of nocturnal predators. Large (> 400 mm TL) piscivorous fish such as *Lutjanus argentimaculatus*, *Acanthopagrus berda*, *Caranx sexfasciatus* and *M. cyprinoides* were observed actively feeding on fish entering the fishway from the estuary during early mornings and evenings. At least two of these species, *L. argentimaculatus*, and *A. berda* are known to be nocturnal hunters (Smith and Heemstra, 1991; Skelton, 1993) and this activity in the vicinity of the fishway may deter fish from moving into it at night. Other species known to be nocturnal hunters (Smith and Heemstra, 1991; Skelton, 1993) were also frequently observed near the fishway entrance in the estuary, these included *A. marmorata* and, during periods of low estuarine water salinity, *C. gariepinus*. Avian predators of small fishes such as the green backed heron *Butorides striatus* and the white fronted cormorant *Phalacrocorax carbo* (Newman, 1991) were also often observed hunting at or in the fishway entrances, particularly during early mornings.

7.4.2.5 Estuary water level

The numbers of migrating fish peaked at relatively high estuary water levels of 2 to 3 m AMSL (Figure 7.4), possibly due to the design of the fishway being such that the optimum entrance area was available at these estuary water levels. At estuary water levels lower than 2 m AMSL, the entrance area was much reduced, possibly making it more difficult for fish to

locate the entrance. At estuary water levels greater than 3 m AMSL, numbers of fish in the fishway decreased, possibly due to the bottom section of the fishway becoming flooded, spreading the flow of water down the fishway into the estuary over a larger area, and making it more difficult for migrants to locate the exact position of entry into the fishway.

7.4.2.6 Estuary water salinity

Average hourly numbers of migrants in the fishway peaked at estuary water salinities of 2 ppt (Figure 7.5). It is possible that fish in the estuary can more easily locate the fishway entrance during periods of high estuarine water salinity when there is a strong gradient between the freshwater flowing down the fishway and the saline estuarine water. However, a gradual gradient in salinity is more favourable for progressive adaptation to a change in the environment from saline to fresh water. In the case of a strong salinity gradient, fish find themselves confronted by a very sudden change from saline estuarine water to freshwater flowing down the fishway. The biological effects in terms of stress or mortality and behavioural responses which could delay or obstruct migration as a result of this sudden change are however still poorly understood or unknown (Larinier, 2002a) and may need further investigation to test the overall significance in the Nhlabane fishway.

7.4.2.7 Estuary mouth open / closed condition

Insufficient data are available to determine the significance, if any, of estuary mouth conditions or tidal effects on migration through the fishway, as mouth-open conditions occurred only briefly during the sampling period and followed near flood conditions driven by the pattern of sluice gate opening. While a link to the sea allows recruitment of juvenile fish a pattern of frequent flooding and breaching in combination with low salinity shocks due to an input of lake water did not provide a stable environment during the early part of the study. Overtopping through high wave action can bring in significant numbers of juvenile fish (Kok and Whitfield, 1986; Whitfield, 1992b; Vivier and Cyrus, 2001) but extended periods of closure and the bulldozing of sand to block off the estuary during the Jolly Rubino oil scare would have minimised links and therefore recruitment from marine breeding grounds to the estuary during the latter part of the study.

7.4.2.8 Fishway water flow

A redefinition of the relationship between water depth over baffle data and water flow volume (Appendix C), as well as conversion to water current speeds, fell beyond the scope of this study but may be useful in future studies. For the purpose of this study, only water flow volumes down the fishway were measured as water depth over baffle and used as an index of water flow speed to determine the effect on fish migration.

The volume of water flowing down the fishway during the 2001 - 2003 sampling period was generally less than 10 l/s. At water flow rates higher than approximately 40 l/s, water in the downstream half of the fishway no longer appeared to flow normally from pool to pool, but moved in an 'oscillating' or 'surging' motion, possibly due to increased turbulence. Sampling in the fishway also became increasingly difficult at higher water volumes as damage to traps was incurred at flows greater than approximately 40 l/s. Consequently only limited sampling was done at these high rates, although fish were still recorded migrating upstream during such times. More sampling in the fishway during high water flow volumes may be needed to confirm whether migration is influenced by this 'surging' effect.

It was found that between one and 40 l/s, the average number of upstream migrants per hour increased with an increase in flow rate (Figure 7.6). This pattern was independent of season and broadly similar for all three numerically dominant upstream migrant species, although in the case of the resident *O. mossambicus* larger individuals were more common at higher flow rates. Of the migratory species *M. capensis* was markedly more abundant at flow rates of 10-40 l/s. *M. falciformis* was rare at flows <5 l/s but occurred consistently at flows of 5-40 l/s.

Higher flow might assist fish to locate the entrance of the fishway in the estuary. The presence of fish, and large specimens in particular, in the upper half of the fishway during periods of low flows indicated that fish can successfully negotiate the fishway at flows of less than 5 l/s, but increased flow presumably makes location of the fishway entrance easier. An increased freshwater stimulus from operational attraction / auxiliary water pipes may therefore aid migrants in locating the fishway entrance, while a range of flow rates would still suffice for successful negotiation of the fishway itself. This may be particularly useful if it is found that crab megalopae and prawns can only successfully negotiate the fishway at low flow volumes, in which case low flow volumes down the fishway can be supplemented with water down the attraction / auxiliary pipes to attract fish to the fishway entrance. These attraction / auxiliary pipes may however also cause a sufficient increase in water currents and turbulence around the fishway entrance to impact negatively on migration. In order to determine their effect, the flood-damaged and neglected attraction / auxiliary water pipes on the Nhlabane fishway need to be repaired and their influence on upstream migrants tested.

Fish from all size classes recorded in the fishway were found at all flow levels. Fish as small as 10 - 20 mm TL were recorded in the middle of the fishway (pool 81; Appendix B) at water flow volumes as high as 90 l/s. Fish of 225 - 300 mm TL were recorded at volumes of less than 5 l/s in the middle of the fishway, with a size range of 13 - 210 mm TL at flow rates as high as 90 l/s. The design of the Nhlabane fishway therefore is such that fish of all size classes recorded in the fishway can negotiate the fishway successfully under a wide range of water flow rates.

As fish swimming speed is directly related to body length, small fish of 15 to 75 mm TL generally do not reach swimming speeds of more than 1 m/s (Bok, 1997). In the absence of water flow velocity data, it was assumed that at the range of flow rates recorded in the fishway, water velocities did exceed 1 m/s, particularly at high water volumes. The presence of small fish in the fishway at high water flow rates therefore indicates that the design of the fishway is such that there are areas of low water velocities allowing small, weakly-swimming fish to negotiate the entire length of the fishway. This is due to the sloping, forward-facing baffles between pools creating a range of water depths and velocities, as well as the coarse inner surfaces increasing friction and reducing water velocities. At flow rates of approximately one to 40 l/s a splash zone was also available on baffles between pools for climbing and crawling species such as the prawns and larval crabs. At flow rates greater than approximately 40 l/s water flowed over the entire length of the baffle, covering this splash zone. This effect at high flow volumes may negatively affect macro-invertebrate migration but did not seem to have a negative impact on fish migrants.

7.4.2.9 Fishway trap position

During the sampling period, fish were caught from traps placed in the middle to upper section of the fishway (pools 81 and 82; Appendix B) and occasionally from traps placed at the first

bend in the fishway, near the entrance in the estuary. It was found that the average number of upstream migrants recorded per hour in the middle of the fishway was higher than at the entrance. This indicates that fish could negotiate the first half of the fishway successfully and were not entering the fishway and finding it difficult or impossible to negotiate the initial steeper gradient. To keep all factors possibly influencing fish migration as consistent as possible, only data from days when traps were set in both positions on the same day, as well as from traps when water flow volumes were between 10 and 20 l/s were used.

The section of the fishway from the halfway point (pool 80; Appendix B) to the entrance in the lake has a shallower gradient than the first half and fish could easily negotiate this section. One area of concern was the last chamber of the fishway where upstream migrants moved from the fishway into the lake. As the lake water level fluctuated on a daily or weekly basis, the relevant intake sluice on the fishway had to be opened or closed manually to ensure that the final 'step' between the last fishway chamber and the lake was not too steep. This steep 'step' was usually observed at low flow rates down the fishway (< 10 l/s) at high lake levels (5.9 m) when the intake sluice was partially closed to control the amount of water flowing down the fishway. Following a drop in lake level due to a change in wind direction or decrease in wind speed after a strong north-easterly, sufficient water still flowed down the fishway to allow for upstream migration through the fishway, but the partially closed intake sluice formed a barrier preventing fish from moving out of the fishway into the lake. This problem could be easily solved by either operating the fishway at higher water flow volumes (> 20 l/s) where a slight decrease in lake level does not create this effect, or by routine daily checks and manual manipulation of the intake sluice at low flow volumes. Fish were observed successfully moving from the last fishway chamber into the lake when this 'step' was not present.

7.4.2.10 Fishway 'timed-run' experiment

Assuming that all fish exited the fishway into the lake during the 15 hours that the fishway was blocked off at the entrance at the estuary end, and that the fish recorded in pool 82 were the same individuals released into the fishway at the estuary entrance, which was assumed to be the case as the sizes corresponded exactly, it can be estimated that fish can migrate upstream through the fishway from the entrance to pool 82 in approximately five minutes. This section of the fishway has the steepest gradient and it can be safely assumed that fish can migrate from pool 82 to the exit into the lake in no more than five minutes. The total time taken for fish to migrate upstream through the fishway can therefore be estimated at around 10 minutes or possibly even less.

Further experiments with a wider range of sizes and species of fish are needed to confirm this time, as well as to determine the effect, if any, of size and species of fish on the time taken to migrate through the fishway. Tagging could be considered as it would eliminate assumptions regarding the 'identity' of individual fish and allow for experiments that are more accurate with a larger variety of specimens.

7.5 RECOMMENDATIONS AND CONCLUSIONS

7.5.1 FISHWAY DESIGN, MANAGEMENT AND MAINTENANCE

7.5.1.1 Design

The Nhlabane fishway was found to allow for the successful passage of fish over a size range of at least 10 to 310 mm TL. Fishway design is thought to be partly responsible for the upper size limit of upstream fish migrants, but caters well for small and juvenile specimens which are more likely to move between the estuary and upstream freshwater habitat. The design of the fishway caters well for fish within this size range at water flow volumes of between 1 and 40 l/s and even as high as 90 l/s. Fishway water volume affected the numbers, by affecting the location of the entrance by migrants, but not size classes of upstream migrants. Optimum flow down the fishway is regarded as around 20 to 40 l/s.

Fishway design is also thought to result in higher numbers of upstream migrants at estuary water levels of 2 to 3 m AMSL due to an optimum entrance area available at this level, although migration can still take place at lower and higher levels that occur much less often. The position of the entrance of the fishway near the barrier weir is also regarded as optimum for migratory biota to locate and enter the fishway.

The fishway exits in the lake operate at a range of lake levels, allowing upstream migrants entry into the freshwater habitat. Extensive sampling of the lake fell beyond the scope and logistics of this study, but during the 2002 / 2003 sampling, several mugilids - possibly *Myxus capensis* - of approximately 200 to 300 mm TL were observed in the shallows immediately upstream of the weir in the lake. As no mugilids of this size were recorded in the fishway, this strongly indicates that fish are successfully negotiating the fishway and exiting and surviving in the lake. An area of concern is the lack of data on fish species in Lake Nhlabane at present, combined with the opinion of local subsistence and recreational angler that none of the species of marine origin thought to utilise the fishway have returned to the lake.

The timed-run experiment, although not conclusive, indicated that the design of the fishway is such that migrants can negotiate the entire length of the fishway in a remarkably short time. This is significant as it confirms that fish do not accumulate at points in the fishway, and suggests that fish do not exit the fishway unduly exhausted or stressed.

7.5.1.2 Management and Maintenance

Upstream migration peaked during the warmer spring and summer months due to the seasonal presence and migration of fish in the estuary, while fish were more likely to find the fishway entrance at higher estuary water salinity. Behavioural response of migrants is thought to have resulted in the higher number of migrants during daylight hours. Should management of the Nhlabane system require water saving measurements to be put into place, optimum use of water down the fishway could be made by ensuring that flows down the fishway coincide with such periods of peak migration.

One of the most frequent causes of malfunctioning of fishways is inadequate maintenance (Larinier, 2002b). In order to ensure effective operation of the Nhlabane fishway, daily monitoring of the fishway is therefore necessary. Inlet sluice height needs to be monitored

daily, especially during active migration periods, to adjust water flow volume according to conditions and to prevent a steep 'step' from forming between the last fishway chamber and exit in the lake. Debris blocking fishway chambers and entrances should be cleared on a daily or at least a weekly basis. The growth of terrestrial plants over the fishway, particularly on the estuary side, needs to be checked and cleared when necessary to ensure uninterrupted flow of water down the fishway.

Although few data are available to demonstrate the significance of predation on migration through fishways, Larinier and Travade (2002) state that predation may have a significant impact on mortality rates of fish migrating through fishways. While not much can be done to prevent predation on Nhlabane fishway migrants, ensuring that the steel mesh gratings covering the fishway remain in place will deter avian predators from entering the fishway in areas other than the entrance / exit. In addition, ensuring that 'optimum' conditions for migration are available for migrants in the fishway should minimise stress and exhaustion rates and make migrants less vulnerable to such predation.

Recreational and particularly subsistence fishing is on the increase in the Nhlabane estuary and lake. Due to the concentration of fish near the fishway entrances, fishing in the area surrounding these entrances can be very damaging to the proper functioning of the fishway by removing vulnerable species. The presence of humans near these entrances was also found to act as a deterrent to migratory biota entering the fishway. The use of gill nets by "subsistence" anglers is escalating at an alarming rate indicating minimal control of this activity in both the estuary and the lake and possible long-term impacts on the ichthyofauna of the Nhlabane system. The use of gill nets near the fishway entrances is becoming more frequent; the resulting disturbance renders the fishway useless as a passage for migratory fish and should be prevented at all costs. It is recommended that no fishing, netting or bait-collecting be allowed in the area immediately downstream of the fishway entrance in the estuary, while the use of gill-nets should be banned in the estuary and controlled in the lake.

The University of Venda for Science and Technology (UNIVEN) were commissioned to monitor the Xikundu fishway in the Luvuvhu River and to comment on the applicability of the design.

8. XIKUNDU FISHWAY MONITORING

8.1 INTRODUCTION AND TERMS OF REFERENCE

The experiences of the fish biologists and ecologists of the project team working in conjunction with DWAF engineers used the design criteria and process suggested by Bok *et al.*, (2004) to construct the Xikundu fishway on the Luvuvhu River (Plate 8.1). This fishway was completed in mid 2003. The fishway at Xikundu is a typical pool-type fishway with notched baffles. The fishway consists of three distinct sections with ten pools in the upper, four pools in the middle and nine pools in the lower section. These notches are offset and are constructed to function in way similar to Monk traps where the flow can be regulated by slotting in or taking out the specially constructed concrete slats. The fishway was built so that the deep pools enable the fish to rest before moving up. This fishway has been designed to enable easy monitoring (Plate 8.1).



Plate 8.1: A view of the three sections of the Xikundu fishway

8.2 METHODS AND MATERIALS

8.2.1 Approach

As part of the monitoring programme the following typical questions had to be answered:

- What species, and numbers, of fish and invertebrates use the fishway?
- When do these species move?
- Does the fishway allow organisms to move up and down?
- How long does it take them to move?

- What is the optimum flow rates at which the fishway functions?

It was decided to concentrate on the first two questions listed above during the first year of the project which is reported on in this report. The first year would then also function as a learning exercise in monitoring for UNIVEN and allow time to purchase and construct the necessary equipment. It was decided to embark on a "long term-low intensity" monitoring approach for the first twelve months (May 2004 - April 2005). This approach would help to establish periods of increasing, or peak, migration that occur in the river. This data could be used to determine the environmental cues for fish migration.

This "low intensity" monitoring would then be followed by a period of "intensive short term" monitoring in 2005/2006 aimed at addressing the last three questions above and enabling comments on the design. The protocol of the second monitoring period would largely be shaped by the findings of the first monitoring period. The results of the second phase of this survey will be presented in the WRC Project No. K5/1409.

A desktop study was also undertaken before onset of monitoring to determine the fish diversity in the relevant river reach. This was used to determine the migratory status of the species present.

8.2.2 Monitoring frequencies

As part of the low intensity approach it was decided to monitor the fishway once per month for a 24-hour period at intervals of four hours. The monitoring commenced in May 2004 and concluded in April 2005.

8.2.3 Format of field forms

The data collection sheets developed for the Nhlabane fishway were adapted and used for the Xikundu fishway data collection. (Appendices F to H).

8.2.4 On-site determinations

- a) Weather: At each four-hour interval the following weather conditions were measured on site and recorded: Cloud cover, wind direction and rain. Due to a delay in the delivery of ordered equipment atmospheric pressure were measured in February, March and April 2005 only.
- b) Fishway: During each site visit the pH, water temperature, conductivity and dissolved oxygen was determined on site using a Hannah pHep3 pH meter, a Check temp thermocouple, a Hannah HI 8733 conductivity meter and a WTW Oxi-320 oxygen meter respectively. Care was taken to calibrate the oxygen and conductivity meters before each reading according to the measured water temperature.
- c) Physical aspects and hydraulic data. The water height on the baffle (or over the baffle when overflowing), the depth of the water in the pool, the depth of the water over the notch as well as the water velocities were determined once during each site visit. These velocities were measured in the pool and notch. In the notch it was measured directly above the "floor of the notch", midway in the stream of water and just below the surface of the water flowing over the baffle. Depths and heights were determined with a flat steel meter rule and velocities with a Pasco Scientific velocity meter.

- d) The width of the inlet notch of the fishway was measured once off and during each survey the height of the water flowing through this notch was measured and recorded. The maximum water velocity was then determined in the notch with a Science Workshop velocity meter as meters per second and the discharge (Q) was then calculated using the formula below and expressed in cumec (cubic meters per second):

$$Q = (\text{Water height in notch in meters}) \times (\text{width of notch in meters}) \times (\text{maximum velocity in notch}).$$

- e) A water sample was collected during each site visit and transported to the laboratory for chemical analysis.

8.2.5 Collection of biota

Biota were collected from three pools in the middle and lower section and from six pools in the upper section. In the upper section pools 2, 3 and 4 from the exit of the fish way and the three pools closest to the middle section were monitored. Each set of three pools was closed off at the upstream end with a steel-framed net that fitted in the pre-cast grooves of the notch. At the down stream end of the set of pools a metal framed net with a long bag was fitted into the groove (Plate 8.2). The set of pools was then shocked for 10 minutes, the biota collected from the long bag and placed in plastic buckets with water. Fish that did not wash into the nets were collected with long - handled scoop nets and added to the buckets. Care was taken to label the buckets according to the section where the fish were collected and the time of collection. These buckets were then taken to a sorting table where the species were identified and each individual specimen weighed and measured. The data collected were recorded on a field form (see Appendix H). Representative samples of the different size classes of each species were preserved, labelled and transported to the laboratory. The remaining fish were then released back into the river. Fish collected in the middle and upper sections were placed near the fishway exit while those from the lower section were returned to the area near the entrance of the fishway.

With regard to the invertebrates collected in the nets only the organisms belonging to the order Decapoda was identified and recorded. Other than voucher specimens no samples were kept and the organisms were returned to the river.



Plate 8.2: Placement of the long-bagged net in the notch of the baffle

8.2.6 Laboratory determinations

8.2.6.1 Water analyses

In the laboratory, the turbidity of the water was determined from the water sample collected at each site with an Analite Novasino nephelometer using double distilled water as a standard. To determine the Total Suspended Solids (TSS) a 250ml sub-sample of the water sample was filtered through an oven dried filter paper of a predetermined mass. The filter paper was then dried overnight at 60°C and the increase in mass determined on a Sartorius Handy microbalance to the fourth decimal point. The increase in mass was then expressed as mg/l. The total dissolved salts (TDS) was determined by drying 200 ml of the filtered water sample overnight in a glass beaker with predetermined mass. The increase in mass was then determined and expressed as mg l^{-1} .

8.2.6.2 Biota

In the laboratory the representative fish samples were varifiedand then dissected to expose the viscera and gonads. All the data collected was recorded on a laboratory data form (see Appendix H).

The condition of the fish

In order to express the condition of the fish two aspects namely i) the scale of intestinal fat content and ii) the condition factor were considered. After the viscera have been exposed, the fat deposits surrounding the intestines were assessed and classified according to the scale proposed by Nikolsky (1963). The scale and its criteria are shown in Table 8.1.

The condition of the fish was then expressed by calculating the body mass to body length ratio as a percentage. The Condition Factor (CF) of each specimen was also calculated with the use of the formula used by De Villiers (1991):

$$\text{CF} = \frac{\text{Fish mass}}{L^b} \times 100$$

Where b = exponential derivative that refers to the length mass relationship.

Table 8.1: The scale of fat deposition (Adapted from Nikolsky, 1963)

Fat content scale	Description
Unit 0	No fat present
Unit 1	Thin cord-like strips/globules of fat appearing between the segments/folds of the intestines.
Unit 2	Strips start joining to form dense fat.
Unit 3	Strips that have joined started “growing over” the intestines. Intestines are being covered by fat.
Unit 4	Intestines almost completely covered by fat. No gaps seen.
Unit 5	Intestines completely covered by fat. No gaps seen.

In most cyprinids the length to relationship is usually expressed as follows $L^b = L^3$ (Hamman, 1981, Fouche, 1995). This would imply that in the case of this genus L^3 could be applied. According to Gaigher (1969 and *pers. com*) the body mass to length relationship in the case of *Hydrocinus vittatus* is best described by the formula $W = 0,09852 L^{3,1261}$. This would imply that an exponential derivative of 3 could also be applied in the case of the characidae collected in this survey.

Gonadal development and sexual maturity

After determining the fat content, the intestines were removed to expose the gonads. Gonadal development was then classified according to the prescriptions of De Villiers (1991) shown in Table 8.2. The gonads were then carefully removed and weighed to the nearest 0,0001 g. The reproductive seasonality was then determined by calculating the monthly Gonadosomatic Index (GSI) values (De Villiers, 1991) using the formula:

$$\text{GSI} = \frac{\text{Gonad mass (g)}}{\text{Total fish mass (g)}} \times \frac{100}{1}$$

Table 8.2: The gonadal maturity classes of fish. (De Villiers, 1991)

Maturity Classes		Description
1.	Virgin	Sexual organs small, both ovaries and testis are white, no eggs visible
2.	Developing	Size increase in both male and female, colour changes to cream; eggs visible. Eggs are of various sizes
3.	Ripe	Size increase in both male and female. Testis appear swollen and is cream in colour. Ovaries increase dramatically and occupy large amount or volume of abdominal cavity. Large eggs are visible.
4.	Spent	A marginal size decrease in testis, but still cream in colour, Ovaries decrease in size and in size of eggs.

In order to determine the Maturity Coefficient (MC) of the fish sampled, calculations were made using the following method described by Gaigher (1978) and the formula shown below was used:

$$\text{MC} = \frac{\text{Gonad mass (g)}}{\text{Fish length (cm)}^3} \times 10^4$$

Samples of ovaries belonging to different maturity classes were also preserved. The egg sizes will be determined from these samples using the methods suggested by Gaigher (1976) during the second phase of the project.

In the majority of the fish the stomachs were also removed and preserved so that the feeding habits of the fish could be determined through stomach content analyses.

8.3 RESULTS

8.3.1 The construction of the Xikundu fishway

The fishway at Xikundu is a typical pool-type fishway with notched baffles. These notches are offset which allows for dissipation of the energy and creation of resting areas for the fish where the water velocity is greatly reduced (Plate 8.3). The notches are constructed to function in a way similar to Monk traps where the flow can be regulated by slotting in or taking out the specially constructed concrete slats. During the monitoring period, one slat had been fitted into the notches.



Plate 8.3: Flow pattern in the fishway

The fishway consists of three distinct sections with ten 1.2 m deep pools in the upper, four pools in the middle and nine pools in the lower section (Plate 8.1). The pools are all 2,4 m wide and approximately 2.2 m long. The sections are at right angles to one another with two slightly larger “joining pools” (2.6 X 2.35 m) between the upper and middle and two between the middle and lower sections. The downstream entrance to the fishway is constructed with large boulders to guide the fish into the fishway (Plate 8.4).

8.3.2 Fish diversity in the river reach

Table 8.3 shows the fish diversity observed in surveys of the River Health Programme exercise in 1999. This was used as a reference at this point because of the involvement of the project leader. Although these were not full surveys in the true sense of the word, it does give some indication of the fish biodiversity in the river reach. For the final report, a full survey of the historical collection data will be used. Fish specimens were also collected in the river immediately up and down stream of the fishway. In this survey a seine net, cast net and electro-fisher were used to collect the fish. The species collected are indicated with an * in Table 8.3. Gaigher in DWAF (1999) listed 25 species that he regarded to be still present in the river reach where the fishway is built. He does not list *Chiloglanis engiops*, *Glossogobius guirius* or *Hydrocynus vittatus* but includes *Barbus toppini*, *Labeo congoro*, *L. rosae*, *L. ruddi* and *Schilbe intermedius* (Table 8.3).



Plate 8.4: Entrance of the fishway

8.3.3 The migratory status of the species collected

Ten of the species collected in the river reach are regarded as migratory. According to Skelton (2001) only *Anguilla mossambica* is catadromous and migrate over long distances. The other ten species *Chiloglanis paratus*, *C. pretoriae*, *Hydrocynus vittatus*, *Labeobarbus marequensis*, *Labeo cylindricus*, *L. molybdinus*, *Micralestes acutidens*, *Marcusenius macrolepidotus* and *Petrocephalus wesselsii* are local migrators that migrate for reproductive or feeding reasons during late spring or summer.

8.3.4 Monitoring frequency

The fishway was monitored seven times in 2004 and four times in 2005:

- 17-18 May,
- 17 – 18 June
- 22 – 23 July,
- 6 – 27 August
- 27 –28 September
- 29 – 30 October
- 20 – 21 November, as well as four times in 2005:
- 19 – 20 January
- 23 – 24 February
- 17 – 18 March
- 20 – 21 April.

Due to logistical reasons it was not possible to start the monitoring at the same time during each session. Although it was not planned as such, the feeling is that a full spread over the 24 hours was thus obtained. As stated in the materials and methods the fishway was monitored every four hours during each session.

8.3.5 Fish collected in the fishway

In Table 8.3 the fish collected in all the pools and in all the sessions are combined to illustrate the number of fish utilizing the fishway. Twenty species which included nineteen of the possible twenty-eight species that occur in the river reach as well as *Opsaridium peringueyi*, that had not been recorded previously, were collected in the fishway. As only one sample of each of *Amphilius uranoscopus*, *Barbus unitaeniatus* and *Petrocephalus wesselsii* was collected it would appear as if these species are not utilizing the fishway. This also seems to be the case with *Glossogobius guirius* (where only a few samples were collected on four occasions), *Marcusenius macrolepidotus*, (only collected in November), *Tilapia rendalii* and *Pseudocrenilabrus philander* (collected on two and four occasions respectively) as well as with *O. peringueyi*. These species could be regarded as occasional users of the fishway. *Barbus trimaculatus*, *Chiloglanis engiops*.

Table 8.3: Scientific, English common names and abbreviations for fish species collected in the Luvuvhu River during the 1999 River Health Programme monitoring at the downstream sites at Lambani and Mhinga and upstream at Botsoleni. This fish species marked with an * were collected immediately downstream and upstream of the fishway during the 2004 fishway survey

Scientific name	Common name	Abbreviation	Botso- leni	Mhinga	Lambani
<i>Amphilius uranoscopus</i>	Mountain catfish	AURA		4	4
<i>Anguila mossambica</i>	Longfin eel	AMOS	4		
<i>Barbus paludinosus</i>	Straightfin barb	BPAU	4		
* <i>Barbus trimaculatus</i>	Threespot barb	BTRI	4	4	4
<i>Barbus unitaeniatus</i>	Longbeard barb	BUNI	4		
* <i>Barbus viviparus</i>	Bowstripe barb	BVIV	4	4	
<i>Chiloglanis engiops</i>	Lowveld suckermouth	CENG	4	4	
* <i>Chiloglanis paratus</i>	Sawfin suckermouth	CPAR	4	4	
* <i>Chiloglanis pretoriae</i>	Shortspine suckermouth	CPRE	4	4	4
<i>Clarias gariepinus</i>	Sharptooth catfish	CGAR	4	4	4
<i>Glossogobius guirius</i>	Tank goby	GGUI	4		
* <i>Hydrocynus vittatus</i>	Tigerfish	HVIT	-	-	-
* <i>Labeobarbus marequensis</i>	Largescale lowveld yellowfish	LMAR	4	4	4
* <i>Labeo cylindricus</i>	Redeye labeo	LCYL	4	4	4
* <i>Labeo molybdinus</i>	Leaden labeo	LMOL	4	4	4
* <i>Micralestes acutidens</i>	Silver robber	MACU	4	4	
* <i>Mesobola brevianalis</i>	River sardine	MBRE	4	4	
<i>Marcusenius macrolepidotus</i>	Bulldog	MMAC			4
* <i>Oreochromis mossambicus</i>	Mozambique tilapia	OMOS	4		4
<i>Petrocephalus wesselsii</i>	Churchill	PWES	4		4
* <i>Pseudocrenilabrus philander</i>	Southern mouthbrooder	PPHI	4	4	
<i>Tilapia rendalli</i>	Redbreast tilapia	TREN			4
<i>Tilapia sparrmanii</i>	Banded tilapia	TSPAR	4		

Table 8.4: Fish collected in the Xikundu fishway during the period May 2004 to April 2005.

Species	Number collected										
	May	Jun	Jul	Aug	Sep	Oct	Nov	Jan	Feb	Mar	Apr
<i>Amphilius uranoscopus</i>	0	0	0	1	0	0	0	0	0	0	0
<i>Anguila mossambica</i>	0	0	0	0	1	0	0	0	0	0	0
<i>Barbus trimaculatus</i>	0	1	0	0	0	17	3	18	0	2	12
<i>Barbus unitaeniatus</i>	0	0	0	1	0	0	0	0	0	0	0
<i>Barbus viviparus</i>	5	0	0	1	1	3	1	16	1	4	5
<i>Chiloglanis engiops</i>	0	8	1	0	0	0	18	0	1	6	7
<i>Chiloglanis paratus</i>	12	7	13	2	2	1	4	2	0	1	1
<i>Chiloglanis pretoriae</i>	147	180	42	80	24	11	20	27	4	12	18
<i>Glossogobius guirius</i>	0	0	0	2	0	0	0	0	1	1	5
<i>Labeobarbus marequensis</i>	23	26	22	28	154	161	41	46	24	52	86
<i>Labeo cylindricus</i>	28	23	7	5	1	5	48	47	24	52	22
<i>Labeo molybdinus</i>	21	18	3	3	5	70	23	22	26	10	31
<i>Marcusenius macrolepidotus</i>	0	0	0	0	0	0	14	0	0	0	0
<i>Micralestes acutidens</i>	2	3	0	0	22	56	55	144	119	222	167
<i>Mesobola brevianalis</i>	26	0	0	26	0	73	13	57	82	100	159
<i>Opsaridium peringueyi</i>	0	0	0	0	0	0	0	0	4	3	10
<i>Oreochromis mossambicus</i>	6	3	42	0	1	16	6	7	29	24	2
<i>Petrocephalus wesselsii</i>	0	0	0	0	0	0	1	0	0	0	0
<i>Pseudocrenilabrus philander</i>	1	0	0	1	0	4	0	0	0	0	0
<i>Tilapia rendalii</i>	0	0	0	0	0	1	0	0	0	0	10
Total species	10	8	7	11	8	12	13	10	11	13	14

Barbus trimaculatus, *Chiloglanis engiops*, *C. paratus*, *C. pretoriae*, *Labeobarbus marequensis*, *Labeo cylindricus*, *L. molybdinus*, *Micralestes acutidens*, *Mesobola brevianalis* and *Oreochromis mossambicus* were collected in 55% or more of the monitoring sessions. Changes in the numbers collected in the majority of these species could be construed as patterns were observed. The relationships of these patterns with physiological aspects will be discussed at a later stage. It is however disturbing that only one specimen of *Anguilla mossambica* was collected but this could be ascribed to the absence of migration which in turn could be the result of river fragmentation or the absence of floods or even freshets.

Tables 8.5 to 8.15 show the fish collected in the lower and upper sections of the fishway during the four monitoring sessions. These tables are included to give an indication of possible movement through the fishway. The data shown in Table 8.9 illustrates that *M. macrolepidotus* and *P. wesselsii* had entered the fishway, seemingly from the impounded area, and were not moving through at all.

Table 8.5: Fish species collected in the upper and lower sections of the Xikundu fishway during the May 2004 monitoring session

Lower section	Upper section
<i>Barbus viviparus</i>	
<i>Chiloglanis engiops</i>	
<i>Chiloglanis paratus</i>	<i>Chiloglanis paratus</i>
<i>Chiloglanis pretoriae</i>	<i>Chiloglanis pretoriae</i>
<i>Labeobarbus marequensis</i>	<i>Labeobarbus marequensis</i>
<i>Labeo cylindricus</i>	<i>Labeo cylindricus</i>
<i>Micralestes acutidens</i>	<i>Labeo molybdinus</i>
<i>Mesobola brevianalis</i>	
<i>Oreochromis mossambicus</i>	

Table 8.6: Fish species collected in the upper and lower sections of the Xikundu fishway during the June 2004 monitoring session

Lower Section	Upper Section
	<i>Barbus trimaculatus</i>
<i>Chiloglanis engiops</i>	<i>Chiloglanis paratus</i>
<i>Chiloglanis paratus</i>	<i>Chiloglanis pretoriae</i>
<i>Chiloglanis pretoriae</i>	<i>Labeobarbus marequensis</i>
<i>Labeobarbus marequensis</i>	<i>Labeo molybdinus</i>
	<i>Micralestes acutidens</i>
<i>Labeo molybdinus</i>	<i>Oreochromis mossambicus</i>

Table 8.7: Fish species collected in the upper and lower sections of the Xikundu fishway during the May 2004 monitoring session. ** = From 16h15 to 22h15 the majority were collected in the upstream net of each section)

Lower Section	Upper Section
	<i>Chiloglanis engiops</i>
<i>Chiloglanis paratus</i>	<i>Chiloglanis paratus</i>
<i>Chiloglanis pretoriae</i>	<i>Chiloglanis pretoriae</i>
<i>Labeobarbus marequensis</i>	<i>Labeobarbus marequensis</i>
<i>Labeo cylindricus</i>	<i>Labeo cylindricus</i>
	<i>Labeo molybdinus</i>
<i>Mesobola brevianalis</i>	
<i>Oreochromis mossambicus</i>	<i>Oreochromis mossambicus</i> **

Table 8.8: Fish species collected in the upper and lower sections of the Xikundu fishway during the August 2004 monitoring session.

Lower Section	Upper Section
<i>Amphilius uranoscopus</i>	<i>Barbus viviparus</i>
<i>Chiloglanis pretoriae</i>	<i>Chiloglanis pretoriae</i>
<i>Glossogobius guirius</i>	<i>Labeobarbus marequensis</i>
<i>Labeobarbus marequensis</i>	<i>Labeo cylindricus</i>
<i>Labeo cylindricus</i>	<i>Labeo molybdinus</i>
<i>Mesobola brevianalis</i>	<i>Mesobola brevianalis</i>
	<i>Pseudocrenilabrus philander</i>

Table 8.9: Fish species collected in the upper and lower sections of the Xikundu fishway during the September 2004 monitoring session.

Lower Section	Upper Section
<i>Barbus viviparus</i>	<i>Chiloglanis paratus</i>
<i>Chiloglanis pretoriae</i>	<i>Chiloglanis pretoriae</i>
<i>Labeobarbus marequensis</i>	<i>Labeobarbus marequensis</i>
	<i>Labeo cylindricus</i>
<i>Labeo molybdinus</i>	<i>Labeo molybdinus</i>
<i>Micralestes acutidens</i>	<i>Micralestes acutidens</i>

Table 8.10: Fish species collected in the upper and lower sections of the Xikundu fish way during the October 2004 monitoring session.

Lower Section	Upper Section
<i>Barbus viviparus</i>	<i>Barbus trimaculatus</i>
<i>Barbus trimaculatus</i>	<i>Chiloglanis swierstrai</i>
<i>Chiloglanis pretoriae</i>	<i>Chiloglanis pretoriae</i>
<i>Labeobarbus marequensis</i>	<i>Labeobarbus marequensis</i>
	<i>Labeo cylindricus</i>
<i>Labeo molybdinus</i>	<i>Labeo molybdinus</i>
<i>Micralestes acutidens</i>	<i>Micralestes acutidens</i>
<i>Mesobola brevianalis</i>	<i>Mesobola brevianalis</i>
<i>Oreochromis mossambicus</i>	<i>Oreochromis mossambicus</i>
<i>Pseudocrenilabrus philander</i>	<i>Pseudocrenilabrus philander</i>

Table 8.11: Fish species collected in the upper and lower sections of the Xikundu fish way during the November 2004 monitoring session.

Lower Section	Upper Section
<i>Barbus viviparus</i>	<i>Barbus viviparus</i>
<i>Chiloglanis engiops</i>	<i>Barbus trimaculatus</i>
<i>Chiloglanis paratus</i>	<i>Chiloglanis engiops</i>
<i>Chiloglanis pretoriae</i>	<i>Chiloglanis pretoriae</i>
<i>Labeobarbus marequensis</i>	<i>Labeobarbus marequensis</i>
<i>Labeo cylindricus</i>	<i>Labeo cylindricus</i>
<i>Labeo molybdinus</i>	<i>Labeo molybdinus</i>
	<i>Marcusenius macrolepidotus</i>
<i>Micralestes acutidens</i>	<i>Micralestes acutidens</i>
<i>Mesobola brevianalis</i>	<i>Mesobola brevianalis</i>
	<i>Oreochromis mossambicus</i>
	<i>Petrocephalus wesselsii</i>

Table 8.12: Fish species collected in the upper and lower sections of the Xikundu fish way during the January 2005 monitoring session.

Lower Section	Upper Section
<i>Barbus viviparus</i>	<i>Barbus viviparus</i>
<i>Barbus trimaculatus</i>	<i>Barbus trimaculatus</i>
<i>Chiloglanis pretoriae</i>	<i>Chiloglanis pretoriae</i>
<i>Labeobarbus marequensis</i>	<i>Labeobarbus marequensis</i>
<i>Labeo cylindricus</i>	<i>Labeo cylindricus</i>
<i>Labeo molybdinus</i>	<i>Labeo molybdinus</i>
<i>Micralestes acutidens</i>	<i>Micralestes acutidens</i>
<i>Mesobola brevianalis</i>	<i>Mesobola brevianalis</i>
<i>Oreochromis mossambicus</i>	<i>Oreochromis mossambicus</i>

Table 8.13: Fish species collected in the upper and lower sections of the Xikundu fish way during the February 2005 monitoring session.

Lower Section	Upper Section
<i>Chiloglanis engiops</i>	<i>Chiloglanis pretoriae</i>
<i>Chiloglanis pretoriae</i>	<i>Labeobarbus marequensis</i>
<i>Labeobarbus marequensis</i>	<i>Labeo cylindricus</i>
<i>Labeo cylindricus</i>	<i>Labeo molybdinus</i>
<i>Labeo molybdinus</i>	<i>Micralestes acutidens</i>
<i>Micralestes acutidens</i>	<i>Mesobola brevianalis</i>
<i>Mesobola brevianalis</i>	<i>Opsaridium peringueyi</i>
<i>Opsaridium peringueyi</i>	<i>Oreochromis mossambicus</i>
<i>Oreochromis mossambicus</i>	

Table 8.14: Fish species collected in the upper and lower sections of the Xikundu fish way during the March 2005 monitoring session.

Lower Section	Upper Section
<i>Barbus viviparus</i>	<i>Barbus viviparus</i>
<i>Chiloglanis swierstrai</i>	<i>Barbus trimaculatus</i>
<i>Chiloglanis pretoriae</i>	<i>Chiloglanis swierstrai</i>
<i>Labeobarbus marequensis</i>	<i>Chiloglanis pretoriae</i>
<i>Labeo cylindricus</i>	<i>Glossogobius guirius</i>
<i>Labeo molybdinus</i>	<i>Labeobarbus marequensis</i>
<i>Micralestes acutidens</i>	<i>Labeo cylindricus</i>
<i>Mesobola brevianalis</i>	<i>Labeo molybdinus</i>
<i>Oreochromis mossambicus</i>	<i>Micralestes acutidens</i>
	<i>Mesobola brevianalis</i>
	<i>Opsaridium peringueyi</i>
	<i>Oreochromis mossambicus</i>

Table 8.15: Fish species collected in the upper and lower sections of the Xikundu fish way during the April 2005 monitoring session.

Lower Section	Upper Section
<i>Barbus viviparus</i>	<i>Barbus viviparus</i>
<i>Barbus trimaculatus</i>	<i>Barbus trimaculatus</i>
<i>Chiloglanis engiops</i>	<i>Chiloglanis engiops</i>
<i>Chiloglanis paratus</i>	
<i>Chiloglanis pretoriae</i>	<i>Chiloglanis pretoriae</i>
<i>Glossogobius guirius</i>	<i>Glossogobius guirius</i>
<i>Labeobarbus marequensis</i>	<i>Labeobarbus marequensis</i>
<i>Labeo cylindricus</i>	<i>Labeo cylindricus</i>
<i>Labeo molybdinus</i>	<i>Labeo molybdinus</i>
<i>Micralestes acutidens</i>	<i>Micralestes acutidens</i>
<i>Mesobola brevianalis</i>	<i>Mesobola brevianalis</i>
<i>Opsaridium peringueyi</i>	<i>Opsaridium peringueyi</i>
<i>Tilapia rendalii</i>	

In Figure 8.1 the number of fish of five of the migratory species collected in the upper and lower sections of the fishway are shown as a percentage of the total number of fish collected during the seven months during which migratory patterns had been observed.

In *L. marequensis*, *L. molybdinus*, *L. cylindricus* and *M. brevianalis* the increase in percentage in the upper section coincided with an increase in the total number of fish collected. In the first three species the percentage lowered as the total number decreased and in *M. brevianalis* the percentage increased, as is the case with the total number of fish collected.

The percentage collected of *M. acutidens* in the upper section decreased in November but then remained approximately the same for the rest of the time. This pattern mirrors the observations concerning the total numbers of the species collected in the same period.

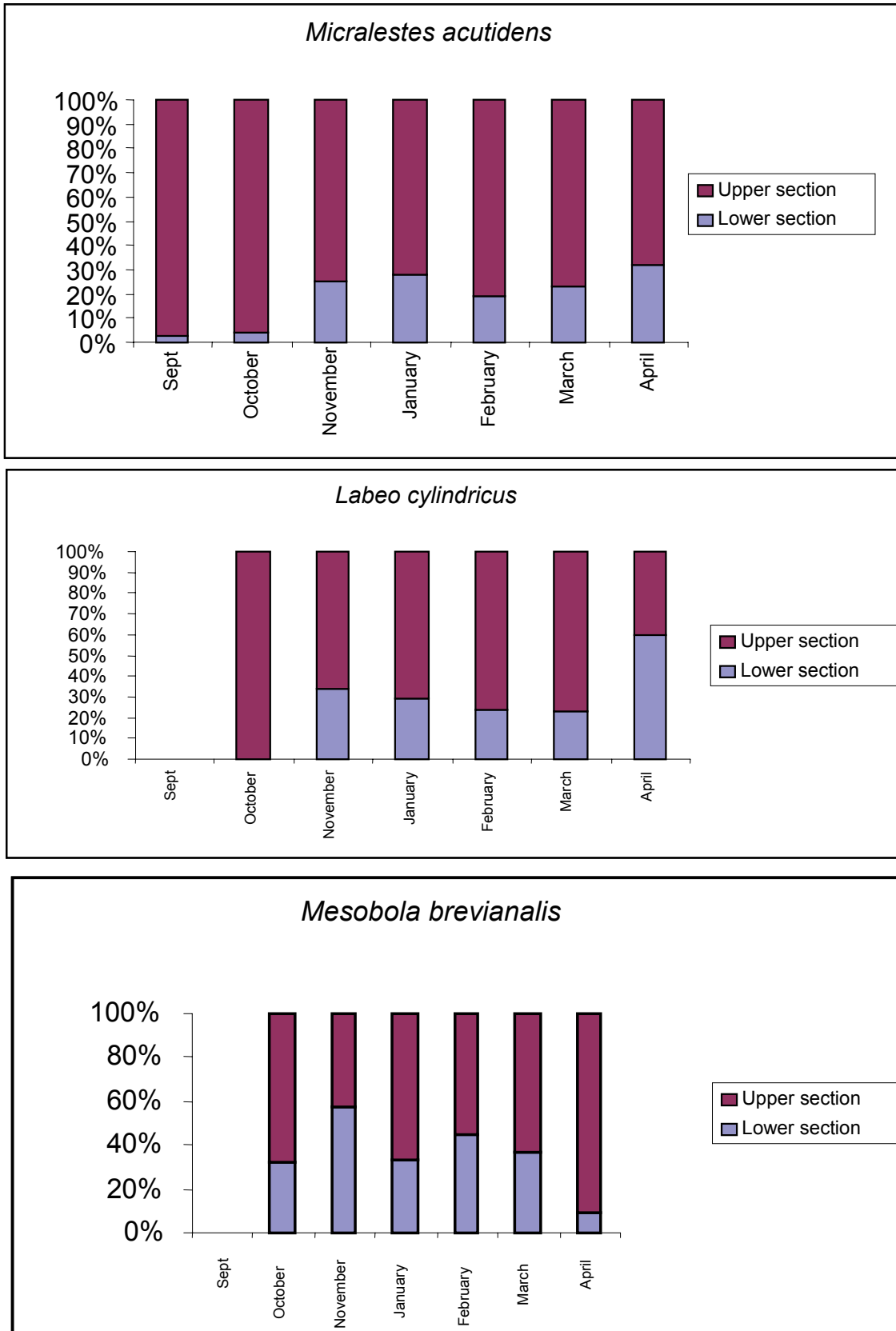


Figure 8.1: A comparison of the number of fish, expressed as a percentage of the total number collected, in the upper and lower sections of the Xikundu fishway from September 2004 to April 2005.

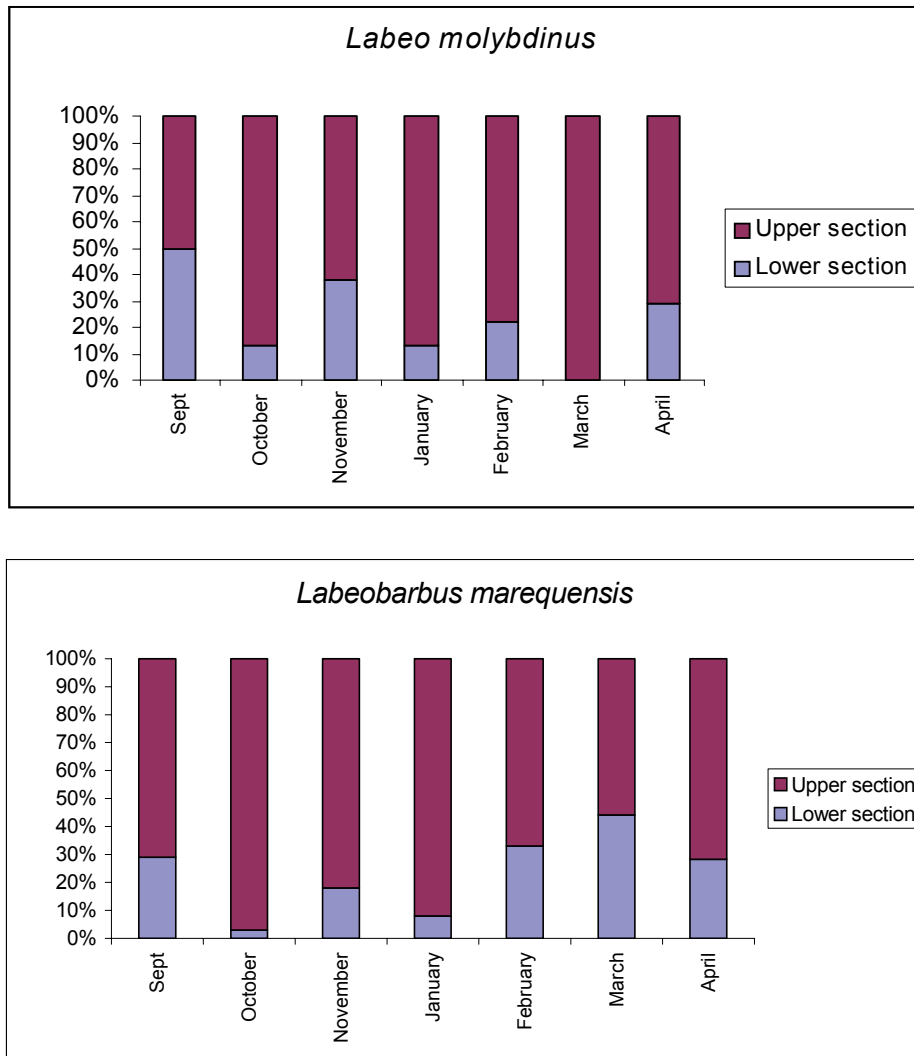


Figure 8.1 (Cont.): A comparison of the number of fish, expressed as a percentage of the total number collected, in the upper and lower sections of the Xikundu fishway from September 2004 to April 2005.

8.3.6 Invertebrates

Two crabs were collected in the nets during the October monitoring session but were also observed negotiating across the baffles during the times when the baffles were overtopped (Plate 8.5).



Plate 8.5: A crab negotiating across an overtopped baffle

Freshwater prawns (Family: Palaemonidae) with sizes varying between 40 – 60 mm were collected during the monitoring and the results are shown in Table 8.16. Single specimens of freshwater shrimps were only collected on two occasions.

Table 8.16: Prawns and shrimps collected in Xikundu fishway from May 2004 to April 2005

Organism	May	June	July	Aug	Sept	Oct	Nov	Jan	Feb	Mar	Apr
Palaemonidae	36	0	1	0	0	8	23	520	168	110	13
Atyidae	0	0	0	1	0	0	1	0	0	0	0

8.3.7 Atmospheric parameters

The variation and changes in the weather that was observed over the 12-month period is shown in Table 8.17. Note should be taken that the atmospheric pressure was only determined as from March 2005 due to logistic problems with the acquired apparatus.

8.3.8 Physico-chemical results

In Tables 8.18 and 8.19 the physico-chemical parameters, determined both in the field and in the laboratory are shown to illustrate the environmental trends observed during the survey.

8.3.9 Hydraulic parameters

The hydraulic data presented in table includes data measured in the fishway and the water depth at the measuring plate in the weir proper. The drop between or the water height difference between pools was measured from November 2004.

Table 8.17: Atmospheric parameters at the Xikundu fishway from May to November 2004 (nm : not measured)

Parameter	May	Jun	July	Aug	Sept	Oct	Nov	Jan	Feb	Mar	Apr
Max. air temperature (°C)	27	21	24	27	25	27	29	29	32	33.7	37.5
Min. air temperature (°C)	11	9	5	15	18	16	19	21	22	23.2	39.0
Range of cloud cover	0/8-1/8	0/8-7/8	0/8	2/8-8/8	7/8	7/8 - 8/8	1/8 - 7/8	7/8 - 8/8	3/8 - 8/8	0/8 - 8/8	0/8 - 8/8
Atmospheric pressure (mBar)	nm	nm	nm	nm	nm	nm	nm	nm	nm	965.7 - 969.8	961.2 - 967.9
Rain	No	No	No	No	No	No	No	drizzle	No	drizzle	heavy
Prevalent wind direction	SW/NW	NW/NE	N/E	NW/W	S/W	NW / S	S/NE	S / SW	E/SE	S/SE	S/SW

Table 8.18: Results of laboratory determinations performed on the water samples collected monthly at Xikundu fishway in the period from May 2004 to April 2005. (TDS refers to the Total Dissolved Solids and TSS refers to the Total Suspended Solids)

Parameters	Units	May	Jun	Jul	Aug	Sep	Oct	Nov	Jan	Feb	Mar	Apr
TDS	mg/l	0.25	0.30	0.50	0.50	0.45	0.60	0.65	0.40	0.40	0.35	0.30
TSS	mg/l	26	25	34	48	6	6	2	6	8	8	8
Turbidity	NTU	10	20	20	20	12	10	8	5	3	3	3

Table 8.19: The physico-chemical aspects of the water determined during the field visits at Xikundu fishway in the period from May 2004 to April 2005

Parameters	Units	May	Jun	Jul	Aug	Sep	Oct	Nov	Jan	Feb	Mar	Apr
Range of dissolved oxygen in still water.	mg/l	8.3 - 8.4	8.2 - 9.8	8.5 - 9.0	7.2 - 8.6	7.9 - 8.5	6.7 - 7.02	7.6 - 8.5	6.75 - 7.5	6.42 - 7.2	6.84 - 7.49	7.3 - 8.0
Range of dissolved oxygen in turbulent water	%	95.0 - 98.9	96.0 - 99.0	91.0 - 96.0	84.0 - 100.0	94.0 - 98.0	78.0 - 88.0	90.0 - 98.0	90.0 - 100.0	88.6 - 103.0	86.3 - 97.0	97.0 - 105.0
Min. temperature	°C	8.4 - 8.6	9.4 - 9.5	8.9 - 9.2	7.3 - 8.8	8.4 - 8.8	6.8 - 7.7	8.3 - 8.8	6.88 - 7.6	6.59 - 7.3	7.01 - 7.56	7.44 - 8.11
Max. temperature	°C	97.5 - 101.0	100.0 - 101.0	93.0 - 98.0	85.0 - 100.0	97.0 - 100.0	85.0 - 95.0	97.0 - 100.0	91.3 - 101.0	90.0 - 103.5	88.9 - 98.5	98.0 - 106.0
pH		20.1	15.9	15.3	19.6	20.0	23.2	20.2	26.7	28.6	25.1	25.2
Conductivity	µS/cm	20.9	17.2	15.7	20.8	23.5	23.8	23.5	27.9	29.8	27.2	27.1
		7.6	8.7	7.8	7.9	7.9	8.0	7.9	8	7.8	7.9	7.8
		97	112	109	112	110	138	110	109	103	100	92

Table 8.20: Hydraulic data measured at the Xikundu fishway during the period May 2004 to April 2005

Parameters	Units	May	Jun	Jul	Aug	Sep	Oct	Nov	Jan	Feb	Mar	Apr
Drop between pools	m	mm	mm	mm	mm	mm	mm	0,21	0,21	0,21	0,18	0,20
Velocity min	m/s	1.155	1.155	1.155	0.99	1.155	0.99	0.825	0.825	0.825	0.70	0.60
Velocity max	m/s	1.815	1.485	1.815	1.65	1.815	1.65	1.32	1.485	1.518	1.46	1.31
Height of water in notch	m	0.33	0.33	0.295	0.22	0.29	0.27	0.26	0.24	0.24	0.25	0.25
Discharge	Cumec	0.299	0.245	0.268	0.182	0.263	0.223	0.72	0.178	0.182	0.183	0.164
Height of water in pool	m	1.15	1.1	1.15	1.06	1.1	1.09	1.03	1.03	1.00	1.02	1.04
Height on gauge plate at weir	m	4.4	4.4	4.4	4.3	4.3	4.3	4.3	4.2	4.2	4.2	4.2

8.3.10 Gonadal development and condition classes of the fish collected in the fishway

Only ten species of those currently still occurring in this river reach (*A. mossambica*, *C. paratus*, *C. pretoriae*, *H. vittatus*, *L. marequensis*, *L. cylindricus*, *L. molybdinus*, *M. acutidens*, *M. macrolepidotus* and *P. wesselsi*) are regarded as migratory. Five species were not considered for this part of the study for various reasons. *H. vittatus* was not collected in the fishway and *M. macrolepidotus* and *P. wesselsi* were collected only on one occasion. Only one specimen of *A. mossambica* was collected throughout the duration of the project. The number of chiloglanids deteriorated as the stream velocity reduced and it is postulated that they did not utilize the fishway for migratory reasons but rather inhabited the fishway because of the suitable fast, deep habitat it provided. For this reason and to enable the student involved coping with the large numbers of fish it was decided to exclude the chiloglanids for this report. Only the condition, gonadal development and the maturity coefficient of four species namely *L. marequensis*, *L. cylindricus*, *L. molybdinus*, *M. acutidens* is therefore be shown in this report.

Tables 8.21 to 8.45 illustrates what was observed in the four species mentioned above. In *M. acutidens* the number of fish collected in January is a sharp increase from the number collected in the previous month (Table 8.4). This correlates well with the findings shown in Table 8.34, which clearly illustrates that, an increase in the gonadosomatic index (GSI) and maturity coefficient (MC) is again occurring. As both indices had already shown an increase in September and October, these findings could be an indication that a second spawning event was due to occur or occurring. It is envisaged that the analyses of the gonadal material as well as the outstanding analyses of the MC and GSI would shed light upon these aspects. In the case of *L. marequensis* the increase in the GSI and MC peaked in September and all indications are that thereafter it is on the decline, which could be an indication that spawning had been completed. (Tables 8.21 – 8.28 and Figure 8.1)

Table 8.21: Body dimensions, condition and sexual maturity of the different length classes of *L. marequensis* collected in the Xikundu fishway during May 2004 (FL : fork length, CF : condition factor, GSI : gonadosomatic index, MC : maturity coefficient).

Body dimensions				Condition			Gonadal development and maturity			
Size Class (mm)	N	Ave. mass (g)	Ave. FL (cm)	Ave. condition	Ave. CF	Range of cond. classes	Ave. gonad mass (g)	Ave. GSI	Ave. MC	Range of maturity classes
81 - 90	1	4.34	8.7	0.51	0.659	4	0.0492	1.13	0.7471	1
91 - 100	3	12.78	9.7	1.32	1.401	4	0.0968	0.76	1.0606	1-3
111 - 120	1	20.01	11.1	1.8	1.062	4	0.0967	0.48	0.7071	1
121 - 130	2	31.42	12.35	2.5	1.668	5	0.2071	0.66	1.0995	1-3
131 - 140	1	43.72	13.3	3.28	1.858	4	0.2293	0.53	0.9746	3

Table 8.22: Body dimensions, condition and sexual maturity of the different length classes of *L. marequensis* collected in the Xikundu fishway during June 2004 (FL : fork length, CF : condition factor, GSI : gonadosomatic index, MC : maturity coefficient).

Body dimensions				Condition			Gonadal development and maturity			
Size class (mm)	N	Ave. mass (g)	Ave. FL (cm)	Ave. condition	Ave. CF	Range of cond. classes	Ave. gonad mass (g)	Ave. GSI	Ave. MC	Range of maturity classes
61 -70	1	4.55	6.7	0.67	1.513	3	0.0181	0.39	0.6018	2
71- 80	3	5.95	7.63	0.78	1.341	1-3	0.0458	0.77	1.0311	2
81 - 90	4	9.795	8.68	1.13	1.497	2-3	0.0623	0.64	0.9526	1-3
91 - 100	1	14.95	10	1.5	1.495	3	0.0311	0.21	0.3111	1
101 - 110	1	21.8	10.9	2	1.683	3	0.1071	0.49	0.8271	3
121 - 130	1	31.5	12.3	2.56	1.693	5	0.2221	0.71	1.1967	3
141 - 150	1	47.4	14.3	3.31	1.621	4	0.2001	0.42	0.6842	3

Table 8.23: Body dimensions, condition and sexual maturity of the different length classes of *L. marequensis* collected in the Xikundu fishway during July 2004 (FL : fork length, CF : condition factor, GSI : gonadosomatic index, MC : maturity coefficient).

Body dimensions				Condition			Gonadal development and maturity			
Size class (mm)	N	Ave. mass (g)	Ave. FL (cm)	Ave. condition	Ave. CF	Range of cond. classes	Ave. gonad mass (g)	Ave. GSI	Ave. MC	Range Of maturity Classes
61 -70	2	5.99	7	0.86	1.746	4	0.0679	1.13	1.9796	1
71- 80	3	8.08	7.83	1.03	1.683	2-5	0.0412	0.51	0.8583	1
81 - 90	7	11.79	8.74	1.35	1.766	1-5	0.1187	1.01	1.778	1-2
91 - 100	4	13.28	9.3	1.48	1.651	1-5	0.0721	0.54	0.8964	1-2

Table 8.24: Body dimensions, condition and sexual maturity of the different length classes of *L. marequensis* collected in the Xikundu fishway during August 2004 (FL : fork length, CF : condition factor, GSI : gonadosomatic index, MC : maturity coefficient).

Body dimensions				Condition			Gonadal development and maturity			
Size class (mm)	N	Ave. mass (g)	Ave. FL (cm)	Ave. condition	Ave. CF	Range of cond. classes	Ave. gonad mass (g)	Ave. GSI	Ave. MC	Range of maturity classes
71- 80	1	5.3	7.5	0.76	1.256	5	0.3908	7.37	0.9263	3
81 - 90	4	11.07	8.85	1.25	1.897	3-5	0.1638	1.48	2.3631	1-3
91 - 100	3	15.43	9.77	1.58	1.655	2-5	0.1445	0.94	1.5495	1-3
101 - 110	4	19.35	10.33	1.87	1.755	1-3	0.1881	0.97	1.7064	1-2
111 - 120	2	25.28	11.75	2.15	1.558	4-5	0.3913	1.54	2.4121	1-2
121 - 130	2	29.87	12.5	2.38	1.529	3	0.2879	0.96	1.2237	3
131 - 140	1	37.03	13.3	2.78	1.574	3	0.5115	1.38	2.1742	1-2

Table 8.25: Body dimensions, condition and sexual maturity of the different length classes of *L. marequensis* collected in the Xikundu fishway during September 2004 (FL : fork length, CF : condition factor, GSI : gonadosomatic index, MC : maturity coefficient).

Body dimensions				Condition			Gonadal development and maturity			
Size class (mm)	N	Ave. mass (g)	Ave. FL (cm)	Ave. condition	Ave. CF	Range of cond. classes	Ave. gonad mass (g)	Ave. GSI	Ave. MC	Range of maturity classes
71- 80	1	8.53	7.6	1.12	1.943	5	0.0739	0.87	1.6834	3
81 - 90	4	11.68	8.85	1.32	1.685	2-5	0.0579	0.51	0.8534	1-3
91 - 100	6	14.65	9.78	1.49	1.566	3-5	0.2585	1.76	2.7634	1-3
111 - 120	18	27.07	11.63	2.32	1.721	2-5	0.2161	0.81	1.3738	1-3
121 - 130	8	38.77	12.78	3.03	1.857	3-5	0.2788	0.72	1.3357	1-3
131 - 140	6	51.21	13.77	3.72	1.961	4-5	0.6286	1.23	2.4075	1-2
141 - 150	3	57.94	14.37	4.03	1.798	2-5	0.6662	1.15	2.0675	2
151 - 160	3	73.28	15.4	4.75	2.006	4	0.9937	1.36	2.7208	3
161 - 170	2	82.91	16.7	4.96	1.781	5	1.0449	1.26	2.2435	2
171 - 180	1	102.6	17.2	5.96	2.016	5	0.9118	0.89	1.7919	3
181-190	1	135.94	18.2	7.46	2.254	5	2.0958	1.54	3.4764	3

Table 8.26: Body dimensions, condition and sexual maturity of the different length classes of *L. marequensis* collected in the Xikundu fishway during October 2004 (FL : fork length, CF : condition factor, GSI : gonadosomatic index, MC : maturity coefficient).

Body dimensions				Condition			Gonadal development and maturity			
Size Class (mm)	N	Ave. mass (g)	Ave. FL (cm)	Ave. condition	Ave. CF	Range of cond. classes	Ave. gonad mass (g)	Ave. GSI	Ave. MC	Range of maturity classes
81 - 90	1	11.61	9	1.29	1.593	4	0.0501	0.43	0.6872	1
101 - 110	7	23.65	10.8	2.19	1.877	5	0.1476	0.62	1.1717	1-3
111 - 120	12	28.47	11.75	2.42	1.755	4-5	0.1717	0.61	1.0584	1-3
121 - 130	16	37.67	12.68	2.97	1.847	3-5	0.2392	0.63	1.1733	1-3
131 - 140	13	47.19	13.65	3.46	1.855	3-5	0.3314	0.71	1.3031	1
141 - 150	11	57.87	14.71	3.93	1.818	3-5	0.4215	0.73	1.3242	2-3
151 - 160	11	70.74	15.62	4.53	1.856	3-5	0.7206	1.02	2.0259	2-3
161 - 170	5	84.75	16.34	5.19	1.943	4-5	0.8129	0.96	1.8633	2-4

Table 8.27: Body dimensions, condition and sexual maturity of the different length classes of *L. marequensis* collected in the Xikundu fishway during November 2004 (FL : fork length, CF : condition factor, GSI : gonadosomatic index, MC : maturity coefficient).

Body dimensions				Condition			Gonadal development and maturity			
Size Class (mm)	N	Ave. mass (g)	Ave. FL (cm)	Ave. condition	Ave. CF	Range of cond. classes	Ave. gonad mass (g)	Ave. GSI	Ave. MC	Range of maturity classes
61 -70	1	6.71	6.5	1.03	2.367	1	0.0023	0.03	0.0831	1
71- 80	1	12.21	8.1	1.51	2.297	4	0.0202	0.16	0.3811	1
81 - 90	1	13.46	8.5	1.58	2.191	4	0.0421	0.31	0.6855	1
101 - 110	1	22.56	10.2	2.21	2.126	4-5	0.0112	0.05	0.1055	1
111 - 120	2	28.59	11.6	2.46	1.831	5	0.0484	0.17	0.3101	2-3
121 - 130	2	33.14	12.3	2.69	1.782	4-5	0.1344	0.41	0.7224	1-2
131 - 140	3	46.71	13.9	3.36	1.739	4	0.1558	0.33	0.5801	1
141 - 150	1	60.67	14.5	4.18	1.991	4-5	0.0992	0.16	0.3254	1-2
151 - 160	2	78.02	15.9	4.91	1.941	4-5	0.5664	0.73	1.4091	1-2

Table 8.28: Body dimensions, condition and sexual maturity of the different length classes of *L. marequensis* collected in the Xikundu fishway during January 2005 (FL : fork length, CF : condition factor, GSI : gonadosomatic index, MC : maturity coefficient).

Body dimensions				Condition			Gonadal development and maturity			
Size Class (mm)	N	Ave. mass (g)	Ave. FL (cm)	Ave. condition	Ave. CF	Range of cond. classes	Ave. gonad mass (g)	Ave. GSI	Ave. MC	Range of maturity classes
71- 80	1	8.43	7.1	1.19	2.355		0.0431	0.51	1.204	
81 - 90	2	9.91	8.45	1.17	1.642		0.0416	0.42	0.689	
111 - 120	1	26.37	11.3	2.34	1.827		0.0861	0.32	0.597	
121 - 130	1	33.73	12.2	2.76	1.857		0.1122	0.33	0.618	
141 - 150	1	62.88	15.1	4.16	1.826		0.5885	0.94	1.709	
151 - 160	1	79.52	15.6	5.09	2.095		0.4098	0.52	1.079	
171 - 180	1	106.32	17.5	6.07	1.984		0.6884	0.65	1.284	
201 - 210	1	138.76	20.4	6.79	1.634		0.8881	0.64	1.046	

Table 8.29: Body dimensions, condition and sexual maturity of the different length classes of *M. acutidens* collected in the Xikundu fishway during May 2004 (FL : fork length, CF : condition factor, GSI : gonadosomatic index, MC : maturity coefficient).

Body dimensions				Condition			Gonadal development and maturity			
Size Class (mm)	N	Ave. mass (g)	Ave. FL (cm)	Ave. condition	Ave. CF	Range of cond. classes	Ave. gonad mass (g)	Ave. GSI	Ave. MC	Range of maturity classes
71-80	1	7.24	7.8	0.93	1.526	5	0.4478	6.18	9.4363	1

Table 8.30: Body dimensions, condition and sexual maturity of the different length classes of *M. acutidens* collected in the Xikundu fishway during June 2004 (FL : fork length, CF : condition factor, GSI : gonadosomatic index, MC : maturity coefficient).

Body dimensions				Condition			Gonadal development and maturity			
Size Class (mm)	N	Ave. mass (g)	Ave. FL (cm)	Ave. condition	Ave. CF	Range of cond. classes	Ave. gonad mass (g)	Ave. GSI	Ave. MC	Range of maturity classes
71-80	1	5.27	7.3	0.72	1.35	5	0.0341	0.06	0.8766	1

Table 8.31: Body dimensions, condition and sexual maturity of the different length classes of *M. acutidens* collected in the Xikundu fishway, September 2004 (FL : fork length, CF : condition factor, GSI : gonadosomatic index, MC : maturity coefficient).

Body dimensions				Condition			Gonadal development and maturity			
Size Class (mm)	N	Ave. mass (g)	Ave. FL (cm)	Ave. condition	Ave. CF	Range of cond. classes	Ave. gonad mass (g)	Ave. GSI	Ave. MC	Range of maturity classes
61-70	4	4.93	6.73	0.73	1.621	3-5	0.5086	10.31	16.7225	2-4
71-80	9	6.25	7.41	0.84	1.597	4-5	0.7005	16.1	17.2172	1-4
81-90	1	7.77	8.1	0.96	1.462	5	1.1394	14.66	21.4396	3

Table 8.32: Body dimensions, condition and sexual maturity of the different length classes of *M. acutidens* collected in the Xikundu fishway, October 2004 (FL : fork length, CF : condition factor, GSI : gonadosomatic index, MC : maturity coefficient).

Body dimensions				Condition			Gonadal development and maturity			
Size Class (mm)	N	Ave. mass (g)	Ave. FL (cm)	Ave. condition	Ave. CF	Range of cond. classes	Ave. gonad mass (g)	Av GSI	Ave. MC	Range of maturity classes
61-70	27	4.72	6.948	0.68	1.407	5	0.2671	5.66	7.9631	3-4
71-80	35	6.16	7.302	0.84	1.582	5	0.5658	9.18	14.5322	3-4

Table 8.33: Body dimensions, condition and sexual maturity of the different length classes of *M. acutidens* collected in the Xikundu fishway, November 2004 (FL : fork length, CF : condition factor, GSI : gonadosomatic index, MC : maturity coefficient).

Body dimensions				Condition			Gonadal development and maturity			
Size Class (mm)	N	Ave. mass (g)	Ave. FL (cm)	Ave. condition	Ave. CF	Range of cond. classes	Ave. gonad mass (g)	Ave GSI	Ave. MC	Range of maturity classes
61 -70	7	4.84	6.729	0.72	1.588	5	0.3508	7.24	11.5137	1-3
71- 80	2	6.47	7.35	0.88	1.629	5	0.3198	4.94	8.0541	4

Table 8.34: Body dimensions, condition and sexual maturity of the different length classes of *M. acutidens* collected in the Xikundu fishway, January 2005 (FL : fork length, CF : condition factor, GSI : gonadosomatic index, MC : maturity coefficient).

Body dimensions				Condition			Gonadal development and maturity			
Size Class (mm)	N	Ave. mass (g)	Ave. FL (cm)	Ave. condition	Ave. CF	Range of cond. classes	Ave. gonad mass (g)	Ave GSI	Ave. MC	Range of maturity classes
61 -70	2	5.63	6	0.94	2.606	5	0.4952	8.79	22.9259	4
71- 80	26	6.3	6.64	0.95	2.152	5	0.5488	8.71	18.7461	4
81 - 90	8	8.36	7.38	1.13	2.079	5	0.8161	9.76	20.3031	4
> 90	0									

Table 8.35: Body dimensions, condition and sexual maturity of the different length classes of *L. cylindricus* collected in the Xikundu fishway May 2004 (FL : fork length, CF : condition factor, GSI : gonadosomatic index, MC : maturity coefficient).

Body dimensions				Condition			Gonadal development and maturity			
Size class (mm)	N	Ave. mass (g)	Ave. FL (cm)	Ave. condition	Ave. CF	Range of cond. classes	Ave. gonad mass (g)	Ave. GSI	Ave. MC	Range of maturity classes
191 - 200	1	124.95	19.2	6.51	1.765	1	0.0432	0.03	0.0611	1
221 - 230	1	189.52	22.4	8.46	1.686	3	0.4908	0.25	0.8897	2

Table 8.36: Body dimensions, condition and sexual maturity of the different length classes of *L. cylindricus* collected in the Xikundu fishway June 2004. (FL : fork length, CF : condition factor, GSI : gonadosomatic index, MC : maturity coefficient).

Body dimensions				Condition			Gonadal development and maturity			
Size Class (mm)	N	Ave. mass (g)	Ave. FL (cm)	Ave. condition	Ave. CF	Range of cond. classes	Ave. gonad mass (g)	Ave. GSI	Ave. MC	Range of maturity classes
131 - 140	1	31.06	13.5	2.31	0.818	2	0.0945	0.31	0.3841	1
151 - 160	1	54.15	15.6	3.47	1.426	2	0.4427	0.82	1.1661	3

Table 8.37: Body dimensions, condition and sexual maturity of the different length classes of *L. cylindricus* collected in the Xikundu fishway August 2004. (FL : fork length, CF : condition factor, GSI : gonadosomatic index, MC : maturity coefficient).

Body dimensions				Condition			Gonadal development and maturity			
Size Class (mm)	N	Ave. mass (g)	Ave. FL (cm)	Ave. condition	Ave. CF	Range of cond. classes	Ave. gonad mass (g)	Ave. GSI	Ave. MC	Range of maturity classes
121 - 130	1	32.19	12.4	2.59	1.688		1.688	0.1751	0.54	0.9183

Table 8.38: Body dimensions, condition and sexual maturity of the different length classes of *L. cylindricus* collected in the Xikundu fishway November 2004 (FL : fork length, CF : condition factor, GSI : gonadosomatic index, MC : maturity coefficient).

Body dimensions				Condition			Gonadal development and maturity			
Size Class (mm)	N	Ave. mass (g)	Ave. FL (cm)	Ave. condition	Ave. CF	Range of cond. classes	Ave. gonad mass (g)	Ave. GSI	Ave. MC	Range of maturity classes
71 - 80	1	11.81	7.9	1.49	2.395	2-3	0.0093	0.08	0.0188	1
81 - 90	1	12.86	8.7	1.48	1.952	2	0.0209	0.16	0.3174	1

Table 8.39: Body dimensions, condition and sexual maturity of the different length classes of *L. molybdinus* collected in the Xikundu fishway May 2004. (FL : fork length, CF : condition factor, GSI : gonadosomatic index, MC : maturity coefficient).

Body dimensions				Condition			Gonadal development and maturity			
Size Class (mm)	N	Ave. mass (g)	Ave. FL (cm)	Ave. condition	Ave. CF	Range of cond. classes	Ave. gonad mass (g)	Ave. GSI	Ave. MC	Range of maturity classes
151 - 160	2	62.5	15.6	0.54	1.646	2-3	0.2077	0.33	0.5471	1-3
201 - 210	1	165.29	20.3	8.14	1.976	2	0.2093	0.13	0.2501	3
221 - 230	3	221.7	22.6	9.84	1.921	1-4	0.9684	0.43	0.8389	2-3

Table 8.40: Body dimensions, condition and sexual maturity of the different length classes of *L. molybdinus* collected in the Xikundu fishway June 2004. (FL : fork length, CF : condition factor, GSI : gonadosomatic index, MC : maturity coefficient).

Body dimensions				Condition			Gonadal development and maturity			
Size Class (mm)	N	Ave. mass (g)	Ave. FL (cm)	Ave. Condition	Ave. CF	Range of cond. classes	Ave. gonad mass (g)	Ave. GSI	Ave. MC	Range of maturity classes
91 - 100	1	11.2	9.2	1.21	1.438	1	0.0173	0.15	0.2221	2
101 - 110	1	14.13	10.3	1.37	1.293	2	0.0701	0.49	0.6415	2
111 - 120	1	25.51	12.1	2.13	1.439	2	0.0781	0.31	0.4408	1
171 - 180	1	29.03	17.3	1.67	0.561	1	0.0888	0.31	0.1715	1

Table 8.41: Body dimensions, condition and sexual maturity of the different length classes of *L. molybdinus* collected in the Xikundu fishway July 2004. (FL : fork length, CF : condition factor, GSI : gonadosomatic index, MC : maturity coefficient).

Body dimensions				Condition			Gonadal development and maturity			
Size Class (mm)	N	Ave. mass (g)	Ave. FL (cm)	Ave. condition	Ave. CF	Range of cond. classes	Ave. gonad mass (g)	Ave. GSI	Ave. MC	Range of maturity classes
91 - 100	1	16.41	10.1	1.63	1.592	2	0.0351	0.21	0.3407	1
121 - 130	2	37.95	12.95	2.93	1.747	1	0.0673	0.18	0.3099	1-2
191 -200	1	152.03	20	7.61	1.901	5	0.7661	0.51	0.9576	3

Table 8.42: Body dimensions, condition and sexual maturity of the different length classes of *L. molybdinus* collected in the Xikundu fishway August 2004. (FL : fork length, CF : condition factor, GSI : gonadosomatic index, MC : maturity coefficient).

Body dimensions				Condition			Gonadal development and maturity			
Size Class (mm)	N	Ave. mass (g)	Ave. FL (cm)	Ave. condition	Ave. CF	Range of cond. classes	Ave. gonad mass (g)	Ave. GSI	Ave. MC	Range of maturity classes
61 -70	1	4.26	6.9	0.62	0.304	2	0.0192	0.45	0.5844	1
81 - 90	1	11.33	8.7	1.31	1.796	1	0.0679	0.59	1.0311	2
251 - 260	1	387.4	25.9	14.9	2.229	5	7.4676	1.93	4.2981	3

Table 8.43: Body dimensions, condition and sexual maturity of the different length classes of *L. molybdinus* collected in the Xikundu fishway September 2004. (FL : fork length, CF : condition factor, GSI : gonadosomatic index, MC : maturity coefficient).

Body dimensions				Condition			Gonadal development and maturity			
Size Class (mm)	N	Ave. mass (g)	Ave. FL (cm)	Ave. condition	Ave. CF	Range of cond. classes	Ave. gonad mass (g)	Ave. GSI	Ave. MC	Range of maturity classes
131 - 140	1	41.47	13.5	3.07	2	1.685	0.1511	0.36	0.6141	2
151 - 160	1	80.03	15.5	5.16	5	2.149	0.5069	0.63	1.3593	3
251 - 260	1	265.46	25.3	10.49	4	1.639	8.6261	3.24	5.3266	3

Table 8.44: Body dimensions, condition and sexual maturity of the different length classes of *L. molybdinus* collected in the Xikundu fishway October 2004. (FL : fork length, CF : condition factor, GSI : gonadosomatic index, MC : maturity coefficient).

Body dimensions				Condition			Gonadal development and maturity			
Size Class (mm)	N	Ave. mass (g)	Ave. FL (cm)	Ave. condition	Ave. CF	Range of cond. classes	Ave. gonad mass (g)	Ave. GSI	Ave. MC	Range of maturity classes
211 - 220	1	255.58	23	11.11	2.1	5	44.63	17.46	36.68	3

Table 8.45: Body dimensions, condition and sexual maturity of the different length classes of *L. molybdinus* collected in the Xikundu fishway November 2004. (FL : fork length, CF : condition factor, GSI : gonadosomatic index, MC : maturity coefficient).

Body dimensions				Condition			Gonadal development and maturity			
Size Class (mm)	N	Ave. mass (g)	Ave. FL (cm)	Ave. condition	Ave. CF	Range of cond. classes	Ave. gonad mass (g)	Ave. GSI	Ave. MC	Range of maturity classes
191 -200	1	179.31	19.2	9.33	5	0.273	60	33.46	84.77	5

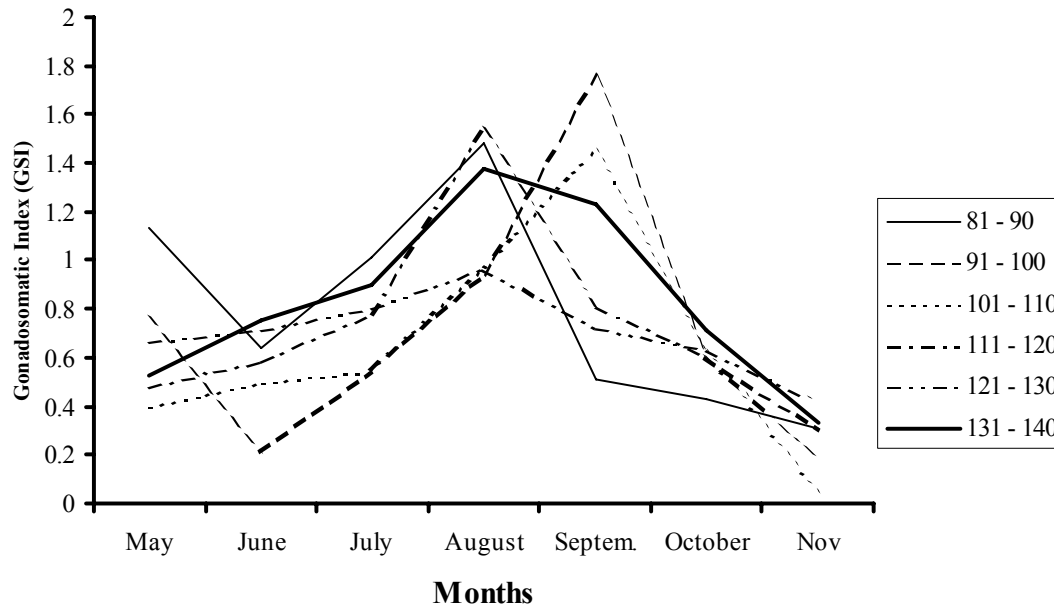


Figure 8.2: The Gonadosomatic Index (GSI) calculated for the 81 – 140mm length size classes of *L. marequensis* collected in the Xikundu fishway during the period May to November 2004.

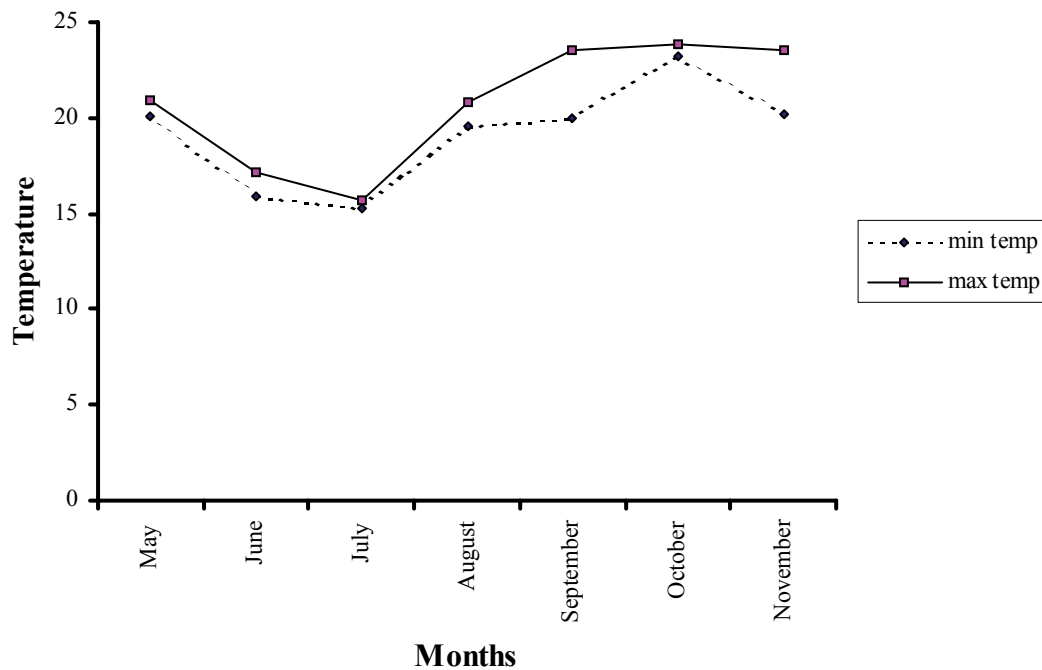


Figure 8.3: The maximum and minimum water temperatures measured in the Xikundu fishway for the period May – November 2004

In Figure 8.3 the temperatures recorded in the same period as the GSI shown in Figure 8.2 it is of interest to note that the increase in GSI of *L. marequensis* coincides with the rise in temperature. This would also be the case for the first increase in GSI and MC of *M. acutidens*.

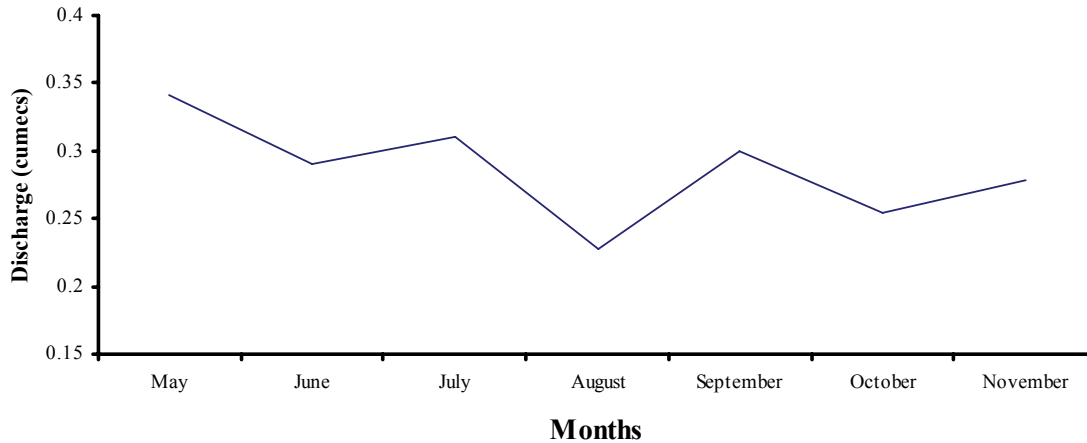


Figure 8.4: The calculated discharge in the Xikundu fishway for the period May – November 2004

Figure 8.4 shows the decrease in flow that was observed in the survey and it can be concluded that for the two species discussed above migration was taking place regardless of the absence of floods or freshets.

At the exit of the fishway the water depth is in excess of 4 m and temperatures were measured at 0,5m intervals. A temperature difference of 0.2 °C between the surface water and the water at 3,5m depth was found to exist. Because the fish enter the impoundment at surface level, where the overflow in the final notch is 0.2 m deep, this temperature difference should not affect the fish.

At the entrance to the fishway the water is quite shallow (>1m) and no temperature differences were encountered.

Water from the hypolimnion was constantly released through an outlet parallel to the fishway. This water then joins up with the water that flows out at the fishway entrance. As this water is colder it would therefore affect the temperature of the water at the fishway entrance.

Because of the strong current of the outlet a problem was experienced to monitor the temperature using the apparatus available. A temperature probe that is built into a rod that can extend to 3m has now been purchased and the sampling will form part of the second phase of the project. The temperature was monitored in October and November and the results are reflected in Table 8.46.

Table 8.46: A comparison of the water temperatures (° C) measured in the fishway and the outlet next to the fishway.

		10h00	14h00	18h00	22h00	02h00	06h00
Oct.	Fishway	23.8	23.5	23.2	23.2	23.2	23.2
	Outlet	23.2	23.2	23.2	23.2	23.2	22.9
Nov.	Fishway	27.0	27.4	26.6	26.3	26.3	26.4
	Outlet	27.2	27.2	26.6	26.3	26.3	26.4

From these results, it appears that the influence of the outlet water temperature can be ignored.

8.4 THE FUNCTIONING OF THE XIKUNDU FISHWAY

The effectiveness of a fishway, according to Travade *et. al.*, (1998), is a qualitative concept, which consists of checking whether the fishway is capable of letting certain numbers of all fish species through within the range of environmental conditions observed during a migration period. Larinier (2002) stated that a fishway is effective if a significant or reasonable proportion, with respect to the different fish populations up or downstream moves through the fishway.

The efficiency of a fishway is a more quantitative description of its performance and may also be expressed as the percentage of the population that passes through the fishway.

8.4.1 The effectiveness of the Xikundu fishway

It can be deduced that the design of the Xikundu fishway (a typical pool-type fishway with notched baffles) allows for effective movement of fish through the fishway. Twenty of a possible 28 species (reflected in historical data) were able to locate and enter the fishway. This clearly indicates that the entrance to the fishway is well placed and accessible. A significant number of these species, namely fifteen were collected in the top and lower pools of the fishway, which indicates that the hydraulic characteristics within the fishway allowed for movement through the fishway. These characteristics include suitable resting areas with minimized flow and velocity and connections between the pools where the height difference and water velocity allow movement of all the size groups of the different species. The characteristics exist as a result of the specific design of the fishway and it can be concluded that the design of the fishway is suitable for the fish encountered in the river reach.

Of the eleven species broadly classified as migratory, eight were collected in the fishway. The fact that *H. vittatus* had been collected upstream of the fishway for the first time in many years while it had been collected on a regular basis downstream in the KNP may also be an indication that they had utilized the fishway. Based on this, and if *H. vittatus* is included, 82% of the migratory species had utilized the fishway. If *H. vittatus* is not considered the figure drops to 73%.

A distinct increase, or decrease, in fish numbers was observed throughout the sampling period for the species of *C. paratus*, *C. pretoriae*, *L. marequensis*, *L. cylindricus*, *L. molybdinus*, *M. acutidens* and *M. brevianalis* (Table 8.2). This could be construed as patterns and were illustrated to either coincide with flow, in the case of *C. paratus* and *C. pretoriae*, or with rise in water temperature in the case of the other species.

An investigation into the gonadal development of *L. marequensis*, *L. cylindricus*, *L. molybdinus* and *M. acutidens* clearly showed that these patterns coincide with the actual spawning migration events (Tables 8.21 – 8.45).

8.4.2 The efficiency of the fishway

To determine this characteristic of a fishway would require an in depth investigation of the fish population and fish assemblage composition in the specific river reach. Because of the magnitude of such an exercise, it was not done in the first phase of the study. If logistics and finance allows, it will be included in the second phase although it is not part of the formal project proposal for the second phase

8.4.3 Monitoring in the Xikundu fishway

Fishways are regarded as successful if they are both effective and efficient and to determine this success it should be possible to monitor the movement of fish and other biota with ease and in relative safety.

The aspects of the Xikundu fishway that relate to the above that were encountered during this phase of the project are discussed below:

8.4.3.1 Access to the fishway

The design and sturdy structure of fishway system at the fishway allows for easy and safe access in both high and low flow conditions.

8.4.3.2 Lighting

The lighting provided is adequate to allow for monitoring in the fishway throughout the night without using additional lighting as flashlights. There is also sufficient lighting at the top of the weir so that the area can be utilized as a weighing and measuring station. Electrical plug points would have been a useful addition for equipment such as scales.

8.4.3.3 Ability to move around on the fishway

The outer retaining walls as well as the baffle walls of the fishway are wide enough to serve as excellent walkways that allows for easy and safe movement. Movement is even possible when equipment is placed on the walls.

It is however quite difficult to climb up and down to the baffles but portable fishways can be used to climb up and down. These fishways can double up as walkways to get across the pools. The latter aspect will be important during the second phases when the directionality of fish movement has to be determined.

8.4.3.4 Safety of the monitoring personnel

The adequate lighting provided allows monitoring personnel to have both hands free while working. The wide walls allow for safe movement. The sturdy structure of the fishway can also be utilized as anchoring points for safety cords attached to the personnel. The latter aspect is of extreme importance during high flows.

The safety can be enhanced if anchoring points, e.g. rings in the walls, are provided to which safety cords can be attached.

8.4.3.5 Access from the river

Local residents have access to the fishway from the downstream side of the river when the flows are low. This renders the fishway vulnerable to poaching. To counteract this, the fishway could be covered with a grid (as was originally planned in the design). This would however be costly and the sheer weight of these structures would make monitoring very difficult.

The same effect could be achieved if the fishway is fenced off downstream and a railing is provided on the walls closest to spill over side of the weir and at the entrance. Such a railing could also assist with the safety of the monitoring staff by doubling up as attachment points for safety cords.

8.4.4 Problems encountered at fishway

8.4.4.1 The causeway/low-water bridge

The causeway/low-water bridge that was constructed downstream of the weir has not been demolished and although the flow at low levels will allow fish to move through the culvert the scenario will definitely change as soon as flows increase. Fish will not be able to negotiate the obstruction during flows higher than that encountered during the monitoring periods.

The obstruction should be removed as soon as possible to enable migration during higher flows.

8.4.4.2 Use of fishway by the local community

In the period from January to March 2005, when flow in the river was low, the local community started using the fishway for recreation and other purposes. These included:

- Washing of clothes on the rocks that were placed to create the entrance of the fishway,
- People entering the fishway and using it to bath themselves.
- People using the fishway as a diving platform.

This use of the fishway illustrates the need for recreation and washing facilities that exist in the community. Discussions with people also brought to the fore that locals believe crocodiles are unable move into the structure and that they are therefore safe if they use the fishway. On more than one occasion crocodiles were observed in the entrance to the fishway. Discussions also indicated that nobody using the fishway was aware of what it was and what it was built for.

It is suggested that in order to prevent local people from entering the fishway and endangering themselves, a process of information transfer takes place within the local communities. It is of no use if communities are involved in the EIA process but play no role or are ignored once the structure is completed.

8.4.4.3 *Illegal netting of fish in the river*

On two occasions men were observed fishing in the pools below the fishway and next to the entrance with cast nets. Although the fishermen were informed that their gear was illegal the project team could do no more with regards to these activities.

Harvesting of fish at the entrance of the fishway has a very negative impact on the effectiveness of the fishway and prevention thereof needs to form part of the management plan of a successful fishway. If DWAF were to manage the fishway this aspect would therefore be their responsibility.

8.5 WORK STILL TO BE DONE

The following results are still outstanding and will be reported on in the next WRC project K5/1409 on fishways.

- Egg development analysis
- Continued monitoring of the fish movements at the fishway
- Statistical analyses to determine relationships between fish movement and biological conditions of the fish on the one hand and environmental conditions (cues) on the other.

8.6 SHORTCOMINGS IDENTIFIED IN DATA COLLECTION

The following shortcomings were identified in the first phase of the project and will be addressed and rectified in the second phase:

- a) Too few specimens were collected of some species.
This specifically refers to the two *Labeo* species. Care will be taken to overcome this by putting a record system in place so that the number and size class of the specimens collected is updated at each monitoring session.
- b) The condition, gonadal development and the maturity coefficient of the Chiloglanids need to be determined. Because of their small size the dissection and accompanying measurements is time consuming. During the next phase, an extra technical assistant will be engaged to help with this aspect.
- c) The improved results over time could be as a result of improving sampling skills of collection.
- d) The fish as an artificial environmental cue could use the light used at night by the samplers.
- e) The fish collected in the fishway, such as Chiloglanids, could be living and feeding in the fishway.

9. PRELIMINARY DESIGN AND MONITORING REFINEMENT

As discussed in Chapter 2 there are other WRC sponsored projects dealing with fishways. There are obvious overlaps between these projects one of the products of Bok *et al.*, (2005) was a set of design guidelines for fishways. The final delivery of the WRC funded research is a document titled: Guidelines for the planning and design of fishways in South Africa. The title of the report dealing with the first project will be “**Preliminary guidelines for the design of fishways in South Africa**”.

Due to the overlap of the study of fishways in the WRC projects, the results developed on the design criteria of fishways (Bok *et al.*, 2005) were not duplicated in this project but rather assessed during the monitoring programmes of Nhlabane and Xikundu fishways (Chapters 7 and 8). The results of all these South Africa fishway studies will be used and incorporated into each of the WRC reports. All these studies have the same common goal of producing a definitive guideline book of **how to design, monitor and maintain fishways for South African conditions**.

The hydraulic design of fishways is discussed and examples of these are related to South African conditions (Bok *et al.*, 2005). The basic hydraulic theory and design criteria is given as well as the advantages and disadvantages of various types of fishways.

In summary, the recommendations of Bok *et al.*, (2005), with regards to design guidelines for fishways are as follows:

- The fishway designs currently being used in South Africa (Appendix B) are only a few of the possibilities.
- A proper and appropriate design can only be made once the needs of the fish species to be catered for are known.
- The hydrology of the river needs to be considered before the fishway is designed to take into account the specific migratory requirements of the fish (when they need to move)
- It is important to remember that fish have to migrate during high flows and that the designs such as Vertical-slot fishways will be preferred.
- From the examples used it is clear that it is often possible to design a cheap Pool and Weir type fishway for small fish migrating in small rivers with long periods of low flow at which the water level at the barrier remains relatively constant.
- In large rivers where the flow level varies the Vertical-slot type of fishway is recommended.
- The combination of Pool and Weir and a Vertical-slot fishway by providing a sloping sill in the slot has a high potential for South African river.

The design criteria principles described above were used in the development of both the Nhlabane and Xikundu fishways. The Nhlabane fishway is a modified pool-and-weir fishway with 98 pools arranged in a folded-staircase type design giving a total length of 47 m. The Xikundu fishway is a Pool and Weir with deep pools also arranged in a folded-staircase type design. The results of the monitoring programme undertaken on both these fishways (Chapters 7 and 8) will be used in the further refinement of South African fishway design criteria (WRC project K5/1409) and used to develop field and laboratory tests to determine fish movement patterns under different flows and fishway designs.

10. RECOMMENDATIONS FOR FURTHER WORK

It is interesting to note that the recent world-wide survey of fish experts mentioned that the three most important research topics on fishways are (in order of priority, White *et al.*, 2001):

- assessing the relative swimming abilities and behavioural characteristics of indigenous migrating fishes with respect to fishways;
- assessing the relative performance of different fishway types;
- entrance and exit conditions adjacent to fishways (including tidal conditions).

It is significant that the WRC fishway research programmes (initiated in 2001 and continuing until 2007), includes projects that are aimed at:

- assessing the effectiveness of existing hydraulically-rated fishways of various designs in passing indigenous fish under various flow regimes,
- determine accurately the numbers of fish that enter the fishway and move out at the opposite end (both up and downward movements), and
- field trials using model fishway prototypes at barriers to natural fish migration in rivers.

Furthermore recommendations have been made in this report and Bok *et al.*, (2004) on the importance of the location of the entrance and exit of a fishway. The exact location of the entrance and exit has been built into the design criteria developed for South African fishways.

10.1 STRUCTURED NATIONAL FISHWAY MONITORING PROGRAMMES

It is anticipated that carefully designed monitoring programmes on the various existing fishways in South Africa will make a valuable contribution to the current fishway provision programme in South Africa. Not only will the information allow the effectiveness of the individual fishways monitored to be improved, but also this data should further facilitate the development of fishway designs suitable for the hydrological conditions and migratory species found in this country. Furthermore the standardisation of sampling methods and data collection sheets will enable the results to be captured on a centralised database (such as those being developed on the fishway website, <http://www.fishways.co.za/>). The accessibility of the data will greatly assist with further design development and refinements.

10.2 GUIDELINES FOR FISHWAY PROVISION

The fishway research programme in South Africa, sponsored by the WRC, is aimed at developing guidelines for the provision of fishways suitable for the wide variety of migratory aquatic species found within the various climatic and hydrological regions of the country. A preliminary report has been published, entitled: “*Guidelines for the planning, design and operation of fishways in South Africa: First Edition*” (Bok *et al.*, 2004) and is an initial product stemming from these on-going projects.

The next phase of the WRC funding (Project No. K5/1409) has the following terms of reference:

- GIS data base

- Protocols for ranking & need for fishways
- Database on swimming & migratory behaviour
- Laboratory studies – swimming, species
- Field studies - swimming, species
- Hydraulic field studies
- Hydraulic laboratory studies

The objectives of the above project are:

- quantify extent of problem relating to the blocking of free passage of migratory biota in South African rivers;
- develop an assessment method/protocol around the provision of fishways for use in EIA and Ecological Reserve determinations;
- develop an understanding of biological/physiological requirements of fish for successful fishway implementation; and
- develop/review fishway designs that are suitable for different species and river systems

The final product of the WRC fishway funding will be a book entitled “Guidelines for the planning and design of fishways in South Africa.”

10.3 IDENTIFYING PRIORITY FISHWAY SITES

In addition to developing suitable fishway designs for placement on instream barriers, it is also important to quantify the extent to which natural migrations in rivers have been blocked by man-made structures. Preliminary protocols have been developed to assess the need for a fishway at any instream structure, as well as to quantify the impact of the barrier on migratory species present (Bok *et al.*, 2004). These protocols will enable priority sites for the provision of fishways to be identified and the limited available funding to be spent optimally.

The inventory as discussed in Chapter 4 and Appendix A of South Africa instream barriers to fish movement on a catchment basis is a start that is required so as to prioritise these barriers in terms of their ecological impact. A national inventory of barriers to migration will allow these high priority barriers identified and a cost-effective fishway strategy developed. The database structure for this inventory is presently under development and can be seen on the following website: <http://www.fishways.co.za/>.

The protocols developed by Bok *et al.*, (2004) for fishway requirements and importance in South African rivers will be further tested and refined in project K5/1409.

10.4 TESTING OF FISHWAY DESIGNS IN DIFFERENT ZOOGEOGRAPHICAL ZONES

The ongoing refinement of South African fishway designs will continue in WRC project K5/1409. This will entail the use of at least two types of portable fishways that can be taken to a river when fish migrations are expected. The success of these fishways will be tested and design modifications recommended. The design modifications will then be implemented and retested both in the field and laboratory (both at Rhodes and Johannesburg University).

10.5 EXPERIMENTAL LABORATORY WORK ON FISH SWIMMING ABILITY

Internationally there is a wealth of literature on the swimming ability of fish. Locally this data is virtually non-existent. The swimming abilities and behavioural characteristics of a selected number of key indigenous migrating fishes will be tested in project K5/1409. These tests will take place within environmentally stable conditions (controlled light and water temperature as well as within an array of chosen fishway designs).

10.6 DISCHARGE RELATED TO FLOW DEPTH

In order to determine the flows at a specific fishway when monitoring it is important that the hydraulic characteristics of the fishway are understood per flow. Once the fishway has been hydraulically calibrated it is easy for the sampler to record the water level or depth and then convert this to flow. It is important that a hydraulics engineer undertakes these surveys at the fishways indicated in Appendix A (if they have not been calibrated).

10.7 DWAF LIAISON

It is suggested that a workshop is held with the various civil engineers with DWAF as well as some of DWAF's design consultants to present the findings of the WRC fishway studies to date. There are different practices being applied for the design of fishway's and not all of them are using the best available practice as has been developed in the WRC fishway programme. This workshop should take place in the latter part of 2006 so as to bring the design engineers up to speed with the latest developments.

10.8 INTERNATIONAL COLLABORATION

The researchers in this project have been communicating with international experts. The international fishway designs used in Canada, Europe and Australia have been critically reviewed for local conditions. It is recommended that a workshop is held within the next year to which we invite some international experts from say Australia to act as reviewers of our developments as well as give insights into ongoing developments.

10.9 CONCLUSIONS

It is apparent that these WRC research projects should be designed to provide answers relating to the three priority research topics given above. The most promising fishway designs for South African conditions, as indicated by both local and overseas studies, have been identified in this report. It is important that these designs are selected and thoroughly tested and then modified and fine-tuned for local species and conditions in these proposed field trials.

Once the appropriate designs for fishways have been thoroughly tested it is suggested that some form of accreditation process takes place so that the correct fishways are built in South Africa.

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