

# THUKELA WATER PROJECT DECISION SUPPORT PHASE

## RESERVE DETERMINATION STUDY

### THUKELA BANK: IMPACTS OF FLOW SCENARIOS ON PRAWN AND FISH CATCH

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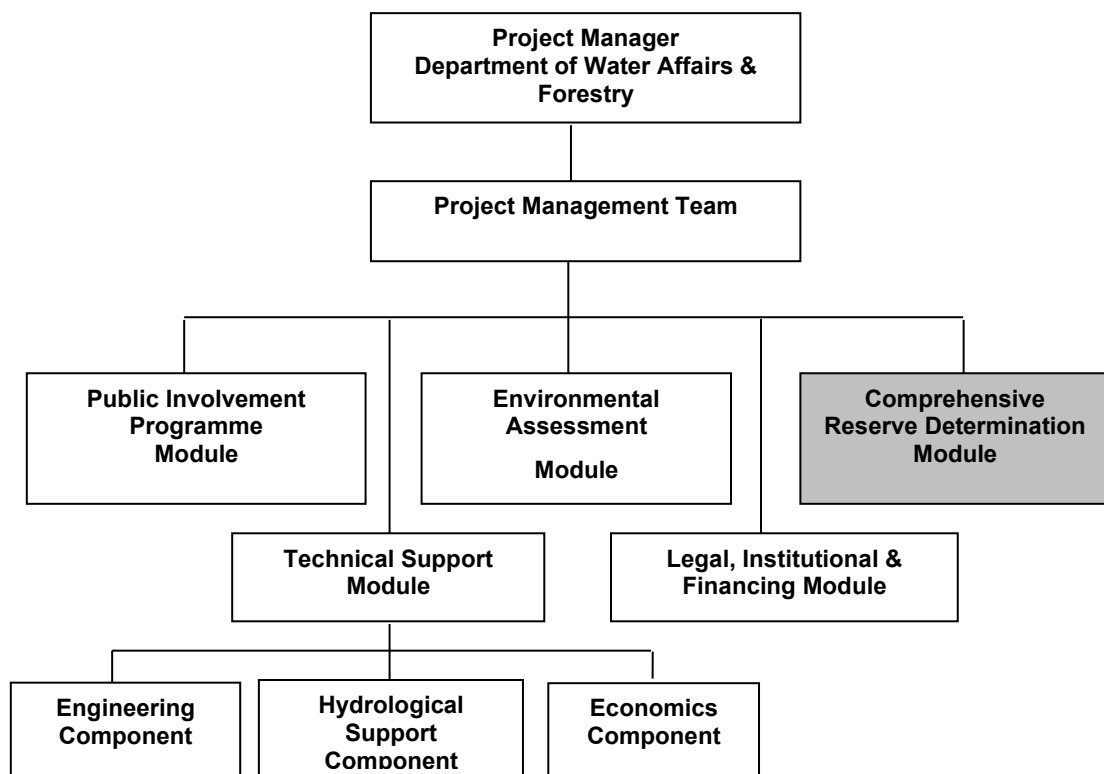
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## STRUCTURE OF DECISION SUPPORT PHASE



**DEPARTMENT OF WATER AFFAIRS & FORESTRY  
DIRECTORATE WATER RESOURCES PLANNING**

**THUKELA WATER PROJECT DECISION SUPPORT PHASE  
RESERVE DETERMINATION STUDY  
THUKELA BANK: IMPACTS OF FLOW SCENARIOS ON PRAWN  
AND FISH CATCH**

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**FEBRUARY 2004**

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# EXECUTIVE SUMMARY

## BACKGROUND

This study follows a study undertaken by Marine and Estuarine Research (MER) to assess, on the basis of existing information, the potential ecological impacts of the proposed Thukela catchment dams on the coastal and shelf environments. This was undertaken during 2000 as part of the Thukela Water Project Feasibility Study. It was initially intended that this marine study establish the freshwater and sediment requirements for the Thukela Bank. After careful consideration and the lack of methodologies, it was decided that the team should only assess the ecological impacts and the economic implications of changes in fishery catches due to different flow regimes.

## OBJECTIVES OF THE STUDY

The objectives of the study were to

- Determine whether there is a link between flow and catch (assuming that nutrient and sediment function is being provided by flow).
- Define the link if it does exist.
- Isolate the contribution of the Thukela flows.
- Assess the economic implications of various flow scenarios.

## Tasks

Sequential tasks to undertake this study were identified and undertaken as follows:

- Task 1: Select rivers/estuaries that contribute significantly to the Thukela Bank.
- Task 2: Collect available hydrological data.
- Task 3: Analyse prawn catch data.
- Task 4: Carry out scoping exercise to investigate potential linkages between fish catch, flow and prawn catch.
- Task 5: Calibrate catch-flow relationship and impact of flow changes (Reserve scenarios).
- Task 6: Estimate economic value of the resource and link to Reserve and other scenarios.

## HYDROLOGY

Monthly historical flow records for all catchments within the study area covering the period from 1980 to 2000 were required. Gauging stations are the only source of historical flow data, but not all the rivers have gauging stations and not all the stations cover the required record period. Supplementary data was sourced from the following models: ACRU, WR90, WRYM data and WRS90.

The different flow scenarios evaluated in this study:

- **Natural:** This scenario provides the upper boundary for the results and is based on the naturalised or virgin flow regime for the Thukela River.
- **Scenario 1:** 2000 development in the Thukela with **Reserve Scenario 1** (High category freshwater Reserve) in place. This scenario will result in the highest inflow to the Bank.
- **Scenario 8:** This scenario represents a realistic 2015 development scenario with no dedicated releases for instream flow requirements, a full Thukela-Vaal transfer allocation and expected in-basin development allowed. No TWP dams in place.
- **Worst Case:** This scenario was included to provide a lower boundary for the results. This is a future scenario with development at 2025 level, with the TWP dams in place.

The full Tukela-Vaal transfer capacity to the Vaal of 35m<sup>3</sup>/s was assumed and no releases were made for the Reserve.

## PRAWNS

The Thukela Bank in KwaZulu-Natal (KZN) provides the only significant habitat in South African waters for this commercially valuable group of crustaceans. The trawl fishery operating in this area is based on three co-occurring prawn species. All three species are distinguished by their life cycle which, because of their general occurrence in shallow marine waters and the dependence of the juvenile phase on estuarine habitats, brings them into situations where they are exposed to catchment driven environmental variables. This means that factors such as estuarine salinities, nutrient supply and general catchment events have the potential to become major determinants of prawn abundance.

River discharge has long been accepted as having a profound effect on physical, chemical and biological processes in coastal waters. In the KZN context this influence may be more pronounced given the oligotrophic nature of the receiving coastal waters. Earlier investigations suggested a link between Thukela River flows and annual Catch Per Unit Effort (CPUE) but did not differentiate between these flows and the possible contributions made by other rivers which may also influence the Thukela Bank.

The Directorate of Marine and Coastal Management (MCM) of the Department of Environmental Affairs and Tourism (DEAT) provided commercial catch statistics for the period 1988 – 2000, for the prawn fishery on the Thukela Bank. Unfortunately the time value data were found to be entered incorrectly for a large proportion of the records. This meant that the data had to be compared and verified using the additional dataset held by MER. This dataset, obtained from the fishing companies records for the period 1984 – 1995 and from the actual drag and landing records from 1996 – 2000, overlaps the dataset provided by MCM (1988 – 2000).

## PRAWN CATCH-FLOW RELATIONSHIP

The predictive prawn catch equations independent variables had to be developed. The purpose of the predictive equation was to determine a link between historical river flows and historical prawn catch of the Thukela Bank. This equation was then used to quantify the impact of revised Thukela flows on the prawn catch.

The rivers and estuaries provide a habitat and nursery area and also provide nutrients and/or detritus to the Bank. These two main functions are summarised below:

- **Nursery Function:** River estuaries provide a crucial habitat for the postlarvae and juvenile stage of the prawn life cycle. Only two catchments have been identified as nursery grounds and were treated separately as Nursery Rivers. These nursery rivers are provided below:
  - Lake St Lucia (Mkuze, Mezene, Hluhluwe and Nyalazi Rivers).
  - Mhlathuze River.
- **Nutrient Function:** All the rivers in the study area contribute to the nutrient and organic input available to the Thukela Bank.

### Nursery function

The prawns in the **postlarval** stage generally enter the estuaries (**recruitment**) during July, August and September and remain there about 8 months. The **juvenile** prawns start leaving the estuaries (**emigration**) during February, March and April. The prawn catch season was constrained to fall between March and September. The flows from the Nursery Rivers were converted to an equivalent **Nursery Index**, based on the following relationship:

$$\text{Nursery Index (NI)} = \text{Recruitment Index (RI)} + \text{Emigration Index (EI)}$$

The RI indicates the period (July, August and September) where the prawns in the **postlarval** stage enter the estuaries where they will mature to the **juvenile** stage from where they return to the Bank. This is an indicator of the *catch in the following year* from March to September.

The EI indicates the period where the juvenile prawns leave the estuary area and return to the Bank (February to April).

### Nutrient Function

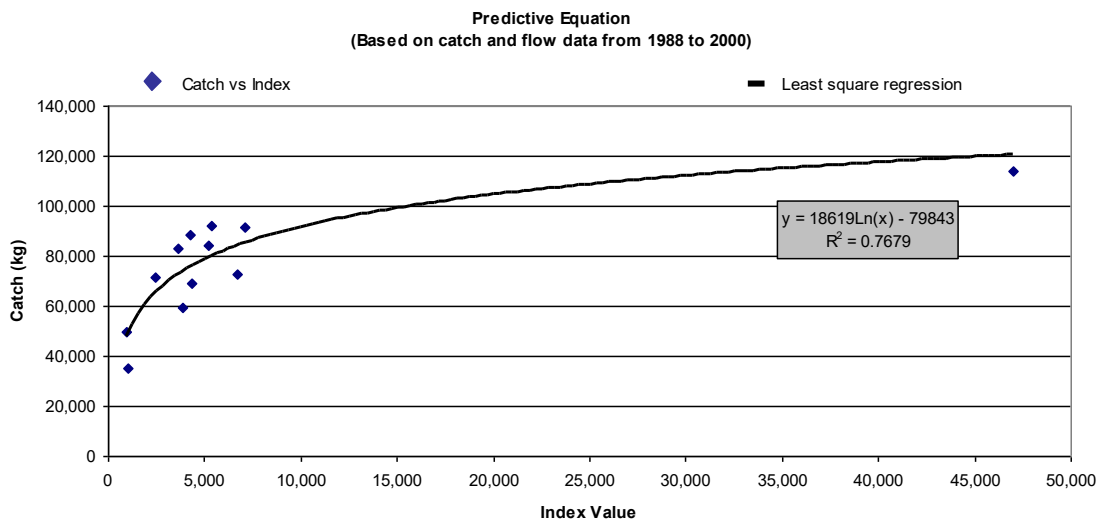
All the rivers in the catchment contribute to the nutrient load available on the Bank, and the nutrient index values will therefore be based on the sum of all the rivers. Both the larval and adult stages of the prawn life cycle are spent in the inshore marine environment. These two life stages have been treated separately in the equation, as they are dependant on different periods of flow. The Nutrient Index for the Larval stage (NUTIL) is the sum of the flows from the Thukela and other rivers from **July to October**. The Nutrient Index for the Adult stage (NUTIA) is the sum of the flows from the Thukela and other rivers from **November to February**.

Different flow regimes in the Thukela River can now be included and the NI will remain unchanged but the NUTIL and NUTIA indices will be affected.

The three independent variables will be combined based on a weighting system in order to provide a single independent variable called the **Index Value**.

Regression analysis was undertaken in order to determine the final predictive equation. The **NUTIL** and **NUTIA** variables were determined based on the historical flows in the Thukela. The regression equation was based on the weighted annual totals of the three monthly independent variables and the total catch during the main season. The most appropriate regression analysis was a log function where X is the independent variable (Index Value) and Y the dependant variable (Prawn Catch in kg). The results of the analysis are provided in the figure below.

### Regression Analysis



This equation has a Coefficient of Determination = 0.77 ( $R^2$ ). Effectively this means that the predictive equation explains 77% of the variance in the observed catch data.

The predictive equation was used to predict catch for the period from 1988 to 1995 for the four scenarios. The scenarios were simulated and the results are compared to the predicted historical catch.

## Scenario Results

Year	Predicted Catch (kg)	Percentage Change (%)			
		Natural	Scenario 1	Scenario 8	Worst Case
1988	120 455.01	0.6	0.2	-0.4	-0.7
1989	84 158.46	1.8	-0.3	-2.4	-4.4
1990	76 255.92	3.8	2.0	-0.5	-2.2
1991	75 593.37	4.2	2.2	-0.4	-4.0
1992	72 911.72	9.8	5.9	3.2	-3.2
1993	47 665.02	19.8	11.7	1.4	-11.2
1994	79 346.30	6.1	2.1	0.1	-3.5
1995	49 327.14	21.8	15.6	5.8	-3.9
Average Percentage Change		8.5	4.9	0.9	-4.1
Standard Deviation		8.1	5.8	2.6	3.1

The results indicate that the catch would always be better under the **natural** condition (8% higher on average), with **Scenario 1** being generally better (little worse in one year) and **Scenario 8** being better in some years and worse in others. The **worst-case** scenario will always result in lower catches (4% lower on average).

## FISH

River flows influence marine fish and fisheries directly and indirectly through the export of nutrients, sediment and detritus. Freshwater flows also provide cues for the migration of estuarine-dependent juvenile and adult fish into and out of the estuarine environment. The strength of these cues will ultimately dictate how many individuals of these species recruit into the marine fisheries. From a fisheries perspective, altered freshwater flows and consequently any of the above variables, can cause changes in catch composition, resource base (e.g. demersal vs pelagic fish abundance), fleet structure, the spatial and temporal distribution of effort and ultimately the economic value of the fishery concerned.

The commercial and recreational boat-based linefishery is the most important marine fishery in KwaZulu-Natal, accounting for 40% of the total landed mass there. Effort is distributed fairly evenly to the north and south of Durban, with 40-50 boats and 200-300 crew operating in the vicinity of the Thukela Bank.

In all, 140 species, 60 of which are regarded as important, are caught by the KZN linefishery, and approximately 1 200 tons are landed annually. The commercial and recreational sectors are responsible for 62% and 38% of this catch respectively.

## FISH CATCH AND FLOW LINK

Exploratory analyses of the relationships between monthly flows and catches were performed using Spectral Analysis and General Linear Models (GLMs). The information available comprised 17 years (1985-2001) of monthly commercial catch and effort data for 140 species from the National Marine Linefish System (NMLS, MCM, DEAT), and monthly flow data from seventeen catchments to the north of Durban compiled by WRP. Spectral Analysis examines the relationships between two time series (flow and catch) in terms of

their similarity in frequency and intensity of recurring events. Cross spectral density provides a measure of the intensity of the relationships. The GLMs were run using the direct monthly flow vs CPUE data as well as with the lag-times associated with the highest cross spectral densities from the spectral analysis.

The predicted catches under the Reserve scenarios 1-6 do not differ much from the present day, varying from no change for Dane and rubberlip to a maximum of 1.58% for slinger. Slinger (14%), squaretail kob (11%) and dorado (7%) experience a substantial decline in catches under scenario 8. Slinger and squaretail kob are the two most important species, and provide 50 % of the landed mass, of the Thukela Bank commercial linefishery. Under scenario 8, the decline in catches of these two species would result in a 20t (7%) drop in the total annual catch from the Bank.

Under the worst-case scenario, catches of slinger, squaretail kob and dorado decline by 36, 28 and 18% respectively. This equates with a 50t (17%) reduction in the total landed catch of the commercial linefishery from the Thukela Bank. Overall, under the worst-case scenario, and despite the predicted increase in the CPUE of some species, there is likely to be a 20% reduction in the total landed catch of the Thukela Bank commercial linefishery. Increased catches of those species responding positively to a reduction in flow are unlikely to compensate for those lost. Most of these species either occur naturally in low abundance, and / or have already been fished down to such an extent that the required increase in CPUE is highly unlikely.

In summary, flow from the Thukela River appears to have a major impact on the catch of squaretail kob with a reduction in catch of 28% predicted under the worst case scenario. In South Africa, remedial measures aimed at rebuilding linefish stocks are almost exclusively confined to changing fisher behaviour and limiting fishing effort. If the squaretail kob stock is to be successfully rebuilt, the management plan will have to deviate from the traditional path and take the influence of the Thukela and other KZN catchments into consideration.

## **ECONOMIC IMPLICATIONS OF THUKELA FLOW CHANGES**

The commercial crustacean fishery is estimated to have a total gross value of R37 million (2003 Rands), but this ranges between R21 and R43 million due to the variability in catches. Inshore catches are estimated to contribute R10 million of this (R8.5 million from prawns), with about a quarter of the fishing effort providing a quarter of the overall value. The impact of the scenarios described in this document was estimated to range from a R240 000 increase in the under scenario 1 to a R260 000 decrease in the worst case scenario. These values are small, and only amount to a -1.0 to +1.1% change in the value of the crustacean fishery. The reported changes are unlikely to affect viability of the fishery for the companies involved. Even much larger changes would be expected to be weathered without much economic impact, through a change in the way in which the inshore and offshore banks are utilised.

In comparison, the commercial boat-based line fishery on the Thukela banks has an estimated gross income of R3 million (1997 Rands). The impacts of the different scenarios on this fishery are greater in terms of percentage change. While there is very little change under Scenario 1, Scenario 8 results in a loss of income of R185 000, spread (unevenly) among 40-50 boats, and the worst case scenario results in a loss of almost R0.5 million (1997 Rands).

Recreational fishing is also a large recreational boat-based line fishery which has no commercial value in terms of landed catch but which is very valuable in terms of its contribution to the economy through expenditure by anglers. However, the predictions made in this study suggest that there would be no measurable impact on this value, since the changes in catches would be small, and recreational anglers do not generally change their behaviour in response to minor changes in catch.

Overall, the results of this study indicate that the proposed scenarios are unlikely to have major impacts on the crustacean fishery, but could have measurable impacts on the commercial linefishery. The changes are summarised in the table below.

<b>Sector</b>	<b>Current Value</b>	<b>Change in value under worst case scenario</b>	<b>% Change under "worst case scenario"</b>
Crustaceans (including bycatch)	R37 million	R260 000	- 1.0%
Fish	R 3 million	R500 000	- 16.7%

<b>ACKNOWLEDGMENTS .....</b>	<b>i</b>
<b>EXECUTIVE SUMMARY.....</b>	<b>ii</b>
<b>GLOSSARY OF ACRONYMS AND ABBREVIATIONS.....</b>	<b>xiii</b>

## TABLE OF CONTENTS

	Page
<b>1 INTRODUCTION AND BACKGROUND.....</b>	<b>1-1</b>
1.1 Background.....	1-1
1.2 Introduction .....	1-1
1.3 Approach.....	1-1
1.4 Objectives of the marine study .....	1-2
1.5 Study area.....	1-2
1.6 Purpose of this report.....	1-2
1.7 Structure of the report .....	1-2
<b>2 RATIONALE AND DATA REQUIREMENTS.....</b>	<b>2-1</b>
2.1 Previous prawn assessment.....	2-1
2.2 Previous prawn catch link.....	2-1
2.3 Shortcomings of the previous study.....	2-1
2.4 Motivation for addressing the dependency of the marine Bank on freshwater (and nutrients and sediments).....	2-1
2.5 Approach.....	2-2
2.6 Task description .....	2-2
2.7 Potential pitfalls .....	2-3
<b>3 HYDROLOGY .....</b>	<b>3-1</b>
3.1 Study Area .....	3-1
3.2 Data sources and associated confidence .....	3-2
3.2.1 Observed Data (Gauging stations).....	3-3
3.2.2 ACRU .....	3-3
3.2.3 Water Resources Yield Model (WRYM) .....	3-4
3.2.4 Water Resources Simulation Model (WRSM90).....	3-4
3.2.5 Surface Water Resources of South Africa 1990 (WR90).....	3-4
3.3 Extension of hydrologies and patching of runoff records .....	3-5
3.4 Analysis results .....	3-5
3.4.1 Mkuze River (Lake St Lucia) .....	3-6
3.4.2 Mezene (Mzinene) River (Lake St Lucia) .....	3-6
3.4.3 Hluhluwe River (Lake St Lucia) .....	3-6
3.4.4 Nyalazi River (Lake St Lucia).....	3-7
3.4.5 Mfolozi River .....	3-7
3.4.6 Mhlathuze River.....	3-7
3.4.7 Mlalazi/Siyai Rivers.....	3-7
3.4.8 Matigulu/Nyoni Rivers .....	3-7
3.4.9 Thukela River.....	3-7
3.4.10 Mvoti River.....	3-7
3.4.11 Mhlali/Seteni Rivers .....	3-7
3.4.12 Tongati River .....	3-8
3.4.13 Mdloti/Mhlanga Rivers.....	3-8
3.4.14 Mgeni River.....	3-8
<b>4 SHALLOW WATER PRAWNS.....</b>	<b>4-1</b>
4.1 Background.....	4-1
4.2 Life cycle of the shallow water penaeids in KZN.....	4-1
4.3 Functional significance of estuaries and their relationship to the KZN prawn fisheries.....	4-2
4.3.1 Estuarine nursery areas .....	4-2
4.3.2 Rivers providing sediment and nutrient input to the coastal zone .....	4-2

4.4	Prawn catches between 1988 – 2000.....	4-3
4.4.1	Catch Data.....	4-3
4.4.2	Annual Catch Statistics .....	4-3
4.4.3	Monthly Catch Statistics.....	4-4
<b>5</b>	<b>FISH.....</b>	<b>5-1</b>
5.1	Background.....	5-1
5.2	The KwaZulu-Natal linefishery.....	5-1
5.2.1	Catch composition .....	5-2
5.2.2	Economic contribution.....	5-4
5.3	Establishing fish Catch hydrology relationship.....	5-4
5.3.1	Spectral Analysis .....	5-4
5.3.2	General Linear Models.....	5-7
5.3.3	Fish catch predictions for the Reserve scenarios .....	5-7
5.4	Conclusion .....	5-11
<b>6</b>	<b>PRAWN CATCH HYDROLOGY RELATIONSHIP: DEVELOPMENT OF PREDICTIVE EQUATION INDEPENDENT VARIABLES .....</b>	<b>6-1</b>
6.1	Nursery function.....	6-1
6.1.1	Recruitment Index (RI).....	6-1
6.1.2	Emigration Index (EI) .....	6-2
6.2	Nutrient Function.....	6-3
<b>7</b>	<b>PREDICTIVE EQUATION AND RESULTS .....</b>	<b>7-1</b>
7.1	Independent variables.....	7-1
7.2	Combination of the components to calculate the independent variable .....	7-1
7.3	Regression analysis .....	7-2
7.4	Results: Scenario analysis .....	7-3
<b>8</b>	<b>ECONOMIC IMPLICATIONS OF THUKELA FLOW CHANGES .....</b>	<b>8-1</b>
8.1	Introduction .....	8-1
8.2	The crustacean fishery.....	8-1
8.2.1	Fishing grounds and species caught.....	8-1
8.2.2	The fishing fleet and effort.....	8-2
8.2.3	Effort and catches.....	8-3
8.2.4	Marketing and prices.....	8-7
8.2.5	Value of the crustacean fishery .....	8-8
8.2.6	The economic implications of changes in freshwater outputs.....	8-10
8.3	The Thukela bank boat based linefisheries .....	8-12
8.3.1	The nature and value of the commercial linefisheries.....	8-12
8.3.2	The nature and value of the recreational linefisheries .....	8-13
8.3.3	The economic implications of changes in freshwater outputs.....	8-13
<b>9</b>	<b>CONCLUSIONS .....</b>	<b>9-1</b>
<b>10</b>	<b>REFERENCES .....</b>	<b>10-1</b>

## ELECTRONIC APPENDICES

### Hydrological appendix

- 1 Nursery Index.xls (WRP, du Toit): Calculation of the nursery index.
- 2 Summary final not smoothed.xls (WRP, du Toit):
  - Chart 1: Monthly volumes for all rivers
  - Chart 2: Monthly volumes for all rivers as a % of the total
  - Chart 3: Volumes for all rivers used for analysis (excluding the smaller rivers)
  - Chart 4: Volumes used for each reserve scenario.

- 3 Final prediction 04. xls (WRP, du Toit): Provides the calculations for the predictive equation and the Reserve scenario results.

Prawn database appendix (Provided by Ms N Demetriades)

Fish database appendix (Provided by Mr S Lamberth)

## LIST OF FIGURES

Fig 1.1	Map of KwaZulu-Natal showing major rivers and the continental shelf to the 200m depth contour .....	1-4
Fig 3.1	Illustration of the relevant quaternary catchments and study area (Fig not to scale) .....	3-1
Fig 3.2	Thukela River contribution .....	3-6
Fig 4.1	Life cycle of a typical shallow water penaeid prawn .....	4-2
Fig 4.2	Annual catch and effort in the shallow water penaeid fishery on the Thukela Bank 1988 - 2000 .....	4-4
Fig 4.3	Annual CPUE in the shallow water penaeid fishery 1988 – 2000.....	4-4
Fig 4.4	Monthly CPUE in the shallow water penaeid fishery 1988 – 2000 .....	4-5
Fig 4.5	Mean monthly catches and CPUE for the period 1988 – 2000. The vertical lines represent 95 % confidence limits for the mean. ....	4-6
Fig 5.1	Time series of monthly volumes from the Thukela River and monthly catch-per-unit-effort of king mackerel by the commercial boat-based linefishery operating on the Thukela Bank for the period 1985-2001.....	5-9
Fig 5.2	Time series of monthly volumes from the Thukela River and monthly catch-per-unit-effort of squaretail kob by the commercial boat-based linefishery operating on the Thukela Bank for the period 1985-2001 .....	5-10
Fig 6.1	Adopted Recruitment Index .....	6-2
Fig 6.2	Adopted Emigration Index .....	6-3
Fig 7.1	Regression Analysis .....	7-2
Fig 7.2	Predictive catch comparison.....	7-3
Fig 8.1	Mean cumulative inshore prawn catch over the year for the period 1988 – 2000 (data source: N. Demetriades).....	8-4
Fig 8.2	Percentage years in which inshore fishing takes place in any month, for the period 1988-2000 (data source: N. Demetriades).....	8-5
Fig 8.3	Mean percentage years fished in a given month vs the mean CPUE for that month over the period 1988 – 2000 (Data source: N. Demetriades) .....	8-5
Fig 8.4	Mean percentage years fished in a given month vs the mean total catch for that month over the period 1988 – 2000 (Data source: N. Demetriades). ....	8-6
Fig 8.5	Retained bycatch biomass relative to total retained catch for inshore catches between 1988 and 1993. (Source data: Fennessy & Groeneveld 1997) .....	8-6
Fig 8.6	Composition of retained catch for the overall crustacean trawl fishery (inshore and offshore), for the period 1992 - 2002. (Data source: Ocean trawling).....	8-7
Fig 8.7	Changes in the nominal price of selected categories of inshore (white) and offshore (pink) prawns from 1993 to 2003 .....	8-8
Fig 8.8	Expected difference in catches for the period 1988 – 1995 under different flow scenarios, where ‘present day’ is the actual flows recorded over that period ....	8-11

## LIST OF TABLES

Table 3.1	Catchments within study area, used for analysis .....	3-2
Table 3.2	Catchments within study area, not included for analysis.....	3-2
Table 3.3	Available data sources .....	3-3
Table 3.4	Gauging stations used in the study.....	3-3
Table 3.5	ACRU systems used in the study .....	3-4
Table 3.6	WRYM systems used in the study .....	3-4
Table 3.7	WRSM90 systems used in the study .....	3-4
Table 3.8	Catchments within study area, used for analysis .....	3-5

Table 4.1	Abridged prawn catch statistics showing raw data used in the prawn catch analyses.....	4-3
Table 5.1	Mean annual catch and economic contribution by the recreational and commercial boat-based linefishery in KwaZulu-Natal. Stock statuses, depending on available data, are ratios of present versus historic, spawner biomass (SBPR <sub>current</sub> i.e. % pristine remaining), catch per unit effort (CPUE) or catch composition, all expressed as percentage. Economic values include value added and all contributions by subsidiary industries. ....	5-3
Table 5.2	Age at first capture and results of spectral analysis and general linear models (GLM) using 17 years (1985-2001) of monthly volumes from 17 catchments and commercial linefish CPUE of selected species as the dependent and independent variables respectively. Cross spectral density and lags apply only to the short term periods of 11-12 months. With the exception of squaretail kob, the highest cross spectral densities for all species were with the Thukela system. Squaretail kob had a strong relationship with the Mfolozi and St Lucia as well as the Thukela. The GLMs are preliminary and only used 1-3 month lags. Significant contributions were made by the Thukela, Mfolozi, Mlalazi, Matigulu, Mhlali, Mdloti and Mgeni systems. ....	5-6
Table 5.3	Predicted catch as a percentage of the present day catch for the eight Reserve scenarios using General Linear Models. Scenario 7 was assumed to be the most representative of present day conditions in the Thukela and flows were the average monthly volumes (m3) from each system. With the obvious exception of the Thukela, the flows for all the other systems were kept constant for each scenario.....	5-7
Table 6.1	Adopted recruitment index .....	6-2
Table 6.2	Adopted Emigration index (EI).....	6-2
Table 6.3	Nursery Index Summary.....	6-3
Table 7.1	Weighting of the Index Value components (Independent Variable) .....	7-2
Table 7.2	Predictive catch comparison.....	7-3
Table 7.3	Scenario Results .....	7-4
Table 8.1	Permits in 2003 .....	8-3
Table 8.2	Estimated total average catch by species and size class for the KZN crustacean trawl fishery, and the gross landed value (in 2003 Rands) of this catch (based on data from Ocean Trawling).....	8-8
Table 8.3	Estimated costs of the crustacean fishery in 2000.....	8-10
Table 8.4	Expected total catch and gross landed value of inshore prawn catches (1993 prices) for four Thukela flow scenarios, compared with the present.....	8-11
Table 8.5	Expected magnitude of change in overall average annual value of the crustacean fishery (1993 prices) for four Thukela flow scenarios, compared with the present .....	8-12
Table 8.6	Expected change in total catch, landed value of the catch and total economic contribution by the commercial linefisheries on the Thukela Bank, as a result of changes in flow of the Thukela. Data source: S. Lamberth, this study & unpublished data. Scenarios 1, 8 and Worst case experience 101.9%, 83.5% and 56.2% of present day flows, respectively .....	8-14

## ACRONYMS AND ABBREVIATIONS

CPUE	Catch per Unit Effort
DEAT	Department of Environmental Affairs and Tourism
EI	Emigration Index
GGP	Gross Geographic Product
GLM	General Linear Model
KZN	KwaZulu-Natal
MCM	Marine and Coastal Management
MER	Marine and Estuarine Research
NI	Nursery Index
NMLS	National Marine Linefish System
NUTIA	Nutrient Index of the Adult stage
NUTIL	Nutrient Index of the Larval stage
PMT	Project Management Team
RI	Recruitment Index
TWPDSP	Thukela Water Project Decision Support Phase
WRYM	Water Resources Yield Model
WRP	Water Resource Planning

# 1 INTRODUCTION AND BACKGROUND

## 1.1 BACKGROUND

The Reserve Determination Module (Module 3 of 5 for the Thukela Water Project Decision Support Phase) is designed, *inter alia*, to meet the requirements of the National Water Act No 36 of 1998. As such the study has been guided by three major parameters. These are:

- The objectives of Chapter 3 of the National Water Act No 36 of 1998 for a comprehensive Reserve Determination and the subsequent RDM protocols released by DWAF.
- The specific requirements of the Terms of Reference as supplied by Department of Water Affairs and Forestry (Tender WF7405).
- The needs of the Thukela Water Project and associated organs of the Department of Water Affairs and Forestry. These include broad based planning required to meet overall water resource management objectives in the catchment.

The Reserve Determination module involves quantification of the water resource required to meet objectives for the Thukela system under a series of scenarios which will be defined during the course of the study. This need for a scenario based approach was mooted so as to enable recommendations regarding water resource planning based on a suite of alternatives with regard to the needs of the Reserve and stipulated management classes for the Thukela system. Out of the Reserve Determination study information will be made available in a manner that will allow the Project Management Team (PMT) of the TWPDSF to make informed recommendations and decisions for the way forward. The specific objectives of this Reserve Determination Module are, therefore:

- Develop scenarios and test these with the DWAF and stakeholders;
- recommend one of these scenarios to represent the Ecological Reserve for the quality, quantity components for the river and estuary;
- determine the impact of the recommended Reserve on the allocatable yield;
- determine whether it is possible to supply the Reserve from existing and proposed schemes;
- and to provide mitigation measures or alternative flow scenarios if it is not.

## 1.2 INTRODUCTION

A study follows a study undertaken by Marine and Estuarine Research (MER) to assess, on the basis of existing information, the potential ecological impacts of the proposed Thukela catchment dams on the coastal and shelf environments. This work was undertaken during the Thukela Water Project Feasibility Study which was finalised during 2000.

During the proposal phase of this Reserve study, the emphasis (for the marine environment) was on establishing the freshwater requirements (or the Reserve) for the Thukela Bank. Due to the lack of suitable tools and the perceived difficulty associated with this approach, a specialist meeting with the appropriate specialists were held on 15 February 2002 to consider the Thukela Bank and the way forward within the Reserve Determination.

This meeting led to a proposal to DWAF for a variation order to include an assessment of the impacts and economic consequences of various flow scenarios on the prawn and fish production of the Thukela Bank. This variation order was approved early in 2002.

## 1.3 APPROACH

The approach adopted within the Reserve module is scenario based. As such the study will generate a series of likely flow scenarios that will be determined by an interactive series of discussions between key specialists, the study management and the TWP. Quantification of

the resource will be attached to these scenarios. As such they will be worked through in terms of their economic consequences. These will then be put to stakeholders for their consideration.

In line with this approach, it was required to further investigate the potential link between freshwater flow and catch. If this relationship can be established, it would play a major role in quantitatively establishing the economic consequences of each flow scenario.

#### **1.4 OBJECTIVES OF THE MARINE STUDY**

The objectives of the study were to

- Determine whether there is a link between flow and catch (assuming that nutrient and sediment function is being provided by flow).
- Define the link if it does exist.
- Isolate the contribution of the Thukela flows.
- Assess the economic implications of various flow scenarios.

#### **1.5 STUDY AREA**

The study area is illustrated in the Figure 1.1 as well as Figure 3.1. The focus is on the Thukela Bank which fall within the area where the continental shelf widens known as the Natal Bight.

#### **1.6 PURPOSE OF THIS REPORT**

The purpose of the report is to document the

- Preparatory work undertaken to establish the link between flow and catch;
- outcomes of a specialist meeting during which the link was established;
- the economic analysis of the impact of different flow scenarios on the fisheries.

#### **1.7 STRUCTURE OF THE REPORT**

The report was documented by various authors (see list of chapters and authors below) and each chapter documents a specific phase and data collated within the study. The chapters therefore represent the sequential approach followed during the study.

Chapter 1: Introduction and Background (D Louw)  
This chapter.

Chapter 2: Rationale and Data requirement (D Louw)  
This chapter provides the background and rationale for the initiation of this study. Shortcomings of previous studies are identified and the motivation for addressing the dependency of the Marine banks on freshwater are outlined. Sequential tasks for the study are identified and data requirements are addressed.

Chapter 3: Hydrology (Mr A du Toit)  
A general overview of the hydrological data required and acquired for the analysis is provided. Catchments included in the analysis are identified, as well as the source data available and the confidence linked to this data is discussed.

Chapter 4: Shallow water prawns (Ms N Demetriades and Prof T Forbes)  
An overview of the significance of shallow water prawns on the Thukela bank, and the importance of Estuaries and Rivers in their life cycle are provided. Monthly and annual prawn catch statistics for 1988 – 2000 were analysed. Prawn production was examined in

terms of catch, effort and catch per unit effort (CPUE) on an annual and monthly basis to identify fluctuations in abundance.

**Chapter 5: Fish (Mr S Lamberth)**

The importance of freshwater flows for fish are summarised and the impact that altered freshwater flows can have on the catch composition is provided.

**Chapter 6: Prawn catch hydrology relationship: Development of predictive equation independent variables (Mr A du toit and Prof D Hughes)**

This chapter describes the assumptions made in the development of the predictive prawn catch equations independent variables. The purpose of the predictive equation was to determine a link between historical river flows and historical prawn catch of the Thukela Bank. This equation was then used to quantify the impact of revised Thukela flows on the prawn catch.

**Chapter 7: Predictive equation and results (Mr A du toit and Prof D Hughes)**

The three variables attained in chapter 6 are combined based on a weighing system in order to provide an independent variable. This chapter explores the weighing system and to determine the impact of four flow scenarios on catch.

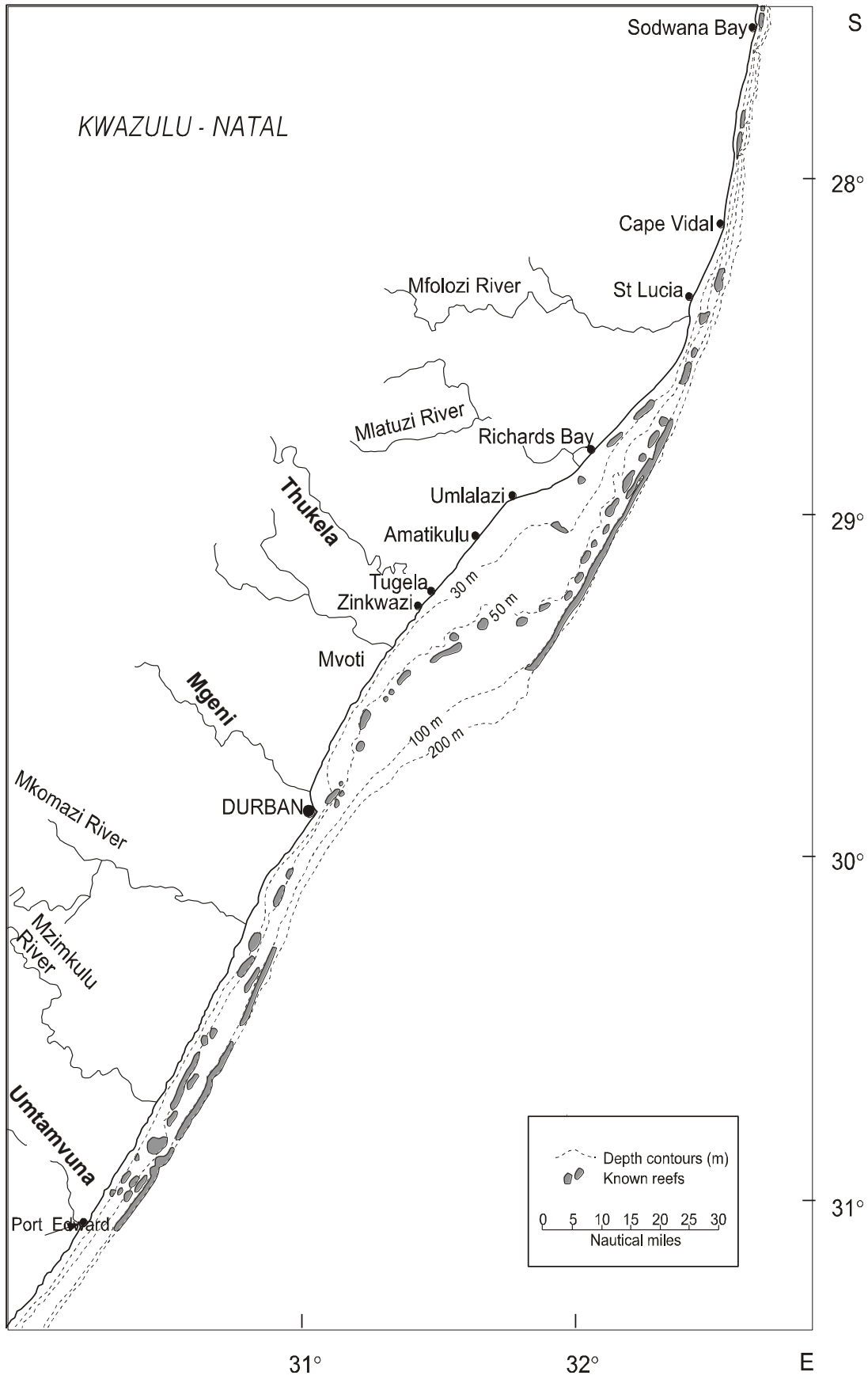
**Chapter 8: Economic implications of Thukela flow changes (Dr J Turpie)**

This chapter builds on the data and findings on the preceding chapters as a basis for assessing the economic implications of alternative flow scenarios on the affected inshore marine fisheries.

**Chapter 9: Conclusions (Dr J Turpie)**

Based on the results of the economic analysis, the conclusions are provided in this chapter regarding the consequences of the changes flow regimes on the prawn and fish catch.

**Fig 1.1 Map of KwaZulu-Natal showing major rivers and the continental shelf to the 200m depth contour**



## **2 RATIONALE AND DATA REQUIREMENTS**

### **2.1 PREVIOUS PRAWN ASSESSMENT**

The objectives addressed by the previous reports (Demetriades 2000, Forbes and Demetriades 2000) were to provide an assessment of the impact of the proposed Thukela Water Project on the penaeid prawn resource which, in terms of economic value, is the most important of the commercial fisheries in this area. This was done by preliminary investigations into the relationship between freshwater outflow from the Thukela River and abundance of prawns by reviewing existing annual catch statistics for the KZN shallow water prawn fishery and simulated Thukela River flows.

### **2.2 PREVIOUS PRAWN CATCH LINK**

A significant correlation between prawn abundance on the Thukela Bank as measured by annual catch per unit effort (CPUE) and the simulated Thukela River flows were found to exist. This appeared to be linked to both the volume of water and seasonality. The best correlations were found between CPUE and summer flows provided these included data from September onwards. September coincides with the maximum abundance of large mature females and hence is most likely to coincide with the presence of planktonic larvae on the Bank. The timing of the high flows was considered to be critical for the successful recruitment of larvae and required further investigation.

### **2.3 SHORTCOMINGS OF THE PREVIOUS STUDY**

A similar study was undertaken at a scoping level with limited budget during the previous Thukela studies. Some of the shortcomings of this study are listed below:

- The entire prawn catch was correlated with flows from the Thukela without taking the contributions from other KZN catchments into account.
- Annual hydrology was used, and it seems mostly, either modelled natural and present day rather than using the actual historical data.
- A link was established previously, but it was not taken further, liaison between the different groups did not take place (the link was done by the hydrological specialists only), and a predictive equation was not available to determine the changes in catch linked to various flow scenarios.
- No evaluation was undertaken of the economic consequences.

Within this more detailed Reserve Determination study, it was therefore deemed appropriate to investigate the consequences of different flows on the Thukela Bank and to address some of the shortcomings of the previous study.

### **2.4 MOTIVATION FOR ADDRESSING THE DEPENDANCY OF THE MARINE BANK ON FRESHWATER (AND NUTRIENTS AND SEDIMENTS)**

The following is summarised from a presentation by Mr S Lamberth.

Ecological processes include those driving fisheries production (harvestable biomass) in the freshwater, estuarine and marine environment. Most catchment developments therefore carry an element of risk that can be detrimental to ecological processes. There is a risk that fishery stocks could decline and collapse and that fisheries will face economic/financial collapse.

Global fisheries production peaked in the mid 1990s. Global estuarine fisheries production peaked in the mid 1980s. Estuarine dependant species contribute 50% of the landed mass in the USA, 55% of the fisheries in Australia and 51% of the value of the South African inshore fin-fisheries. However, in the USA, estuarine dependent fisheries production is down

by 20 to 30%. In Egypt, estuarine dependant fisheries production is down by 90%. In South Africa, decline or collapse of 15 important estuarine dependent species can be contributed to habitat degradation (estuarine degradation, reduced flows, loss of cues etc.) and to overexploitation in the estuarine and marine environment.

A relationship between prawn abundance and rainfall or river discharge has been shown to exist in Australia (Glaister 1978, Staples 1986), Peru (Maschii and Rodriguez 1990), the Mediterranean (Bishara 1985) and more locally in Mozambique (da Silva 1985, Hogueane 1997). Studies in these areas have shown that a strong correlation exists between prawn production and freshwater outflow. Unfortunately in all documented cases river regulation has produced a negative response in the fishery. Preliminary investigations into the prawn catches on the Thukela Bank have indicated that this may also be true with catches increasing after floods and declining during drought years (Demetriades 1990, 1998).

It is therefore illustrated that any proposed changes to freshwater flows into the marine environment could have serious implications. Tools to address these issues within time frames of consulting studies are limited. There is also limited liaison and integration between the relevant governmental departments to address these matters in a more cohesive way.

## 2.5 APPROACH

There are two possible approaches to address the issues relating to the Thukela Bank:

- Determine the ecological integrity of the Bank and the freshwater requirements of the Bank (i.e. a similar approach to the Reserve).
- Determine the economic consequences of changed flow regimes on the Thukela Bank.

In the light of the lack of information on the natural functioning of the Bank, as well as the lack of methodologies to determine freshwater requirements, the impact evaluation route was selected. This does however not imply that this route is a substitute for determining the ecological integrity and freshwater requirements for the Bank. The impact evaluation route can be addressed within this study as the links between flow, catch and economics have been identified, even if not completely understood.

## 2.6 TASK DESCRIPTION

Sequential tasks to undertake this study were identified and are tabled below. Links to the chapters within these reports are made and data requirements are briefly presented.

### ***Task 1: Select rivers/estuaries that contribute significantly to the Thukela Bank (Chapters 3 and 6)***

Key estuaries in KwaZulu-Natal that provide the major portion of the MAR (and assumed sediment and organic input) and are representative of various estuarine functions must be selected. From these estuaries, those that provide similar functions to the Thukela (e.g. the Mfolozi and Mgeni) were then selected. Estuaries providing key nursery habitats were identified, and that contribute to the prawn biomass, even though these may not provide for the flow/sediment/nutrient function, i.e. similar functions to the Thukela.

### ***Task 2: Collect available hydrological data (Chapter 3)***

Relevant hydrological data was sourced, evaluated and tabled for each of the catchments contributing to the Thukela Bank. A reasonable record of the historical discharges from the larger catchments into the ocean was required. A number of different sources of flow data were investigated in this regard, these being

- Observed streamflow record.
- Water Resources (WR) 90 hydrology.

- Water Resources Yield Model (WRYM) model.

**Task 3: Analyse prawn catch data (Chapter 4)**

Prawn data was analysed on an annual and seasonal (monthly) basis. Available data had to be obtained and analysed and a period selected for which the most accurate data is available. Monthly data were required as the evaluation of flow scenarios were conducted on a monthly basis.

**Task 4: Carry out scoping exercise to investigate potential linkages between fish catch, flow and prawn catch (Chapter 5)**

Fish information was available, however not at the same level of accuracy as for prawns. A desktop exercise was therefore undertaken to determine whether there is any link between fish catches and flows as well as prawn catch trajectories. It was planned that data analysis be confined to the 30 most important species in the landed catch in KZN. Annual, and where possible, monthly catch data were compared with flows.

**Task 5: Calibrate catch flow relationship and impact of flow changes (Reserve scenarios) (Chapter 6)**

Calibration of the catch-flow relationship using historical data, allowing for monthly scale time lags, was conducted. Using these results, it was necessary to determine the changes (from present conditions) in catch linked to different Reserve scenarios (from the yield model with the various Reserve options).

**Task 6: Estimate economic value of the resource and link to Reserve and other scenarios (Chapter 7)**

The exact detail of this task was dependant on the outcome of Task 5 and is provided in Chapter 7.

## 2.7 POTENTIAL PITFALLS

A potential lack of data in the required format was a constraint within the study. Catch information on a monthly basis for as long a period as possible is required. Historical hydrological data at the inflow of the relevant estuaries were also required and for the same period as for which catch data was available. The reliability of hydrological data was dependant on the existence of hydrological gauging weirs in the vicinity of the estuaries and/or an existing system model that can provide modeled historical data at the estuaries.

Certain assumptions had to be made regarding the relationship between sediment, organics and flow. Flow is potentially the most accessible information available, whereas the sediment contributions from the various rivers are not available. Knowledge about the different functioning of the estuaries and whether they provide sediment versus a nursery function was used as a substitute for this data. Flow information (as a substitute for sediment and organic data) from estuaries that provide a sediment/organics function was used.

Furthermore, estimating the lag period between the inflows and the biotic response might proved to be problematic.

Last but not the least, the differences between flow scenarios were of such a scale that differences in catch were usually undetectable. This could have possibly influenced the economic analysis of scenarios. The economic analysis of these scenarios was classified as pioneering work in Southern Africa and a model was developed for these tasks.

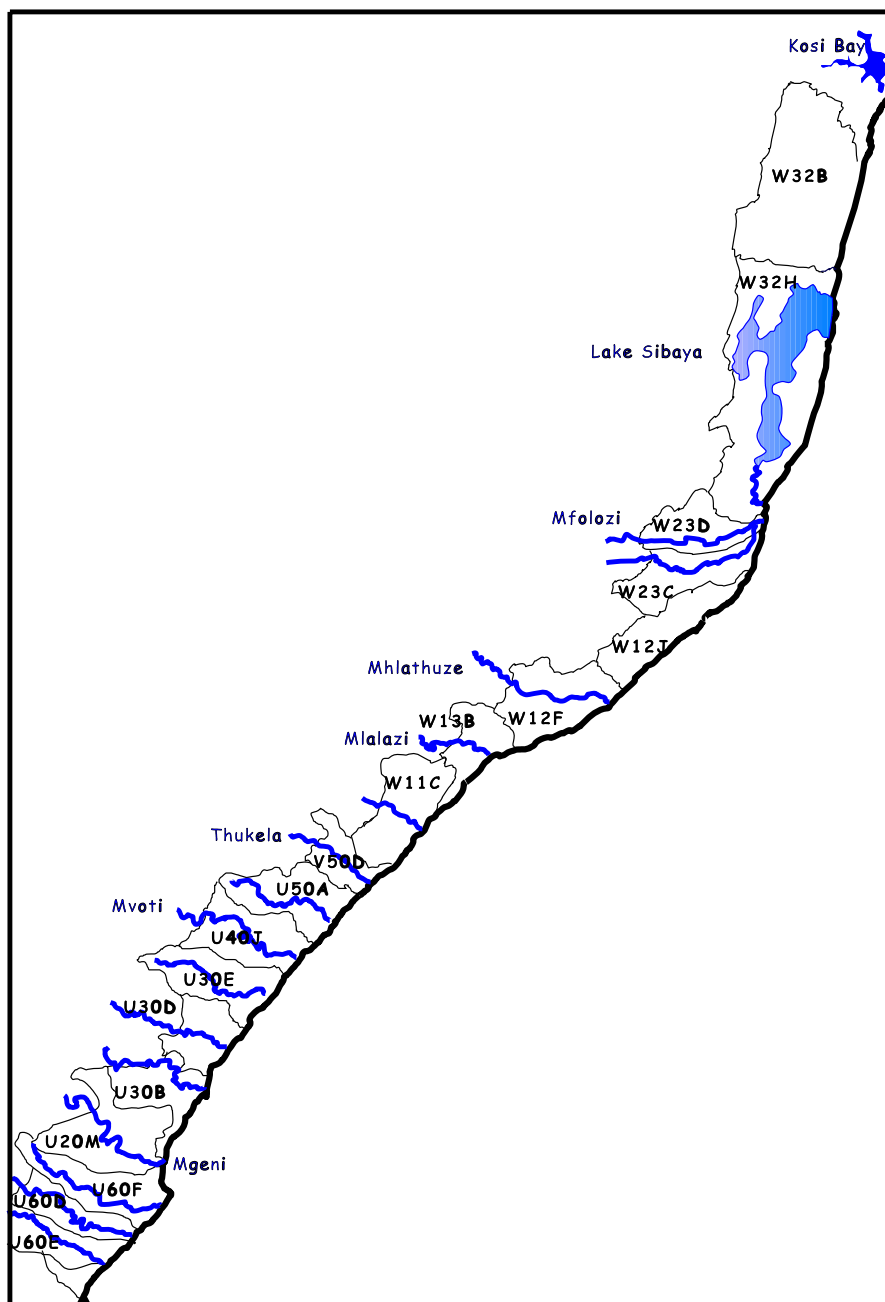
### 3 HYDROLOGY

Historical flow records for all catchments within the study area covering the period from 1980 to 2000 were required. Gauging stations are the only source of historical flow data, but not all the rivers have gauging stations and not all the stations cover the required record period. Several other sources of data were used in order to provide data for all the catchments, these are summarised in Section 3.2, with the study area being described below.

#### 3.1 STUDY AREA

The study area covered all catchments from St Lucia in the north to Durban Bay in the south (Figure 3.1). This area covers several significant catchments of which the Thukela, Mfolozi and Mgeni Rivers are the largest. The major catchments included in the analysis are summarised in Table 3.1.

**Fig 3.1** Illustration of the relevant quaternary catchments and study area (not to scale)



**Table 3.1 Catchments within study area, used for analysis**

WR90 Catchment Number	Catchment Name	Catchment Area <sup>1</sup>	Natural MAR <sup>1</sup>	
		km <sup>2</sup>	10 <sup>6</sup> m <sup>3</sup>	% of total
W31, W32 A, B	Mkuze River <sup>2</sup>	5983	291.3	3.94
W32C	Mezene River <sup>2</sup>	728	25.4	0.34
W32D, E, F	Hluhluwe River <sup>2</sup>	910	49.0	0.66
W32G	Nyalazi River <sup>2</sup>	648	49.0	0.66
W2	Mfolozi River	10008	971.9	13.13
W12	Mhlathuze River <sup>3</sup>	3877	495.1	6.69
W13	Mlalazi/Siyai Rivers	498	147.7	2.00
W11	Matigulu/Nyoni Rivers	954	206.0	2.78
V	Thukela River	29046	3993.9	53.96
U40	Mvoti River	2737	352.6	4.76
U30C, D	Tongati River	423	80.0	1.08
U20	Mgeni River	4439	739.9	10.00
	<b>Total</b>	<b>60251</b>	<b>7401.8</b>	<b>100.00</b>

1 Surface Water Resources of South Africa 1990 (1920 – 1989).

2 Lake St Lucia inflow.

3 Excluding W12J.

Table 3.2 summarises the catchments that were excluded from the analysis due to their relative small contribution to the freshwater input of the Thukela Bank. Note that there are seven catchments that were included in the analysis that have a low freshwater contribution (see Table 3.1). However this is due to their importance as nursery areas.

**Table 3.2 Catchments within study area, not included for analysis**

WR90 Catchment Number	Catchment Name	Catchment Area <sup>1</sup>	Natural MAR <sup>1</sup>
		km <sup>2</sup>	10 <sup>6</sup> m <sup>3</sup>
W12J	Mpungase River	332	82.3
U50A	Zinkwazi/Nonoti/Mdlotane Rivers	298	59.5
U30E	Mhlali/Seteni Rivers	290	59.0
U30A, B	Mdloti/Mhlanga Rivers	597	101.2
U60F	Mhlathuzana River	272	42.6
Total		1789	344.6

1 Surface Water Resources of South Africa 1990 (1920 – 1989).

### 3.2 DATA SOURCES AND ASSOCIATED CONFIDENCE

In order to derive a realistic correlation between historical prawn catch and flow, individual historical flow records were generated for all the catchments listed in the previous section. The data sources available for this task with their associated confidence is summarised in Table 3.3.

**Table 3.3 Available data sources**

Source	Confidence	Comments
Gauge	High	Observed historical data.
ACRU	High	Simulated data at a certain development level.
Water Resources Yield Model (WRYM)	High	Simulated data at a certain development level.
Water Resources Simulation Model (WRSM90)	High	Simulated historical data.
Surface Water Resources SA 1990 (WR90)	Medium	Naturalised flow (1920 – 1989), available for all catchments.

The three levels of confidence mentioned in the Table 3.3 is expanded on below:

- **High confidences** indicate the best available data and would not be improved greatly by undergoing an intensive hydrological study.
- **Medium confidence** was associated with the WR90 data that represents naturalised runoff. This source was used as a last option where no other data was available over the record period. In highly developed catchments this would greatly overestimate the flows. In general these flows would be higher than the historical observed flows.
- **Low confidence** was associated with any patched or extended data. The reason for this was that there were only two gauges close to the coastline and covering the entire record period that could be used to patch and extend stream flow in other catchments (Thukela and Mdloti). This and the fact that no extended rainfall was available resulted in low confidence patching. The larger events should however be adequately represented.

The data sources indicated in Table 3.3 along with the catchments for which data was available is summarised in the following sections.

### 3.2.1 Observed Data (Gauging stations)

Only gauging stations close to the coast were considered for this study. These gauges would best represent the historical flows entering the ocean. The gauging stations used in this study are provided in Table 3.4.

**Table 3.4 Gauging stations used in the study**

Gauge Number	River Name	Record Period	Catchment Area (km <sup>2</sup> )
W3H011	Mkuze River	1970-1989	5027
W2H032	Mfolozi River	1993-2002	
W1H032	Mhlathuze River	1993-2001	
V5H002	Thukela River	1959-2001	28920
U3H001	Tongati River	1966-1985	236
U3H005	Mdloti River	1977-2001	
U2H054	Mgeni River	1989-2002	

### 3.2.2 ACRU

ACRU systems were available for the following catchments:

**Table 3.5 ACRU systems used in the study**

Catchment	Record period	Development level
Mvoti River <sup>1</sup>	1950 - 1996	1996
Mhlali River <sup>2</sup>	1958 – 1993	1995
Tongati River <sup>2</sup>	1958 – 1993	1995
Mdloti River <sup>2</sup>	1958 – 1993	1995

1 Mvoti Abstraction Works Detailed Feasibility Study.

2 Hydrological Study of Water Resources of the Mdloti, Tongati and Mhlali catchments.

### 3.2.3 Water Resources Yield Model (WRYM)

The WRYM is based on monthly average figures, and was run for a certain development level. For the purpose of this study the results were assumed to apply to the entire study period. WRYM systems were available for the following catchments:

**Table 3.6 WRYM systems used in the study**

Catchment	Record period	Development level
Mpungase River <sup>1</sup>	1920-1994	1995
Mhlathuze River <sup>1</sup>	1920-1994	1995
Thukela River <sup>2</sup>	1925-1994	1995
Mgeni River <sup>3</sup>	1925-1995	1995

1 Mhlathuze Operating Rules and Future Phasing. System Analysis Module Report. (PBV000-00-127/02)

2 Thukela Water Project Decision Support Phase. Water Resources and Hydrology Module.

3 Mgeni River System. System Analysis.

### 3.2.4 Water Resources Simulation Model (WRSM90)

Essentially the model routes rainfall to runoff through interception and soil moisture storage while deducting evaporation and transpiration losses. The system is generally calibrated against measured flow at a gauge and therefore caters for growth in demands. The system is therefore not necessarily run at a certain development level and produces historical flows. WRSM90 set-ups was available for the following catchments:

**Table 3.7 WRSM90 systems used in the study**

Catchment	Record period
Mhlali River <sup>1</sup>	1925-1995
Tongati River <sup>1</sup>	1925-1995
Mdloti River <sup>1</sup>	1925-1995
Mgeni River <sup>1</sup>	1925-1995
Mhlathuzana River <sup>1</sup>	1925-1995

1 Mgeni River System. Mkomazi/Mgeni/Mooi River Hydrology Update.

### 3.2.5 Surface Water Resources of South Africa 1990 (WR90)

The Surface Water Resources of South Africa 1990 provides monthly average naturalised flows on a quaternary basis for the entire country. The record period covers the hydrological years from 1920 to 1989. Naturalised flows are the flows as they would have been without any catchment development and growth (as for a pristine catchment). These flows will, depending on the development within the catchment, often overestimate the historical flow

record. The WR90 data was therefore only used as a last resort where no other data sources were available.

### 3.3 EXTENSION OF HYDROLOGIES AND PATCHING OF RUNOFF RECORDS

Extending a hydrology is an extensive and involved exercise involving patching and classification of rainfall gauges using packages such as PATCHR and CLASSR. This was however not the objective of this study and the package **PATCHS** was used to extend and patch runoff records where required.

**THE PATCHED AND EXTENDED DATA PRODUCED AS PART OF THIS STUDY IS OF LOW CONFIDENCE DUE TO THE METHODOLOGY USED. THE DATA SHOULD NOT BE USED FOR PLANNING PURPOSES. IF MORE DETAILED RESULTS ARE REQUIRED A DETAILED HYDROLOGICAL STUDY SHOULD BE UNDERTAKEN FOR THE CATCHMENT AREA.**

**PATCHS** is a streamflow data patching program for infilling and performing modest extensions to monthly streamflow data using Kalman Filtering and the EM Algorithm. (Written for the Department of Water Affairs by Geoff Pegram).

Areas north and south of the Mhlathuze River catchment is generally effected by different weather systems and it was decided that catchments north of the Mhlathuze would not be extended or patched with gauged data south of the area and visa versa.

### 3.4 ANALYSIS RESULTS

The results of the hydrology component are provided electronically (Electronic appendix accompanying the report) as a monthly average historical time series for the 21-year period from 1980 to 2000. The annual average historical runoff of the selected catchments as developed for this study is compared to the naturalised runoff for the common period from 1980 to 1989 in Table 3.8.

**Table 3.8 Catchments within study area, used for analysis**

Catchment Name	MAR (1980-1989)			
	Simulated	% of Total	% of Natural	Natural <sup>1</sup>
Mkuze River	192.95	2.85	47.3	407.57
Mezene River	42.93	0.63	100.0 <sup>2</sup>	42.93
Hluhluwe River	79.99	1.18	100.0 <sup>2</sup>	79.99
Nyalazi River	78.22	1.15	100.0 <sup>2</sup>	78.22
Mfolozi River	1309.11	19.33	95.8	1366.23
Mhlathuze River	201.37	2.97	31.0	648.56
Mlalazi/Siyai Rivers	183.78	2.71	100.0 <sup>2</sup>	183.78
Matigulu/Nyoni Rivers	274.28	4.05	100.0 <sup>2</sup>	274.28
Thukela River	3353.23	49.50	71.7	4674.17
Mvoti River	456.98	6.75	100.6 <sup>3</sup>	454.33
Tongati River	115.25	1.70	100.2 <sup>3</sup>	115.04
Mgeni River	485.55	7.17	53.4	908.58
Total	6773.64	100.00	73.4	9233.68

1 Surface Water Resources of South Africa 1990 (1920 – 1989)

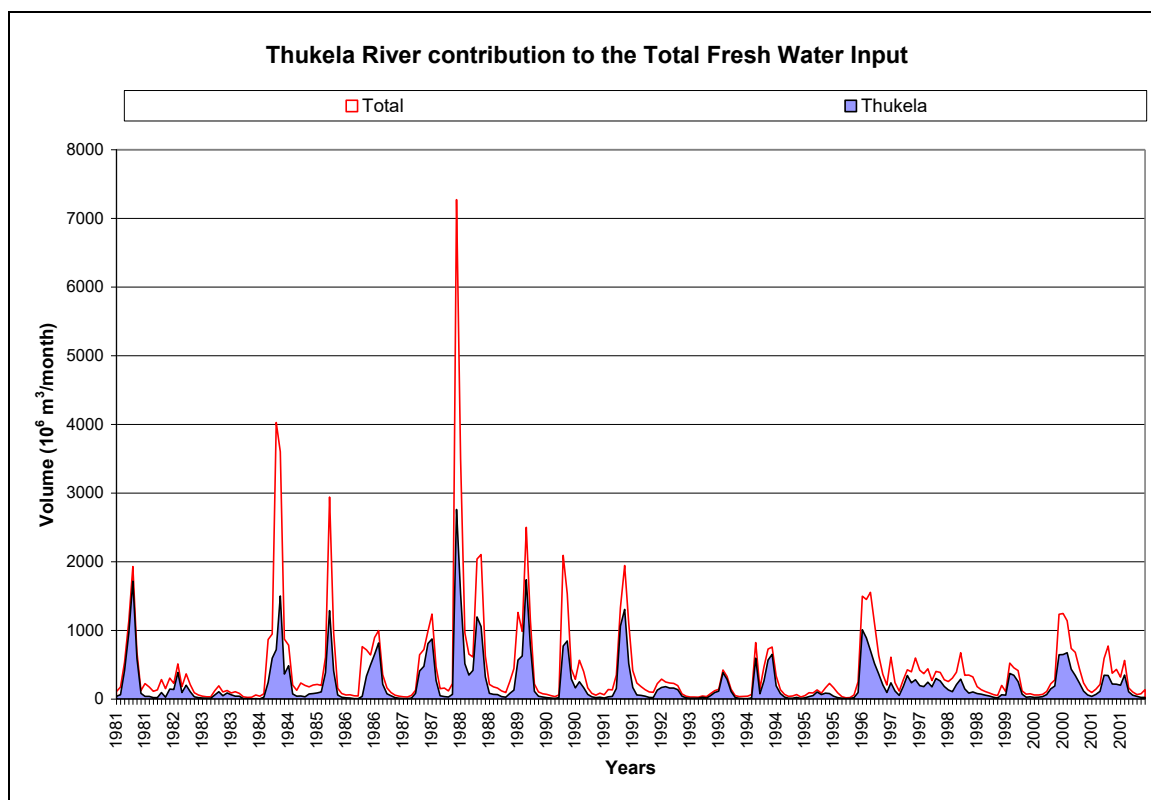
2 Only WR90 data available

3 ACRU data used

Table 3.8 shows that the Thukela River is the largest contributor to the fresh water input to the Thukela Bank with a contribution of almost 50% of the total volume over the selected

comparison period. The dominance of the Thukela is shown graphically in Figure 3.2 where it is plotted against the total fresh water input.

**Fig 3.2 Thukela River contribution**



The data and methodology used in order to determine the above results are summarised for each catchment in the following sections.

### 3.4.1 Mkuze River (Lake St Lucia)

The flow record for weir W3H011 on the Mkuze River only extends to the 1989 hydrological year. The patched data for the Mhlathuze River catchment was used to extend the data to the 2001 hydrological year.

W3H011 is situated at the outlet of W31J and W31L and excludes quaternary W32B. In order to represent the flows entering Lake St Lucia quaternary W32B needed to be added the gauge. The WR90 natural record for W32B was extended using the, already patched, record of gauge W3H011 and added together in order to represent the Mkuze River patched flow record.

### 3.4.2 Mezene (Mzinene) River (Lake St Lucia)

There was only WR90 data available for this catchment. The WR90 data was extended to the 2001 hydrological year by patching it with the patched W1H032 data and with the patched Mkuze data.

### 3.4.3 Hluhluwe River (Lake St Lucia)

The gauge on the river, W3R001, only covers two years of the required record period. WR90 data was therefore used and extended to the 2001 hydrological year by patching it with the patched W1H032 data and with the patched Mkuze data.

#### **3.4.4 Nyalazi River (Lake St Lucia)**

Similar to the Mezene River, there was only WR90 data available for this catchment. The WR90 data was extended to the 2001 hydrological year by patching it with the patched W1H032 data and with the patched Mkuze data.

#### **3.4.5 Mfolozi River**

Gauge W2H032 has data from 1993-2001. This data requires patching and the record needs to be filled in prior to 1993. The patched Mkuze and W1H032 data was used to this end. The result of the patching prior to 1993 was compared to natural and was found to be unrealistic. It was decided to use WR90 data for the period prior to 1993 and patch the remaining gaps as before.

#### **3.4.6 Mhlathuze River**

The gauge W1h032 and WRYM for the Mhlathuze system is available. The gauge data was available from 1993 to 2001 with missing data from December 2000 to June 2001. The WRYM data was used from 1980 to 1992 hydrological years. No gauges north of the Mhlathuze had data over the period with missing data, and the patched Thukela data was used for the patching.

#### **3.4.7 Mlalazi/Siyai Rivers**

There was only WR90 data available for this catchment. The WR90 data was extended to the 2001 hydrological year by patching it with the patched Mhlali and Mdloti data.

#### **3.4.8 Matigulu/Nyoni Rivers**

There was only WR90 data available for this catchment. The WR90 data was extended to the 2001 hydrological year by patching it with the patched Mhlali and Mdloti data.

#### **3.4.9 Thukela River**

The Thukela gauge, V2H005, has gaps in the record from 1998 to 1999. It was decided to patch these gaps with the patched Mdloti and Mhlali data. The gauge is situated at the outlet of quaternary V50C excluding quaternary V50D. The patched V2H005 data was used to extend the WR90 data for V50D and this extended data was added to the patched gauge data in order to produce the final Thukela data. The gauge data was replaced with the WRYM data wherever the rating limit of the gauge was exceeded.

#### **3.4.10 Mvoti River**

The ACRU data from the Mvoti Abstraction Works Detailed Feasibility Study was used and extends to the 1996 hydrological year. The data was extended to the 2001 hydrological year using the patched data from the Mgeni River catchment.

#### **3.4.11 Mhlali/Seteni Rivers**

This catchment was not included for the final analysis but was however used in the patching and extension process. The Mhlali River has ACRU (1958-1993) and WRSM90 (1925-1995) set-ups available with a correlation of 0.81. The ACRU data was used from 1980 to 1993 with the WRSM90 data being used from 1994 to 1995. This data was then extended to 2001 by using the patched Mdloti data.

### **3.4.12 Tongati River**

The ACRU set-up from the Hydrological Study of Water Resources of the Mdloti, Tongati and Mhlali catchments, was used for this catchment and covers the period up to 1995. The patched Mdloti data was used to extend the ACRU data to 2001.

### **3.4.13 Mdloti/Mhlanga Rivers**

This catchment was not included for the final analysis but was however used in the patching and extension process. Gauge U3H005 (1977-2001) is situated downstream of Hazelmere Dam and excluding quaternary U30B. The ACRU set-up is for the Mdloti River only and does not include the Mhlanga River. The gauge had four months of missing data and these were patched with the ACRU data. The patched gauge data was used to extend the WR90 data for U30B up to the 2001 hydrological year. The extended U30B data was added to the gauge data to provide the final Mdloti data.

### **3.4.14 Mgeni River**

The gauge, U2H054 (1989-2001, with missing data from April 1997 to February 1999), is situated downstream of Inanda Dam and excludes quaternary U20M. WRYM and WRSM90 data are available for the catchment and the WRSM90 (1920-1995) data presented the best correlation with the measured data. The WRSM90 data was used from 1980 to 1988 with the gauge data being used for the remainder of the record. The missing gauge data was patched with the final Mdloti patched data.

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## 4 SHALLOW WATER PRAWNS

### 4.1 BACKGROUND

The Thukela Bank in KwaZulu-Natal (KZN) provides the only significant habitat in South African waters for this commercially valuable group of crustaceans. The trawl fishery operating in this area is based on three co-occurring prawn species *viz Fenneropenaeus indicus* the Indian white prawn, *Penaeus monodon* the giant tiger prawn and *Metapenaeus monoceros* the brown prawn. All three species are distinguished by their life cycle (cf section 4.2 of Chapter 4) which, because of their general occurrence in shallow marine waters and the dependence of the juvenile phase on estuarine habitats, brings them into situations where they are exposed to catchment driven environmental variables. This means that factors such as estuarine salinities, nutrient supply and general catchment events have the potential to become major determinants of prawn abundance.

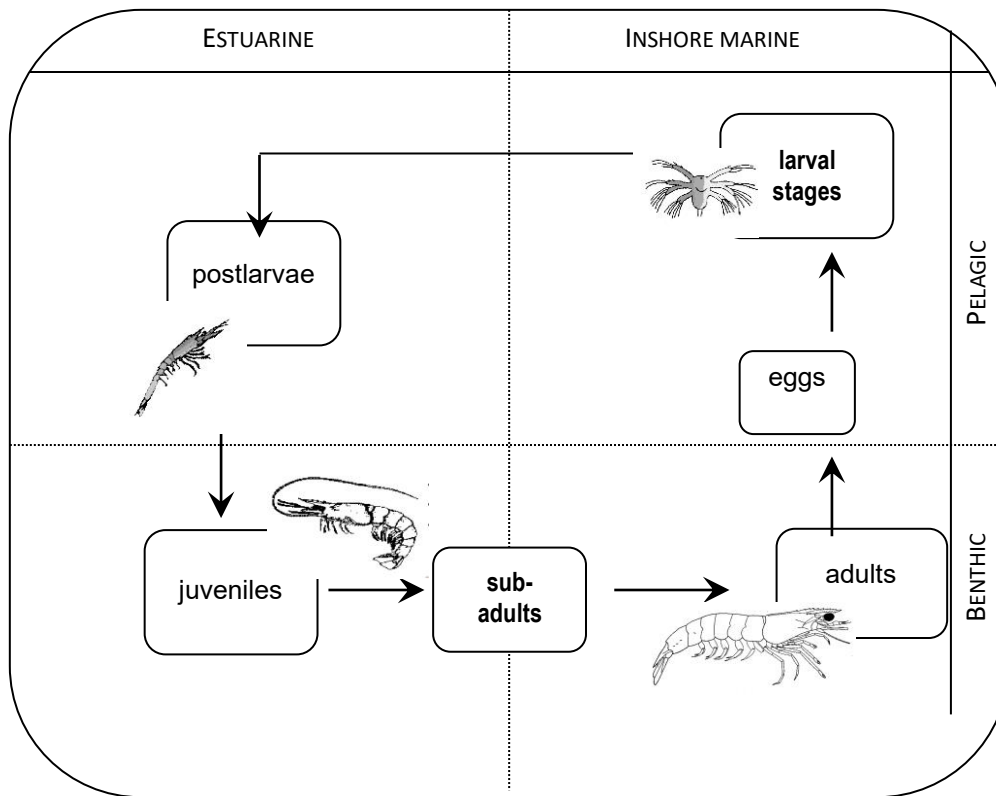
River discharge has long been accepted as having a profound effect on physical, chemical and biological processes in coastal waters (Drinkwater 1986). In the KZN context this influence may be more pronounced given the oligotrophic nature of the receiving coastal waters. Earlier investigations suggested a link between Thukela River flows and annual catch per unit effort (CPUE) but did not differentiate between these flows and the possible contributions made by other rivers which may also influence the Thukela Bank (Demetriades, Forbes, Mwanyama and Quinn 2000). River flow has the capacity to influence near shore and estuarine conditions and thereby influence larval, juvenile and adult stages in the life cycle via effects on both food supplies and the physico-chemical nature of the estuarine environment. This particular study aimed to refine the results and conclusions obtained in the earlier investigation of the link between Thukela River flow and prawn catches. In particular the objectives of the study were to:

- Identify rivers with the potential to influence adjacent coastal waters and their functional significance in terms of the penaeid prawn resource.
- Analyse prawn catches between 1988 – 2000 using monthly data as recommended in the previous report.
- Calibrate the catch-flow relationship and estimate the impact of different flow scenarios.

### 4.2 LIFE CYCLE OF THE SHALLOW WATER PENAIDS IN KZN

Most of the species of the genera *Fenneropenaeus*, *Penaeus* and *Metapenaeus* inhabit shallow, inshore, tropical and sub-tropical waters and have postlarvae and juveniles which have a preference for estuaries or estuarine-like environments. The life span of these species is relatively short and generally lasts one to two years. Figure 4.1 represents the typical life cycle of a shallow water penaeid. Adults are found in inshore marine waters and copulation and spawning occur exclusively in the marine environment. In KZN this occurs in the shallow waters of the continental shelf (15 – 40m) between Zinkwazi in the south and Richards Bay in the north. Most species reach sexual maturity at six months and, with further growth become increasingly fecund. An 11 - 12 month old female can produce hundreds of thousands of eggs at a single spawning and may spawn more than once in a season. The eggs sink to the bottom after release and hatch into pelagic larvae within 24 hours. These larvae grow through a number of larval stages over the next three weeks, culminating in the final planktonic stage, the postlarva. Once these postlarvae reach suitable coastal nursery habitats they are able to settle and adopt a benthic lifestyle. Nursery preference vary between species, but generally tend to be in sheltered areas such as estuaries or seagrass beds. After approximately three months in these nursery grounds the young prawns move back to the marine adult habitat.

**Fig 4.1 Life cycle of a typical shallow water penaeid prawn**



### **4.3 FUNCTIONAL SIGNIFICANCE OF ESTUARIES AND THEIR RELATIONSHIP TO THE KZN PRAWN FISHERIES**

In order to separate the influence of the Thukela from other rivers in the province those rivers providing significant flow to the coastal zone were selected and their functional significance identified. These were then split into two groups, viz. rivers with estuaries which provide the major nursery grounds utilised by the juvenile penaeids and those rivers particularly significant in providing nutrients and sediments to the coastal zone.

#### **4.3.1 Estuarine nursery areas**

Along the KZN coast three systems provide the majority of the suitable nursery habitat for penaeid prawns viz St Lucia, Richards Bay and the Mhlatuze estuary. Penaeids have been recorded in many other estuaries but are not found in high numbers and therefore these are not considered to constitute significant nursery areas.

#### **4.3.2 Rivers providing sediment and nutrient input to the coastal zone**

Rivers providing sediment and nutrients to the coastal zone were selected only from those north of Durban and included the Umgeni, Umvoti, Mlalazi, Thukela and Mfolozi. Although the smaller systems provided fairly regular inputs to the coastal zone, the Thukela system remains dominant providing more than 50% of the total run off from all KZN rivers in most years (Figure 3.1 and Table 3.8).

## 4.4 PRAWN CATCHES BETWEEN 1988 – 2000

### 4.4.1 Catch Data

Commercial catch statistics for the period 1988 – 2000 for the prawn fishery on the Thukela Bank were provided by the Directorate of Marine and Coastal Management (MCM) of the Department of Environmental Affairs and Tourism (DEAT). Unfortunately the time value data were found to be entered incorrectly for a large proportion of the records. This meant that the data had to be compared and verified using the additional dataset held by the authors. This dataset, obtained from the fishing companies records for the period 1984 – 1995 and from the actual drag and landing records from 1996 – 2000, overlaps the dataset provided by MCM (1988 – 2000).

The value of using such a complete dataset is that information on time, duration of trawl, depth, position and catch size composition for each drag (*i.e. the time a net spends actually fishing*) is available for detailed analyses if required (Table 4.1). Prawn production was examined in terms of catch, effort and catch per unit effort (CPUE) on an annual and monthly basis to identify fluctuations in abundance.

**Table 4.1 Abridged prawn catch statistics showing raw data used in the prawn catch analyses**

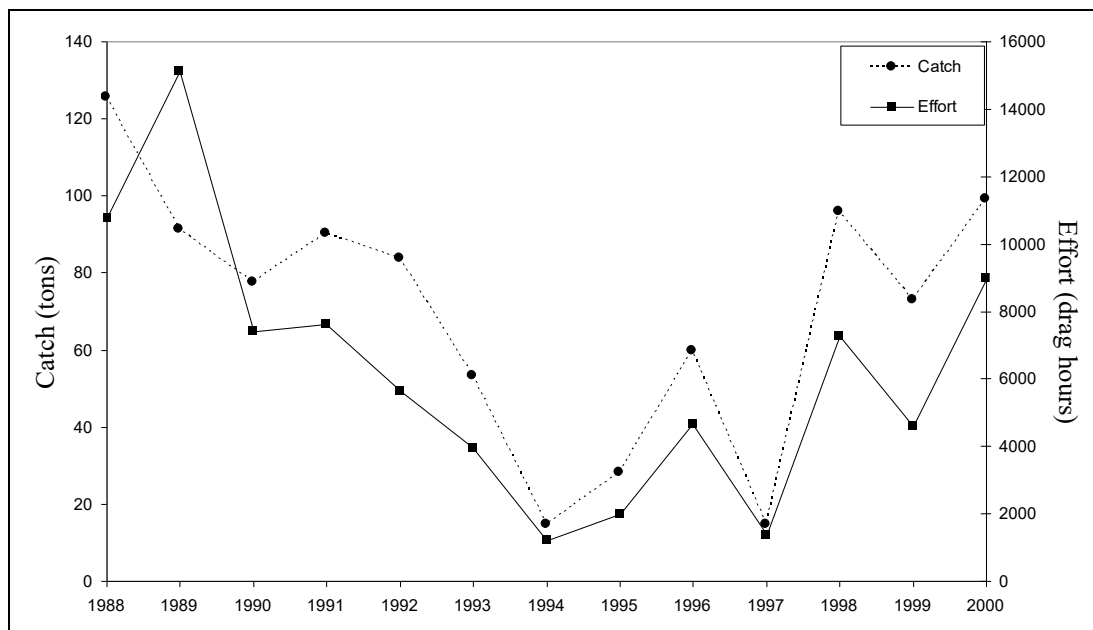
Drag set	Drag haul	Down Time (hrs)	Depth (m)	Lat	Long	Species code	Size cat	Whole weight (kg)
01-05-96 4:15	01-05-96 9:30	5.15	21	29.16	31.5	TPRN	S	2
01-05-96 5:25	01-05-96 8:15	2.50	28	29.16	31.5	TIPN	TG	2
01-05-96 8:55	01-05-96 12:05	3.10	30	29.16	31.5	TPRN	SS	4
01-05-96 11:00	01-05-96 17:00	6	21	29.16	31.5	TIPN	TM	2
01-05-96 13:00	01-05-96 16:40	3.40	30	29.16	31.5	TIPN	TG	4
01-05-96 18:00	01-05-96 23:00	5	25	29.16	31.5	TIPN	TG	2
01-05-96 18:00	01-05-96 19:10	1.10	32	29.16	31.5	TPRN	SS	8

### 4.4.2 Annual Catch Statistics

The annual catch during 1988 – 2000 fluctuated between 14 – 125 metric tons (Figure 4.2) with an average of 70 metric tons. Such fluctuations are typical of prawn fisheries worldwide. Annual catches declined from 1988 to 1997 with a low of 14 tons during 1994. During this time, however, effort levels also declined substantially (Figure 4.2). It has been suggested that the standard effort measures of hours trawled or operational units do not give a true reflection of increasing effort in the KZN fishery (Groeneveld and Melville-Smith 1995). Although the numbers of boats fishing on the Bank has remained fairly constant during the past 25 years it is believed that effort increases have occurred due to technological advances and increased boat capacity. This would include, for example, an increase in the number of nets carried by each boat, GPS and fish finding technology. There has been recognition worldwide of this problem and a previous report (Demetriades 1998, 2000) detailed the issues of incorporating increased efficiency into the effort measurement for this fishery.

Since the low catches taken between 1993 and 1997 the annual catch has returned to the pre-1988 levels. Previous reports (Demetriades 1998, Demetriades *et. al.* 2000) have attributed the increase to the improved rainfall regime in KZN during this period. Along with this increased abundance of the prawns there has been a concomitant increase in effort levels.

**Fig 4.2 Annual catch and effort in the shallow water penaeid fishery on the Thukela Bank 1988 - 2000**



During the same period annual CPUE has also fluctuated but less markedly varying from 6 – 16 kg.drag-hour<sup>-1</sup> (Figure 4.3) with a mean of 12kg.drag-hour<sup>-1</sup>.

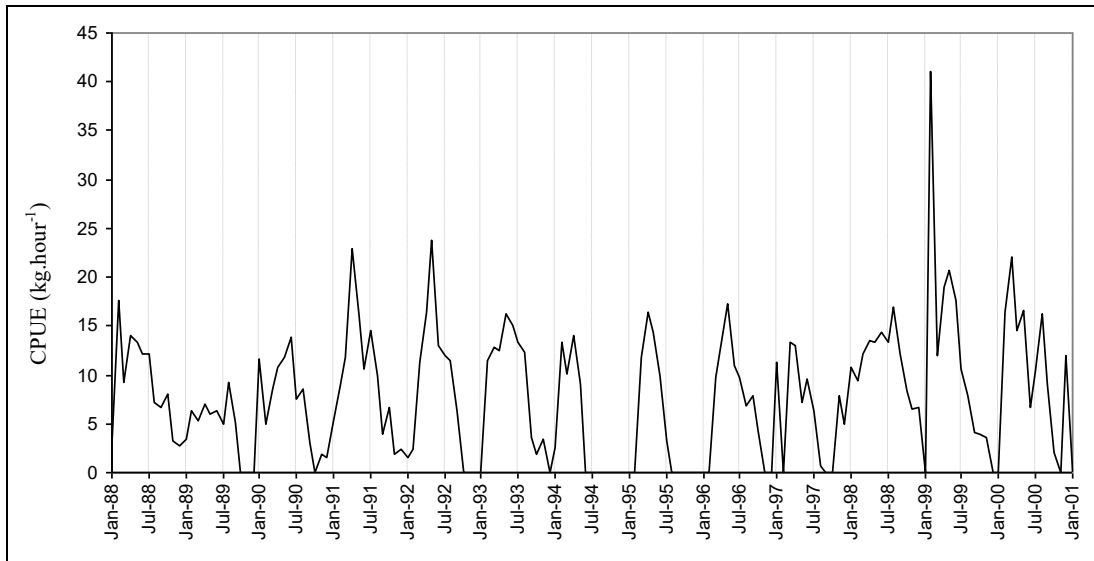
**Fig 4.3 Annual CPUE in the shallow water penaeid fishery 1988 – 2000**



#### 4.4.3 Monthly Catch Statistics

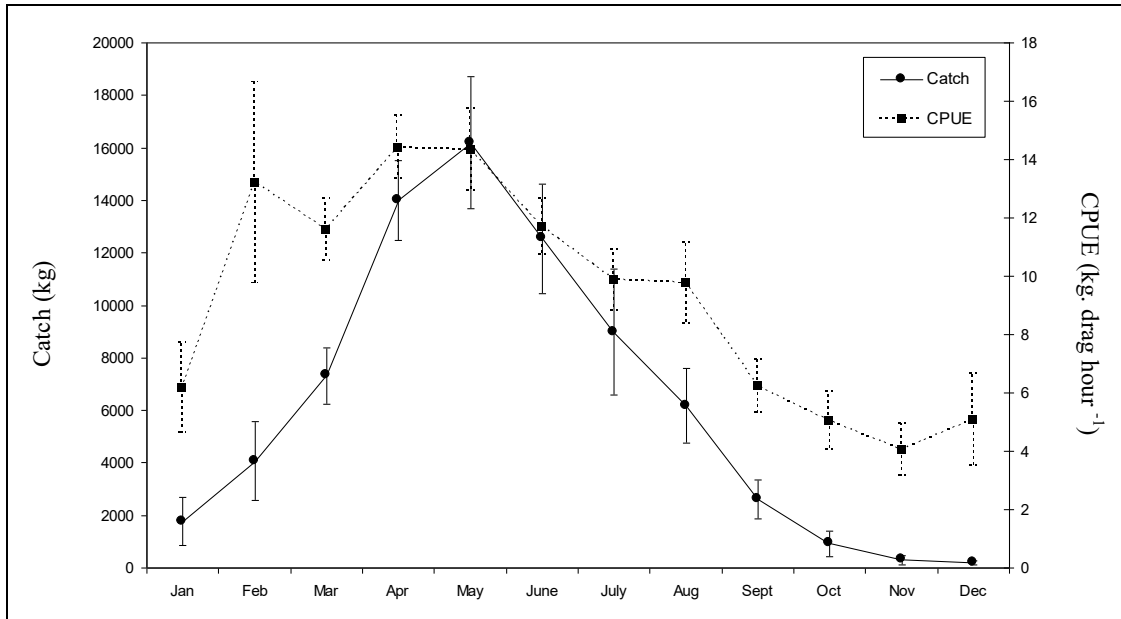
Since 1998 the trawlers have only been allowed to begin fishing on the Thukela Bank in March and the season then goes through to as late as October/November in years of high prawn abundance (Figure 4.4). Any catches taken during January and February post-1998 are taken in the area of the St Lucia mouth and are discounted.

**Fig 4.4 Monthly CPUE in the shallow water penaeid fishery 1988 – 2000**



Monthly catches for the period 1988 – 2000 show clearly that prawn abundance as reflected by the CPUE and total catches usually peak during May with an average catch of 16 tons (Figure 4.5). Wide confidence limits during the peak fishing months indicate the high degree of fluctuation through each fishing season. One of the effects of low prawn abundance is a shortening of the fishing season. For example, during the lower catch/CPUE years of 1997 the season was considerably shortened with catches peaking in May and fishing ceasing by the end of July. Since 1998 however the fishing season has steadily extended and the 1999 and 2000 season terminated in October reflecting the pattern recorded during previous studies (Demetriades 1990). The low overall catch towards the end of the season is indicative of a general decline in the adult population as the older animals are either caught or die off.

**Fig 4.5 Mean monthly catches and CPUE for the period 1988 – 2000. The vertical lines represent 95 % confidence limits for the mean.**



## 5 FISH

### 5.1 BACKGROUND

River flows influence marine fish and fisheries directly and indirectly through the export of nutrients, sediment and detritus. Nutrient supply stimulates production of phytoplankton and zooplankton, and ultimately, the larval, juvenile and adult fish that depend on them as a food source. Detritus may be broken down into useful nutrients, serve as a substrate for microflora and fauna or be consumed directly by detritivorous fish and invertebrates. Sediment export replenishes the nearshore habitats that are continuously eroded by oceanic currents and also provides a refuge for many fish by increasing turbidity. Turbidity tends to increase the catchability of many species, especially larger individuals that move into the turbid environment in search of concentrated prey. Freshwater flows also provide cues for the migration of estuarine-dependent juvenile and adult fish into and out of the estuarine environment. The strength of these cues will ultimately dictate how many individuals of these species recruit into the marine fisheries following their obligatory estuarine-dependent phase. High river flow conditions (floods) also contribute to marine fisheries via the direct export of fish that were previously trapped in predominantly closed estuaries. From a fisheries perspective, altered freshwater flows and consequently any of the above variables, can cause changes in catch composition, resource base (e.g. demersal vs. pelagic fish abundance), fleet structure, the spatial and temporal distribution of effort and ultimately the economic value of the fishery concerned.

A catchment-derived nutrient supply is especially important in oligotrophic nearshore waters such as the Thukela Bank where nutrient supply from upwelling events is limited. In turn, nutrient export from the Thukela is likely to be greater than elsewhere in KwaZulu-Natal because, besides providing approximately 40% of the annual volume, it has a small estuarine area (classified as a river mouth), whereas in other true estuarine systems such as St Lucia the bulk of the nutrients are incorporated into phytoplankton production before being exported into the marine environment. The Thukela also supplies the bulk of the terrigenous sediment on the adjacent marine Bank at approximately  $10 \times 10^6$  metric tons per year (Fleming & Hay 1988). Reductions in flow and changing land use practices in the catchment may see an increase or decrease in the sediment load reaching the sea as well as a change in the proportions of fine and coarse sediments. In the long term, an increase in fine sediments could favour penaeid prawns and flatfish species, but be detrimental to invertebrate filter-feeders and ultimately the reef-dwelling fish species that prey on them. In the short term, increased turbidity would provide refuge and foraging area for many fish species. The Thukela Estuary is a river mouth, relatively unimportant as a nursery area and altered freshwater flows are unlikely to be of consequence to the eventual recruitment of estuarine-dependent species into the marine fisheries. However, the opposite is the case for the Thukela Bank, where freshwater flows are likely to provide cues for spawning and the recruitment of juveniles that utilise the Bank as a nursery area.

### 5.2 THE KWAZULU-NATAL LINEFISHERY

The commercial and recreational boat-based linefishery is the most important marine fishery in KwaZulu-Natal, accounting for 40% of the total landed mass there. The linefishery had its inception in the early 1900's when 10 boats operated in the fishery (Penney *et al.* 1999). The fishery remained fairly small until the end of the Second World War and the introduction of relatively cheap, trailable, beach-launched ski-boats. This development resulted in rapid expansion of the fishery as the coast became more accessible and the fishery more affordable and lucrative to both recreational and commercial fishers. Participation and effort peaked in 1995, with 140 and 2 000 boats (10 000 anglers) registered in the commercial and recreational sector respectively. Since then, the continued decline in catch rates coupled with the opening up of Mozambique has resulted in a substantial decrease of the number of boats operating in KwaZulu-Natal. By 2001, there were approximately 100 boats employing

600 crew operating in the commercial linefishery. Effort is distributed fairly evenly to the north and south of Durban, with 40-50 boats and 200-300 crew operating in the vicinity of the Thukela Bank.

### **5.2.1 Catch composition**

In all, 140 species, 60 of which are regarded as important, are caught by the KZN linefishery, and approximately 1 200 tons are landed annually (Table 5.1). The commercial and recreational sectors are responsible for 62% and 38% of this catch respectively. Some 90% of the catch, is however, contributed by 15 species. Of these, slinger (21%), king mackerel (15%), geelbek (11%), yellowfin tuna (8%), santer (6%) and squaretail kob (6%) are the most important.

The recreational and commercial sectors differ in that king mackerel (33%) and yellowfin tuna (19%) provide the bulk of the recreational catch, whereas slinger (31%) and Geelbek (15%) are the most important commercial species. Overall, recreational fishers tend to target the pelagic gamefish species, whereas the commercial fishers tend to target the more high value reef and shoaling species.

Slinger are important in the commercial linefishery throughout KZN. The catch composition of the commercial fishery to the north of Durban and on the Thukela Bank differs from that in the south, squaretail kob rather than geelbek being the second dominant species (Table 5.1). Geelbek migrate from the cooler south and east coasts to KZN in winter where they spawn in spring. Most are caught on the KZN south coast during winter. In contrast, squaretail kob appear to be resident in soft sediment areas in water < 50 m deep, such as the Thukela Bank where 80% of the KZN commercial catch is taken. In all, 38% of the total commercial linefish catch in KZN comes from north of Durban, mostly from the Thukela Bank.

In terms of mass, the KZN linefishery only provides 7.2% of the national catch. However, KZN falls within the subtropical biogeographical region at the southernmost range of many species and consequently for most fish, e.g. slinger, king mackerel, squaretail kob, the KZN linefishery provides the bulk of the South African catch (Table 5.1). In addition, some of the species comprise shared stocks with other southern African countries such as Mozambique and Tanzania, and rely at least partially on recruitment from those waters. To a degree, fisheries management and sustainable catches rely on co-operation between South Africa and these neighbouring countries.

**Table 5.1 Mean annual catch and economic contribution by the recreational and commercial boat-based linefishery in KwaZulu-Natal. Stock statuses, depending on available data, are ratios of present versus historic, spawner biomass (SBPR<sub>current</sub> i.e. % pristine remaining), catch per unit effort (CPUE) or catch composition, all expressed as percentage. Economic values include value added and all contributions by subsidiary industries. (from: National Marine Linefish System MCM (DEAT), National Linefish survey 1994 – 1996, MCM (DEAT) & MacGrath *et al.* 1997)**

Species	Common name	Stock	Recreational boat			Commercial boat			Total recreational & commercial			Thukela Bank commercial boat		
		status	Catch/yr	% catch	Value	Catch/yr	% catch	Value	Catch/yr	% catch	% National	Catch/yr	% catch	% KZN
		% pristine	tons		Rands (M)	tons		Rands (M)	tons		catch	tons		catch
<i>Chrysoblephus puniceus</i>	Slinger	14	17.9	3.8	1.8	238.1	31.1	7.8	256.1	20.7	96.7	103.7	35.6	43.5
<i>Scomberomorus commerson</i>	King mackerel	33	156.2	33.2	15.6	26.3	3.4	1.2	182.5	14.8	99.9	14.8	5.1	56.2
<i>Atractoscion aequidens</i>	Geelbek	5	15.4	3.3	1.5	115.0	15.0	5.0	130.4	10.6	24.1	11.3	3.9	9.8
<i>Thunnus albacares</i>	Yellowfin tuna	30	88.7	18.9	8.9	9.9	1.3	0.1	98.6	8.0	50.4	0.2	0.1	2.5
<i>Cheimerius nufar</i>	Soldier/santer	30	11.3	2.4	1.1	63.0	8.2	1.03	74.3	6.0	63.8	33.5	11.5	53.3
<i>Argyrosomus thorpei</i>	Squaretail kob	17	18.6	4.0	1.9	55.4	7.2	2.4	74.0	6.0	98.7	43.9	15.1	79.3
Serranidae spp.	Rockcods					54.2	7.1	2.8	54.2	4.4	91.03	28.0	9.6	51.7
<i>Argyrosomus</i> spp.	Kob					46.3	6.1	2.0	46.3	3.8	5.8	20.9	7.2	45.1
<i>Epinephelus andersoni</i>	Catface rockcod	13	37.6	8.3	3.8	4.5	0.6	0.2	42.1	3.4	99.8	1.5	0.5	32.8
<i>Chrysoblephus anglicus</i>	Englishman	10	6.8	1.4	0.7	34.7	4.5	1.5	41.5	3.4	93.2	3.1	1.1	8.9
<i>Polysteganus coeruleopunctatus</i>	Blueskin	55				39.6	5.2	1.7	39.6	3.2	96.7	12.5	4.3	31.5
<i>Euthynnus affinis</i>	Eastern little tuna	50	29.3	6.2	2.9	0.9	0.1	0.0	30.2	2.4	100.0	0.0	0.02	5.6
<i>Scomberomorus plurilineatus</i>	Queen mackerel	50	9.4	2.9	0.9	4.0	0.5	0.2	13.5	1.1	100.0	3.0	1.04	75.1
<i>Polyprion americanus</i>	Wreckfish	55				13.2	1.7	0.7	13.2	1.1	64.6	0.2	0.1	1.3
<i>Polysteganus praeorbitalis</i>	Scotsman	10	3.9	0.8	0.4	8.8	1.2	0.4	12.7	1.0	80.3	0.5	0.2	5.8
<i>Istiophorus platypterus</i>	Sailfish	55	9.1	1.9	0.9	0.3	0.04	0.01	9.4	0.8	100.0	0.1	0.03	26.9
<i>Coryphaena hippurus</i>	Dolphinfish/dorado	60	4.3	0.9	0.4	4.3	0.6	0.2	8.6	0.7	91.9	1.2	0.4	28.1
<i>Caranx sem</i>	Blacktip kingfish	60	7.3	1.5	0.7	0.1	0.01	0.01	7.3	0.6	100.0	0.0	0.0	4.3
<i>Cymatoceps nasutus</i>	Poenskop	15				6.0	0.8	0.3	6.0	0.5	60.1	2.2	0.7	36.2
<i>Pomatomus saltatrix</i>	Elf / shad	34	5.7	1.2	0.6	0.2	0.03	0.01	5.9	0.5	11.0	0.0	0.01	17.8
<i>Pomadasyus kaakan</i>	Javelin grunter	45	2.6	0.6	0.3	2.8	0.4	0.1	5.4	0.4	100.0	1.1	0.4	40.0
<i>Scomber japonicus</i>	Mackerel	50	2.7	0.6	0.3	2.5	0.3	0.02	5.2	0.4	5.7	0.2	0.1	6.1
Lethrinidae spp.	Emperors					4.7	0.6	0.2	4.7	0.4	94.4	0.8	0.3	17.2
<i>Otolithes ruber</i>	Snapper kob	60	3.1	0.7	0.3	1.4	0.2	0.1	4.5	0.4	100.0	0.0	0.0	0.3
<i>Epinephelus albomarginatus</i>	White-edged rockcod	10	1.4	0.3	0.1	2.2	0.3	0.1	3.7	0.3	99.9	0.1	0.04	5.3
	Other (102 species)		38.7	12.5	3.9	23.4	3.1	0.9	62.1	5.03		5.8	2.0	9.3
	<b>Total</b>		<b>470</b>		<b>46.9</b>	<b>765</b>		<b>29</b>	<b>1235</b>		<b>7.20</b>	<b>291</b>		<b>38.0</b>

## 5.2.2 Economic contribution

The contribution of the various species to the economic value of the KZN linefishery was determined according to the method used by Lamberth and Joubert (1999). The mean price per kg of each species was multiplied by the total mass of that species caught, and summed to obtain the total landed catch value for each sector. The proportion that each species contributed to this landed value was multiplied by the total economic contribution of that sector (including subsidiary industries), as determined by McGrath *et al.* (1997).

The KZN boat-based linefishery contributes approximately R76 million to the Gross Geographic Product (GGP) of the province annually (Table 5.1). Of interest is that, although responsible for only 38% of the catch, the recreational component provides 62% (R47 million) of the value of the boat-based linefishery. The commercial sector is worth R29 million per annum. King mackerel (22%), slinger (13%) and yellowfin tuna (12%) are the most important species, whereas geelbek, rockcods and kobs (including squaretail) each contribute about 9% (R5 million) to the total value of the fishery. Overall, the Thukela Bank commercial and recreational sectors contribute about 40% (R30 million) of the value. The demand for fish in KZN is high and most of the commercial linefish catch is sold on the local market. In turn, to satisfy local demand, KZN imports fish from the other coastal provinces and from other southern African countries such as Mozambique, Tanzania and Angola.

## 5.3 ESTABLISHING FISH CATCH HYDROLOGY RELATIONSHIP

Exploratory analyses of the relationships between monthly flows and catches were performed using Spectral Analysis and General Linear Models (GLMs). The information available comprised 17 years (1985 - 2001) of monthly commercial catch and effort data for 140 species from the National Marine Linefish System (NMLS, MCM, DEAT), and monthly flow data from seventeen catchments to the north of Durban compiled by WRP. Spectral Analysis examines the relationships between two time series (flow and catch) in terms of their similarity in frequency and intensity of recurring events. Cross spectral density provides a measure of the intensity of the relationships. The GLMs were run using the direct monthly flow vs CPUE data as well as with the lag-times associated with the highest cross spectral densities from the spectral analysis. For the GLMs only species were used for which there had been more than 50 entries over the 17-year period, and lags of one, two and three months were applied to each catchment separately. The exception was the Thukela, where additional lags of 0-3, 11, 24 and 36 months were incorporated into the analysis. For comparison, the responses of king mackerel and squaretail kob are discussed separately.

Initially, it was thought that any catch flow relationships would be masked entirely by the noise from other environmental variables, varying levels of fishing effort, the relative longevity of the species considered (8 - 40 years compared to 18 months for penaeid prawns) and the cumulative effects of recruitment and exploitation on different year-classes. It was also believed that the low degree of estuarine-dependency among the species caught by the boat-based linefishery, compared to the high dependency found in the shore-based, rock-and-surf fishery, would also result in a poor relationship between flow and catch (Lamberth and Turpie 2003). However, for many species, despite noise, there appears to be relationships between flow and catch, some of which are likely to be real but some the result of catches responding to other environmental variables (e.g. water temperature, current directions), which follow similar seasonal patterns to rainfall and flow.

### 5.3.1 Spectral Analysis

The CPUE of at least 10 species either responded to, or followed the same pattern as, flow (Table 5.2). The strongest cross-spectral densities were coupled to an annual or seasonal pattern with a periodicity of 11 - 12 months. Some species (e.g. king mackerel, rockcods) showed a second cycle of repeatability through a range of 1.5 - 8 years. The cross-spectral

densities of the second period were in all cases much weaker than the shorter 11 - 12 month period. The most likely cause of this is that the cumulative impact of such variables as fishing mortality, recruitment (survival) and natural mortality of different year-classes, and consequently the noise, is expected to be much greater over the long-term.

The short-term events of 11 - 12 months are likely to be primarily driven by a combination of nutrient and sediment input from the catchments, increased primary production and food availability, coupled with the effort patterns of the commercial fishery. Increased food availability and turbidity will tend to attract fish, as well as the fishers who have learnt the predictability of aggregations. Alternatively, weather or other conditions at the time of high flows may not be conducive to fishing in a particular area causing the fleet to move elsewhere to catch different species. This could easily result in a false correlation as catches of these species would appear to increase in response to flow. Therefore, more reliable data on fishing effort (spatial and targeting effort) is required to gain a better understanding of the effects of increased flow.

The short-term patterns displayed by slinger, javelin grunter and rockcods with a lag of <1 - 2 months are likely to be an immediate response to an increase in turbidity, which promotes aggregations and / or catchability of these species (Table 5.2). The aggregations would persist with an increase in food supply. In turn, the lag between nutrient input, increased productivity and eventual food / prey availability could explain the four month lag between flow events and catches of squaretail kob, dusky kob and poenskop. Catches of the latter could also coincide with an annual spawning migration to KZN, but this cannot be verified in the absence of size-frequency data. CPUE of king mackerel and santer respond to flow events with a lag of 10 - 12 months. The age-at-first-capture of both these species ranges from < 1 - 2 years which possibly suggests that the lag represents fishery recruitment in response to the previous years' wet season that provided suitable conditions or cues for successful spawning.

Long-term responses to flow or periods of 6-8 years were evident for javelin grunter, king mackerel, poenskop, sea catfish and squaretail kob. For these species, it appears that the catches are following long-term wet and dry cycles, catches being higher in the wet years. In turn, the age-at-first-capture (and 50% sexual maturity) of poenskop and sea catfish ranges between 8 and 9 years, which suggests that the life history of these two species may be adapted to optimise the benefits of wet cycles. In addition, sea catfish are estuarine dependent, paternalistic mouth brooders that migrate into estuaries and turbid inshore waters during the mouth brooding phase. Access to estuaries (especially temporarily open / closed systems), and consequently breeding success, is likely to be greater during wet years.

Analysis of flow and rockcod, slinger and squaretail kob CPUE revealed for each a period that more or less corresponded with their age-at-first-capture into the fishery. Squaretail kob's age at first capture of 3.7 years corresponds with a catch vs flow period of 3.5 years (Table 5.2). The age at first capture of 2.5 years for the rockcods (mostly catface and halfmoon) corresponds well with a period of 2.7 years, whereas that of slinger (1 - 2 years) falls within the catch vs. flow period of 1.5 years. Although the cross spectral densities for all three were weak, there appears to be a long-term relationship between flow events and CPUE, with wet years providing suitable conditions for spawning and survival and eventual recruitment into the fishery a few years later. The weak cross spectral densities are to be expected, given the cumulative impact of fishery effects and environmental factors other than flow on catches.

**Table 5.2 Age at first capture and results of spectral analysis and general linear models (GLM) using 17 years (1985-2001) of monthly volumes from 17 catchments and commercial linefish CPUE of selected species as the dependent and independent variables respectively. Cross spectral density and lags apply only to the short term periods of 11-12 months. With the exception of squaretail kob, the highest cross spectral densities for all species were with the Thukela system. Squaretail kob had a strong relationship with the Mfolozi and St Lucia as well as the Thukela. The GLMs are preliminary and only used 1-3 month lags. Significant contributions were made by the Thukela, Mfolozi, Mlalazi, Matigulu, Mhlali, Mdloti and Mgeni systems.**

Species	Common name	Age at 1st capture (yrs)	Spectral analysis				General linear model	
			Cross spectral density	Period (months)	Lag (months)	Period (years)	Multiple R2	P
<i>Polysteganus coeruleopunctatus</i>	Blueskin	1					0.2	n.s.
<i>Epinephelus andersoni</i>	Catface rockcod	2.5					0.1	n.s.
<i>Chrysoblephus cristiceps</i>	Dageraad	5-9					0.2	n.s.
<i>Porcostoma dentate</i>	Dane	unknown					0.4	< 0.05
<i>Coryphaena hippurus</i>	Dolphinfish/dorado	< 1					0.3	< 0.05
Lethrinidae spp.	Emperors	unknown					0.1	n.s.
<i>Chrysoblephus anglicus</i>	Englishman	unknown					0.2	n.s.
<i>Atractoscion aequidens</i>	Geelbek	2					0.2	n.s.
<i>Polyamblyodon germanum</i>	German	unknown					0.5	< 0.05
<i>Pomadasys kaakan</i>	Javelin grunter	unknown	9.7	11.8	1.5	8	0.2	n.s.
<i>Scomberomorus commerson</i>	King mackerel	< 1	15.6	11.8	10.4	6-8	0.4	< 0.05
<i>Argyrosomus</i> spp.	Kob (50 / 50 dusky & squaretail)	1.5 (dusky)	17.8	11.8	4.6	none	0.2	n.s.
<i>Cymatoceps nasutus</i>	Poenskop	8	10.5	11.8	4.1	8	0.6	< 0.05
<i>Scomberomorus plurilineatus</i>	Queen mackerel	unknown	14.3	11.8	7.1	none	0.1	n.s.
Sparidae spp.	Redfish (70 % slinger, 10 % santer)	1-2					0.7	< 0.05
Serranidae spp.	Rockcods (catface & halfmoon)	2.5	9.5	11.8	1.1	2.7	0.5	< 0.05
<i>Pristipomoides filamentosus</i>	Rosy jobfish	unknown					0.1	n.s.
<i>Galeichthys feliceps</i>	Sea catfish	9	5.5	11.8	5.4	8	0.3	< 0.05
<i>Polysteganus undulosus</i>	Seventy four	4					0.3	< 0.05
<i>Chrysoblephus puniceus</i>	Slinger	1-2	8.1	11.8	0.02	1.5	0.3	< 0.05
<i>Cheimerius nufar</i>	Soldier/santer	1-2	7.3	11.8	11.4	none	0.3	< 0.05
<i>Argyrosomus thorpei</i>	Squaretail kob	3.7	7.5	11.8	4.2	3.5 & 6-8	0.3	< 0.05
<i>Epinephelus marginatus</i>	Yellowbelly rockcod	2.9					0.5	< 0.05

### 5.3.2 General Linear Models

The GLMs indicated significant relationships between the CPUE of 14 of the selected species and monthly flow of the Thukela, Mfolozi, Mlalazi, Matigulu, Mhali, Mdloti and Mgeni systems (Table 5.2). All of the significant relationships were using zero and one month lags, none with the two and three month lags. The strongest relationships were between flow and CPUE of redfish (slinger and santer) and poenskop where 67% and 59% of the variability in catch could be explained by flow respectively. Flow could also explain 40 - 50% of the variation in catch of dane, german, king mackerel and yellowbelly, catface and halfmoon rockcods. Overall, with the exception of king mackerel, the strongest relationships were with reef species that typically show a high degree of residency (non-migratory) and hence are unlikely to move much in response to environmental changes. Squaretail kob and santer, although resident, are nomadic within the confines of the Thukela Bank. This may, at least partially, explain why only 28% of the variation in catch could be attributed to flow. The same probably holds for the migratory seventy-four and nomadic sea-catfish for which only 35 and 32 % of the variation in catch could be explained by flow.

### 5.3.3 Fish catch predictions for the Reserve scenarios

The predicted catches under the Reserve scenarios 1-6 do not differ much from the present day, varying from no change for Dane and rubberlip to a maximum of 1.58 % for slinger (Table 5.3). Slinger, squaretail kob, dorado, rockcods, santer and redfish responded positively, whereas poenskop, seacatfish, German, king mackerel, seventy four and yellowbelly rockcod responded negatively to an increase in flow. The decrease in catches of king mackerel and sea catfish in response to higher flow are opposite to that expected. Catches of king mackerel are known to increase in response to good rainfall 11 - 12 months previously whereas in the short-term sea catfish aggregate inshore where turbidity increases after higher flows. In all, these two species are illustrative of how the predicted catches under the different Reserve scenarios using GLMs, appeared, in some cases, to be contradictory to the patterns identified through the spectral analysis.

**Table 5.3 Predicted catch as a percentage of the present day catch for the eight Reserve scenarios using General Linear Models. Scenario 7 was assumed to be the most representative of present day conditions in the Thukela and flows were the average monthly volumes (m<sup>3</sup>) from each system. With the obvious exception of the Thukela, the flows for all the other systems were kept constant for each scenario**

Scenario	Percentage present day catch								Worst case
	1	2	3	4	5	6	7	8	
<b>% Present day flow</b>	<b>101.9</b>	<b>101.4</b>	<b>101.0</b>	<b>101.3</b>	<b>101.1</b>	<b>100.1</b>	<b>100.0</b>	<b>83.5</b>	<b>56.2</b>
Slinger	101.6	101.2	100.8	101.1	100.9	100.6	100.0	86.3	63.6
Squaretail kob	101.2	100.9	100.6	100.8	100.7	100.6	100.0	89.6	72.4
Dorado	100.8	100.6	100.4	100.5	100.5	100.4	100.0	93.1	81.6
Rockcods	100.1	100.1	100.1	100.1	100.1	100.1	100.0	99.1	97.7
Santer	100.1	100.1	100.1	100.1	100.1	100.1	100.0	99.1	97.7
Redfish	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.8
Rubberlip	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9
Dane	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9
Poenskop	99.9	100.0	100.0	100.0	100.0	100.0	100.0	100.6	101.7
Sea catfish	99.9	99.9	99.9	99.9	99.9	99.9	100.0	101.1	102.8
German	99.9	99.9	99.9	99.9	99.9	99.9	100.0	101.1	102.9
King mackerel	99.8	99.9	99.9	99.9	99.9	99.9	100.0	101.4	103.7
Seventy four	99.8	99.9	99.9	99.9	99.9	99.9	100.0	101.6	104.3
Yellowbelly rockcod	99.8	99.9	99.9	99.9	99.9	99.9	100.0	101.7	104.6

Slinger (14%), squaretail kob (11%) and dorado (7%) experience a substantial decline in catches under scenario 8 (Table 5.3). Slinger and squaretail kob are the two most important species, and provide 50 % of the landed mass, of the Thukela Bank commercial linefishery. Under scenario 8, the decline in catches of these two species would result in a 20t (7%) drop in the total annual catch from the Bank. The decline in catch of dorado is unlikely to have much impact on the fishery as it currently provides < 1% of the landed mass. However, flow reductions may impact on its regional abundance as elsewhere in the world they are known to undertake pre-spawning migrations to higher latitudes during spring and summer and spawn inshore whereas eggs, larvae and juveniles have been found on the Thukela Bank. The relationship between flow and this species is unknown but could range from spawning cues to productive success and food availability. In turn, the response of dorado is more likely to be cued by regional rainfall than indirectly through flow from the Thukela or other catchments.

Under the worst-case scenario, catches of slinger, squaretail kob and dorado decline by 36, 28 and 18% respectively (Table 5.3). This equates with a 50t (17%) reduction in the total landed catch of the commercial linefishery from the Thukela Bank. Similar to scenario 8, reductions in flow may alter the distribution and abundance of dorado, but these changes are unlikely to have much impact on the commercial linefishery. Catches of rockcods and santer undergo a 2% decline. In turn, predicted catches of poenskop, sea-catfish, german, king mackerel, seventy four and yellowbelly rockcod are 1 - 5% greater than present day. These are all likely to be an artefact of the drop in CPUE usually experienced at the time of high flows (0 lag) when rain and sea conditions make fishing difficult. Consequently, a modeled decrease in flows will appear to have the effect of increasing catches, even though poor fishing conditions persist. This problem is compounded by the short-term responses (0 lag) having much less noise, and therefore appearing a lot stronger, than the longer-term (1 - 36 month lag) responses.

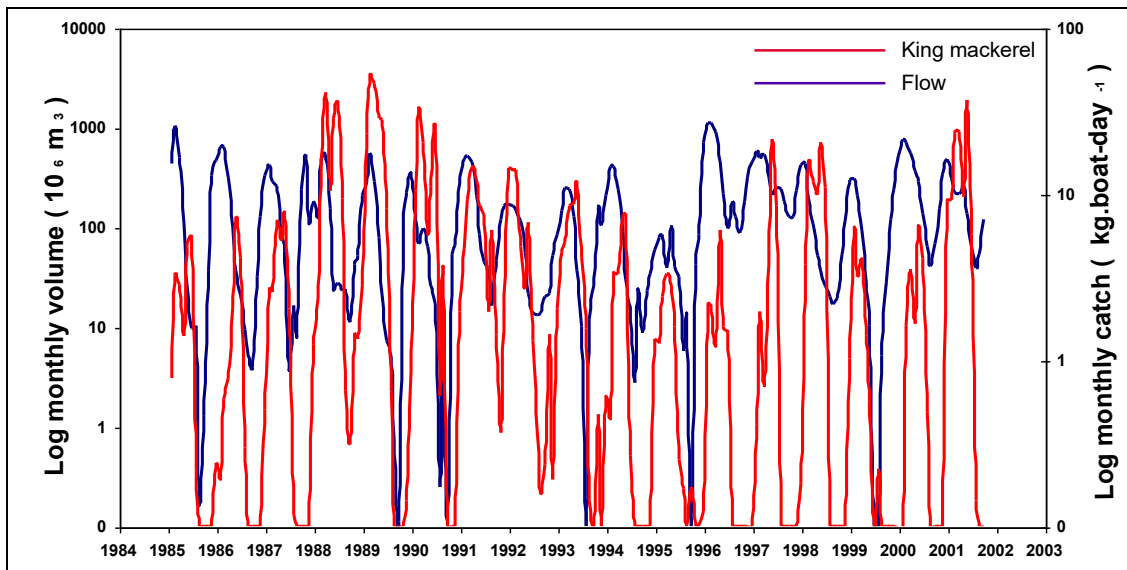
Overall, under the worst-case scenario, and despite the predicted increase in the CPUE of some species, there is likely to be a 20% reduction in the total landed catch of the Thukela Bank commercial linefishery. Increased catches of those species responding positively to a reduction in flow are unlikely to compensate for those lost. Most of these species either occur naturally in low abundance, and / or have already been fished down to such an extent that the required increase in CPUE is highly unlikely.

### **King mackerel (*Scomberomorus commerson*)**

King mackerel are a widespread Indo-Pacific species with a southern African stock extending from Mozambique through to the Transkei (Govender and Radebe 1999). Spawning is thought to occur off Mozambique in summer from November-March. The summer feeding migration of adults into KZN waters mostly comprises immature fish of < 2 years of age. It is the most important species in the recreational boat fishery where it provides 33% of the catch whereas in the commercial linefishery it only provides 3% of the catch (Table 5.1). The Thukela Bank commercial linefishery provides 56% of the KZN, as well as the National, catch of this species.

King mackerel respond to flow with a lag of 10.4 months and also appear to follow the wet and dry cycles with a period of 6-8 years (Table 5.2, Figure 5.1). Using GLMs, the correlation between monthly flows and catch was weak with only 42% of the variation in catch being explained by flow. In turn, the predicted response of an increase in catch to reduced flows was opposite to that expected from the spectral analysis and what could be inferred from Figure 5.1.

**Fig 5.1** Time series of monthly volumes from the Thukela River and monthly catch-per-unit-effort of king mackerel by the commercial boat-based linefishery operating on the Thukela Bank for the period 1985-2001



The apparent 10.4 month response (lag) of king mackerel to higher flows as well as the correlation of catches with the Thukela and other systems in KZN are likely to be “false” in that they are largely representative of conditions in Mozambique rather than in KZN. High rainfalls and the input of freshwater into the marine environment off Mozambique, provide good conditions for spawning and larval survival. This results in good catches when these fast growing fish recruit into the fishery one year later. Ultimately, good catches rely on flows in Mozambique, not KZN, and the correlation between flows and catch are an artefact of the two regions falling within the same rainfall zone. This could also explain the low  $r^2$  values obtained for this species and the reason why it’s catches exhibit limited response to flow.

On the other hand, within a particular season, the enhanced production associated with higher flows, could influence catches as the king mackerel migrating south, move onto the Thukela Bank in response to an increase in prey availability. In the short term (0 lag), the weather and fishing conditions associated with higher flows could see a decline in CPUE. This could explain why the predicted response of king mackerel to reduced flow was an increase in catches. Overall, reductions in flow from the Thukela or other catchments in KZN are unlikely to have much impact on the catches of this species as the major factors driving recruitment into the fishery depend on conditions in Mozambique.

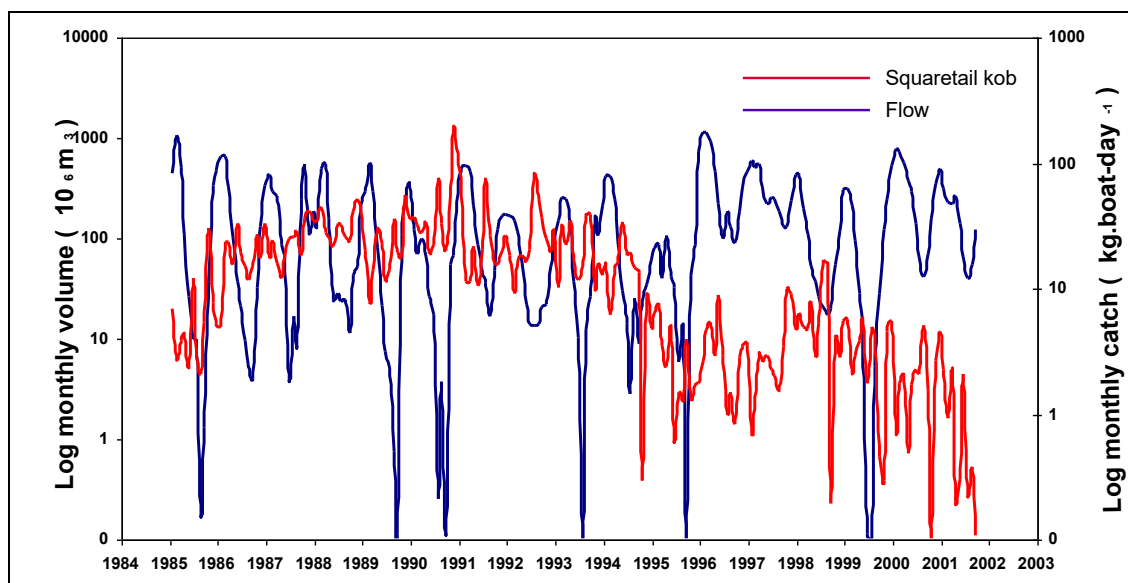
### Squaretail kob (*Argyrosomus thorpei*)

Squaretail kob are endemic to southern Africa with a range extending from Mozambique to Port Elizabeth in the southeastern Cape (Fennessy and Radebe 2000). This species is fairly resident in a particular area with the adults associated with rocky reefs and the juveniles with soft sediments in water < 50 m deep. Age-at-first-capture is 3.7 years. The bulk (99%) of the national catch is landed in KZN. Squaretail kob provide 4 and 7% of the recreational and commercial linefish catch in KZN respectively (Table 5.1). On the Thukela Bank they are the second most important species and provide 15% of the commercial catch. They also comprise a significant proportion of the bycatch in the prawn trawl fishery. Historically, squaretail kob comprised 37 % of the total KZN commercial catch but this has since declined to 4 - 5% and the stock is regarded as collapsed (Fennessy 1994).

Squaretail kob respond to flow with a lag of 4.2 months and CPUE follows the wet and dry cycles with a period of 6 - 8 years (Table 5.2, Figure 5.2). Catches also exhibit a response to flow with a period of 3.5 years that corresponds to the age-at-first-capture of 3.7 years.

Using GLMs, the response to flow was significant but weak with only 28% of the variation in catch being explained by flow.

**Fig 5.2** Time series of monthly volumes from the Thukela River and monthly catch-per-unit-effort of squaretail kob by the commercial boat-based linefishery operating on the Thukela Bank for the period 1985-2001



In the short-term (0 lag), squaretail kob CPUE responds negatively to higher flows probably due to deteriorating fishing conditions at the time and/or due to fisher behaviour with the “fleet” fishing elsewhere for more lucrative catches. The positive response to increased flow occurs at a 4 month lag and may be due to nutrient input, production and an increase in prey availability. It may also be partially due to fishers targeting more effort on this species due to a known increase in catchability.

Spawning of squaretail kob occurs from June-September on the Thukela Bank. Higher flows in the following summer months and associated increases in nutrients, production and turbidity are all conducive to larval and juvenile survival. Consequently, a good rainfall year is likely to have a positive impact on recruitment into the fishery 3.5 years later. This response was apparent from the spectral analysis but the relationship was weak according to the GLM, probably due to the cumulative noise arising from the varying strengths of multiple year classes and flow events that occur between the flow event and when the response is measured 3 years later. In addition, the relationship is likely to have been further weakened by the 90% reduction in CPUE and collapse of the stock that occurred over the last 10 years.

Overall, despite the noise, flow from the Thukela River appears to have a major impact on the catch of squaretail kob with a reduction in catch of 28% predicted under the worst case scenario. In South Africa, remedial measures aimed at rebuilding linefish stocks are almost exclusively confined to changing fisher behaviour and limiting fishing effort. If the squaretail kob stock is to be successfully rebuilt, the management plan will have to deviate from the traditional path and take the influence of the Thukela and other KZN catchments into consideration.

## **5.4 CONCLUSION**

This report provides the first “stab” at assessing the possible effects of altered freshwater flow on the Thukela banks linefishery. It is evident that increased flows (periodic floods) influence the abundance and/or catchability of the most economically important species. The interpretation of the analysed data is hampered by several factors as outlined in the report. A better understanding of the effects is dependent on improved catch data and better knowledge of the ecosystem processes involved.

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## 6 PRAWN CATCH HYDROLOGY RELATIONSHIP: DEVELOPMENT OF PREDICTIVE EQUATION INDEPENDENT VARIABLES

This section describes the assumptions made in the development of the predictive prawn catch equations independent variables. The purpose of the predictive equation was to determine a link between historical river flows and historical prawn catch of the Thukela Bank. This equation will then be used to quantify the impact of revised Thukela flows on the prawn catch. The rivers as summarised in Table 3.8 were used for the assessment. The rivers and estuaries provide a habitat and nursery area and also provide nutrients and/or detritus to the Bank. These two main functions are summarised below:

- **Nursery Function:** River estuaries provide a crucial habitat for the postlarvae and juvenile stage of the prawn life cycle (see Chapter 4). Only two catchments have been identified as nursery grounds and were treated separately as Nursery Rivers. These nursery rivers are provided below:
  - Lake St Lucia (Mkuze, Mezene, Hluhluwe and Nyalazi Rivers)
  - Mhlathuze River
- **Nutrient Function:** All the rivers in the study area contribute to the nutrient and organic input available to the Thukela Bank.

The Nursery Function will be discussed separately as it is based on only the flows from the Nursery Rivers.

### 6.1 NURSERY FUNCTION

The prawns in the **postlarval** stage generally enter the estuaries (**recruitment**) during July, August and September and remain there about 8 months. The **juvenile** prawns start leaving the estuaries (**emigration**) during February, March and April. The prawn catch season was constrained to fall between March and September.

The flows from the Nursery Rivers were converted to an equivalent **Nursery Index**, based on the following relationship:

$$\text{Nursery Index (NI)} = \text{Recruitment Index (RI)} + \text{Emigration Index (EI)}$$

#### 6.1.1 Recruitment Index (RI)

The RI indicates the period where the prawns in the **postlarval** stage enter the estuaries where they will mature to the **juvenile** stage from where they return to the Bank. The recruitment takes place in the months of July, August and September and is an indicator of the *catch in the following year* from March to September.

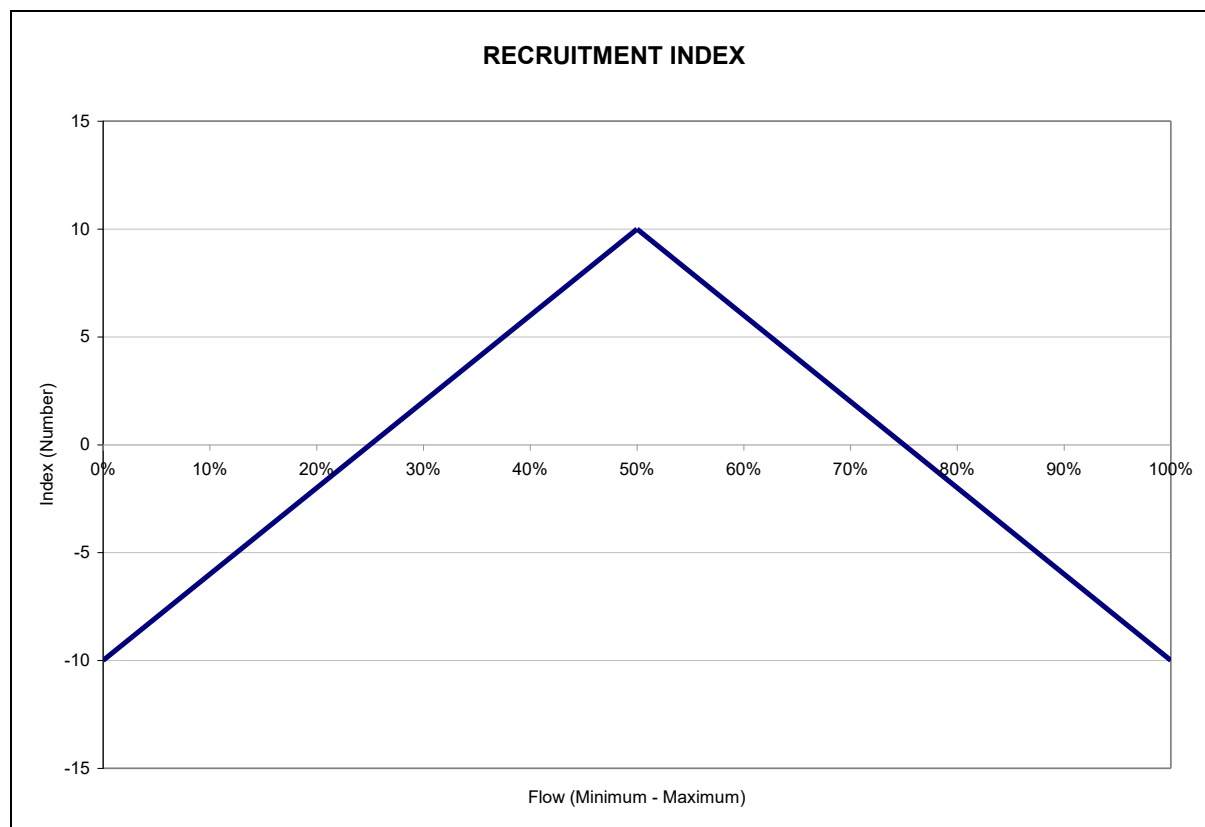
The sum of the monthly average flows for the months from July to September in a specific year are compared to the maximum, median and lowest flows over the same period for the historical record and converted to the RI based on linear interpolation. The adopted Recruitment Index is provided in Table 6.1 and presented graphically in Figure 6.1.

**Table 6.1 Adopted recruitment index**

Total Volume (10 <sup>6</sup> m <sup>3</sup> ) <sup>1</sup>	Index	Comments
Maximum	-10	Salinity too low
Median	10	Favourable
Minimum	-10	Salinity too high

1 Total for the months of July to September.

**Fig 6.1 Adopted Recruitment Index**



The RI calculated for the above mentioned 3 month period would be used for the NI of the following year from March to September.

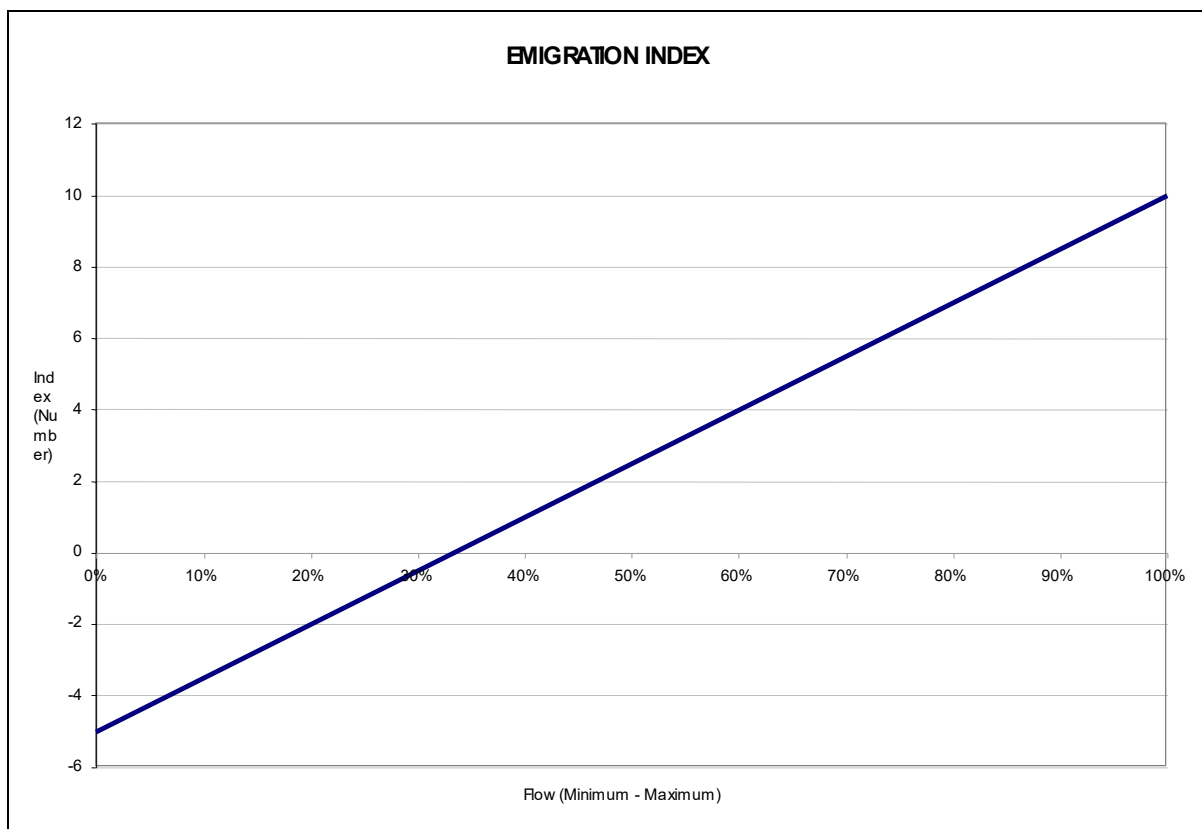
**6.1.2 Emigration Index (EI)**

The EI indicates the period where the juvenile prawns leave the estuary area and return to the Bank. This generally takes place from February to April. Two hydrologically driven triggers have been identified for this event and are low salinity (<10 ppt) and high flows. The adopted EI Index is calculated as described for the RI and is provided in Table 6.2 and presented graphically if Figure 6.2.

**Table 6.2 Adopted Emigration index (EI)**

Total Volume (10 <sup>6</sup> m <sup>3</sup> )	Index	Comments
Maximum	10	High flows and low salinity
Minimum	-5	Not favourable

**Fig 6.2 Adopted Emigration Index**



The methodology to determine the NI is summarised in Table 6.3.

**Table 6.3 Nursery Index Summary**

Index	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
RI <sup>1</sup>						JAS	JAS	JAS	JAS	JAS	JAS	JAS
EI <sup>2</sup>						DJF	JFM	FMA	FMA	FMA	FMA	FMA
NI <sup>3</sup>						Sum	Sum	Sum	Sum	Sum	Sum	Sum

- 1 RI based on flows from July to September (JAS) of the previous year.
- 2 EI for March, April and May is based on the sum of the flows from the previous three months. The EI from June to September is the same as that for May.
- 3 NI is calculated as the sum of RI and EI.

The final NI values will be scaled to represent values between 0 and 100 with a 100 representing the best possible nursery index.

## 6.2 NUTRIENT FUNCTION

The nursery function of the Nursery Rivers has now been captured in the Nursery Index (NI) and the nutrient function will be discussed in the following section.

All the rivers in the catchment contribute to the nutrient load available on the Bank, and the nutrient index values will therefore be based on the sum of all the rivers. Both the larval and adult stages of the prawn life cycle are spent in the inshore marine environment. Prawns in the larval stage is obviously much more dependant on the available nutrients in the water for survival than the adults who can feed of the ocean floor. These two life stages have been treated separately in the equation, as they are dependant on different periods of flow:

- **NUTIL:** Nutrient Index for the Larval stage. Sum of the flows from the Thukela and other rivers from **July to October**. The term nutrients in this context refers specifically to plant nutrients, primarily nitrates and phosphate, which are essential for plant growth. In the Thukela situation these nutrients support the growth of phytoplankton which is a major component of the diets of the planktonic larval prawns. The months July to October were considered to be the major period for development of the larval prawns
- **NUTIA:** Nutrient Index for the Adult stage. Sum of the flows from the Thukela and other rivers from **November to February**. The term nutrient in this index represents the available organic carbon available to the sub-adult and adult prawns and would be derived from both indirectly by input to the marine food chain beginning with phytoplankton production and directly via organic and detrital input from river flow.

Different flow regimes in the Thukela River can now be included and the NI will remain unchanged but the NUTIL and NUTIA indices will be affected.

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## 7 PREDICTIVE EQUATION AND RESULTS

The basic information used for the assessment is summarised below:

- Historical monthly average time series for all the selected Rivers as provided in Chapter 4 (1980 – 2000).
- Four simulated development scenarios for the Thukela River (1980 - 1994)
  - o **Natural:** This scenario provides the upper boundary for the results and is based on the naturalised flows for the Thukela.
  - o **Scenario 1:** 2000 development in the Thukela with **Reserve Scenario 1** (High category reserve) in place. This scenario will result in the highest inflow to the Bank from the Thukela River of the 6 reserve scenarios.
  - o **Scenario 8:** This scenario represents a realistic 2015 development worst-case scenario with no releases for the environment and full transfer allocation and development allowed. No TWP dams in place.
  - o **Worst Case:** This scenario was included to provide a lower boundary for the results. This is a highly unlikely future scenario with development at 2025 level and with the TWP dams in place. The full transfer capacity to the Vaal of 35m<sup>3</sup>/s was utilised and no releases were made for the reserve.
- Monthly prawn catch in kilogram (1988 – 2000). The catch data were found to be more responsive to the testing rather than the previously used CPUE figures. This was assumed to be due to both the inadequacy of the effort measurements to account for technological advances in fishing gear and methods e.g. increased horse power on boats, increased number of nets towed during a drag and inclusion of GPS navigation systems resulting in an underestimation of prawn abundance

All the data is provided electronically.

These data sets were used to make a prediction on annual catch represented by the main catch season, i.e. March to October. These are the dependant variables, which we are trying to predict.

### 7.1 INDEPENDENT VARIABLES

There are three independent variables, which have been discussed in detail in Chapter 6 and will only be summarised below:

- **Nursery Index (NI):** Based on the flows of the Nursery Rivers only and represents the estuaries contribution as a habitat to the postlarvae and juvenile life stages of the prawns.
- **Nutrient Index, Larval Stage (NUTIL):** Represents the nutrient input from all the rivers to the larval life stage of the prawns.
- **Nutrient Index, Adult Stage (NUTIA):** Represents the nutrient input from all the rivers to the adult life stage of the prawns.

These three independent variables will be combined based on a weighting system in order to provide a single independent variable called the **Index Value**. The weighting will be discussed in the following section.

### 7.2 COMBINATION OF THE COMPONENTS TO CALCULATE THE INDEPENDENT VARIABLE

The different weights applied to the components were largely based on optimising the regression analysis and are provided in Table 7.1.

**Table 7.1 Weighting of the Index Value components (Independent Variable)**

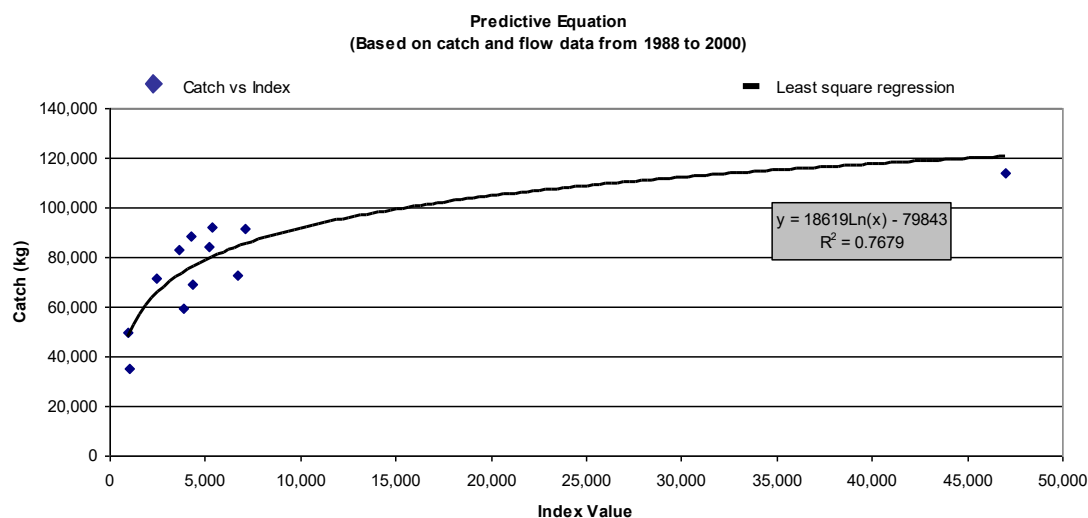
Nursery Index (NI)	NUTIL	NUTIA
4	4	0.5

The importance of nursery area function (NI) and numbers of larvae to recruit to the nursery areas (NUTIL) was considered to be similar and greater for the following fishing year than the direct nutrient input to the current adult phase during a particular fishing year on the Thukela Bank (NUTIA). The **Index Value** is now simply the sum of the weighted components as in Table 7.1.

**7.3 REGRESSION ANALYSIS**

Regression analysis was undertaken in order to determine the final predictive equation. The **NUTIL** and **NUTIA** variables were determined based on the historical flows in the Thukela as provided in Chapter 4. The 1997 catch figures were not considered reliable because effort into the Thukela Bank fishery was low with only two boats operating, both of which spent a large part of the season in Mozambique waters (Walsh<sup>1</sup> *pers comm*). For this reason 1997 was not included in the regression analysis. The regression equation was based on the weighted annual totals of the three monthly independent variables and the total catch during the main season. The most appropriate regression analysis was a log function where X is the independent variable (Index Value) and Y the dependant variable (Prawn Catch in kg). The results of the analysis are provided in Figure 7.1.

**Fig 7.1 Regression Analysis**



The outlier point on the right of the figure was based on the 1987 floods and is deemed to be realistic. This increase in catch with increasing index values supports the earlier interpretations of the effects of flow on the population dynamics of these animals. This equation has a Coefficient of Determination = 0.77 (R<sup>2</sup>). Effectively this means that the predictive equation explains 77% of the variance in the observed catch data.

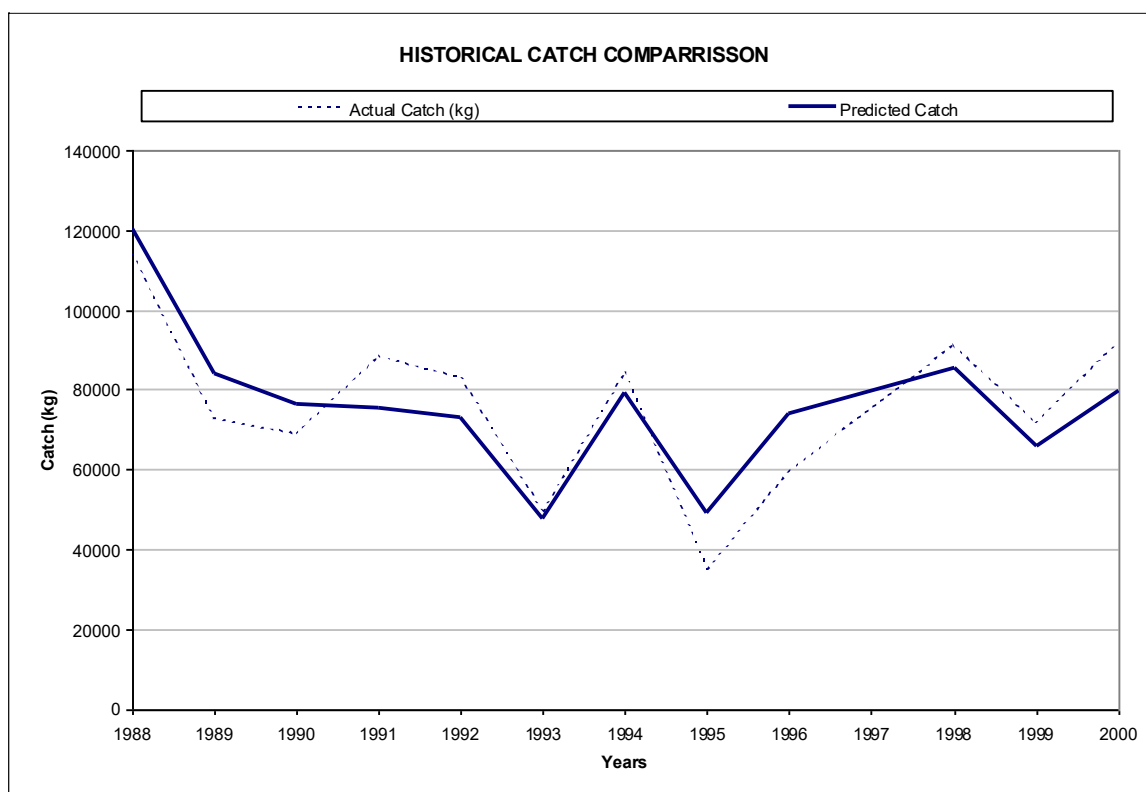
The predicted catch based on the historical flows in the Thukela is compared to the actual catch in Tables 7.2 and provided graphically Figure 7.2. The average change was 2.695 with a Standard Deviation of 17.123.

<sup>1</sup> J.W. Walsh Ocean Trawling Pty (Ltd)

**Table 7.2 Predictive catch comparison**

Year	Historical Catch (kg)	Predicted Catch (kg)	% Error
1988	114 027.00	120 455.01	5.6
1989	72 806.00	84 158.46	15.6
1990	68 896.00	76 255.92	10.7
1991	88 469.00	75 593.37	-14.6
1992	82 902.00	72 911.72	-12.1
1993	49 558.00	47 665.02	-3.8
1994	84 250.00	79 346.30	-5.8
1995	35 093.00	49 327.14	40.6
1996	59 407.00	73 787.85	24.2
1998	91 302.00	85 273.64	-6.6
1999	71 592.00	65 642.15	-8.3
2000	92 085.00	79 942.41	-13.2
<b>Total</b>	<b>910 387.00</b>	<b>910 358.99</b>	

**Fig 7.2 Predictive catch comparison**



**7.4 RESULTS: SCENARIO ANALYSIS**

The predictive equation as provided in Section 7.3 was used to predict catch for the period from 1988 to 1995 for the four scenarios described at the beginning of the section. These scenarios are repeated below for reference purposes:

- **Natural:** This scenario provides the upper boundary for the results and is based on the naturalised or virgin flow regime for the Thukela River.

- **Scenario 1:** 2000 development in the Thukela with **Reserve Scenario 1** (High category freshwater Reserve) in place. This scenario will result in the highest inflow to the Bank.
- **Scenario 8:** This scenario represents a realistic 2015 development scenario with no dedicated releases for instream flow requirements, a full Thukela-Vaal transfer allocation and expected in-basin development allowed. No TWP dams in place.
- **Worst Case:** This scenario was included to provide a lower boundary for the results. This is a future scenario with development at 2025 level, with the TWP dams in place. The full Thukela-Vaal transfer capacity to the Vaal of 35m<sup>3</sup>/s was assumed and no releases were made for the Reserve.

The scenarios were simulated and the results are compared to the predicted historical catch from Table 7.2 in Table 7.3.

**Table 7.3 Scenario Results**

Year	Predicted Catch (kg)	Percentage Change (%)			
		Natural	Scenario 1	Scenario 8	Worst Case
1988	120 455.01	0.6	0.2	-0.4	-0.7
1989	84 158.46	1.8	-0.3	-2.4	-4.4
1990	76 255.92	3.8	2.0	-0.5	-2.2
1991	75 593.37	4.2	2.2	-0.4	-4.0
1992	72 911.72	9.8	5.9	3.2	-3.2
1993	47 665.02	19.8	11.7	1.4	-11.1
1994	79 346.30	6.7	2.1	0.1	-3.5
1995	49 327.14	21.8	15.6	5.8	-4.0
Average Percentage Change		8.5	4.9	0.9	-4.1
Standard Deviation		8.1	5.8	2.6	3.1

The results indicate that the catch would always be better under the **natural** condition (8% higher on average), with **Scenario 1** being generally better (little worse in one year) and **Scenario 8** being better in some years and worse in others. The **worst-case** scenario will always result in lower catches (4% lower on average).

## **8 ECONOMIC IMPLICATIONS OF THUKELA FLOW CHANGES**

### **8.1 INTRODUCTION**

This chapter builds on the data and findings on the preceding chapters as a basis for assessing the economic implications of alternative flow scenarios on the affected inshore marine fisheries. There is little precedent for this type of study, either in South Africa or globally, and the methodology for incorporation of economic considerations into RDM studies is still under development (see Turpie *et al.* 2000). The Thukela RDM study is the first application of reserve determination methodology to incorporate environmental and resource economics.

The decision taken at the level of the overall study is that the economic impacts will be measured in terms of (a) the gross value of production, in this case ex-vessel, and (b) employment, for both the river and inshore marine components, and further value added by this production in the regional or national economy will not be considered (Myles Mander, *pers. comm.*). Recreational fisheries will be considered in terms of change in expenditure. This approach (both for commercial and recreational fisheries) was also used for the FitzRoy Basin study in Australia (Queensland Gov. 2000). This is a rather simple approach which does not take the costs of production into account, and thus does not consider changes in the viability of economic activity at the enterprise level. It also does not consider the important spin-off effects or multipliers of production processes which lead to generally greater levels of expenditure in the economy. This chapter thus provides the basic data required for the overall study, but also attempts to put these values into context wherever the data could be relatively easily acquired.

This study examines the potential economic impacts of proposed changes in flow of the Thukela River on commercial crustacean and linefish fisheries in the affected marine environment. The analysis uses predicted prawn and linefish catch data for four flow scenarios, including the natural situation. It is not intended to be a detailed study, but just to assess whether the broad implications for the fishery, such as whether stocks would be reduced beyond the point of economic extinction.

Data for the economic study of the crustacean and linefish fisheries were obtained from the literature, key informants in the industry, Oceanographic Research Institute, EnvirofishAfrica, and Marine and Coastal Management. This study concentrates on the crustacean fishery, partly because the biological predictions were expected to be more accurate for that fishery than for linefish. Changes in catch were also expected to be greatest for prawns based on earlier work (Demetriades *et al.* 2000). Subsistence fishers who operate in the estuaries that are nursery areas (which do not include the Thukela estuary) were not considered in this study as they would not be measurably affected by changes in Thukela flows. The crustacean and linefish fisheries are described separately below, giving scenario results in each case.

### **8.2 THE CRUSTACEAN FISHERY**

#### **8.2.1 Fishing grounds and species caught**

The crustacean trawl fishery has two distinct fishing grounds, the inshore grounds and offshore grounds. The main inshore fishing ground is the Tugela Bank, some 300km<sup>2</sup> in extent, where trawling takes place in depths of about 10 – 45m, but inshore trawling also takes place on the much smaller St. Lucia ground. The offshore grounds are at depths of 100-600m, and cover an area of about 1000km<sup>2</sup> (EnvirofishAfrica 2002). This study has so far been mainly concerned with the inshore grounds, since it is the inshore resources that are most likely to be affected by changes in flows from the Tugela River. However, the fisheries are not completely separate. A trawler with an inshore permit may also trawl in the offshore grounds, but not vice versa. Furthermore, the fishing season on the inshore Bank is roughly

5 to 7 months, whereas the offshore fishing is year round. Thus catches from inshore-permitted boats usually also include catches from the offshore Bank. This, and the fact that several boats also fish in Mozambican waters, has an important bearing on the economic impacts of potential changes in inshore catches in KwaZulu-Natal.

Inshore and offshore catches are very different. Targetted catches on the Tugela Bank are dominated by the white prawn *Penaeus indicus* (>80% of catch), the balance being made up of the brown prawn *Metapenaeus monoceros* and tiger prawn *Penaeus monodon*. On the St Lucia Bank, catches are dominated by *P. indicus* and the bamboo prawn *P. japonicus*. Apart from tiger prawns, the prawn species are not separated when they are packed, and are collectively referred to as white prawns, even though this name strictly belongs to *P. indicus*. In comparison, the offshore fishery is dominated by pink prawns *Haliporoides triarthrus*, red prawns *Aristaemorpha foliacea*, and langoustines *Metanephrops mozambicus* and *Nephropsis stewarti*, as well as lobsters and crabs (EnvirofishAfrica 2002). In addition to targeted catches, both inshore and offshore prawn trawling includes considerable by-catch. About 75% of the inshore catch and 70% of the offshore catch is discarded (Fennessy and Groeneveld 1997), most of this being fishes, usually slow-swimming demersal species. In the inshore fishery, the retained bycatch is mainly comprised of snapper kob *Otolithes ruber* and longfin kob *Atrobuca nibe*, and also spotted grunter *Pomadysis comersonnii* and javelin grunter *P. kaakan* (Fennessy 1994 in EnvirofishAfrica 2002). In the inshore fishery, the ratio of prawns to by catch can be as high as 1:15, particularly during the early and late part of the season (EnvirofishAfrica 2002).

### 8.2.2 The fishing fleet and effort

The KwaZulu-Natal crustacean trawl fishery is small in terms of numbers of vessels and total retained catch (Fennessy *et al.* 2000), but is considered to be very important both economically and socially (EnvirofishAfrica 2002).

The prawn trawlers are based in Durban. These vessels have been used extensively in Mozambique, where fishing grounds are more extensive and catch rates higher (de Freitas 1995 cited in EnvirofishAfrica 2002). In 1976 the 12 nautical mile inshore trawling limit imposed by the Mozambican authorities was extended to 200 nm, discouraging South African vessels from fishing there. This is when regular trawling by two vessels began in the inshore Tugela Bank grounds. By 1982 there were 20 vessels based in Durban, most of which were fishing in Mozambique, but four of which could also operate in KwaZulu-Natal (EnvirofishAfrica 2002). However, the 1983 moratorium on South African fishing vessels operating in Mozambique led to the Department of Sea Fisheries limiting the total number of trawlers operating in KwaZulu-Natal to ten, of which only **four** were allowed in inshore fishing grounds south of Cape St. Lucia. This was challenged, and the inshore fleet was allowed to increase to 8. However, vessels were readmitted into Mozambique in 1985 and only four of these vessels were still used in KwaZulu-Natal. Eleven other Durban based boats were fishing offshore both in Mozambique and KwaZulu-Natal (EnvirofishAfrica 2002). In 1987, 6 of 15 permits were used in KwaZulu-Natal. In 1989-90, there were **8 inshore and 7 offshore** permits in KwaZulu-Natal. By 1991, when Mozambique insisted that South African boats fishing in their waters had to land their catches there, the Department of Sea Fisheries restricted permits to those actively trawling in KZN. A total of **5 inshore and 3 offshore** permits were allocated. This number has remained constant up to 2002, although Mozambique catches can now be landed in Durban after clearing Mozambican customs, and some trawlers permitted for KwaZulu-Natal also spend much of the year in Mozambique. The current (2003) allocation of permits is listed in Table 8.1, and is now **3 inshore and 4 offshore** permits (MCM, *in litt.*), with the fate of an eighth permit still in the air. The inshore permits can be operated inshore or offshore, while offshore permits do not allow inshore fishing.

**Table 8.1 Permits in 2003**

Company	Inshore	Offshore
KwaZulu Fishing (Pty) Ltd*		1
Spray Fishing (Pty) Ltd*	1	1
Sterling Fisheries & Cold Storage (owned by I&J)	1	1
Viking Fishing Company Deepsea (owns Polana Fishing)	1	1
TOTAL	3	4

\* operated together by Ocean Trawling

While the Ocean Trawling inshore permits (usually 2 permits in the past) are operated full time (these vessels are not permitted for Mozambique), the Sterling (I & J) and Viking inshore permits are seldom operated in KZN inshore waters, except when fishing is bad in Mozambique (J. Walsh, Ocean Trawling, *pers. comm.*). In fact it is argued that I & J and Viking sometimes only run their trawlers in KZN waters in order to retain their licenses as a hedge against an uncertain future in Mozambique. In 2000 these vessels spent about 2 months in South African waters, compared with the average of 9 months for the 'full-time' KZN vessels, though even the latter spent some time in Tanzania. If all five inshore licenses had been fully operational, then CPUE on the inshore Bank would probably have been reduced, and Ocean Trawling claim they would have spent more time fishing offshore.

All the trawlers involved in the fishery are steel vessels of 25-35m with 300-600kW engines. They are equipped with echo sounders, global positioning systems and track plotters, radar, radios and cellphones (EnvirofishAfrica 2002). Trawl sizes range from 25-60m footrope lengths, and 'tickler' chains are attached to the footropes (EnvirofishAfrica 2002). Apart from the less powerful twin-net boom trawler, the entire fleet can operate on either the inshore or offshore grounds (but the former could be upgraded). A typical vessel is worth about R5 million, and carries about 15 to 17 crew (EnvirofishAfrica 2002).

The fishery is regulated in terms of the number of permitted vessels. However, the technological capabilities of the boats have increased dramatically in the last 15 years, and there is no regulation as to the number of nets a vessel can set at one time. Traditionally, they used single otter trawls from the stern. However, by 2001, one of the boats was using two beams to deploy two nets (EnvirofishAfrica 2002), and now three nets are deployed on at least one vessel (J. Walsh, *pers. comm.*). According to J. Walsh, prawn trawlers in 1986 were only about 20% to 50% as efficient as present day vessels, due to advancements in various technologies as well as numbers of nets set. Technological advancements have also had an impact on the costs of catching, which have increased about three-fold over the same period (in nominal terms; J. Walsh, *pers. comm.*).

Trawling is carried out for 24 hours a day, with each drag taking about four hours. Unwanted bycatch is discarded, and the rest is sorted, graded, packed and blast-frozen on board. Crustacean catches are dipped in sodium metabisulphite prior to processing to prevent blackening (EnvirofishAfrica 2002). Most processing is thus at sea, and <3% of prawn tails are shelled and deveined at onshore facilities (EnvirofishAfrica 2002).

### 8.2.3 Effort and catches

No stock assessments have been made for the crustacean fishery. Theoretically the white prawn stock is fairly resilient to exploitation because of its life history characteristics. However, stocks are apparently sensitive to environmental conditions, particularly catchment runoff (Demetriades *et al.* 2000, this study).

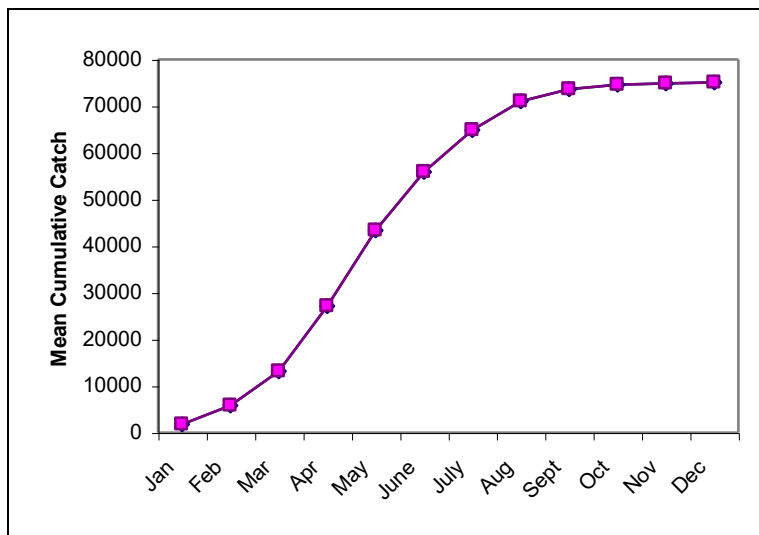
Because of the nature of crustacean fisheries, total catches are not strongly dependent on the number of vessels deployed. For example, double the number of boats would probably not land a much greater catch, and an increase in technology might have increased total

annual catch by as little as 10%, for all other things equal (J. Walsh, *pers. comm.*). This is supported by the fact that, in the offshore fishery, catch rates are negatively correlated with fishing effort (Tomalin 1998 in EnvirofishAfrica 2002). This suggests that the limit to the number of trawling permits benefits those that are involved in the fishery. This has not been demonstrated for the inshore fishery, but would be more difficult to detect due to the fact that variability is compounded by the response of stocks to freshwater flows. However, it can be assumed that the same would hold true.

In any situation where total catch is limited, effort is not completely regulated and there is competition for a resource, there will be technological advancement as competitors attempt to gain a larger slice of the finite pie. Although the crustacean fishery is not limited by a Total Allowable Catch, there is a finite catchable stock which is fairly resilient to intense harvesting pressure due to its biological life-history characteristics. Assuming a declining CPUE as stocks decline over the season, and a declining CPUE with increasing number of competing vessels, individual boats will attempt to increase catch per unit time by increasing instantaneous effort in the form of fish finding and nets. This is apparently what has happened, and because of technological advancements, trends in CPUE may be considered somewhat unreliable as a measure of the status of stocks. This suggests that CPUE, for a more comprehensive measure of effort, may have decreased over the past ten years, if environmental effects (increasing rainfall) are held constant.

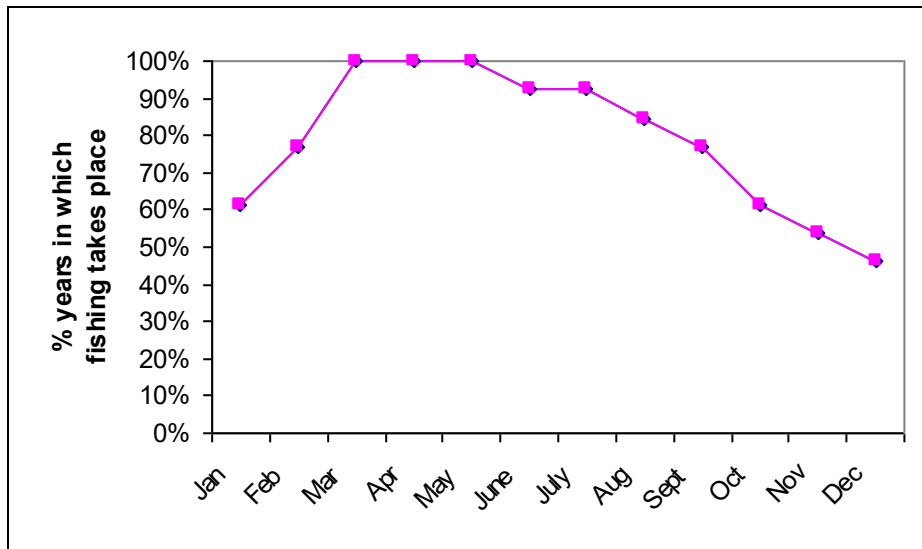
Inshore catches are very seasonal, with peak catches in April to June, declining rapidly to a minimum in November-December (Figure. 4.6). January and February catches, which are also relatively low, take place on the St. Lucia grounds, since the Thukela Bank have been closed for this period since 1997. This closure is to reduce impacts on square-tailed kob, an important linefish species which recruits to the Thukela Bank in January and February. About 6% of the total catch is landed during these first two months. In good years the season extends to October and beyond. However, on average, very little is added in the latter part of the year (Figure. 8.1).

**Fig 8.1 Mean cumulative inshore prawn catch over the year for the period 1988 – 2000 (data source: N. Demetriades)**



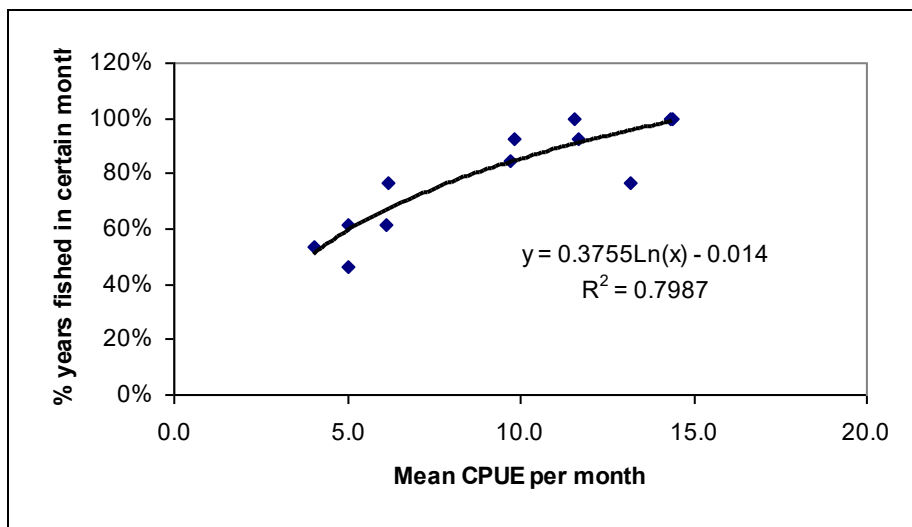
Catch per unit effort follows a similar trend to overall catches, except that it is high for longer, from February to June (Figure. 4.5). The percentage of years in which fishing takes place in a particular month reflects these patterns to a certain extent (Figure. 8.2). The low incidence of fishing in January and February probably has more to do with the closed season, and the fact that fishing can only take place on the St Lucia grounds. In some years these are not productive due to mouth closure, as has been the case in 2003 (J. Walsh, *pers. comm.*).

**Fig 8.2 Percentage years in which inshore fishing takes place in any month, for the period 1988-2000 (data source: N. Demetriades)**

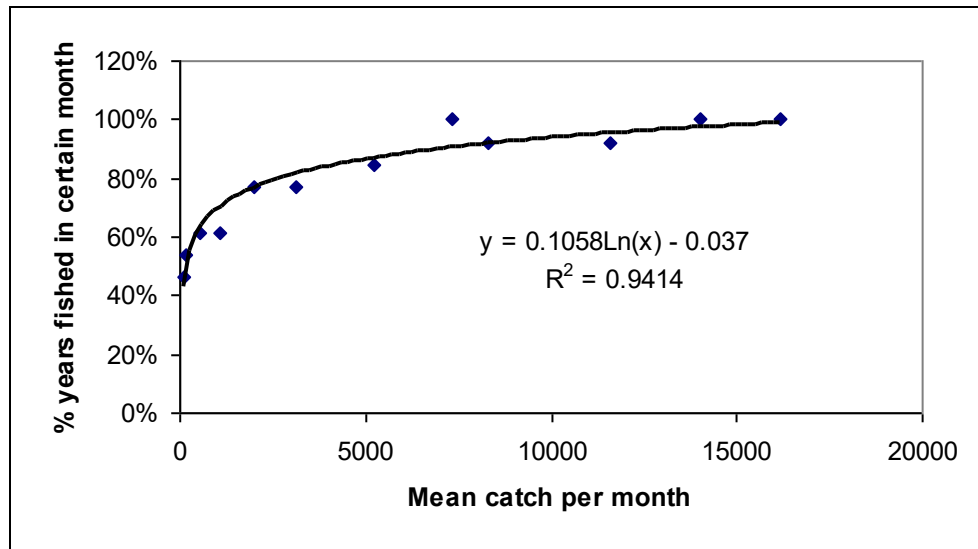


The above can be used to examine the probability of fishing in a particular month as a function of the CPUE or total catches. In fact, there is a clear relationship in both cases, but it is stronger in the latter case (Figures. 8.3 - 4 and 8.5). As the returns to effort in this fishery go down, so boats will be better deployed elsewhere. The probability of fishing falls off very steeply once total catches decline below 2500kg (Figure. 8.5).

**Fig 8.3 Mean percentage years fished in a given month vs the mean CPUE for that month over the period 1988 – 2000 (Data source: N. Demetriades)**

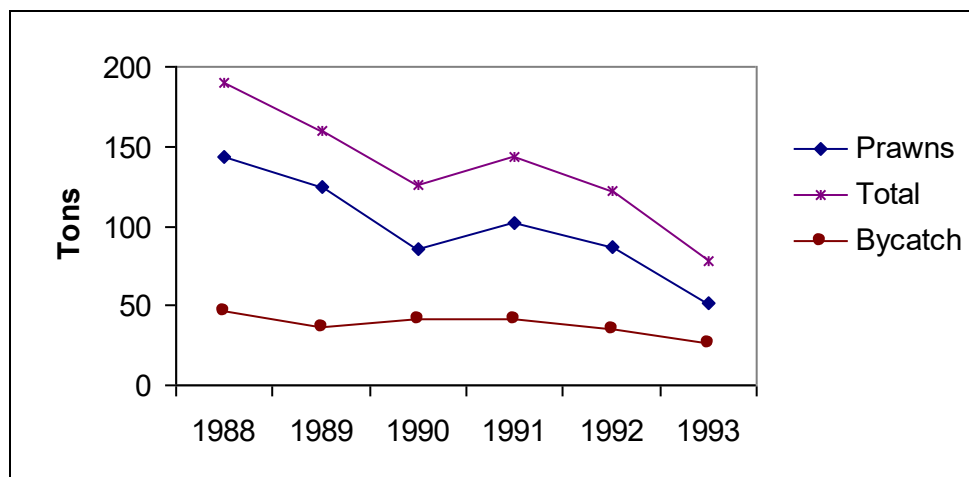


**Fig 8.4 Mean percentage years fished in a given month vs the mean total catch for that month over the period 1988 – 2000 (Data source: N. Demetriades)**



The total prawn catch in the inshore fishery has averaged 70 tons during the period 1988-2000 (see earlier chapter). Total retained bycatch for 1988-1993 has been estimated to be about 38 tons on average, with a mean catch of 23 tons of fish, 10.3 tons of crab and 4.5 tons of cephalopods (based on Fennessy and Groenewald 1997). Interestingly, this catch remains relatively constant over time, compared with prawn catch (Figure. 8.4), presumably because of strong environmental influences on the latter.

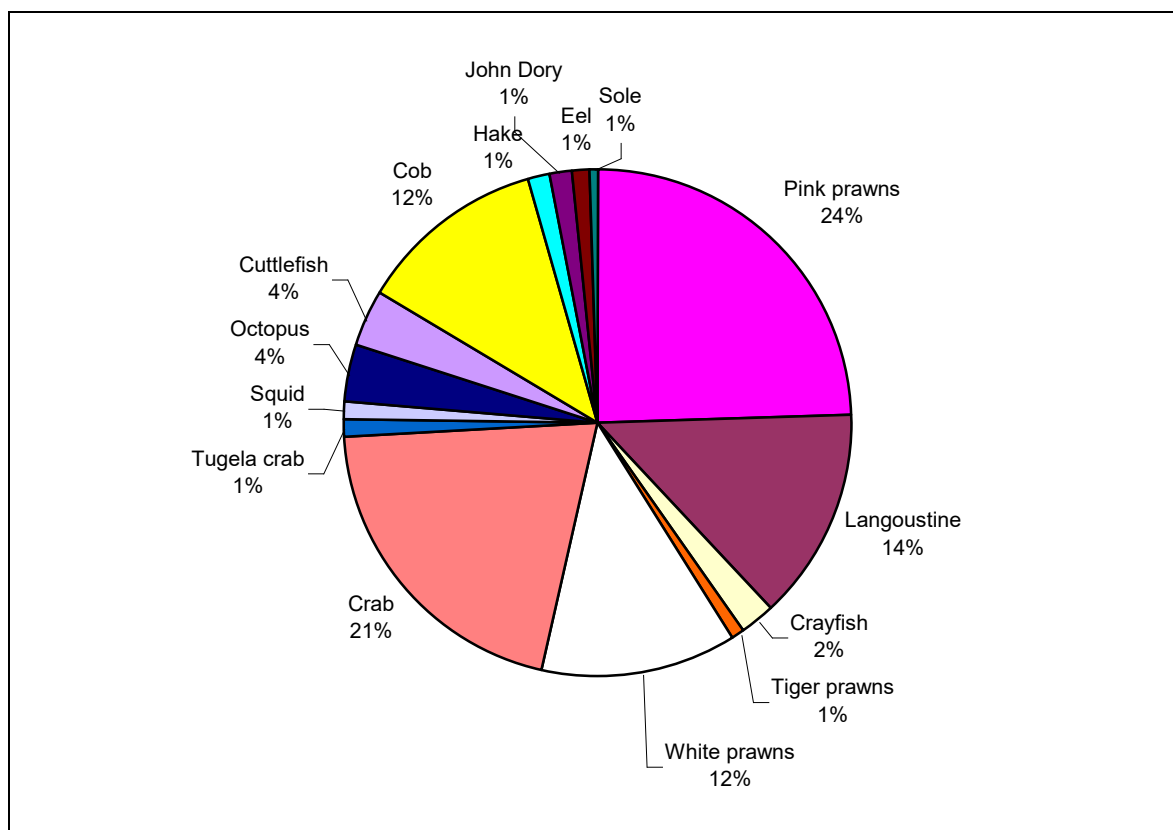
**Fig 8.5 Retained bycatch biomass relative to total retained catch for inshore catches between 1988 and 1993. (Source data: Fennessy & Groeneveld 1997)**



The inshore catches form part of an overall crustacean trawl fishery in which there is greater offshore effort. On average, about a quarter of the total effort within KwaZulu-Natal fishing grounds is estimated as being inshore. An estimate of overall catch for all major landed species was made based on average catches of a pair of vessels (one licenced for inshore and one for offshore) over the period 1992 – 2002. The catch is diverse, with the inshore prawn species making up about 12% of retained catch by weight (Figure. 8.6). The catches of white prawns average 87 tons, higher than the average of 70 tons for the period 1988 – 2000, but this is to be expected since it excludes the bad years of 1993 – 1997. Based on the assumption that half the inshore and offshore fleet spends only a quarter of its fishing days on the KwaZulu-Natal fishing grounds (the rest being in Mozambique), the total catches

of each species are estimated in Table 8.2. The overall catch, including bycatch, is estimated to be in the region of 700 tons.

**Fig 8.6** Composition of retained catch for the overall crustacean trawl fishery (inshore and offshore), for the period 1992 - 2002. (Data source: Ocean trawling)

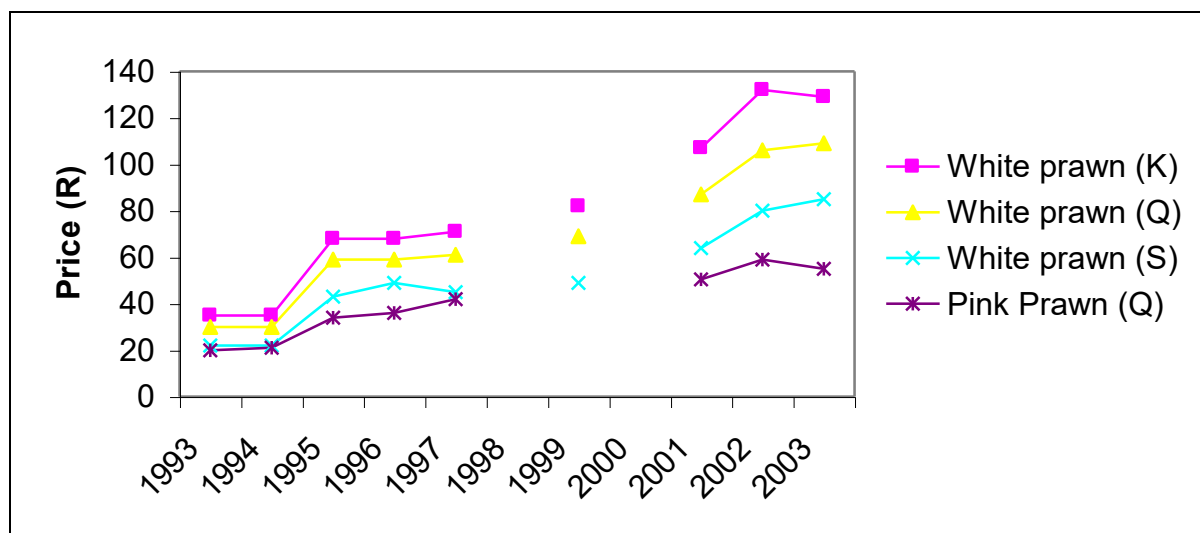


The total fishery is rather small when compared to more tropical prawn producing countries. For example, total catches of prawns alone in Mozambique amount to about 10 000 tons (SADC Marine Fisheries and Resources Sector – [www.schoemans.com.na/sadc](http://www.schoemans.com.na/sadc)).

#### 8.2.4 Marketing and prices

Prawns are landed every 21-28 days on average, though this can be anything from 7 to 42 days. The prawns are marketed in 2kg boxes. Prices are fixed by the sellers, and are usually increased in early summer every year, when the demand for prawns is highest. Very few locally-caught prawns are exported, partly because the industry is too small, and does not even meet local demand. The local industry supplies about 20% of South Africa's demand, with the remainder being imported from a number of countries, including Mozambique and Tanzania, and further afield. Prices are largely determined exogenously by prices on the international market. When the Rand is strong, local producers can demand the same price as imports. When the Rand is weak, local prices are about 10-20% lower than on the international market (e.g. most of 2002). This is because when international prices are high, importers have the option of obtaining B-grade prawns for a lower price. Thus there will be no relationship between prawn prices and catches from the Thukela Bank, and any reduced catch due to environmental change is not likely to be compensated by an increase in the price of prawns due to increased scarcity. Nominal price changes over time are illustrated in Figure 8.7. There is no difference in the trends in prices for inshore and offshore prawn species despite different patterns in supply, since both sets of prices are determined by international market trends.

**Fig 8.7 Changes in the nominal price of selected categories of inshore (white) and offshore (pink) prawns from 1993 to 2003**



### 8.2.5 Value of the crustacean fishery

Based on average catches of a combination of equal numbers of inshore and offshore vessels, and the assumption that half the fleet spends a quarter of its fishing days on South African fishing Bank, the total gross annual value of the fishery is estimated to be about R36.7 million. This is close to the maximum value of annual landings for the eight permitted vessels, in terms of the quayside wholesale price, of about R40 million, estimated by J. Walsh of Ocean Trawling (*in litt.*).

Inshore prawns are estimated to contribute R8.5 million to the total crustacean fishery value. The gross landed value of the inshore fishery, including retained bycatch, is estimated to be in the region of R10 million, or 27% of the overall fishery value. Thus approximately 25% of fishing effort provides the same proportion of overall value.

**Table 8.2 Estimated total average catch by species and size class for the KZN crustacean trawl fishery, and the gross landed value (in 2003 Rands) of this catch (based on data from Ocean Trawling)**

Species	Size	Mean catch (kg)	Price (R/kg)	Value R (2003)
Pink prawns	XL	1 355	65	88 043
	L	34 908	55	1 919 952
	M	39 643	41	1 625 343
	S	51 272	32	1 640 709
	CKT	30 026	32	960 834
	<	14 522	32	464 697
Langoustine (whole)	L	25 554	169	4 318 614
	M	21 625	145	3 135 625
	S	15 024	99	1 487 404
	SS	17 086	85	1 452 316
	<	14 910	85	1 267 380
	<	2 263	85	192 343
Crayfish		15 930	122	1 943 416
Tiger prawns	Giants	5 900	168	991 200
White prawns	Kings	14 772	129	1 905 606

Species	Size	Mean catch (kg)	Price (R/kg)	Value R (2003)
	Queens	14 277	109	1 556 170
	S	22 357	86	1 922 714
	SS	19 426	72	1 398 651
	SSS	10 804	51	550 982
	SSSS	6 078	35	212 738
Crab	L	14 561	60	873 686
	M	22 419	53	1 188 203
	S	43 307	45	1 948 821
	SS	52 888	32	1 692 423
	SSS	11 184	27.5	307 558
Tugela crab		7 344	11	80 781
Squid		7 960	10	79 596
Octopus		25 939	5	129 696
Cuttlefish		25 586	5	127 932
Cob		83 341	12.5	1 041 768
Hake		9 701	7.5	72 758
John Dory		9 718	7	68 028
Eel		7 249	5	36 246
Sole		4 505	6.5	29 280
<b>TOTAL</b>		<b>703 434</b>		<b>36 711 515</b>

The above values are average values, based on seven years of catch data for the whole fishery, spanning the period 1992 – 2002. The value of the fishery fluctuates annually. Assuming fairly constant effort, gross income has a coefficient of variation of about 20%, such that income in a good year can be double that in a bad year, and may range between R21 and R43 million in terms of 2003 prices.

The net income of the fishery is the gross income less the annual operating and overhead costs. Its net economic value also takes the opportunity cost of capital into account, and depends on the level of liability, or the degree to which the capital assets of the company are already paid up. Costs estimated for 2000 (Table 8.2) are inflated at 7% per annum to estimate costs in 2003 Rands. Net income before capital costs is estimated to be about R18 million per annum (R3.6 million per full time vessel, compared with EnvirofishAfrica's (2002) estimated net income of R250 000 per vessel). The capital costs associated with the fishery were calculated assuming an average vessel purchase value (in present day values) of R9.5 million, and repayments over 20 years (the estimated average period between building and rebuilding or replacement) at 16% interest. Under the above assumptions, net income of the fishery is estimated to be in the region of R4.5 million per year, or R900 000 per full-time vessel. However, this calculation is highly sensitive to the assumptions made, and needs further investigation. For example, a much higher net income of R7.4 million, or R1.4 million per vessel, is calculated if average market price of the vessels (about R6 million) is used.

**Table 8.3 Estimated costs of the crustacean fishery in 2000**

Revenues and Costs	Average per full-time vessel	Estimated total for 8 vessels, with 4 operating 25% in SA
<b>Operating costs</b>		
Remuneration	1 012 036	5 060 180
Manning	187 964	939 820
Fuel & lubricants	1 125 930	5 629 650
Maintenance	172 520	862 600
Gear	76 200	381 000
Packaging & processing	93 150	465 750
Insurance	82 560	412 800
Levies	89 355	446 775
<b>TOTAL</b>	<b>2 839 715</b>	<b>14 198 575</b>
<b>Overhead costs</b>		
Annual refits	185 700	928 500
Shore-based overheads	721 333	3 606 667
<b>TOTAL</b>	<b>907 033</b>	<b>4 535 167</b>
<b>Capital costs</b>		
Vessel replacement cost	7 750 000	38 750 000
Working and other capital	1 200 000	6 000 000
<b>TOTAL</b>	<b>8 950 000</b>	<b>44 750 000</b>

One of the results of increasing technology in this fishery (discussed above) has been an increase in its input costs. Thus the costs per unit catch have increased, reducing the profits of the fishery. The best way to minimise this tendency is to have a single rights holder for the entire fishery.

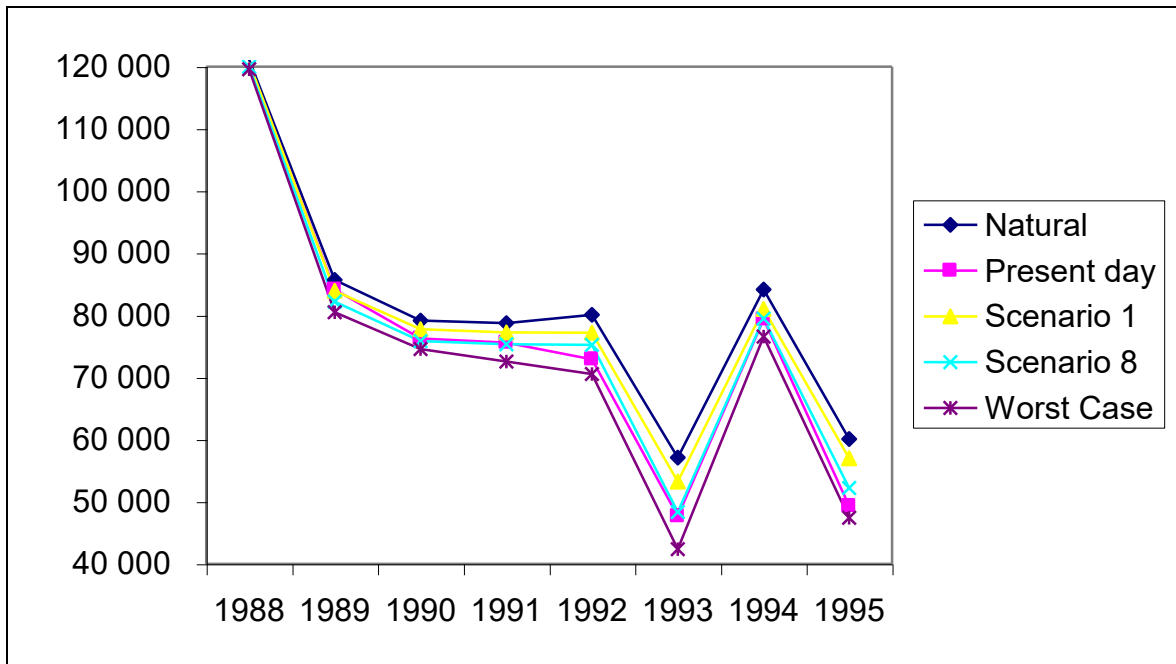
Given the huge interannual fluctuation in gross income, and hence in net income of the fishery, It is probably not insignificant that these vessels are owned by fishery companies that also have other fishing interests, and that are thus able to ride the bad income years. However, consistently bad returns in the inshore fishery would probably lead to the boats having to move offshore or out of the country.

Finally, the crustacean fishery, with eight permits operating, employs some 300 people directly (J. Walsh). This does not include the people employed for distribution, services etc. Assuming a similar multiplier as estimated for the commercial linefishery (calculated from McGrath *et al.* 1997), the total economic contribution of the fishery could be in the region of R130 million per annum. To put this in perspective, the contribution of fisheries products to Gross Domestic Product (GDP) is roughly 0.4%, with a value of R2.5 billion. The crustacean fishery is estimated to make up about 5% of this value.

### 8.2.6 The economic implications of changes in freshwater outputs

The estimated impacts of different flow scenarios on catch are listed in Table 7.3 and represented graphically in Figure 8.8 below. From this it can be seen that the greatest impact is felt during years of poor catch, which corresponded to the dry years over that period. In the time series presented in Figure 8.8, the high catch year ameliorates the overall effect. Whether this set of years is a typical 8 year period in terms of environmental factors is unknown: it may be worse than usual. The scenarios do not take climate change into account, which may lead to increased rainfall in the eastern regions of South Africa, in which case any negative impacts would not be as great as predicted. In any case, the catches are improved for all but the worst case scenario, for which catches decrease only very slightly.

**Fig 8.8** Expected difference in catches for the period 1988 – 1995 under different flow scenarios, where ‘present day’ is the actual flows recorded over that period



The crudest estimate of the economic impact of different freshwater flow scenarios on the inshore prawn catch would be the market value of the change in production. This is, in fact, the measure that is required for the overall resource economics study for the Thukela reserve study. Given that prices are determined exogenously, it is reasonable to assume that a change in South African supply will not influence the prices fetched. Thus the impact of a change in supply would not be buffered by price changes. The percentage change in the gross ex-vessel value is thus expected to be roughly the same as the percentage change in the catches presented in Table 7.3. Both in percentage terms and translated into rands, these amounts are relatively small (Table 8.4).

**Table 8.4** Estimated total catch and gross landed value of inshore prawn catches (2003 prices) for four Thukela flow scenarios, compared with the present. Note that the error margins of these estimates are unknown

Scenario	Expected catch	Total value	Change in value R per year
Present	75 900	6 919 000	-
Natural	80 800	7 367 000	448 000
Scenario 1	78 500	7 161 000	242 000
Scenario 8	76 100	6 938 000	19 000
Worst case	73 000	6 659 000	- 260 000

Spread among only 3 or 4 vessels with inshore licences, it is possible that such changes could make an impact at that level, but only if profit margins are as low as estimated by EnvirofishAfrica (2002). However, it is important to bear in mind that the inshore catches are always part of a larger fishery enterprise. The impacts on the overall crustacean fishery, which includes a valuable bycatch, are summarised in Table 8.5 below. Irrespective of the accuracy of the estimates of total fishery value, the magnitude of the change is shown to be a much smaller percentage of this overall value. Because the fishery is so diverse, it is fairly well buffered against changes of the magnitude predicted here.

**Table 8.5 Expected magnitude of change in overall average annual value of the crustacean fishery (1993 prices) for four Thukela flow scenarios, compared with the present**

	<b>Estimated average annual fishery value</b>	<b>Contribution of inshore prawn catches to value</b>	<b>% Change in value</b>
Present	36 711 515	23.3%	-
Natural	37 436 396	24.7%	2.0%
Scenario 1	37 131 673	24.1%	1.1%
Scenario 8	36 785 540	23.4%	0.2%
Worst Case	36 357 954	22.5%	-1.0%

Although not predicted by this study, a major decrease in inshore prawn stocks due to changes in water flow would lead to a decrease in catch per unit effort. Boats would be expected to move offshore once catch rates fall below a certain threshold such that the financial return to fishing effort is lower than the return that would be gained offshore. This might be costly in that one of the boats would require rebuilding in order to fish offshore (EnvirofishAfrica 2002). As more boats move to the offshore fishing grounds, the CPUE in that fishery will be expected to decrease. This could erode profits to the point that it is no longer viable to maintain the current number of vessels in the fishery. It is unlikely to put vessels entirely out of business, however, as companies will most likely move these vessels elsewhere, such as to Mozambique or Tanzania. Without more sophisticated modeling, it is difficult to estimate what level of decrease in average catch would significantly affect the viability of the fishery such that one or more vessels would have to leave the fishery, with concomitant effects on employment. The biggest clue to this lies in the catch rate at which vessels leave the inshore fishing areas. However, the changes estimated above are probably too small to have any significant impact on the current use of fishing grounds.

Two of the three development scenarios considered are estimated to have positive or neutral impacts on the fishery. Not only are incomes increased in scenario 1, but variability in catches is decreased.

In any event, it must be pointed out that the predictive model developed to estimate catches under different flow scenarios could only explain 77% of the variance in observed catches, whereas the predictions indicate changes of under 10%. Thus the certainty of these estimates, and the economic predictions that follow from them, is fairly low.

### **8.3 THE THUKELA BANK BOAT-BASED LINEFISHERIES**

#### **8.3.1 The nature and value of the commercial linefisheries**

The commercial linefishery is described in more detail in chapter 5. The KwaZulu-Natal commercial linefishery is entirely boat-based, and involves some 100 boats and 600 crew, of which 40-50 boats and 200 - 300 crew operate in the vicinity of the Thukela Bank (Ch. 5). About 38% of the province's commercial catch, some 290 tons, comes from the Thukela Bank, but the KZN fishery is small in comparison to the national fishery. The KwaZulu-Natal commercial linefishery contributes about R29 million (1997 rands) to the national economy (McGrath *et al.* 1997). The contribution of different species to this value is listed in Table 5.1.

Linefish catches are very diverse, but in the commercial sector, slinger *Chrysoblephus puniceus* and geelbek *Atractoscion aequidens* make up 31% and 15% of the catch, respectively. Other fish making up more than 5% of catches include soldier *Cheimerius nufar*, squaretail kob *Argyrosomus thorpei*, rockcods, kob species and blueskin *Polysteganus coeruleopunctatus*.

The gross income (= landed value) of the commercial linefishery on the Thukela Bank is estimated to be about R3 million (1997 rands). Based on McGrath *et al.*'s (1997) estimates of the overall value added to the economy by commercial linefisheries, it contributes some R10.8 million to the economy. These values seem small in relation to the number of boats and crew involved. However, it must be realized that in many, if not most, cases this activity is not the only income earning activity of the boat owners (see also Hutchings *et al.* 2002), and only a fraction of the boats actually go out regularly. Because data are only available at the aggregate scale, it was not within the scope of this study to investigate this further, nor to comment on profitability within the industry.

### **8.3.2 The nature and value of the recreational linefisheries**

The recreational boat-based linefishery is described in Chapter 5. The boat-based recreational catch is dominated by gamefish species, especially King mackerel *Scommeromorus commerson* (33%) and yellowfin tuna *Thunnus albacares* (19%), and with catface rockcod and eastern little tuna also contributing more than 5% of catch.

The entire boat-based recreational linefishing sector has been valued at R128 million (1997 rands) (McGrath *et al.* 1997). The KwaZulu-Natal portion of this is R47 million, with 2000 boats, or 10 000 anglers, being registered in 1995. The boat-based recreational line fishery on the Thukela Bank is estimated to be worth about half of the provincial total.

### **8.3.3 The economic implications of changes in freshwater outputs**

About 34%, 27%, 28% and 46% of the variability in catches of slinger, soldier, squaretailed kob and rockcods was explained by river flow, and there was no such relationship for geelbek or blueskin (Chapter 5). These relationships, including for other less important species, were used to estimate changes in catches of different species on the Thukela Bank under different development scenarios for the Thukela (Table 5.3, Chapter 5).

The changes in catches at a species level were then used to estimate changes in overall catches and values. The catches of those species for which analyses were not carried out, as well as those for which no significant correlation with flow was found, were assumed to remain constant under all scenarios. While there is little change under scenario 1, the values of catches decreased by 6% and 17% under scenario 8 and the worst case scenario, respectively (Table 8.6). The absolute change in value under scenario 8 is relatively small when considered on a per boat basis. When economic multiplier effects are taken into account, the contribution of the fishery to the national economy is seen to be much bigger. Nevertheless, the projected change is very small at the regional or national scale for scenarios 1 and 8. Impacts are more significant for the worst case scenario, and warrant further investigation should such a scenario be seriously considered.

**Table 8.6** Expected change in total catch, landed value of the catch and total economic contribution by the commercial linefisheries on the Thukela Bank, as a result of changes in flow of the Thukela. Data source: S. Lamberth, this study and unpublished data. Scenarios 1, 8 and Worst case experience 101.9%, 83.5% and 56.2% of present day flows, respectively

Scenario	Catch	Total landed value	% of present day value	Change in landed value	Total economic contribution	Change in economic contribution
	(Tons)	(1997 rands)		(1997 rands)	(1997 rands)	(1997 rands)
Present	291 204	2 975 501			10 846 148	
Scenario 1	293 412	2 996 882	101%	21 382	10 930 281	84 133
Scenario 8	272 069	2 790 192	94%	- 185 309	10 176 435	- 669 713
Worst case	240 148	2 481 184	83%	- 494 317	9 049 418	- 1 796 730

The recreational fishery catches are expected to stay the same under scenario 1 (100.05% of present catches), and to decrease only very slightly under scenario 8 (99.55% of present). The worst case scenario would entail a drop to 98.8% of present catches. Given the fact that the recreational sector is not particularly sensitive to catch rates, it is probably safe to assume that fishing effort, and hence expenditure and enjoyment, is not likely to be affected by such a small change. Indeed it is unlikely that these changes would be perceived at all.

Again, it must be pointed out that the regression models used to make these predictions explain less than half the variability in present catches, and thus that there is low confidence in the predictions in the first place.

## 9 CONCLUSIONS

The modelling of catch trends and environmental variations in terms of the historical fluctuations in the flow volumes and patterns of the Thukela River carried out in this study was remarkably successful. The interpretations and more specifically the weightings attached to the timing of the different flow rates were confirmed by the predictions resulting from the model when compared with historical data.

The modelled scenarios appear to suggest very little impact of the proposed changes on the Thukela prawn catches, with an average catch reduction under the worst case scenario of approximately 4 %. This average does result from a predicted range which varies from 0.7% to 11 %. In terms of catch statistics, if the figures presented in the scenario analysis are realistic, the extent of the predicted reductions are unlikely to be detectable although there is the caveat that the estimated negative effects do vary and the possibility of more significant impacts during dry years should be considered.

Although much more complex to analyse, certain fish appear to be more strongly affected by outflows of the Thukela than prawns are. This is surprising, since the connection with freshwater flows is generally thought to be much stronger for prawns. Changes in catches of certain species are expected to be fairly large under some scenarios, but because other species are not affected or are affected in the opposite way, the overall changes in catch are not likely to be as large as for many individual species. Overall, commercial fish catches may decrease by up to 17% in the worst case scenario. However, the models used only explained less than half of the variance in catches, and thus the certainty of this result is low. Recreational catches are only expected to change by up to 1.2%, which is negligible.

The overall Thukela basin Reserve study required economic impacts in the form of change in gross value of production (in this case landed values). The commercial crustacean fishery (including all its retained bycatch) is estimated to have a total gross value of R37 million (2003 Rands), but this ranges between R21 and R43 million due to the high interannual variability in catches. Inshore catches are estimated to contribute R10 million of this (R8.5 million from prawns), with about a quarter of the fishing effort providing a quarter of the overall value. Given that prices are determined exogenously (they are not expected to go up as prawn stocks decline), the impact on gross values of the inshore prawn catch is much the same as the percentage change in catch, ranging from R240 000 increase under scenario 1 to a R260 000 decrease in the worst case scenario. These values are small, and only amount to a -1.0 to +1.1% change in the value of the crustacean fishery. Estimates of net income of the fishery vary according to assumptions about capital ownership, but the reported changes are unlikely to affect viability of the fishery for the three companies involved. Even much larger changes would be expected to be weathered without much economic impact, through a change in the way in which the inshore and offshore Bank are utilised.

In comparison, the commercial boat-based linefishery on the Thukela Bank has an estimated gross income of R3 million (1997 Rands), spread unevenly among 40-50 boats that are used to different extents. The impacts of the different scenarios on this fishery are greater in terms of percentage change, such that the absolute losses are in the order of magnitude as for the prawn fisheries. While there is very little change under Scenario 1, Scenario 8 results in a loss of income of R185 000, and the worst case scenario results in a loss of almost R0.5 million. The profit margins of this fishery were not investigated, thus it is difficult to say how such losses would affect the economic viability of the fishery, which already appears to be very low.

The full economic value of commercial fisheries amount to some 3.6 times the value of the landed catches. Thus any loss in value, as might be expected for the boat-based fishery, may have much more serious repercussions if the fishery was to be reduced in size (in terms of effort or catches).

Recreational fishing is also a large boat-based linefishery which has no commercial value in terms of landed catch but which is very valuable in terms of its contribution to the economy through expenditure by anglers. However, the predictions made in this study suggest that there would be no measurable impact on this value, since the changes in catches would be small, and recreational anglers do not generally change their behaviour in response to minor changes in catch.

Overall, the results of this study indicate that the proposed scenarios are unlikely to have major impacts on the crustacean fishery, but could have measurable impacts on the commercial linefishery. While much of this study was based on relatively solid data sets, it must be emphasised that the confidence in the predictions is not high. This is because the models from which the predictions were made only explained 77% of the variability in catches in the case of prawns, and much less than this for fish. In addition, the cumulative effects of a long-term reduction of freshwater inputs to the Thukela Bank may also be an issue and the means for assessing this aspect were not available during this study, and the possible future effects of climate change, which might increase water runoff and productivity, were not taken into consideration.

Finally, it is recommended that, irrespective of the scenario implemented, there should be an undertaking to follow up this study by more rigorous and regular monitoring of catches and run off in order to validate and refine the existing model and confirm the predicted results.

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