APPROACHES TO ASSESSING THE STATUS OF NEARSHORE AND ESTUARINE FISH AND FISHERIES AND THEIR RESPONSES TO ENVIRONMENTAL CHANGE

By

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For Lara & Kaelan

"I'd take the awe of understanding over the awe of ignorance any day"

Douglas Adams, *The Salmon of Doubt*

DECLARATION

The work presented in this thesis is the sole responsibility of the candidate although all five chapters are to be submitted for publication with one or more co-authors. The candidate is principle author of all five. Papers correspond with the chapter numbers; 1 is co-authored with A.R. Joubert, 2 with J.K. Turpie, 3 with L. van Niekerk and K. Hutchings, 4 with G.M. Branch and B.M. Clark and 5 with L. Drapeau and G.M. Branch. This work has not been submitted for a degree at any other university

Stephen Justin Lamberth, February 2008.

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ABSTRACT

Lamberth, S.J. 2008. Approaches to assessing the status of nearshore and estuarine fish and fisheries and their responses to environmental change. Ph.D. thesis, University of Cape Town.

In multispecies fisheries knowledge, personnel and funding limitations often create the dilemma over which species should be the first to receive management and research attention. This thesis uses a Multi-Criteria Decision Analysis approach to prioritize 176 South African linefish species on the basis of a number of criteria indicating conservation and socio-economic importance. Each species importance was assessed from the points of view of (1) conservation, (2) each fishery sector separately and combined and (3) the overall combined conservation and sectorial importance. Relative scores within each of the fishery sectors were dominated by two or three species such that the scores separating the remaining species from each other were small. On the whole, the top species included those most important in each sector, biogeographic region and in terms of conservation. The separate and overall rankings should assist in the development of broadly acceptable management strategies for different fish.

Catch data for 129 of 255 functional estuaries on the South African coastline were reviewed and the relationships between fish catch and estuarine size, type and biogeographical region analysed using simple and multivariate models. Estuary size alone explained over 80% of the variation in catch in the warm temperate region and over 90% of the variation in catch in the cool temperate and subtropical region. Further analysis of the two main estuarine types (permanently open and temporarily open/closed estuaries) revealed higher productivity for the permanently open systems. Both estuarine size (ha) and type (5 types) were used to explain catches using general linear models. The models were able to explain 82-98% of the variance in catches. The total estuarine catch in South Africa was estimated at 2 480 tons per annum with a total value of R748 million, of which 99% could be attributed to recreational angling. Estuarine contribution to the inshore marine fisheries was estimated at approximately R846 million per year with estuarine dependent species comprising 83% of the catch of the recreational shore and commercial seine and gillnet fisheries and only 7% of the catch of the recreational spearfishery and commercial and recreational boat fisheries. Total value of estuarine and estuary-dependent fisheries was estimated to be R1.594 billion per annum in 2008 rands.

The cool-temperate Olifants and warm temperate Breede estuaries on the west and south coasts of South Africa have both seen a >35% reduction in mean annual runoff (MAR) from a historical reference condition to the present day with a >60% reduction possible under future development. With almost no exceptions, the Olifants Estuary fish assemblage has seen an overall 20% decrease in abundance from reference to the present day and will gradually decline to 55% of reference with a predicted future 60% reduction in MAR. Consequently, future reductions in flow are likely to see the Olifants Estuary progressing towards a low biomass, low diversity, marine-dominated system. In contrast, with the exception of some key exploited species, fish abundance in the Breede Estuary has increased by 6% from reference to the present day and is likely to increase to 115% of reference with future reductions in flow. In all, the fish assemblage will experience a gradual change from a relatively high-diversity low-abundance freshwater-rich system under historical flow conditions to a high-diversity, high-abundance, marine-dominated system with future reductions in flow.

The fish fauna of the Berg River Estuary on the west coast of South Africa was sampled from the mouth to 40 km upstream using a small-meshed seine net before (summer 1993), during (summer 1994) and after (summer 1996) a low-oxygen, hydrogen sulphide "black tide" event that caused a mass mortality of fish in the adjacent sea. The overall catch-per-unit-effort in the estuary during the event was almost double that in the years before and after respectively. All the fish recorded alive in the estuary during the event were species known to have some degree of estuarine association. No representatives of the purely marine species found dead on the adjacent shoreline were recorded live in the estuary during the event. Collectively this circumstantial evidence indicates that (1) fish used the Berg Estuary as a refuge from low oxygen conditions in the marine environment during the "black tide" event, and (2) the ability to secure refuge in the estuary was restricted to species described as 'estuarine-dependent'.

The influence of freshwater flow is not confined to estuaries and their catchments. Exploratory analyses of the relationships between monthly river flows and catch-per-unit-effort of the commercial linefishery on the Thukela Banks, KwaZulu-Natal were performed using spectral analysis and general linear models on a data set comprising 17 years of monthly commercial catch-and-effort data for 140 species and monthly flow data from 17 catchments. Significant relationships existed between flow and the catches of 14 species, which provided over 90% of the total linefish catch on the Thukela Banks. Time lags between flow events (wet and drought periods) and changes in catch-per-unit-effort corresponded in many cases to age at 50% maturity and/or age-at-first-capture of the species concerned. If future predicted flow reductions in the Thukela River materialise, catches of the commercially important species, the slinger *Chrysoblephus puniceus* and the squaretail kob *Argyrosomus thorpei*, are forecast to decline by 36% and 28% respectively. These two species currently provide over 50% of the landed mass on the Thukela Banks. National legislation requires that sufficient freshwater flows be set aside to protect ecosystems, so these findings have important management implications, as the needs of marine ecosystems for freshwater flows have not previously been addressed.

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GENERAL INTRODUCTION

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The southern Africa coast, spanning estuaries to the edge of the continental shelf, is home to an estimated 2 000 species of fish (Heemstra & Heemstra 2004). Approximately 210 of these are exploited by commercial, recreational and subsistence fisheries in estuaries and the nearshore. Estuaries are host to 150 species (Whitfield 1998) of which about 80 are exploited. Almost without exception, declines in catches throughout the southern African coastline have generally been attributed to overexploitation by one or more fisheries, seldom to other causes, anthropogenic or natural, that may influence fish survival (Griffiths & Lamberth 2002). This assumption becomes weak once we are faced with the collapse or extinction of stocks and populations of unexploited species or those that are regarded as optimally exploited. This is especially pertinent when considering the relationships between freshwater flow and nearshore and estuarine fish and fisheries.

The nearshore and estuarine fisheries comprise (legal and illegal) commercial, recreational and subsistence components. In most cases, the subsistence components are not really distinct but comprise participants in the commercial and recreational fisheries who fall within the lower two quintiles of household incomes in South Africa and for whom the fish caught represent a significant contribution to their protein intake (McGrath *et al.* 1997). The commercial sector comprises the boat-based linefishery and the beach-seine and gillnet fisheries, whereas the recreational sector is largely involved with angling and to a much lesser extent spear-fishing (Griffiths & Lamberth 2002). No formal definition exists for artisanal fishing in South Africa but it is generally accepted that the traditional trap, basket and spear fisheries as well as the commercial beach-seine fishery, which do not use motorised boats or other high-tech gear, may be regarded as artisanal in nature (Branch *et al.* 2002).

To put things in perspective, mean annual catches over a 10-year period of the 210 species caught in the nearshore and estuarine fisheries throughout South Africa can be divided up into their respective fisheries and biogeographical regions; cool temperate west, warm temperate south and subtropical and tropical Transkei and KwaZulu-Natal coasts (Emanuel *et al.* 1992, Sink *et al.* 2006). Similarities among nearshore fisheries in each biogeographical region can then be sought using group average hierarchical clustering and the Bray-Curtis similarity index to analyse the species composition of catches (Clarke & Warwick 2001, Clarke and Gorley, 2006). The results reveal two distinct groups, one comprising the "inshore" shore-based and estuarine recreational angling and commercial beach-seine and gillnet fisheries and the other the "offshore" recreational spearfishery and the commercial and recreational boat-based linefisheries (Fig. I). The "inshore" group splits firstly by habitat (shore based/surf-zone vs. estuarine) and fishing method and only then by biogeographical region.

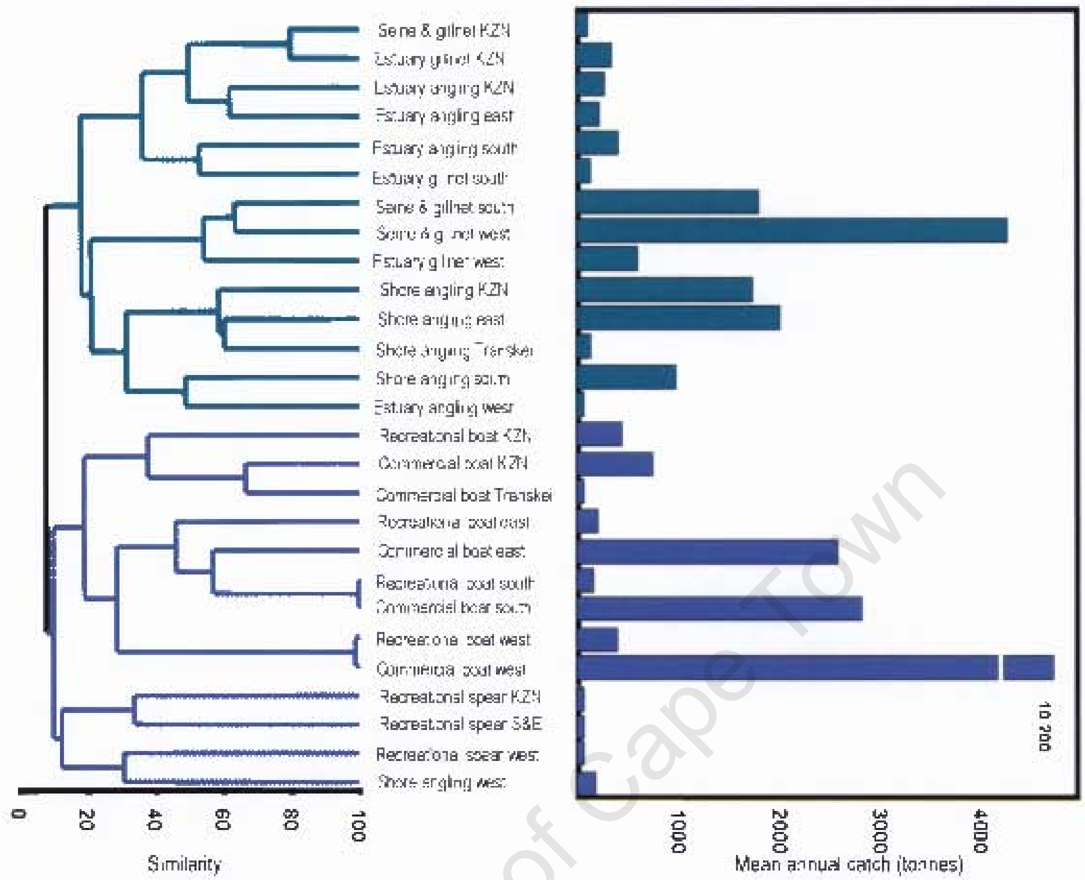


Figure 1 Cluster analysis of the catch contribution by region and fishing sector of 210 species using the Bray-Curtis measure of similarity, and the total annual catch estimated for each sector (bars). "Inshore" catches shaded in teal, "offshore" in indigo.

Similarly, the "offshore" group divides into boat and spearfishing and lastly biogeographical region. Overall, it can be inferred that the "inshore" catches comprise many species with some degree of estuarine-association but the "offshore" catches do not.

The only exception to the above grouping is the (mainly recreational) shore-angling fishery on the west coast, which groups out with commercial and recreational boat-based fishing and then the spearfishery, particularly the west-coast component (Fig. 1). This is largely due to both angling and spearfishery catches on the west coast being dominated by the surf-zone galjoen *Dichistius capensis* and kelp-forest hottentot *Pachymetopon blochii* (Griffiths & Lamberth 2002). A contributing factor is that on the west coast there is a distinct scarcity of estuaries to which the juveniles of exploited estuarine-associated fish species can recruit (Turpie *et al.* 2002). Ultimately, there is low recruitment of estuarine-associated fish species to marine linefisheries on the west coast compared to elsewhere on the South African coastline. This situation may be exacerbated by overexploitation of estuarine-associated fish in the few available estuaries leading to recruitment failure in the marine fisheries (Hutchings & Lamberth 2003). A combination of the two is the most likely scenario explaining why west-coast shore-angling clusters with offshore fisheries in that region.

The "inshore" and "offshore" fisheries are distinguishable by the species composition and abundance of their catches (Fig. I). From this it can be inferred that the species within each group are also likely to have certain distinguishing characteristics such as sex change, longevity, migratory behaviour and estuarine-dependence that make them either vulnerable or resilient to fishing and environmental change (e.g. Buxton 1996, Griffiths 2000a). Consequently, the differential response of these species to stress results in their respective populations and fisheries differing in conservation priority status and requiring different levels and types of management action. A structured approach to assessing exploited fish species in terms of their research, conservation and management requirements, is one of the aspects of this thesis.

The "inshore" group in Fig. I comprises at least 80 estuarine-associated species caught by shore-based and estuarine commercial and recreational fisheries. In fact, by number and mass of species, at least half of the fish caught by the shore-based fisheries have some degree of estuarine association, which allows them to be regarded as "estuarine-dependent fisheries". Hence, all of the fisheries in this group have a strong reliance on estuaries such that overall health and availability of estuarine habitat will ultimately be manifested in catches and the contribution of these fisheries to the national economy. Besides the maintenance of estuarine functioning, management of this group of fisheries requires that the estuarine and shore-based components do not operate at the expense of each another.

In southern Africa where sunken river valleys and fiords are rare or absent, the form and function of most estuaries can be attributed directly or indirectly to freshwater flow. Amongst other things, freshwater flow may determine estuarine type, whether an estuary is permanently open or temporarily open/closed, and its physiochemical profile. In general, estuarine fish assemblages conform to estuarine type whereas fish distribution within an estuary is governed by their life-history characteristics and physiochemical preferences and tolerances. In South Africa, estuarine fish assemblages are protected by water law, which requires a freshwater reserve for rivers and estuaries that provides for basic human needs and the ecological water requirements needed to maintain aquatic ecosystems in a healthy condition (Thompson 2006). Ultimately the ecological freshwater requirements of estuarine and estuarine-dependent fisheries are catered for by the freshwater reserve. However, the responses of estuarine-associated species to changes in freshwater flow are not reconciled with, or weighed against, those attributed to fisheries.

In contrast to the "inshore" group, fewer than 7% of the 160 species regularly caught by the "offshore" commercial and recreational fisheries have some degree of estuarine-association. Regionally however, there is a slight increase in the diversity and biomass of estuarine-associated species in "offshore" catches from the west coast eastwards. This is largely a reflection of the general decline in productivity and increase in diversity of marine and estuarine species as one moves eastwards from the productive upwelling centres on the west and south coasts to the mostly oligotrophic waters of KwaZulu-Natal. Overall though, the "offshore" group is characterised by a lack of diversity and biomass of estuarine-associated species in catches. Therefore, it can be expected that this group have little reliance on estuaries whether it be nursery areas or freshwater flow draining from their catchments.

Thesis outline

Chapter 1 provides a Multi-Criteria Decision Analysis (MCDA) approach to prioritising research and management in multispecies fisheries. The approach is especially pertinent to the management of these fisheries as funding and personnel are limiting, thus creating a dilemma over which species should be the first to receive research and management attention. The study entailed the prioritisation of 176 "linefish" species caught by the commercial line, beach-seine and gillnet fisheries and the recreational shore, boat angling and spear fisheries. Sectorial (e.g. catch) and conservation (e.g. vulnerability) criteria were used and each species was scored with respect to its conservation, sectorial and overall importance. The MCDA procedure developed is relatively simple, robust and globally applicable to multispecies fisheries.

South Africa has 255 functional estuaries. **Chapter 2** assesses these in terms of estuarine fisheries production, their contribution to marine fisheries production and their contribution to the economy on a regional and national basis. Existing catch data were used to develop general linear models that in turn could predict catches for estuaries for which no data exist. Variables used were estuary size, estuary type and biogeographical region.

Water quantity and quality in terms of human use and ecological functioning are increasingly becoming an issue in South Africa and the rest of the world. **Chapter 3** provides a comparison of two estuaries, one falling on the cool temperate west coast and the other on the warm temperate south coast biogeographical regions of South Africa. The emphasis is on altered freshwater flow and the responses of the fish assemblages of each system to changes in mean annual runoff (MAR) from a historical reference condition to the present day and finally to various future scenarios entailing water abstraction in their catchments.

The use of estuaries as refugia from stressful marine conditions is an accepted but often unsubstantiated benefit of estuaries to fish. **Chapter 4** describes the responses of estuarine-associated and marine fish to a large low-oxygen, hydrogen-sulphide generating event that occurred in St Helena

Bay, adjacent to the Berg River Estuary on the west coast of South Africa. Apart from compelling evidence that the Berg Estuary provided a refuge from this event, there were also indications that the ability to utilise estuarine refugia is limited to those species that are regarded as having some degree of estuarine dependence.

The influence of freshwater flow is not limited to estuaries and their catchments. Freshwater flow provides a number of additional functions ranging from the export of terrigenous nutrients, detritus and sediment to the marine environment, to the cueing of fish behaviour. **Chapter 5** analyses the relationships between catchment flow and catches of the Thukela Banks marine linefishery in KwaZulu-Natal. Although the dominant species caught in this fishery have little or no association with estuaries, almost without exception, their catches appear to be correlated with freshwater flow. The results are discussed in terms of proposals for future development in the Thukela River catchment, likely changes in MAR reaching the sea and the consequences for the stocks exploited by the linefishery.

The thesis is concluded by a brief synopsis integrating the findings of the five chapters.

CHAPTER 1

1. PRIORITIZING SPECIES FOR RESEARCH, CONSERVATION AND MANAGEMENT: A CASE STUDY OF EXPLOITED FISH SPECIES.

1.1 Introduction

Within the context of the conservation of biodiversity and when resources are limited, decision criteria are needed to determine which species should be given conservation priority. There are many possible criteria or rationales. For example, if one accepts the notion of biodiversity conservation, then the criterion would be to conserve the maximum number of species, which would imply that the cheapest to conserve would receive priority. On the other hand, if the preservation of the more endangered species were the priority, then the costs might be prohibitive (Jakobsson and Dragun, 1996). Shrader-Freshette and McCoy (1994) discuss the intricacies of choosing species for preservation and the merits of preserving species before habitats or vice versa. They conclude that ethical and scientific rationality should be used when setting conservation priorities especially with regard to species that are not regarded as "biologically" important.

There have been few national-scale, structured exercises to select species on which to focus research, management, and conservation. Internationally, the World Conservation Union (IUCN) criteria categorize species according to risk of extinction into five categories ranging from critically endangered to those of least concern and conservation efforts are encouraged relative to the category within which a species falls. National prioritization exercises have largely been confined to the identification and selection of key areas or habitat for conservation (Margules *et al.* 1988; Turpie 1995; Williams *et al.* 1996; Hockey & Branch 1997; Turpie *et al.* 1999). However, species importance rankings may be implicit in exercises prioritizing conservation areas or habitats (e.g., threatened birds [Williams *et al.* 1996]), but the authors have already decided a priori which species are important. Species ratings may also be implicit when prioritization exercises selecting protected areas include species diversity, rarity, and conservation status (e.g. Turpie 1995).

I illustrate an approach to the prioritization of species, using the South African linefishery as an example. Prioritization is especially critical in a fisheries context. The management of centralized, and easily identifiable, industrial fisheries are generally accorded more government resources than diverse and dispersed small-scale fisheries, despite the economic and social importance of the latter. Sophisticated stock assessment procedures with frequent reappraisal are easily applied to the few species in industrial fisheries but seldom possible in small-scale fisheries where research and management is limited by the availability of personnel, funds and the large number of species to consider. Most fishery management agencies are geared toward crisis management, largely as a result of lack of funds, trained personnel, and political will. Consequently, most species only receive attention when problems arise. These problems are even more prevalent and difficult to detect in multispecies, multiuser fisheries where highly variable levels of effort and targeting are directed at numerous species of differing vulnerabilities and stock status. Consequently, we are faced with two dilemmas: 1) being able to identify which species to address and 2) the choice of which of these to address first.

The American Fisheries Society (AFS) criteria for evaluating extinction risk amongst marine fishes outlined by Musick (1999) included rarity, specialization in terms of habitat requirements, endemicity or small range, and population decline. Categories of risk were endangered, threatened, vulnerable (changed from IUCN special concern), and conservation dependent (Musick 1999). Pauly (1997) describes a triage of fisheries, ranging from those that do not need immediate help to those that are beyond help and require more than fisheries management. Pitcher *et al.* (1998), provide a multivariate technique to gauge the health of fisheries on a scale of "good to bad", based on ecological, economic, social, and technological criteria. Although referring to fisheries rather than species, both of these approaches could be equally valid for categorizing individual species irrespective of whether they are part of a monospecific or multispecies fishery.

The South African linefishery is typical of multispecies, multiuser fisheries within which most participants operate on a small-scale basis. It has commercial, recreational, and subsistence components that catch approximately 25 000 t of fish comprising 200 species, and contribute about US $ 270 million to the economy annually (McGrath *et al.* 1997, Chapter 2). The recreational component may be divided into shore- (450 000 participants), boat- (12 800 participants) and spearfishing (7 000 participants) (Brouwer *et al.* 1997; Mann *et al.* 1997; Sauer *et al.* 1997). The commercial sector comprises about 3 000 line boats and 12 000 fishers as well as 7 000 fishers from the gillnet and beach-seine fishery (Lamberth *et al.* 1997; Sauer *et al.* 1997; Hutchings 2000). The subsistence component is difficult to define because participants occur throughout the lower income groups of the commercial and recreational sectors (McGrath *et al.* 1997).

Despite more than a decade of attempts to limit fisheries effort (i.e. the amount of people and equipment involved) and species-specific catch restrictions in the commercial and recreational sectors, current consensus among fishers, managers, and researchers is that most South African linefish stocks are in decline or have collapsed and that there have been few, if any, success stories of rebuilding (Brouwer *et al.* 1997; Griffiths 2000a). As a result, the suitability and effectiveness of management approaches and monitoring systems of the South African linefishery are in the process of review (Penney *et al.* 1997). An early conclusion has been that the large number of species caught in the linefishery, and the limited quantitative data and personnel available, preclude the rigorous application of conventional research and management procedures to all but the most important species. A first initiative to revise management approaches was the development of a linefish management protocol (LMP), which is structured to execute management plans for the most important species through a cycle of monitoring, assessment and revision of regulations (Griffiths *et al.* 1999).

The implementation of the LMP requires that linefish species be ranked in order of management priority. Data collection and stock assessment efforts should then focus on the higher priority species. The prioritization process should be robust and include participation by user groups and management agencies, and should consider a wide range of indicators of species' importance, including catches, socio-economic value, and existing indications of stock depletion. Subsequent to such a prioritization exercise, conservation and management approaches included in the LMP (such as marine protected areas) could be evaluated in terms of their efficacy with regards to the protection of the priority species identified. However, this subsequent step is not the focus of this paper.

I outline a multicriteria decision analysis (MCDA) approach to such a prioritization exercise. This approach uses criteria such as those of the AFS (Musick 1999) and Pitcher *et al.* (1998), and the resulting priority list can also be placed into categories of risk such as those of the IUCN or Pauly (1997). The MCDA approach is flexible and allows the aggregation of both quantititive and qualitative information, while maintaining detailed (disaggregated) information for simultaneous examination.

1.2 Methods

The MCDA technique was the simple multiattribute rating technique (SMART, e.g., Goodwin & Wright 1998), which is based in multiattribute value theory (e.g., Keeney & Raiffa 1993), but is relatively simple and accessible. This meant undertaking the following tasks (iteratively): 1) choosing relevant criteria for evaluating "importance" from various points of view; 2) forming a "value tree" or hierarchy from the criteria, with broad goals at the higher levels and the specific criteria at the lower levels; 3) scoring each species of fish on the basis of each of these criteria through either direct judgements or translating data into "value" using value functions; 4) weighting the criteria relative to each other through the "swing weight" concept; 5) aggregating the scores of each fish to various levels of the value tree to obtain indications of overall importance; and 6) performing sensitivity analyses to indicate sensitivity to weights, scores, and other assumptions. The "swing" in the term swing weights refers to the range of the swing from "worst" level to "best" level for a criterion (see, e.g., Goodwin & Wright 1998)

Information regarding appropriate criteria and their relationships was obtained from relevant specialists and fishers at a workshop of the Marine Linefish Research Group (MLRG) (members represent government, academic, and private scientific institutions), by questionnaire (at the Third Southern

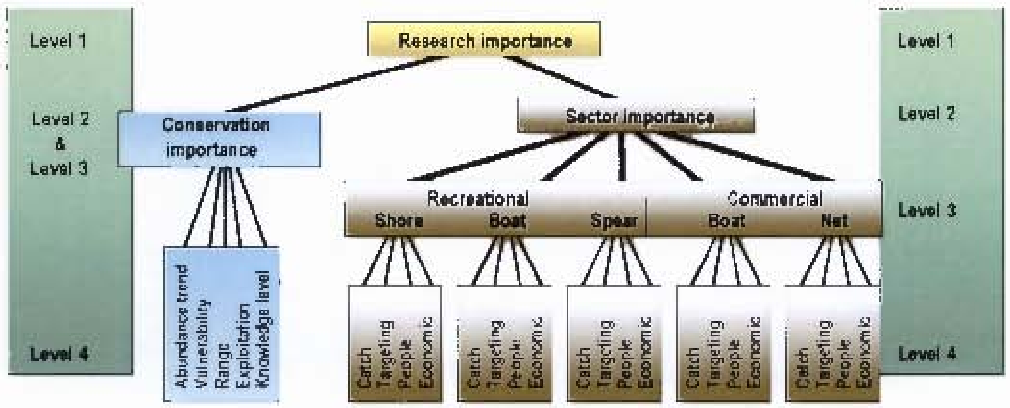


Figure 1.1 Criteria used for prioritization of fish organised into a value tree.

African Marine Linefish Symposium 1999), from available data and literature, and from a previous prioritization exercise (Penney *et al.* 1997). I selected criteria that in some way indicated importance to research and gave each fish scores based on each criterion. The criteria were then weighted to indicate their relative importance, and scores for each fish species were aggregated to give an overall score or rank.

The overall goal was to prioritize fish for research purposes and management action and the representatives felt that the two main factors influencing this priority were conservation importance and importance to the fishery. Five conservation criteria were identified, namely, level of knowledge, endemicity, relative exploitation throughout range, and vulnerable life history stages. Importance to the fishery was the aggregate importance to the five fishery sectors identified as recreational shore-, boat- and spear-fishing; and commercial boat-fishing and netting (beach-seine and gill-net). Within each of the fishery sectors, four criteria were identified; namely, present annual catch, degree of targeting, number of people involved and economic value. In total, 176 species, each caught by at least one of these sectors were included.

The 25 criteria (5 + 5 × 4) were organized into a 'value tree' format (Fig. 1.1). The structure of the value tree helps to explain the relationships between criteria, and defines how criteria scores are aggregated. In all cases, criteria values were converted to a 0 to 100-interval scale in various ways depending on the data source, as described below. An interval scale has no true zero but has equal value intervals which implies, for example, that in terms of "abundance" the difference between a fish that scores 1 and one which scores 2 is the same as the difference between one which scores 91 and one which scores 92. A purely ordinal scale (i.e. a ranking) provides no information regarding the difference between a rank of 1 and 2 or 9 and 10. The use of an interval scale meant that, with appropriate trade-off weights, a weighted summation of scores could be justified.

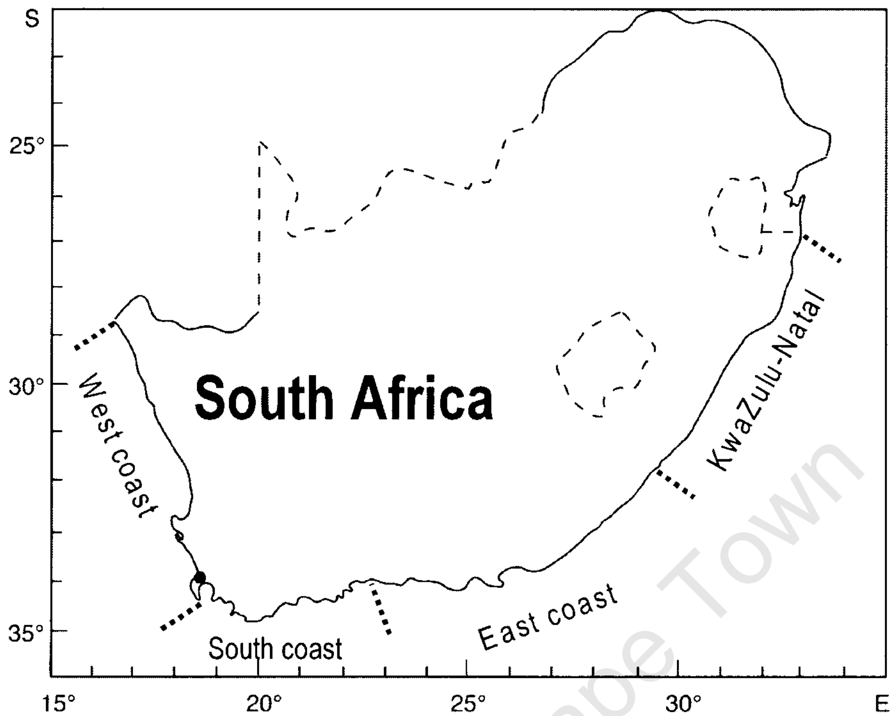


Figure 1.2 Map of South Africa showing the four coastal zones mentioned in the text.

The prioritization was done on a national and regional basis (west, south, east and KwaZulu-Natal coasts, Fig. 1.2). The zones were chosen for practicality but roughly conform to the cool temperate west coast, the warm temperate south and east coast (covering the areas designated south and east coast here) and the subtropical east coast respectively (Emanuel *et al.* 1992; Turpie *et al.* 1999).

1.2.1 Conservation criteria

The conservation criteria I used were abundance, level of knowledge, endemicity, and vulnerable life-history stages. Additional conservation criteria such as habitat availability, condition, and level of protection were considered potentially important but could not be included due to a lack of data.

Abundance was based on the percentage of pristine spawner biomass ($SB/Recruit_{f=0}$) or breeding stock remaining and /or ratios of present versus historical catch per unit effort and catch composition. Known values of $SB/R_{f=0}$ for species for which stock assessments had been completed were arranged on a "thermometer" scale from 0 to 100 (Fig. 1.3). These were used as a baseline against which species with unknown $SB/R_{f=0}$ values could be assessed with the help of ratios of present versus historical catch per unit effort and catch composition. On a broader scale each species fell within either underexploited, optimally exploited, overexploited, or collapsed ranges.

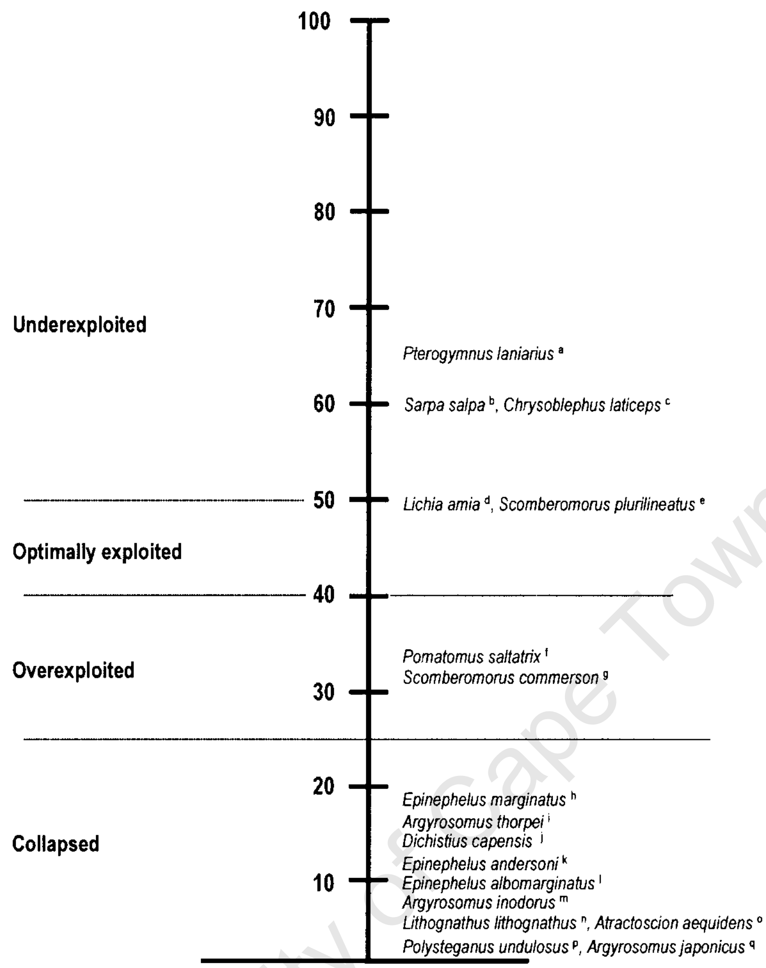


Figure 1.3 "Thermometer" or interval scale scores of known percentage pristine spawner biomass ($SB/R_{f=0}$) used as benchmarks for estimating the abundance scores of species for which data were limited. a. Booth and Buxton 1997, b, Van der Walt and Govender 1996, c. Buxton 1993, d. Van der Elst *et al.* 1993, e. Chale-Matsau 1996, f. Govender 1997, g. Govender 1995, h. Fennessy and Radebe, 2000a, i. Fennessy 1994, j. Bennett 1988, k. Fennessy and Radebe 2000b, l. Fennessy and Radebe 2000c, m. Griffiths 1997a, n. Bennett 1993, o. Griffiths 2000b, p. Govender and Radebe 2000, q. Griffiths 1997b.

I used the factors in van der Elst & Adkin (1991) and Mann (2000) as a template for scoring the level of knowledge for each species (Table 1.1). The number of known factors was summed and the percentage of known factors for each species then subtracted from 100 so that low knowledge achieved a higher score.

A species' range was used as a proxy for endemicity. If the fish occurred in only one of the four zones then it scored 100 for range (Table 1.2). If, for instance, it occurred in two of the zones or was cosmopolitan, it scored 60 and zero respectively. Most of the range data were gleaned from Smith and Heemstra (1986).

Table 1.1 Scoring method for level of knowledge illustrated with hottentot *Pachymetopon blochii,*, bigeye tuna *Thunnus obesus* and red stumpnose *Chrysoblephus gibbiceps.*

		Hottentot	Bigeye tuna	Red stumpnose
Habitat		1	1	1
Reproduction	Spawning	1		1
	Maturity	1		1
	Eggs/larvae	1		
Feeding		1		1
Growth	Age	1		
	Length/weight	1	1	1
	Morphometrics	1		
Population	Structure	1		1
	Migration		1	
Exploitation	Fishery	1	1	1
	Catch statistics	1		1
Stock assessment	Mortality	1		
	Yield/recruit	1		
Total		13	4	8
Percentage: (max=93%)		93	28	57
Score: 100-%		7	72	43
Rescaled score (0to 100):		**0**	**72.04**	**38.71**

A species' relative exploitation throughout its range was scored qualitatively by experts from the four different zones (Table 1.2). For example, if a species was heavily exploited throughout its range then it was given a score of 100. Medium and low exploitation scored 50 and zero respectively.

Eight vulnerable life-history traits were identified during the MLRG workshop as estuarine dependence, sex changes, spawning migrations, predictable aggregations, high age at maturity, longevity, residency, and high catchability. A species displaying four or more of these characteristics scored 100 and a species displaying only one would still score a relatively high 70 (Table 1.2). Other life-history characteristics such as fecundity were also considered, but were not included due to lack of data.

1.2.2 *Fishery sector criteria*

For each of the four sector criteria *i*, the criterion value for fish species *j* was converted to a score v_{ij} on a scale of 0 to 100 based on:

$$v_{ij} = \left\{100 \times \left(x_{ij} - x_i^{\min}\right) / \left(x_i^{\max} - x_i^{\min}\right)\right\}, \qquad (1)$$

where x_{ij} is the original criterion value for fish species *j* (e.g., catch in kilograms), x_i^{max} is the maximum value for criterion *i* (e.g., the maximum catch) and x_i^{min} is the minimum value for criterion *i* (e.g., the minimum catch). For example, the economic value ranged from $0 to $54 713 015 for the recreational

Table 1.2 Scoring guidelines for "range", "relative exploitation throughout range", and "vulnerable life history stages".

Range Levels	Score	Relative exploitation throughout range Levels	Score	Vulnerable life history stages Levels	Score
Species occurred in only 1 of 4 zones[1]	100	Very high exploitation throughout range	100	Species displays more than four of the eight characteristics	100
Species occurred in 2 of 4 zones	60	Medium to high exploitation throughout range	75	Species displays three of the eight characteristics	90
Species occurred in 3 of 4 zones	40	Medium exploitation throughout range	50	Species displays two of the eight characteristics	80
Species occurred in 4 of 4 zones, i.e. throughout SA	20	Medium to low exploitation throughout range	25	Species displays one of the eight characteristics	70
Species was limited to southern Africa	10	Low exploitation throughout range	0	Species displays none of the eight characteristics	0
Species was cosmopolitan	0				

1. The zones are west coast, south coast, east coast, Kwazulu-Natal.

shore sector, giving scores of 0 and 100 respectively, whereas a contribution of $110 636 885 would be scored 20. Thus, the data were simply converted linearly into a score, implying that economic value in dollars has a linear relationship to its importance. In many instances linearity is an incorrect assumption, particularly for economic criteria where, for example one dollar more when one is poor is worth much more than one dollar more when one is well off. However, for this initial exercise, I believed the linear assumption was adequate.

1.2.2.1 Present catch

For the commercial boat fishery, mean annual catches between 1992 and 1996 that were reported on the National Marine Linefish System (NMLS) were used. (The NMLS is a national database run by the Department of Marine and Coastal Management, South Africa). Mean annual recreational boat catches were estimated from the NMLS and from catches and effort monitored during the National Linefish Survey (NLS) of 1994-1996, which evaluated participation in, and management of the South African linefishery (Brouwer *et al.* 1997; Sauer *et al.* 1997).

Recreational shore-angling catches were estimated from catch and effort data collected from on-site angler interviews and catch inspections during the NLS (Brouwer 1996; Sauer & Erasmus 1996, Lamberth 1996; Mann *et al.* 1996). Recreational spearfishing data were collected during the NLS and augmented by additional, site-specific data from Mann *et al.* (1997) and Lechanteur (2000).

Commercial beach-seine and gill-net catches for the west, south and east coasts were estimated according to catch reports on the Marine and Coastal Management Netfish System (NS), and corrected using validated catches from Lamberth *et al.* (1997) and Hutchings & Lamberth (1999). KwaZulu-Natal catches were based on data in Beckley & Fennessy (1996), Mann (1995 & 1996) and Kyle (1996).

1.2.2.2 Targeting

For commercial boat and net fishing, targeting was taken as the number of boat or net days a particular species was reported over a 5-year period (1992-1996). Netfish targeting in KwaZulu-Natal was based on data in Beckley and Fennessy (1996), Mann (1995 & 1996), and Kyle (1996).

Recreational, shore, boat and spear fishing targeting were obtained from approximately 4,000 onsite interviews during the NLS. Each interviewee was asked to name, in order of preference, their three most targeted species.

1.2.2.3 Number of people involved

The number of people involved in catching a particular species was used as a measure of fishers' dependence on a species. For the commercial boat fishery, the number of people involved was taken as the sum of the mean number of crew carried by the boats that had reported catching a particular species to the NMLS over a 5-year period (each boat's crew was counted only once). The number of people involved for the beach-seine and gill-net fisheries was estimated as the sum of the number of permit holders that reported catching a particular species to the netfish system, multiplied by the mean crew number of the nets used (Lamberth *et al.* 1997).

The number of people involved in recreational shore, boat and spearfishing was taken as the number of people who actually caught a particular species at the time of the interview during the NLS. This is an underestimate, because those who had not caught a fish on the day of interview were not counted as being involved. However, the relative importance of each species should remain the same given the large interviewee sample size (n=7 952).

1.2.2.4 Economic value

The economic value of each sector was obtained from data collected during the NLS and analyzed by McGrath *et al.* (1997). Fish prices were obtained, by telephone interview, from dealers countrywide. The mean price per kg (whole weight) of each species was multiplied by the total mass caught of that species and then summed to produce a total landed catch value for each sector. The proportion each species contributed to this landed value was then multiplied by the total economic value of that sector (including subsidiary industries) as determined by McGrath *et al.* (1997).

1.2.3 Aggregation of scores and derivation of weights

I aggregated the individual criterion scores using a weighted summation and following the structure of the value tree (Fig. 1.1), such that:

$$V_j = \sum_{i=1}^{n} w_i v_{ij}, \qquad (2)$$

where V_j is the overall score for fish j, w_i is the weight of criterion i, and v_{ij} is the score of fish j for criterion i (in some cases obtained from equation 1). Importance could thus be assessed at any level of the value tree, for example, from the point of view of conservation alone, each fishery sector seperately, or the aggregated sectors. At each aggregation level scores were rescaled again so that the lowest score was zero and the highest score was 100.

Appropriate weights needed to be determined for each of the levels of the value tree (levels 2 to 4 on Fig. 1.1). The use of a weighted summation implies there are tradeoffs between criteria. To appropriately capture this, the scaling constants or swing weights need to, in effect, stretch or shrink the 0-100 scales.

For example, strepie *Sarpa salpa*, had the following scores for the criteria within recreational shore fishing: 89.4 (catch), 18.5 (targeting), 73.2 (people), 20.2 (economics) from applying equation 1 to the data. With "equal" weights this gives a total score of 50.3. However, using one of the weights sets described below (WT3, Table 1.3), the total score, V_j, becomes $V_j = 0.272 \times 89.4 + 0.199 \times 18.5 + 0.181 \times 73.2 + 0.295 \times 20.2 = 49.9$ (from equation 2).

In all, nine weight sets (WT1 to WT9) were used to assess overall ranks and sensitivity (Table 1.3). In combination WT1 to WT7 had the same weights for level 2 and 3, but different weights at level 4. The WT8 and WT9 were the same as WT3 except that the level 2 weights (conservation relative to the combined fishery sectors) were varied. The level 3 weights (between sectors) were the same throughout. The WT3 was regarded as the set of weights that best represented the reality of the data, the swing-weighting concept and the values of the people involved. Figure 1.4 shows the overall contribution of the weights in WT3 and WT5 as examples. The differences between the weights sets are reasonably small, although, for example, the ratio of the "abundance" weight to the "recreational shore catch" weight changes from 1.5 to 2.4 in these two weight sets.

Table 1.3 The nine different weight systems applied in the aggregation of scores[1].

	Level 4[2]							Level 3[3]		Level 2[4]			
Criterion	WT1	WT2	WT3	WT4	WT5	WT6	WT7	Criterion Group	WTs 1-9	Criterion Group	WTs 1-7	WT8 with WT3	WT9 with WT3
Abundance	20	20	27.5	27.5	39.4	39.4	27.5						
Vulnerability	20	20	19.1	19.1	19.9	19.9	19.1						
Range	20	20	14.3	14.3	16.8	16.8	14.3			Conservation	50	40	60
Exploitation	20	20	21.5	21.5	17.5	17.5	21.5						
Knowledge	20	20	17.6	17.6	6.4	6.4	17.6						
Catch	25	28.7	28.7	25	25	28.7	41.8						
Targeting	25	21.0	21.0	25	25	21.0	30.5	Recreational Shore	64.3				
People involved	25	19.1	19.1	25	25	19.1	27.8						
Economics	25	31.2	31.2	25	25	31.2							
Catch	25	17.4	17.4	25	25	17.4	32.8						
Targeting	25	14.2	14.2	25	25	14.2	26.8	Recreational Boat	11.7				
People involved	25	21.4	21.4	25	25	21.4	40.3						
Economics	25	47.0	47.0	25	25	47.0	0.0						
Catch	25	27.1	27.1	25	25	27.1	42.4						
Targeting	25	18.4	18.4	25	25	18.4	28.9	Recreational Spear	1.69	Sectors	50	60	40
People involved	25	18.3	18.3	25	25	18.3	28.7						
Economics	25	36.1	36.1	25	25	36.1	0.0						
Catch	25	42.3	42.3	25	25	42.3	42.3						
Targeting	25	18.5	18.5	25	25	18.5	18.5	Commercial Boat	18.6				
People involved	25	7.4	7.4	25	25	7.4	7.4						
Economics	25	31.7	31.7	25	25	31.7	31.7						
Catch	25	33.0	33.0	25	25	33.0	33.0						
Targeting	25	32.5	32.5	25	25	32.5	32.5	Commercial Net	3.68				
People involved	25	9.0	9.0	25	25	9.0	9.0						
Economics	25	25.6	25.6	25	25	25.6	25.6						

1. Levels refer to the levels of the value tree in Fig. 1.2.
2. Different ways of deriving weights in level 4 were combined to form WT1 to WT7.
3. Level 3 weights were held constant for all weights sets (WT1 to WT9)
4. Level 2 weights were held constant for WT1 to WT7. WT8 and WT9 used WT3 for level 4 and 3 weights, but changed level 2 weights.

1.2.3.1 Within fishery sector weights

The manipulation of the data to obtain scores for the four fishery sector criteria should be kept in mind when considering weights and implied trade-offs: the data were converted to percentages and then normalized to scores on a 0 to 100 scale through equation 1.

For the within-sector weights, three approaches, based on suggestions made at the MLRG workshop, were used to estimate weights. First, each criterion could be considered "equally" important in determining overall priority. This implies that the range of importance from lowest scoring fish to highest scoring fish for each of the four criteria is the same. For example, from Table 1.4, the swing from a species with a catch of 0 (minimum caught) to a species with a catch of 1 438 112 (maximum caught) is the same importance as the range from a fish with 0 people involved to a fish with 56 360 (maximum) people involved. These "equal" weights were used in WT1, WT4, and WT5 (Tables 1.3 and 1.4).

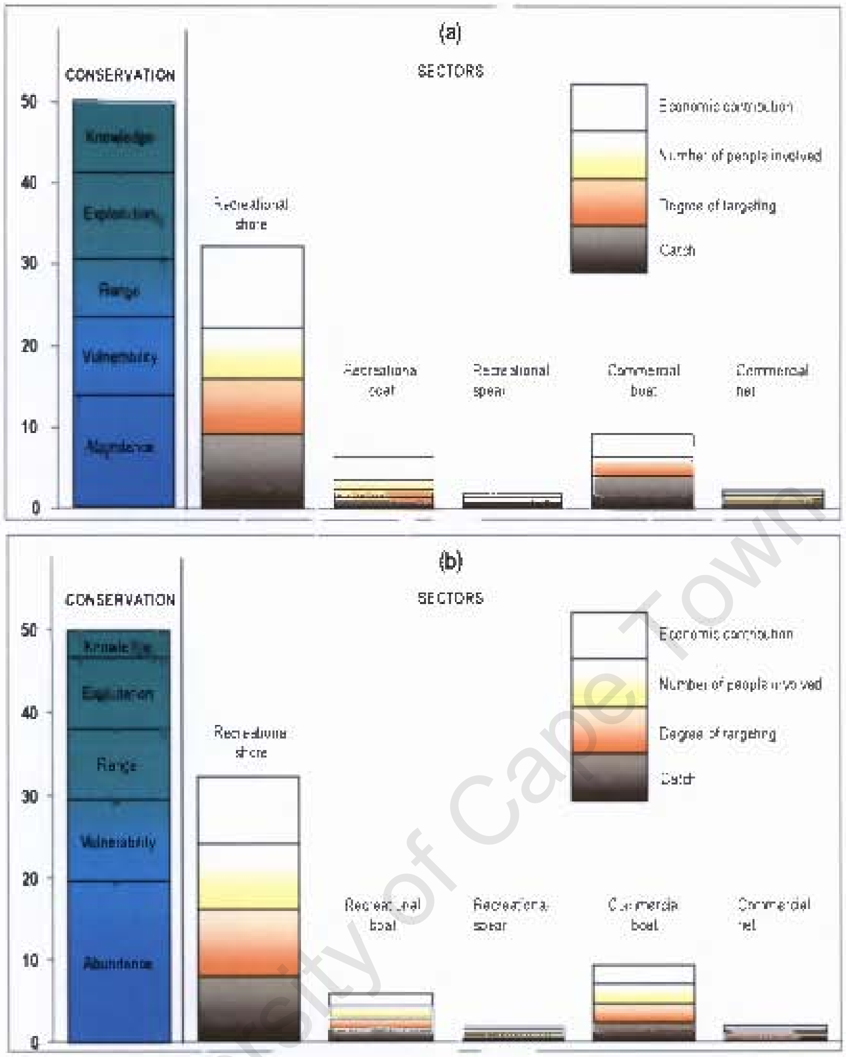


Figure 1.4 Examples of the contribution of weights in (a) weight set 3 (WT3) and (b) weight set 5 (WT5)

However, this is unlikely to be a realistic reflection of the importance of these criteria, and the second approach therefore attempted to take this into account. The raw data were converted into percentages, and in each case, the distributions were dominated by a few species (e.g. Fig. 1.5). The extent to which a criterion was dominated by a particular fish (i.e., the maximum percentage) could be considered indicative of that criterion's relative importance in determining the overall priority of fish. The maximum percentage of each criterion was therefore converted to a weight by normalizing them to sum to 1 within a sector for WT2, WT3, WT6, WT8, and WT9 (Tables 1.3 and 1.4). For example, from Table 1.4, the weight for catch would be 27.18/(27.18+9.85+18.06+29.54) = 28.7. Third, because of the close relation between total catch and economic value in the recreational sector, economic value was given a zero weight in WT7, and weights redistributed between the remaining criteria (Tables 1.3 and 1.4).

Table 1.4 The derivation of within sector weights for the recreational shore sector

	Catch	%	Score	Targeting%	Score	People	%	Score	Economics	%	Score
Maximum	1 438 112	27.18	100	19.85	100	56 360	18.06	100	$67 149 012	29.54	100
Minimum	0	0	0	0	0	0	0	0	0	0	0
WT1,4,5-"equal" weights		25		25			25			25	
WT2,3,6,8,9-weight from max%		28.7		21.0			19.1			31.2	
WT7- without economics		41.8		30.5			27.8			0	

1.2.3.2 Between fishery sector weights

The interest groups at the MLRG workshop made two suggestioins regarding the relative importance of the fishery sectors (level 3, Fig. 1.1). One was that the total number of people involved in a sector indicated its relative importance, and the other was that the relative economic value of each sector indicated its importance (Table 1.5). Because these two indicators showed broadly similar ratios, it was felt to be appropriate to take the average of the ratios of number of people and economic value and convert these to weights by normalizing to sum to 1 (Table 1.5). This was applied for all weights sets, WT1 to WT9.

1.2.3.3 Conservation criteria weights

Three weights sets were used for the within-conservation criteria. "Equal" weights were used for WT1 and WT2. To obtain swing weights, the perceived importance of the different conservation criteria (level 4, Fig. 1.1) was assessed using a questionnaire completed by attendees at the Third Southern African Marine Linefish Symposium, 1999. The questionnaire used two questioning approaches, and was structured in a way that, it was hoped, would encourage people to think of the swing weight meaning of weights.

The average weights from respondents were derived for each of the two different approaches. The two questioning approaches resulted in slightly different weights (a not unexpected result), and so the results were kept separate and both sets of weights were used. The weights from the first approach were used in WT3, WT4, and WT7 and the weights from the second approach were used in WT5 and WT6. The main difference between the resulting weights was that "abundance" was given a far higher relative weight, and "knowledge" a far lower weight in the second approach (Table 1.3, Fig. 1.4).

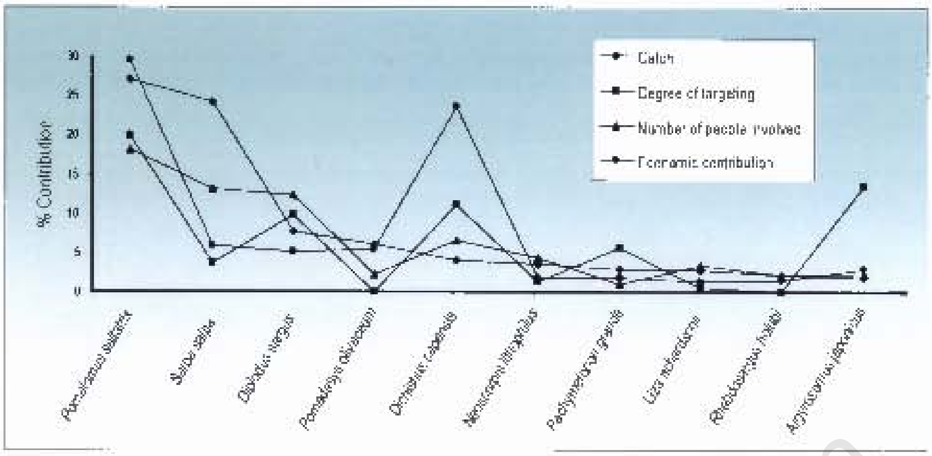


Figure 1.5 Percentage contribution of the ten highest scoring fish in the recreational shore sector, showing the domination by two or three species for each criterion.

1.2.3.4 Weights between conservation and the combined sectors

Because there was no opportunity to further examine with the interest groups the weight to be given to conservation relative to the combined sectors (level 2, Fig. 1.1), these two criteria groups were simply given "equal" weights (i.e. 50:50) for WT 1-7. This implies that a score of 100 for conservation has the same effect on priority as a score of 100 for the combined sectors. For sensitivity analyses these weights were changed to (40:60) and (60:40) for WT8 and WT9 respectively, otherwise WT8 and WT9 used the same weights as in WT3.

1.2.3.5 Heuristics

In addition to the weighted aggregation procedure a heuristic decision rule was applied for comparison using the rankings produced by the five sectors and the conservation criteria group separately (level 3, Fig. 1.1). All fish that appeared at least twice in the top 10 or top 20 ranked fish for these six criteria (using WT3) were listed as potential priority species. Heuristic decision rules can be useful, because they are easily understandable and it is immediately obvious why any particular fish is included. However, they can be simplistic, because they do not take into account the relative effects of criteria.

1.3 Results

The results of aggregation were reasonably insensitive to the different weight sets tested. The fish that ranked in the top 15 were generally common with all different weights sets, and with a few exceptions the top 30 were the same (Table 1.6). Strepie *Sarpa salpa* and geelbek *Atractoscion aequidens* showed the highest range of resulting ranks (Fig. 1.6).

Table 1.5 Derivation of between-sector weights from the number of people involved and the economic value.

	Recreational Shore	Recreational Boat	Recreational Spear	Commercial Boat	Commercial Net
	Number of people involved				
Total	312 030	107 349	6 682	126 124	38 624
Weight	0.528	0.182	0.011	0.213	0.065
	Economic value (Rands)				
Total	$227 316 541	$15 709 380	$6 713 700	$47 373 588	$2 462 740
Weight	0.759	0.052	0.022	0.158	0.008
Average weight	0.643	0.117	0.017	0.186	0.037

The relative scores within the five fishery sectors were dominated by two or three species. For example, the recreational shore fishery is dominated by elf *Pomatomus saltatrix* and to a lesser extent strepie and galjoen *Dichistius capensis* (Fig. 1.5). The scores separating the remaining fish from each other are therefore small. This meant that in many cases, even where the rank of a fish changed by a number of places with a different weight set, the differences in score were slight (Fig. 1.6). The highly skewed distributions of the scores within sectors (Fig. 1.7), might have been reduced through the use of a nonlinear relationship between the data (e.g., economic value in dollars) and the resulting score. However, there is no *a priori* reason why the distributions should not be skewed, and the nature of any nonlinear relationship would be based on considerations other than reducing this skew, (e.g. by asking wether there are reasons why increasing economic value from $14 000 a year to $15 000 a year would be worth more (or less) than increasing from R36 000 to R37 000 a year).

Of further interest is a comparison of the priority list obtained by using the average of the ranks from the nine different weight sets (Fig. 1.6, Table 1.6), the priority lists for conservation and the five sectors separately, and the list obtained from the heuristic decision rule (Table 1.7). Of note are red roman *Chrysoblephus laticeps* and yellowtail *Seriola lalandii*, which occur in the top 20, three and four times respectively but are not in the combined top 30. Yellowtail was ranked 33, which is still a high rank, but red roman only ranked 54 overall. This is because of its low rank for conservation (ranked 88 with WT3) which stems from its relatively low scores for abundance (21 because it is estimated to be at around 60% percent spawner biomass), range (40 as it is relatively widespread, occurring in three of the four zones), and knowledge (0 as it had the highest relative level of knowledge).

Thirteen of the 18 species selected in a previous crude prioritization exercise (Penney *et al.* 1997) appeared in the top 30 list (Table 1.7). The five fish not included in the list were red roman, yellowtail, leervis/garrick *Lichia amia*, white musselcracker *Sparodon durbanensis* and smooth houndshark *Mustelus mustelus* (Penney *et al.* 1997).

Table 1.6 The top 30 ranked fish (average ranks) showing their ranks (R) and scores (S) from the 9 weights sets[1].

	WT1		**WT2**		**WT3**		**WT4**		**WT5**		**WT6**		**WT7**		**WT8**		**WT9**	
	R	**S**	**R**	**S**	**R**	**S**	**R**	**S**	**R**	**S**	**R**	**S**	**R**	**S**	**R**	**S**	**R**	**S**
Pomatomus saltatrix	1	76	1	76	1	79	1	79	1	80	1	80	1	79	1	83	1	74
Dichistius capensis	2	57	2	59	2	61	2	60	2	63	2	65	5	53	2	59	2	64
Diplodus sargus	5	51	7	49	5	51	4	53	5	52	5	50	2	55	4	48	10	54
Argyrosomus japonicus	8	49	8	48	4	51	5	52	3	57	3	55	3	55	6	46	7	57
Chrysoblephus puniceus	4	51	5	50	8	50	6	52	4	53	4	52	7	53	9	41	4	59
Argyrosomus spp.	3	52	6	49	6	51	3	54	6	51	10	48	6	53	7	43	5	59
Epinephelus albomarginatus	7	50	4	50	7	50	8	50	7	50	6	50	9	50	10	40	3	60
Thyrsites atun	6	50	3	51	3	51	7	51	11	48	9	48	8	51	3	50	14	52
Polysteganus praeorbitalis	9	48	10	47	9	49	9	49	12	47	12	47	10	49	12	39	6	58
Lithognathus lithognathus	12	47	12	46	10	48	10	49	9	49	8	48	12	48	8	41	9	55
Epinephelus andersoni	11	47	11	46	11	47	11	48	13	47	13	46	13	48	13	38	8	56
Argyrosomus inodorus	14	44	14	43	13	46	13	47	8	50	7	49	11	48	11	39	13	53
Sarpa salpa	10	47	9	48	12	47	12	47	17	45	15	45	4	54	5	48	26	47
Chrysoblephus cristiceps	16	43	15	42	15	44	14	45	10	48	11	47	15	45	16	36	12	53
Chrysoblephus lophus	13	46	13	46	14	45	15	45	15	46	14	45	14	45	15	36	11	54
Polysteganus undulosus	20	41	19	40	16	43	16	44	16	45	16	45	16	44	19	35	15	52
Pachymetopon grande	22	40	21	40	19	42	20	42	18	45	17	45	17	44	14	36	22	48
Chrysoblephus gibbiceps	17	42	17	41	18	42	18	43	22	44	21	43	21	43	21	34	16	50
Rhabdosargus globiceps	19	41	22	40	17	42	17	43	23	44	22	43	18	43	17	36	19	49
Argyrosomus thorpei	18	42	16	41	21	41	23	42	20	45	18	44	23	42	24	33	17	49
Pachymetopon blochii	15	43	18	41	22	41	19	43	21	45	23	43	19	43	18	35	27	47
Petrus rupestris	23	40	25	38	20	41	22	42	19	45	20	44	22	42	23	33	18	49
Chrysoblephus anglicus	21	40	20	40	23	41	24	41	25	42	25	42	25	41	26	33	20	49
Atractoscion aequidens	32	38	41	35	25	40	21	42	14	46	19	44	20	43	22	34	29	46
Cymatoceps nasutus	28	38	27	37	26	40	26	40	24	43	24	42	28	40	30	32	23	47
Epinephelus marginatus	31	38	28	37	24	40	25	41	28	39	27	38	26	40	27	32	21	48
Diplodus cervinus	24	39	23	39	27	40	29	40	30	38	30	38	31	40	28	32	24	47
Liza richardsonii	25	39	24	39	28	40	30	40	35	36	33	36	27	40	20	34	33	45
Argyrops spinifer	38	36	33	36	30	39	31	39	29	38	28	38	32	39	34	31	25	47
Serranidae spp.	29	38	29	37	29	39	28	40	36	36	38	35	30	40	33	32	28	47

1. See Table 1.3 and text for a description of the weights.

The latter three, important for three of the fishery sectors are of low importance according to the conservation criteria (ranking 106, 34 and 110 respectively with WT3).

On the whole, the top 30 fish on the combined sectors list or the combined conservation and sectors list were representative of the most important species in terms of catch for all sectors. This is despite the fact that recreational fishing, particularly the shore sector, dominated the sector weights (Fig. 1.4). With the exception of snoek *Thyrsites atun* and strepie *Sarpa salpa*, the stocks of all fish on the overall list were either overexploited or collapsed (Mann 2000). This supports the fact that the conservation criteria I used were appropriate and the obvious conclusion that the most sought-after species are also those in the most perilous state.

The data were also analysed for the four coastal zones separately based only on the fishery data and ignoring conservation importance (Table 1.8). Between 33% (west coast) and 50% (east coast) of each zone's 30 highest scoring fish were included in the 30 highest ranked fish from the combined data (Tables 1.6 and 1.7).

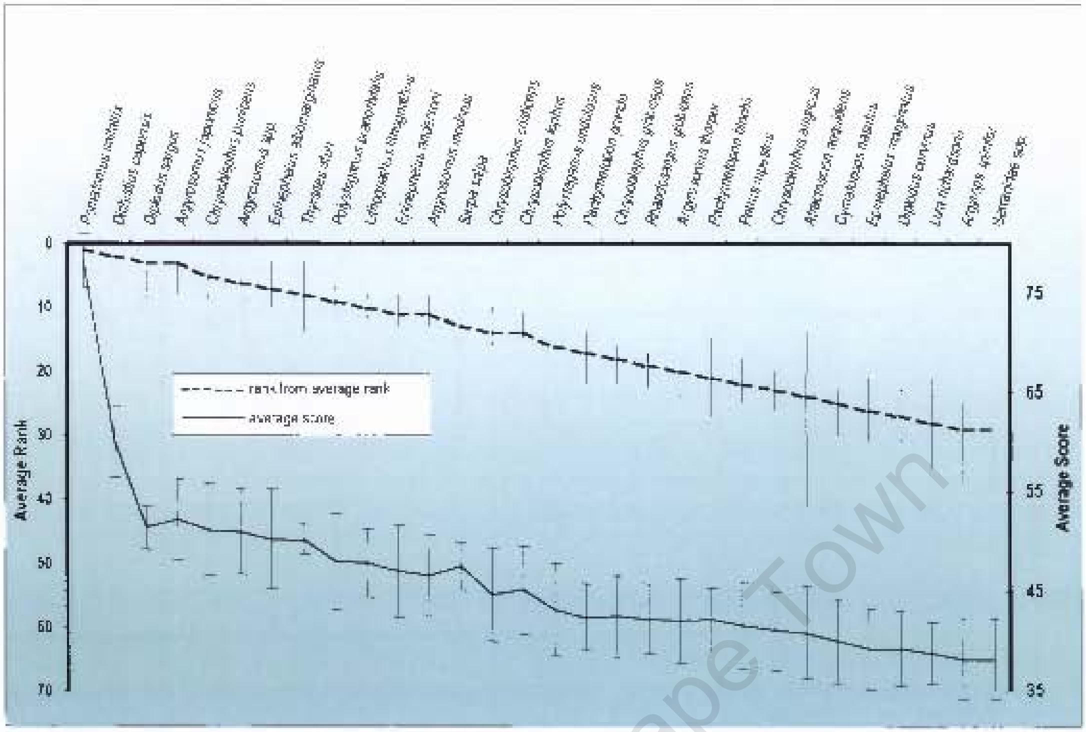


Figure 1.6 Average ranks and average scores of the 30 highest scoring fish based on average scores from 9 different weight sets in Table 1.3. On the line showing average ranks, the "error bars" indicate the minimum and maximum ranks obtained, while the error bars on the line showing scores gives the standard deviation of the scores. Average ranks were the ranked average of all nine rank orders obtained.

Dassie/blacktail *Diplodus sargus*, kob *Argyrosomus* spp., and elf *Pomatomus saltatrix* were in the top 30 from the combined data as well as in the top 30 for all four zones, while more occur in the combined top 30 and at least three of the zones. Others, although important in only one zone (e.g. catface rockcod *Epinephelus andersoni* in Kwazulu Natal), were also important overall due to their high conservation importance.

Yellowtail, red roman, yellowfin tuna *Thunnus albacares*, piggy *Pomadasys olivaceum*, and mackerel *Scomber japonicus* occurred in the top 30 of three of the four zones, but not in the top 30 for the combined data. They had a low priority from the point of view of conservation because they generally occurred in all zones, and had reasonable abundance levels.

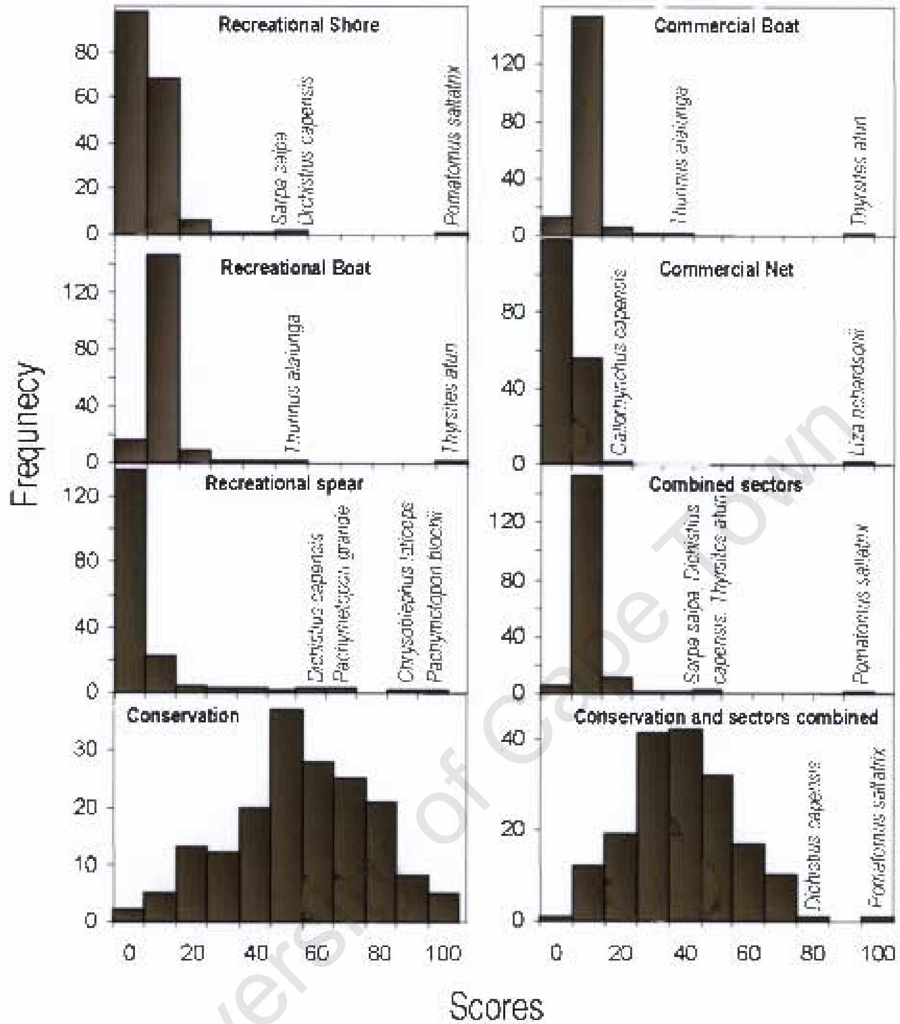


Figure 1.7 Frequency of occurrence of scores within each of the criteria groups at level 3, showing the domination of the sector scores by one or two species.

1.4 Discussion

Besides providing a coherent framework within which to work, MCDA also provides a consistent and theoretically justifiable means of scoring alternatives (fish in this instance) on the basis of a number of criteria. The basic assumptions of using the weighted summation in equation (2) are that 1) criteria are preferentially independent (i.e. preference can be indicated with respect to one criterion without reference to performance levels on other criteria - statistical independence is not important), 2) scores are on an interval rather than ordinal scale, and 3) the weights are so-called swing weights.

Table 1.7 Top 30 fish for conservation and sectors using WT3.

Conservation	Rank	Recreational shore	Rank	Recreational boat	Rank	Recreational spear	Rank
Epinephelus albomarginatus[1]	1	*Pomatomus saltatrix*[1]	1	*Thyrsites atun*[1]	1	*Pachymetopon blochii*[1]	1
Polysteganus praeorbitalis[1]	2	*Sarpa salpa*[1]	2	*Thunnus alalunga*[3]	2	*Chrysoblephus laticeps*[3]	2
Chrysoblephus puniceus[1]	3	*Dichistius capensis*[1]	3	King mackerel[3]	3	*Dichistius capensis*[1]	3
Epinephelus andersoni[1]	4	*Diplodus sargus*[1]	4	*Chrysoblephus laticeps*[3]	4	*Pachymetopon grande*[1]	4
Argyrosomus spp. [1]	5	*Argyrosomus japonicus*[1]	5	*Seriola lalandii*[3]	5	*Sparodon durbanensis*[3]	5
Chrysoblephus lophus[1]	6	*Pomadasys olivaceum*[3]	6	*Atractoscion aequidens*[1]	6	*Lichia amia*[3]	6
Chrysoblephus cristiceps[1]	7	*Pomadasys commersonni*[3]	7	*Chrysoblephus puniceus*[1]	7	*Umbrina* spp	7
Polysteganus undulosus[1]	8	*Lithognathus lithognathus*[1]	8	*Thunnus* spp. [3]	8	*Umbrina ronchus*	8
Chrysoblephus gibbiceps[1]	9	*Pachymetopon grande*[1]	9	*Pachymetopon blochii*[1]	9	*Scomberomorus plurilineatus*[3]	9
Lithognathus lithognathus[1]	10	*Neoscorpis lithophilus*	10	*Thunnus albacares*	10	*Gymnocrotaphus curvidens*	10
Argyrosomus thorpei[1]	11	*Argyrosomus inodorus*[1]	11	*Merluccius capensis*[3]	11	*Oplegnathus conwayi*	11
Chrysoblephus anglicus[1]	12	*Rhabdosargus sarba*	12	*Argyrosomus* spp. [1]	12	*Seriola lalandii*[3]	12
Petrus rupestris[1]	13	*Liza richardsonii*[1]	13	*Argyrosomus inodorus*[1]	13	*Scomberomorus commerson*[3]	13
Argyrosomus japonicus[1]	14	*Rhabdosargus globiceps*[1]	14	*Argyrozona argyrozona*[3]	14	Serranidae spp. [1]	14
Argyrosomus inodorus[1]	15	*Rhabdosargus holubi*	15	*Scomberomorus plurilineatus*[3]	15	*Diplodus cervinus*[1]	15
Epinephelus marginatus[1]	16	*Sparodon durbanensis*[3]	16	*Cheimerius nufar*[3]	16	*Argyrosomus japonicus*[1]	16
Argyrops spinifer[1]	17	*Lichia amia*[3]	17	*Pterogymnus laniarius*[3]	17	*Argyrosomus* spp. [1]	16
Cymatoceps nasutus[1]	18	*Liza tricuspidens*[3]	18	*Epinephelus andersoni*[1]	18	*Cymatoceps nasutus*[1]	18
Epinephelus tukula	19	*Pachymetopon blochii*[1]	19	*Argyrosomus japonicus*[1]	19	*Pachymetopon aeneum*	19
Diplodus cervinus[1]	20	*Rhinobatos annulatus*	20	*Petrus rupestris*[1]	20	*Chirodactylus brachydactlus*	20
Serranidae spp.	21	*Diplodus cervinus*[1]	21	*Argyrosomus thorpei*[1]	21	*Rhabdosargus sarba*	21
Rhabdosargus globiceps[1]	22	*Coracinus multifasciatus*	22	*Lichia amia*[3]	22	*Pomadasys commersonni*[3]	22
Promicrops lanceolatus	23	*Trachinotus botla*	23	*Rhabdosargus globiceps*[1]	23	*Pomadasys* spp.	23
Epinephelus malabricus	24	*Carcharhinus brachyurus*	24	*Corphaena hippurus*	24	*Chirodactylus grandis*	24
Dichistius capensis[1]	25	*Lithognathus mormyrus*	25	*Chrysoblephus cristiceps*[1]	25	*Chrysoblephus gibbiceps*[1]	24
Porcostoma dentate	26	*Galeichthyes feliceps*	26	*Euthynnus affinis*	26	*Plectorhinchus flavomaculatus*	26
Umbrina spp.	27	*Umbrina* spp.	27	*Scomber japonicus*[3]	27	*Diplodus sargus*[1]	27
Cephalopholis sonnerati	28	*Mustelus mustelus*	28	*Chrysoblephus gibbiceps*[1]	28	*Parascorpis typus*	28
Atractoscion aequidens[1]	29	*Carcharhinus obscurus*	29	Serranidae spp. [1]	29	*Petrus rupestris*[1]	29
Lutjanus sanguineus	30	*Galeichthyes ater*	30	*Pomatomus saltatrix*[1]	30	*Oplegnathus robinsoni*	30

Commercial boat	Rank	Commercial net	Rank	Sectors combined	Rank	Overall average rank*	Rank
Thyrsites atun[1]	1	*Liza richardsonii*[1]	1	*Pomatomus saltatrix*	1	*Pomatomus saltatrix*[2]	1
Thunnus alalunga[3]	2	*Callorhynchus capensis*	2	*Sarpa salpa*	2	*Dichistius capensis*[2]	2
Argyrosomus spp. [1]	3	*Seriola lalandii*[3]	3	*Dichistius capensis*	3	*Diplodus sargus*[2]	3
Seriola lalandii[3]	4	*Pomatomus saltatrix*[1]	4	*Thyrsites atun*	4	*Argyrosomus japonicus*[2]	4
Merluccius capensis[3]	5	*Argyrosomus* spp. [1]	5	*Diplodus sargus*	5	*Chrysoblephus puniceus*	5
Argyrozona argyrozona[3]	6	*Lithognathus lithognathus*[1]	6	*Argyrosomus japonicus*	6	*Argyrosomus* spp.	6
Atractoscion aequidens[1]	7	*Dichistius capensis*[1]	7	*Thunnus alalunga*	7	*Epinephelus albomarginatus*	7
Pachymetopon blochii[1]	8	*Argyrosomus japonicus*[1]	8	*Pomadasys olivaceum*	8	*Thyrsites atun*[2]	8
Chrysoblephus laticeps[3]	9	*Pomadasys commersonni*[3]	9	*Pomadasys commersonni*	9	*Polysteganus praeorbitalis*	9
Thunnus spp. [3]	10	*Argyrosomus inodorus*[1]	10	*Lithognathus lithognathus*	10	*Lithognathus lithognathus*[2]	10
Chrysoblephus puniceus[1]	11	*Sarpa salpa*[1]	11	*Liza richardsonii*	11	*Epinephelus andersoni*	11
Cheimerius nufar[3]	12	*Trachurus trachurus*	12	*Pachymetopon grande*	12	*Argyrosomus inodorus*[2]	12
Pterogymnus laniarius[3]	13	*Diplodus sargus*[1]	13	*Argyrosomus inodorus*	13	*Sarpa salpa*[2]	13
Rhabdosargus globiceps[1]	14	*Mugil cephalus*	14	*Pachymetopon blochii*	14	*Chrysoblephus cristiceps*	14
Serranidae spp. [1]	15	*Liza tricuspidens*[3]	15	*Chrysoblephus laticeps*	15	*Chrysoblephus lophus*	15
Petrus rupestris[1]	16	*Scomber japonicus*[3]	16	*Seriola lalandii*	16	*Polysteganus undulosus*[2]	16
Scomber japonicus[3]	17	*Pomadasys olivaceum*[3]	17	*Argyrosomus* spp.	17	*Pachymetopon grande*	17
Pomatomus saltatrix[1]	18	*Scomberomorus plurilineatus*[3]	18	*Neoscorpis lithophilus*	18	*Chrysoblephus gibbiceps*	18
Galeorhinus galeus	19	*Otolithes ruber*	19	*Rhabosargus globiceps*	19	*Rhabdosargus globiceps*[2]	19
Chrysoblephus gibbiceps[1]	20	*Decapterus russelli*	20	*Rhabosargus sarba*	20	*Argyrosomus thorpei*	20
Thunnus albacares	21	*Sphyraena jello*	21	*Merluccius capensis*	21	*Pachymetopon blochii*	21
Chrysoblephus anglicus[1]	22	*Scomberoides lysan*	22	*Atractoscion aequidens*	22	*Petrus rupestris*[2]	22
Argyrosomus inodorus[1]	23	*Rhabdosargus sarba*	23	*Argyrozona argyrozona*	23	*Chrysoblephus anglicus*	23
Chrysoblephus cristiceps[1]	24	*Trichiurus lepturus*	24	*Scomberomorus commerson*	24	*Atractoscion aequidens*[2]	24
Argyrosomus thorpei[1]	25	*Trachinotus africanus*	24	*Lichia amia*	25	*Cymatoceps nasutus*[2]	25
Spondyliosoma emarginatum	26	*Sillago sihama*	26	*Sparodon durbanensis*	26	*Epinephelus marginatus*	26
Argyrosomus japonicus[1]	27	*Mustelus mustelus*	27	*Thunnus* spp.	27	*Diplodus cervinus*	27
Cymatoceps nasutus[1]	28	*Rhabdosargus globiceps*[1]	28	*Rhabdosargus holubi*	28	*Liza richardsonii*	28
Pachymetopon aeneum	29	*Umbrina* spp.	29	*Chrysoblephus puniceus*	29	*Argyrops spinifer*	29
Polysteganus coeruleopunctatus	30	*Merluccius capensis*[3]	30	*Cheimerius nufar*	30	Serranidae spp.	30

*. From the average rank of all nine weight sets in Table 1.3 (repeats the first column of Table 1.6).

1. Included in the overall top 30 ranked fish.

2. Included in the prioritized list in Penney *et al.* (1997).

3. Occur at least twice in the top 20 of conservation and the sectors separately but are not included in the overall top 30.

Table 1.8 The ranks and scores of the top 30 fish for the four zones using weights derived in the same way as WT3.

Rank	KwaZuluNatal	Score	East coast	Score	South coast	Score	West coast	Score
1	*Pomatomus saltatrix*[1]	100	*Pomatomus saltatrix*[1]	100	*Pomatomus saltatrix*[1]	100	*Thyrsites atun*[1]	100
2	*Sarpa salpa*[1]	78	*Merluccius capensis*	96	*Dichistius capensis*[1]	95	*Pachymetopon blochii*[1]	66
3	*Diplodus sargus*[1]	42	*Argyrosomus japonicus*[1]	69	*Seriola lalandii*	54	*Thunnus alalunga*	36
4	*Pomadasys commersonni*	25	*Argyrosomus* spp. [1]	66	*Atractoscion aequidens*[1]	52	*Dichistius capensis*[1]	26
5	*Argyrosomus japonicus*[1]	21	*Chrysoblephus laticeps*	64	*Argyrosomus inodorus*[1]	50	*Rhabdosargus globiceps*[1]	18
6	*Rhabdosargus sarba*	18	*Sarpa salpa*[1]	58	*Lithognathus lithognathus*[1]	32	*Liza richardsonii*[1]	14
7	*Neoscorpis lithophilus*	15	*Diplodus sargus*[1]	42	*Thyrsites atun*[1]	26	*Thunnus* spp.	11
8	*Chrysoblephus puniceus*[1]	14	*Pomadasys olivaceum*	40	*Argyrosomus* spp. [1]	17	*Seriola lalandii*	5
9	*Pomadasys olivaceum*	9	*Argyrozona argyrozona*	37	*Argyrozona argyrozona*	16	*Spondyliosoma emarginatum*	3
10	*Thunnus albacares*	8	*Argyrosomus inodorus*[1]	32	*Diplodus sargus*[1]	14	*Trachurus trachurus*	2
11	*Scomberomorus commerson*	7	*Pachymetopon grande*[1]	31	*Chrysoblephus laticeps*	12	*Thunnus albacares*	2
12	*Lichia amia*	7	*Pterogymnus laniarius*	24	*Pachymetopon blochii*[1]	11	*Argyrosomus inodorus*[1]	2
13	Serranidae spp. [1]	7	*Dichistius capensis*[1]	21	*Sarpa salpa*[1]	8	*Callorhynchus capensis*	1
14	*Liza tricuspidens*	6	*Lithognathus lithognathus*[1]	20	*Galeorhinus galeus*	8	*Thunnus obesus*	1
15	*Atractoscion aequidens*[1]	6	*Sparodon durbanensis*	20	*Sparodon durbanensis*	7	*Lithognathus lithognathus*[1]	1
16	*Rhabdosargus holubi*	6	*Atractoscion aequidens*[1]	19	*Umbrina canariensis*	7	*Chelidonichthyes capensis*	1
17	*Cheimerius nufar*	5	*Liza richardsonii*[1]	16	*Carcharhinus brachyurus*	7	*Sebastes capensis*	1
18	*Trachinotus botla*	5	*Rhabdosargus holubi*	14	*Rhabdosargus globiceps*[1]	6	*Pomatomus saltatrix*[1]	1
19	*Argyrosomus thorpei*[1]	4	*Cheimerius nufar*	13	*Liza richardsonii*[1]	6	*Merluccius capensis*	1
20	*Chrysoblephus anglicus*[1]	4	*Lichia amia*	12	*Rhinobatos annulatus*	6	*Chrysoblephus laticeps*	1
21	*Scomberomorus plurilineatus*	4	*Pomadasys commersonni*	10	*Galeichthyes feliceps*	5	*Scomber japonicus*	1
22	*Coracinus multifasciatus*	3	*Thunnus albacares*	10	*Galeichthys ater*	5	*Argyrosomus* spp. [1]	0
23	*Argyrosomus* spp.[1]	3	*Lithognathus mormyrus*	10	*Mustelus mustelus*	5	*Diplodus sargus*[1]	0
24	*Carcharhinus obscurus*	3	*Seriola lalandii*	9	*Diplodus cervinus*[1]	4	*Pterogymnus laniarius*	0
25	*Pachymetopon grande*[1]	3	*Chrysoblephus cristiceps*[1]	8	*Umbrina ronchus*	4	*Katsuwonis pelamis*	0
26	*Trachinotus africanus*	3	*Petrus rupestris*[1]	8	*Triakis megalopterus*	4	*Galeorhinus galeus*	0
27	*Polysteganus coeruleopunctatus*	3	*Scomber japonicus*	7	*Pomadasys olivaceum*	3	*Brama brama*	0
28	*Epinephelus andersoni*[1]	2	*Chrysoblephus gibbiceps*[1]	7	*Spondyliosoma emarginatum*	3	*Isurus oxyrinchus*	0
29	*Mugil cephalus*	2	*Neoscorpis lithophilus*	6	*Petrus rupestris*[1]	3	*Hyperoglyphe antarctica*	0
30	*Otolithes ruber*	2	*Diplodus cervinus*[1]	5	*Scomber japonicus*	2	*Genypterus capensis*	0

1. Occur in the top 30 fish found using the combined data for all zones (Tables 1.6 and 1.7)

The criteria were not rigorously examined for preference independence, although intuitively in most cases, they appear to be independent. Where 1) is violated another means of aggregation (e.g., a multiplicative form) is appropriate. It has, however been shown that using an additive rather than multiplicative form has little effect on the resulting rank orders (Stewart, 1994). With regards to requirement 2), the scoring systems developed for all criteria represented interval scales reasonably well. With respect to assumption 3), for WT3 to WT7 the swing weighting concept was applied with reasonable success at all levels except level 2 (Fig. 1.1). The weights within conservation (level 4) were derived from a questionnaire that emphasised this concept. The weights within sectors (level 4) were based on the percentages of each of the criteria (i.e. the higher the maximum percentage contribution of a fish within any of the four criteria, the higher the overall priority of the criterion should be). The weights between sectors (level 3) were based on the idea that the more people involved and the higher the economic value the greater the effect on the overall priority of the species, which corresponds to the swing weight concept. I did not use swing weights at level 2 (relative importance of conservation and the combined sectors). At this level it is difficult and perhaps less necessary to do so, as one can compare ranks before the final aggregation and examine sensitivity analyses to highlight discrepancies.

As in the AFS approach (Musick, 1999), the selection of criteria in this exercise was made by consensus among groups of scientists familiar with particular species. Musick (1999) criticizes the usefulness of the IUCN system of using standardized quantitative risk criteria in predicting risk of extinction across all phyla in that, apart from being inflexible, the criteria do not include the vast array of life-history parameters and other ecological features that contribute to the vulnerability of different taxa. The conservation criteria were similar to AFS's and the ecological criteria of Pitcher *et al.* (1998) and included rarity, endemicity or small range, and population decline. Other biological or ecological criteria we considered (e.g. fecundity) could not be included due to lack of data, and because participants felt they could not even give qualitative scores. The fishery sector criteria parallel some of Pitcher *et al.'s* although I have far fewer.

The AFS criteria allow the assessment of distinct population segments (DPSs) as opposed to rigidly assigning a species to a category despite it having identifiable populations with differing levels of health or status. Assigning a DPS to a category also depends on its level of productivity or resilience, ultimately its ability to recover or maintain its desired status. A shortfall of the AFS approach is that, in developing countries, DPSs have only been identified for a handful of species. Pitcher *et al.* (1998) used multidimensional scaling (MDS) on a number of criteria. Most criteria had associated qualitative scores (usually a 3- or 4- point ordinal scale) and some had information available on cardinal scales (e.g. catch per fisher in tonnes/fisher/year). The criteria were grouped under the headings ecological, economic, sociological, and technological. Multivariate techniques are useful for summarizing large databases and gaining insights into the main groupings within the data and into what contributes to the formation of the groups. I believe that this approach improves on the use of MDS alone. Firstly, the information available (including expert opinion) was used to advantage, in that, for all criteria, scores on a 0-100-interval scale were used rather than ordinal information. Although for some of the criteria only 4 or 5 levels were defined, these were on an interval scale, and intended as guidelines so that specialists could also use intermediate points. Secondly, the ratings for any individual criterion or any level of aggregation are all immediately available and easy to compare, making it straightforward to determine reasons for inclusion or exclusion of particular fish. In contrast, the interpretation of the biplots produced by MDS may be difficult to translate to management action.

The five IUCN categories of risk of extinction (critically endangered to least concern), the AFS categories (endangered, threatened, vulnerable, conservation dependent) (Musick 1999), Pauly's (1997) triage and Pitcher *et al*'s.' (1998) good to bad categories are all aimed at focussing efforts on a manageable group of species (or fisheries). In this paper, priority for research and management is defined due to the combined importance from the point of view of conservation and fishers. Resources will determine how many can be addressed, but certainly those ranking in the top twenty deserve immediate attention.

The appearance of the small-bodied species, namely strepie, piggy, harder *Liza richardsonii* and stonebream *Neoscorpis lithophilus*, on the recreational shore angling list may be surprising to fishers. However, these four species reflect the increasing importance of a "subsistence" subcomponent within this sector, and so their appearance on this list may promote pro-active management decisions (strepie, piggy and harder are also important commercial net species). In turn, the popularity of competitive angling explains why the "inedible" lesser guitarfish *Rhinobatos annulatus*, targeted only during competitions, is on the recreational shore list, but of little management importance overall. On the other hand, some species, for which substantial fisheries have only recently developed in South Africa, e.g. broadbill swordfish *Xiphius gladius*, do not feature high up on the lists, but might do so when the database is updated with new catch numbers.

The *Serranidae* (rockcods), when considered as a family, feature high up, perhaps disproportionately, on the overall list. This is largely a result of high conservation importance values. However, these species are fished and reported mostly as a family and it may be better to rate them as a group rather than separately. In contrast, for the genera *Argyrosomus* and *Thunnus*, all attempts should be made to treat the species within these genera separately because they differ vastly in life history and stock status. In the longer term, fishers should be encouraged to distinguish between species in all reported catches.

Many South African linefish species could be placed in the IUCN or AFS critically endangered or endangered categories, but the reality is that many of these, e.g. dusky kob *Argyrosomus japonicus* and geelbek *Atractoscion aequidens*, are still important commercially and recreationally even though stocks are regarded as collapsed (Penney *et al.* 1997). Although justifiable from a conservation perspective, placing these species into categories that would require a complete cessation of fishing would be unacceptable to fishers, daunting to politicians and unenforceable by management. Prioritization of fish species for conservation, as well as for research and management, requires additional criteria that reflect the importance of the species to the different fishery sectors concerned. Incorporating into the process, specific criteria that relate to the fishery and socio-economic significance of the resources, not only allows one to assess the relative need for management steps, but also helps in defining the appropriate action to be taken. Appropriate action constitutes, within limits, what is acceptable to both fishers and management.

It is, therefore important to look at the priority ranks for conservation, the combined sectors separately as well as the overall ranks (e.g., Table 1.7 columns 1, 7 and 8). It may be sensible and justifiable to apply different rules to the fish in column 1 (high priority from a conservation point of view) from those in column 7 (high importance to fisheries). For example, species appearing in columns 1, 7 and 8 (i.e.

galjoen, dusky kob, geelbek, slinger *Chrysoblephus puniceus*, white steenbras *Lithognathus lithognathus*, silver kob *Argyrosomus inodorus*, and white stumpnose *Rhabdosargus globiceps*) need the most urgent attention in terms of stock assessments and the development of management plans, but cannot be removed from the fishery immediately because of the socioeconomic and political ramifications (Table 1.7). On the other hand, fish in columns 1 and 8, but not in column 7, might be placed under stricter restrictions with less controversy.

Through this exercise linefish species could, according to their rankings, be grouped into various levels of action that provide for, among others, frequency of stock assessments, bag limits, and sector exclusivity. Species of low rank would receive low research and conservation priority. Under the new South African Marine Living Resources Act (no. 18 of 1998), the precautionary principle has to be adhered to in the absence of reliable scientific information. Consequently, there is a danger that low-priority species of which little is known may end up under more conservative measures than medium-priority species, especially if the status of the latter has been compromised through negotiation with fishers. I hope I have negated some of this data deficiency effect by including degree of knowledge as a criterion.

CHAPTER 2

2. THE ROLE OF ESTUARIES IN SOUTH AFRICAN FISHERIES: PRODUCTION, ECONOMIC IMPORTANCE AND MANAGEMENT IMPLICATIONS

2.1 Introduction

It is generally appreciated that estuaries are productive systems which provide a valuable supply of goods and services ranging from fisheries to recreational opportunities (Swallow 1994, Costanza *et al.* 1997, Morant & Quinn 1999. Costanza *et al.* (1997) estimate that estuaries are worth R 153 000 per ha per year on average. The bulk of this value can be attributed to food production R 3 500 per ha, recreation R 2 550 per ha and nutrient cycling R 141 000 per ha (1 US$ = R 6.7 in 2000). Few studies have attempted to estimate the full economic contribution of estuaries to a national economy. South Africa is well endowed with estuaries, having roughly 255 functioning estuaries along its approximately 3100 km coastline. Yet, the economic value of these ecosystem services is unknown. Indeed, the supply of goods ands services is not even well understood in physical terms, and there is little understanding of how the characteristics of estuaries, which are highly variable, influence these services.

Partly due to a lack of incentive due to little appreciation for their full value, and partly because of their situation between land and sea, the management of estuaries in South Africa has been inadequate and never a priority (Boyd *et al.* 2000). Lack of management and other attention generally means that estuaries have been subject to increasing pressures, both indirectly from the effects of catchment utilisation, which affect their water supply, and directly from the increasingly large numbers of people who reside in or visit the coastal zone.

Many human activities which are carried out in estuaries and their catchment areas impact directly on estuarine biodiversity and resource stocks, and different activities often conflict with one another through such impacts. If estuaries and their catchments are to be managed in an optimal sustainable way, it is necessary to understand the full economic value of the goods and services that they provide.

One of the most important values of estuarine systems is their contribution to fisheries. Resident fish populations are exploited directly in estuarine recreational and subsistence fisheries. But more importantly, estuaries provide nursery areas for numerous species of fishes which are exploited by recreational and commercial harvesting in the inshore marine environment. These species are dependent on estuaries for the early stages of their growth (Whitfield 1994b).

The management of estuaries in South Africa has not been well organised in the past. Now, with the increasing realisation of their value, as well as of the pressures that threaten these systems, efforts are being made to redress the situation and to set in place sound decision-making processes regarding the management and conservation of estuaries (Boyd *et al.* 2000, Breen & McKenzie 2001). This is both in terms of the management of catchments and determination of freshwater inflows into estuaries, and in terms of the direct management of estuaries and activities within them.

This study reviews the available published and unpublished data on the exploitation of fish (excluding invertebrate fisheries) within South African estuaries. The main aims of this study were to:

- list the estuarine fish species exploited in South African fisheries, giving their degree of dependence on estuaries;
- describe the types of estuarine and marine fisheries exploiting estuarine fishes, and their total participation and effort;
- estimate the total catches of estuarine species in estuaries and the marine environment;
- explain the contribution to fisheries made by different types of estuaries and;
- estimate the contribution that estuarine and estuary-dependent fishes make to the economic value of estuarine and marine catches.

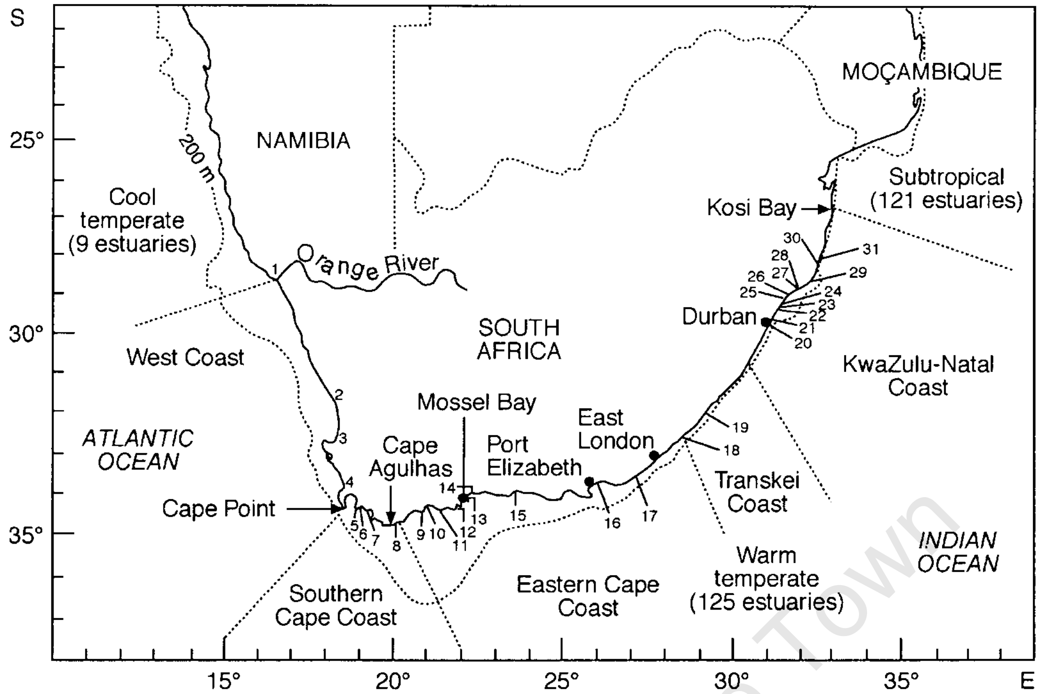
In doing so I discuss the above findings in terms of the stock status of important estuarine fish species and assess them in terms of their implications for estuary management.

2.2 Methods and study approach

2.2.1 Subdivision of the study area

The South African coast can be considered in terms of three biogeographical regions these being the *cool temperate region* on the West Coast, the *warm temperate region* from Cape Point to approximately the Mbashe River in the former Transkei; and the *subtropical region* to the northeast of the Mbashe River (Fig. 2.1). The second boundary is rather poorly defined, largely because the presence or absence of fish is strongly influenced by a major tropical subtraction effect from Kosi to Cape Point (Turpie *et al.* 2000), rather than any natural geographical break.

For practical purposes, the South African coast has often been divided into five regions for the collection of fisheries data, corresponding with the Cape Point biogeographical division, but not the second division: These are the *West coast* (Orange/Gariep River to Cape Point, *South coast*: (Cape Point to



1. Orange/Gariep	11. Goukou	21. Umgeni
2. Olifants	12. Gouritz	22. Nonoti
3. Berg	13. Klein Brak	23. Zinkwazi
4. Rietvlei/Diep	14. Groot Brak	24. Thukela (was Tugela)
5. Kleinmond	15. Knysna	25. Amatikulu/Nyoni
6. Bot	16. Swartkops	26. Umlalazi
7. Klein	17. Keiskamma	27. Richard's Bay
8. Heuningnes	18. Great Kei	28. Mhlatuze
9. Breede	19. Mbashe	29. Nhlabane
10. Duiwenhoks	20. Durban Bay	30. Msundusi/Mfolozi
		31. St Lucia

Figure 2.1 Map of South Africa showing the areas and estuaries (numbered) mentioned in the text.

Port Elizabeth), *East coast* (Port Elizabeth to Kei River), *Transkei* (Kei River to Port Shepstone) and *KwaZulu-Natal* (Port Shepstone to Kosi Bay) (Fig 2.1).

Thus the warm temperate zone is mostly divided into two sections, and the former Transkei (hitherto referred to simply as the Transkei) constitutes a very broad transition area between biogeographical zones.

2.2.2 *Estuarine fish and their dependence on estuaries*

General information on biology and distribution of estuarine fish species was obtained from Whitfield (1998) and Mann (2000). Information on which of these species are utilised was derived from a variety of sources, including the National Marine Linefish System (NMLS) database, the Netfish System database, and various published papers and reports.

Table 2.1 The five major categories and subcategories of fishes that utilise southern African estuaries (Whitfield 1994b).

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

This study is only concerned with utilised fish species. Of these, different species have different degrees of association with estuaries, and estuarine fish have been classified into five broad categories of association, which may be further subdivided into 9 types (Whitfield 1994b, Table 2.1). Category I and IIa species are entirely dependent on estuaries, as are category V species. Category IIb species are largely dependent on estuaries, while numbers of category IIc species are augmented by estuaries. Category III species are found in estuaries, but are not dependent on them.

2.2.3 Types of fisheries, participation and effort

For estuarine fisheries, I included legal and illegal seine and gillnet fisheries, recreational shore, castnet and recreational boat fisheries, as well as traditional fisheries. For marine fisheries, the recreational boat, recreational shore, recreational spear and commercial boat and beach seine and gill net fisheries were considered. Pelagic fisheries were excluded as none involve estuary-associated species.

There are no comprehensive nationwide studies of estuarine fishing participation or effort. However, these were obtained from published and unpublished literature on a number of individual estuaries (Beckley *et al.* 2000, Hutchings & Lamberth 1999, 2002a,b,c, Kyle 1995, 1999, Mann 1994, 1995, 1996, Sowman *et al.* 1997, Guastella 1994, Lamberth 2000a,b, Baird & Pradervand 1999, Baird *et al.* 1996, Pradervand & Baird in preparation, Marais & Baird 1980), as well as extrapolation from coastal fisheries. For marine fisheries, participation and effort in recreational shore angling, boat fishing and spear fishing was estimated from the regional reports of the National Linefish Survey (Brouwer 1996, Brouwer *et al.* 1997, Lamberth 1996, Sauer & Erasmus 1996, Sauer *et al.* 1997, Mann *et al.* 1996, 1997, 1998, McDonald *et al.* 1998), and attributed to particular species on the basis of the proportion of successful fishers that had caught that species, extrapolated to the total estimated number of fishers. For the commercial boat fishery, participation was gauged as the sum of the mean number of crew carried by the boats that reported catches of particular species to the NMLS over a five-year period. Similarly, participation for the beach seine and gill-net fisheries was estimated as the sum of the number of permit holders that had reported catching a particular species to the NMLS multiplied by the mean crew size (Lamberth *et al.* 1997, Hutchings & Lamberth 1999).

2.2.4 Estuarine catch estimates

Estimates of estuarine catches and their species composition were obtained from the literature (Hutchings & Lamberth 1999, Kyle 1995, 1996, 1999 2000a,b, Mann 1994, 1995, Beckley *et al.* 2000, Sowman *et al.* 1997, Guastella 1994, Lamberth 1996, 2000a,b, Baird & Pradervand 1999, Pradervand & Baird in preparation, Baird *et al.* 1996, Marais & Baird 1980) and from unpublished data and estimates supplied by Bruce Mann (Oceanographic Research Institute) and Paul Cowley (South African Institute for Aquatic Biodiversity). Estimates were based on sampling, counts of fishers, surveys, and confiscated catches. Of the 255 functional estuaries considered in this study, information allowing catch estimates was available for about half the estuaries (n = 129): all 9 estuaries on the west coast, 24 out of 52 estuaries on the south coast (Cape Point to Mosselbay), 23 out of 54 on the east coast (Swartkops to Keiskamma), none of the 67 Transkei estuaries, and all 73 estuaries in KwaZulu-Natal. In terms of biogeographical regions, data exist for all 9 estuaries in the cool temperate region, 47 out of 125 in the warm temperate region, and 73 out of 121 in the subtropical region.

In order to extrapolate the existing catch estimates to the remaining estuaries, the relationships between estuarine catches and estuary size, type and biogeographical region were analysed using simple and multivariate models. General linear modelling was used to create predictive models to estimate catches for the remaining estuaries. Dependent variables used were estuary size (Brian Colloty, UPE, unpublished data), biogeographical region and estuary type (Whitfield 1992). The best predictive models were obtained by analysing data separately for each biogeographical region. The St Lucia estuary in KwaZulu-Natal, and the Bot and Klein estuaries on the south coast, were excluded from analyses: these are large estuaries in which catches are disproportionately low (in the case of St Lucia this is partly due to exclusion zones).

2.2.5 *Marine catch estimates*

For marine fisheries, total catches for each species were estimated from the regional reports of the National Linefish Survey (recreational shore angling and spear fishing catches, 1994-1996; Brouwer 1996, Brouwer *et al.* 1997, Lamberth 1996, Sauer & Erasmus 1996, Sauer *et al.* 1997, Mann *et al.* 1996, 1998, Lechanteur 2000, McDonald *et al.* 1998), the NMLS (commercial boat catches, recreational boat catches, 1992-1996) and catch reports from the Marine & Coastal Management Netfish System (commercial beach-seine and gill net catches, excluding KwaZulu-Natal, 1992-1996). The latter were corrected using validated catches from Lamberth *et al.* (1997) and Hutchings & Lamberth (1999, in press a,b). KwaZulu-Natal net fish catches were estimated from Beckley & Fennessy (1996).

It is difficult to attribute the actual contribution of individual estuaries to the marine catch, but data were disaggregated as far as possible, to coastal sections.

Inshore marine fishery catches were analysed in terms of the amount made up of estuary-associated fish, and the percentage dependency of the total catch on estuaries. The latter was estimated on the basis of the dependence categories (Whitfield 1994b) of different estuarine species in catches, assigning a percentage to each category reflecting the degree to which that species would be lost from marine catches if all estuaries were to disappear.

2.2.6 *Economic value*

Estimates of the economic value of fisheries in South Africa have mainly been confined to marine commercial and recreational fisheries. Estimates of the economic contribution of each of the marine line fisheries were obtained from McGrath *et al.* (1997), based on NMLS data, and of the marine and estuarine net fisheries were obtained from Hutchings & Lamberth (1999) and Hutchings & Lamberth (2002b).

For marine fisheries, the relative contribution of each species was determined according to the methodology used by Lamberth & Joubert (1999, Chapter 1). Fish prices were obtained in telephonic interview with dealers countrywide. 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) and Hutchings & Lamberth (1999, 2002b). Overall values obtained for each species were reduced according to the percentage dependence on estuaries for that species to estimate the estuarine contribution to the marine fishery values.

No comparable estimate of the overall economic value of estuaries has been made. Consequently, the economic value of estuarine fisheries was estimated on the basis of catch estimates. For recreational fisheries and commercial fisheries, I assume that the value per landed kg of fish is the same as for marine fisheries. Traditional estuarine fisheries were assigned the same value per landed kg as commercial marine gillnet fisheries, which is close to market values.

2.2.7 *Stock status and vulnerability of utilised estuarine fish species*

The conservation status of exploited estuarine fish species was gauged according to abundance (stock status), level of knowledge, endemicity, level of exploitation throughout a species' range and vulnerable life history traits, following the methods of Lamberth & Joubert (1999), all attributes being scored on a scale of 1-100:

(a) *Abundance*. Depending on availability of data this score was based on the percentage of pristine spawner biomass remaining, ratios of present to historical catch per unit effort (CPUE), or ratios of present to historical contribution to total catches. Data were obtained from various sources, e.g. the NMLS, CMS (1999) & Mann (2000). Each species was scored on a scale of 1-100, with score ranges indicating the stock as underexploited, optimally exploited, over exploited or collapsed (Griffiths *et al.* 1999).

(b) *Level of knowledge*. 14 factors described in Van der Elst & Adkin (1999) and Mann 2000, were used for scoring the current level of knowledge for each species on a scale of 1 to 100.

(c) *Endemicity*. Each species was scored according to how many regions it occurred in, as follows: one region = 100, two regions = 60, three regions = 40, four regions = 20, southern Africa = 10, cosmopolitan = 0. Range data was mostly obtained from Smith & Heemstra (1986).

(d) *Level of exploitation*. This was scored qualitatively on the basis of Mann (2000), CMS (1999) and expert opinion. For example, a species heavily exploited throughout its range scored 100, medium = 50, and low = 0.

(e) *Vulnerability*. This was gauged using 8 life history traits, namely estuarine dependence, sex changes, spawning migrations, predictable aggregations, high age at maturity, longevity, residency and high catchability. Species displaying none of these characteristics scored 0, those with one, two or three characteristics scored 70, 80 or 90, and those displaying four or more of these characteristics scored 100 (see Chapter 1 for rationale).

2.3 Results and discussion

2.3.1 *Utilised estuarine fish species, their distribution and dependence on estuaries*

About 160 species occur in South African estuaries, of which about 80 species are utilised in fisheries. Of the 80 utilized species, 3, 47, 21, 3 and 6 species fall into categories I to V, respectively (Table 2.2). Of particular importance are the category I and II species, for which management of estuaries plays a crucial role in fisheries. Catches of estuarine-associated fish species differ from west to east around the coast, following biogeographical changes from the cool temperate region on the west coast through to the subtropical region north of the Mbashe River in the Transkei. The cool temperate region is relatively species poor but productive, and the fisheries include only about 19 estuarine-associated species (Table 2.2). Numbers of estuarine species in catches almost double immediately east of Cape Point, and increase towards the east, with up to 71 species in KwaZulu-Natal (Table 2.2). Some 28 estuarine-associated species are caught only or predominantly in KwaZulu-Natal. Within regions, species composition of catches within estuaries also differs between estuaries of different types and sizes, with greater species richness associated with larger and permanently open estuaries.

2.3.2 *Estuarine fisheries*

2.3.2.1 Types of fisheries, participation and effort

Linefishing

Linefishing, from the shore or from boats (canoes to skiboats), and using handlines or rods, is popular in estuaries throughout South Africa. This is primarily a recreational angling pursuit (requiring a permit). A small number of subsistence fishers are active, mainly from Port Elizabeth to KwaZulu-Natal, and subsistence permits are in the process of being introduced. No commercial linefishing is permitted in estuaries. Studies of angling participation or effort are confined to a few specific estuaries. I thus estimated angling participation and effort for each region as follows.

Angling is limited on the west coast due to lack of suitable angling fish, but assuming angler densities similar to adjacent shorelines, there may be up to 0.12 anglers per km of estuary at any one time, or a maximum of 4400 angler days per year on west coast estuaries. This represents the effort of approximately 147 fishers (Lamberth 2000a). All the effort is currently recreational, although about 14% of these anglers admit to selling part of their catch (Lamberth 1996).

Table 2.2 Estuarine-associated species caught in South African fisheries, given in order of estuarine dependence category (Table 2.1), and giving distribution of catches around the coast. Distribution is divided into West coast (Orange River to Cape Point), South Coast (Cape Point to Port Elizabeth), East Coast (Swartkops to Kei River), Transkei and Kwazulu Natal (Port Edward to Kosi Bay). The three biogeographical provinces are separated by Cape Point and roughly at the Mbashe River in the Transkei (Emanuel *et al.* 1992, Turpie *et al.* 1999, Maree *et al.* 2000a,b).

Species	Common name	Dependence category	Distribution				
			Cool temperate	Warm temperate			Sub-tropical
			West	South	East	Transkei	KZN
Ambassis productus	Longspine glassy	Ia					X
Ambassis gymnocephalus	Bald glassy	Ib		X	X	X	X
Ambassis natalensis	Slender glassy	Ib					X
Rhabdosargus holubi	Cape stumpnose	IIa	X	X	X	X	X
Argyrosomus japonicus	Dusky kob	IIa		X	X	X	X
Mugil cephalus	Flathead/springer mullet	IIa	X	X	X	X	X
Elops machnata	Ladyfish/tenpounder	IIa		X	X	X	X
Lichia amia	Leervis/garrick	IIa	X	X	X	X	X
Acanthropagrus berda	Perch/riverbream	IIa				X	X
Pomadasys commersonni	Spotted grunter	IIa		X	X	X	X
Lithognathus lithognathus	White steenbras	IIa	X	X	X	X	X
Monodactylus falciformis	Cape/Oval moony	IIa			X	X	X
Liza macrolepis	Largescale mullet	IIa					X
Valamugil cunnesius	Longarm mullet	IIa				X	X
Valamugil robustus	Robust mullet	IIa				X	X
Terapon jarbua	Thornfish	IIa			X	X	X
Galeichthyes feliceps	Barbel	IIb	X	X	X	X	X
Sphyraena barracuda	Barracuda	IIb					X
Caranx sexfasciatus	Bigeye kingfish	IIb					X
Caranx ignobilis	Giant kingfish	IIb				X	X
Rhabdosargus sarba	Natal stumpnose	IIb				X	X
Scomberoides lysan	Doublespotted queenfish	IIb					X
Liza tricuspidens	Striped mullet	IIb		X	X	X	X
Thryssa vitrirostris	Orangemouth glassnose	IIb					X
Gerres acinaces	Smallscale pursemouth	IIb					X
Gerres methueni/rappi	Evenfin pursemouth	IIb					X
Leiognathus equula	Slimy	IIb					X
Monodactylus argenteus	Natal/Round moony	IIb				X	X
Liza alata	Diamond mullet	IIb				X	X
Liza dumerilii	Groovy mullet	IIb		X	X	X	X
Liza luciae	St Lucia mullet	IIb					X
Platycephalus indicus	Bartailed flathead	IIc			X	X	X
Diplodus sargus	Dassie/blacktail	IIc		X	X	X	X
Pomatomus saltatrix	Elf	IIc	X	X	X	X	X
Liza richardsonii	Harder	IIc	X	X	X		
Pomadasys hasta/kakaan	Javelin grunter	IIc					X
Johnius dussumieri	Mini kob	IIc			X	X	X
Sphyraena jello	Pickhandle barracuda	IIc					X
Lutjanus argentimactulus	River snapper	IIc				X	X
Sillago sihama	Silver sillago	IIc					X
Sarpa salpa	Strepie	IIc		X	X	X	X
Rhabdosargus globiceps	White stumpnose	IIc	X	X	X		
Carcharhinus leucas	Zambezi shark	IIc					X
Strongylura leiura	Yellowfin needlefish	IIc					X
Caranx melampygus	Bluefin kingfish	IIc					X

continued..

Table 2.2 continued.

Species	Common name	Dependence category	Distribution: Cool temperate	Warm temperate			Sub-tropical
			West	South	East	Transkei	KZN
Caranx papuensis	Brassy kingfish	IIc					X
Chanos chanos	Milkfish	IIc					X
Lutjanus fulviflamma	Dory snapper	IIc					X
Valamugil buchanani	Bluetail mullet	IIc					X
Valamugil seheli	Bluespot mullet	IIc					X
Dasyatis chrysonota	Blue stingray	III	X	X	X		
Himantura uarnak	Honeycomb stingray	III					X
Gymnura natalensis	Butterfly/diamond ray	III		X	X	X	X
Myliobatus aquila	Eagleray	III	X	X	X		
Mustelus mustelus	Smooth houndshark	III	X	X	X	X	X
Rhinobatos annulatus	Lesser guitarfish/sandshark	III	X	X	X	X	
Epinephelus andersoni	Catface rockcod	III				X	X
Epinephelus malabaricus	Malabar rockcod	III					X
Pomadasys multimaculatum	Cock grunter	III					X
Pomadasys olivaceum	Piggy	III	X				
Chelidonichthyes capensis	Gurnard	III	X	X	X		
Trachurus trachurus	Maasbanker	III	X	X	X		
Lithognathus mormyrus	Sand steenbras	III	X	X	X		
Otolithes ruber	Snapper kob	III					X
Trachinotus africanus	Southern pompano	III			X	X	X
Spondyliosoma emarginatum	Steentjie	III	X	X	X	X	X
Sparodon durbanensis	White musselcracker	III		X	X	X	X
Diplodus cervinus	Zebra/wildeperd	III		X	X	X	X
Kuhlia mugil	Barred flagtail	III			X	X	X
Muraenesox bagio	Pike conger	III			X	X	X
Thrysoidea macrura	Slender giant moray	III					X
Oreochromis mossambicus	Mozambique tilapia	IV	X	X	X	X	X
Clarius gariepinus	Sharptooth catfish	IV	X	X	X	X	X
Glossogobius giuris	Tank goby	IV					X
Anguilla bengalensis	African mottled eel	Va		X	X	X	X
Anguilla bicolor	Shortfin eel	Va		X	X	X	X
Anguilla marmorata	Giant mottled eel	Va		X	X	X	X
Anguilla mossambica	Longfin eel	Va		X	X	X	X
Megalops cyprinoides	Oxeye tarpon	Vb					X
Myxus capensis	Freshwater mullet	Vb		X	X	X	X
TOTAL	**80**		**19**	**34**	**41**	**43**	**71**

On the south coast, from Cape Point to Mossel Bay, based on angler densities on adjacent shorelines and angler and boat counts on the Breede, Klein, Bot and Heuningnes estuaries, there are an estimated 66 200 angler-days per year in estuaries along this coast. This represents the effort of approximately 2 209 fishers. These effort estimates are probably extremely conservative, as the Overberg district council issues 1200 boat permits per year, mostly for the Breede River. In addition, current confusion over estuarine regulations and commercial linefish permits has led to commercial linefishers moving illegally into estuaries to an unknown extent. Extrapolating to the entire south coast, I estimate a total effort of 133 000 angler days and a total of 7400 anglers.

Little is known about angling effort on the east coast, but it is estimated that there are at least 130 000 angler days of effort expended per year in estuaries from the Swartkops to the Keiskamma, representing about 8000 anglers (extrapolated from Pradervand & Baird, in preparation). Extrapolating to the entire east coast region, I estimate that there are approximately 168 000 angler days and 9300 anglers in total.

There is no information on estuarine angling for the entire Transkei coastline. However, a shore-angling survey in the Transkei found about 400 000 angler-days per year, representing the effort of about 19 000 anglers (McDonald *et al.* 1998, Mann *et al.* 1998). Using similar assumptions as for other parts of the South African coastline, it is estimated that there are approximately 112 000 angler days spent in estuaries, representing the effort of 5-6000 anglers.

In KwaZulu-Natal, some preliminary estimates have been made of angling effort in Kosi Bay (10 000 boat angling outings per year), St Lucia (30 000 boat angler outings and 18 000 shore-angler outings per year), Durban Bay (21 000 boat angler outings and 100 000 shore angler outings per year) and Umgeni estuary (11 000 shore-angler outings per year) (Beckley *et al.* 2000). The number of anglers using estuaries in KwaZulu-Natal is estimated to be over 50 000 (Beckley *et al.* 2000).

The total number of anglers using estuaries in South Africa is estimated to be in the region of 67 000. This is similar to van der Elst's (1989) estimate of 50 000 anglers operating from light tackle boats in estuaries.

Castnetting

Castnetting is mainly used by recreational and subsistence anglers to catch baitfish such as mullet, is practised throughout South Africa, and requires a permit. There is one commercial castnet permit in KwaZulu-Natal, for Durban Bay. The gear used is restricted to a weighted monofilament or braided nylon net of 1.5-4m diameter, with a mesh size of 15-20mm. On the east and KwaZulu-Natal coasts, the larger nets are used for catching linefish species, but amendments to the regulations are intended to curtail this practice. The regulations will restrict castnets to 2m in diameter, with mesh sizes of 13-20mm.

Table 2.3 Estimated numbers of fishers participating in different types of fisheries around the South African coast (legally and illegally).

Estuarine fisheries	West	South	East	Transkei	KZN-Natal	TOTAL
Linefishing	147	7 400	9 300	5 500	50 000	72 347
Castnetting	95	300	600	75	4 500	5 570
Gillnetting	550	50	? 50+	? few	550	~1 200
Seine netting	0	<5	0	?	140	~150
Traditional methods	0	0	0	0	120+	120+
TOTAL*	**697**	**7 455**	**9 350**	**5 500**	**50 810**	**73 812**

* excludes castnet figures as most are anglers.

On the west coast, castnets are used regularly by about 95 recreational shore anglers, almost exclusively targeting harders, with a total effort of about 2837 angler days per year. This accounts for approximately 1.2% of angler effort (Lamberth 2000a,b). On the south coast, approximately 300 shore-anglers use castnets regularly, with a total effort of approximately 8972 angler days per year (Lamberth 1996). The amount of castnetting along the east coast is unknown, but is estimated to be about 10 800 days per year by 600 fishers (based on Brouwer 1996). Castnetting is less common in the Transkei, where there are probably about 75 castnet users, with an estimated effort of 1300 days per year. In KwaZulu-Natal, 4511 recreational castnet licences were issued in 1997 (Mann 2000). Effort is unknown, but probably amounts to at least 10 800 days per year. Also important is that an effort limitation system has been developed for estuaries in KwaZulu-Natal, with a set number of castnet permits for each estuary (Beckley *et al.* 2000). The total number of castnetters using estuaries in South Africa is estimated to be about 5 700 (Table 2.3).

Gillnetting

Gillnetting is a passive form of fishing using monofilament or woven nylon nets, deployed either from a boat or walking out from the shore, in the hope that a shoal of fish will swim into them and become entangled. These nets may either drift, be staked or be anchored, but in terms of legislation they may not be left unattended except in KwaZulu-Natal where they are set overnight and retrieved in the morning. Permits for estuaries are only issued on the west coast and KwaZulu-Natal, where permit-holders are restricted to the use of one net, ranging from 35-75m in length, depending on the estuary in which they operate. In addition to legal netting, substantial illegal gillnetting occurs in estuaries throughout South Africa. Overall, catch rates dictate that the fishery changes from a largely commercial venture on the west coast to more subsistence in nature as one moves eastwards to KwaZulu-Natal.

On the west coast, gillnetting takes place in the Olifants, Berg and Rietvlei/Diep estuaries. There are 85 gillnet permit holders in the Olifants estuary, and an additional 20-30 people operating without permits. Annual effort is about 15 300 net days/year (Lamberth 2000a). On the Berg River estuary, there are 120 gillnet permit holders, plus about 100 illegal operators, and annual effort is about 13 230 net days of legal effort plus at least 4000 net days of illegal effort (Hutchings & Lamberth 1999). The Rietvlei-Diep system is fished by about 10 or 12 illegal netters (Lamberth 2000a).

Along the south coast, at least 3 teams of illegal netters operate in the Bot/Kleinmond and Klein estuaries (2-6 people per team), and according to Cape Nature Conservation, up to 5 nets have been found in either estuary at any one time. There are also up to 10 illegal nets used in the Breede and Duiwenhoks estuaries, mostly by landowners and holiday home owners, but sometimes also by west-coast gillnetters targeting spotted grunter and flathead mullet. Similar effort probably takes place in the Goukou, Gouritz, Klein Brak and Groot Brak estuaries.

Little is known about illegal gillnetting in the east coast estuaries, but it occurs sporadically in several of these systems, where poachers often make use of cheap fine-meshed nets such as the netting used in fruit packing. It is also reported that illegal operators in this region sometimes make use of local people in rural areas to masquerade as subsistence collectors (Cowley 2000). There is evidence that gillnetting has been increasing along the east coast over the last few years. Almost nothing is known about gillnetting activities in the Transkei.

In KwaZulu-Natal, available information suggests that there is currently gillnetting in about 12 estuaries, most of which is illegal (Beckley *et al.* 2000). In Kosi, 45 permits are rotated amongst approximately 90 people, and there are roughly 90 regular illegal gillnetters, excluding transient people from Mozambique and the Pongola floodplain. In St Lucia, there are 37 gillnet permits, with an additional estimated 270 people operating illegally in the system. There is a small experimental gillnet fishery in the Msundusi/Mfolozi system, involving about 28 fishers. Illegal netting also occurs in Richards Bay, Nhlabane, Umlalazi, Amatikulu/Nyoni, Tugela, Zinkwazi, Nonoti, Durban Bay and Kosi.

I estimate that there are approximately 1200 gillnetters operating in estuaries in South Africa (Table 2.3).

Seine netting

Seine netting is an active form of fishing in which woven nylon nets are either rowed or walked out to encircle a shoal of fish. The net is then hauled to shore by a crew of 6 to 30 persons, depending on the size of the net and the length of the haul (Lamberth *et al.* 1997). There are currently no seine net permits estuaries on the west, south, east and Transkei coasts, and only one permit issued in Richards Bay, KwaZulu-Natal, for mullet for bait (Beckley *et al.* 2000). Nevertheless, a small amount of seine netting also occurs illegally in estuaries throughout South Africa, often using fine-meshed shade cloth for nets. Illegal seine netting occurs in the Heuningnes and Breede estuaries. In KwaZulu-Natal illegal seine netting is known to occur in Lake St. Lucia, Richard's Bay, Mhlatuze, Amatikulu/Nyoni, Zinkwasi, Tugela, Mlalazi, Nhlabane and Mfolozi estuaries. Some of this illegal effort is targeted at prawns. Thus the total number of seine netters using South African estuaries probably does not exceed 150 (Table 2.3).

Traditional fisheries

Traditional fishing methods, which are common in tropical countries to the north, are mostly, if not exclusively, confined to the Kosi system in South Africa. These fisheries use fish traps, spears and baskets. Traditional fish traps are parallel guide fences made of poles, sticks and brushwood collected from the surrounding coastal forest, which channel fish into a terminal collecting pen on the falling tide. There are about 120 bonefide trappers operating about 150 traps in Kosi (Kyle 2000b). Traditional spear fishing is carried out using a long straight branch with a sharpened piece of iron reinforcing rod inserted in the end (Kyle 1995). Fish are stalked in the shallows and the spear is thrown at them. Fishing baskets are oblong baskets that are baited to catch fish. In addition, children also fish in the Kosi system with sticks and lines, providing a vital supply of protein to their households. An average of 50 children are found fishing in these lakes daily (Kyle 2000b).

2.3.2.2 Influence of estuary characteristics on catch

With the exclusion of St Lucia and the Bot and Klein estuaries, estuary size alone explains over 80% of the variation in catch in the warm temperate region and over 90% of variation in catch in the cool temperate and subtropical regions (Fig. 2.2). The steeper slope in the cool temperate region reflects greater productivity in that region as compared with the other two, which have similar slopes.

Data for the warm temperate and subtropical regions were further analysed to examine the effect of estuary type (specifically permanently open and temporarily closed estuaries which are the two predominant types) on catches. The slope of the regression between estuary area and catch is steeper for permanently open estuaries (Fig. 2.3), indicating higher productivity. Note also, that temporarily closed estuaries are generally smaller than 150 ha, whereas permanently open estuaries include large estuaries of up to 500 ha.

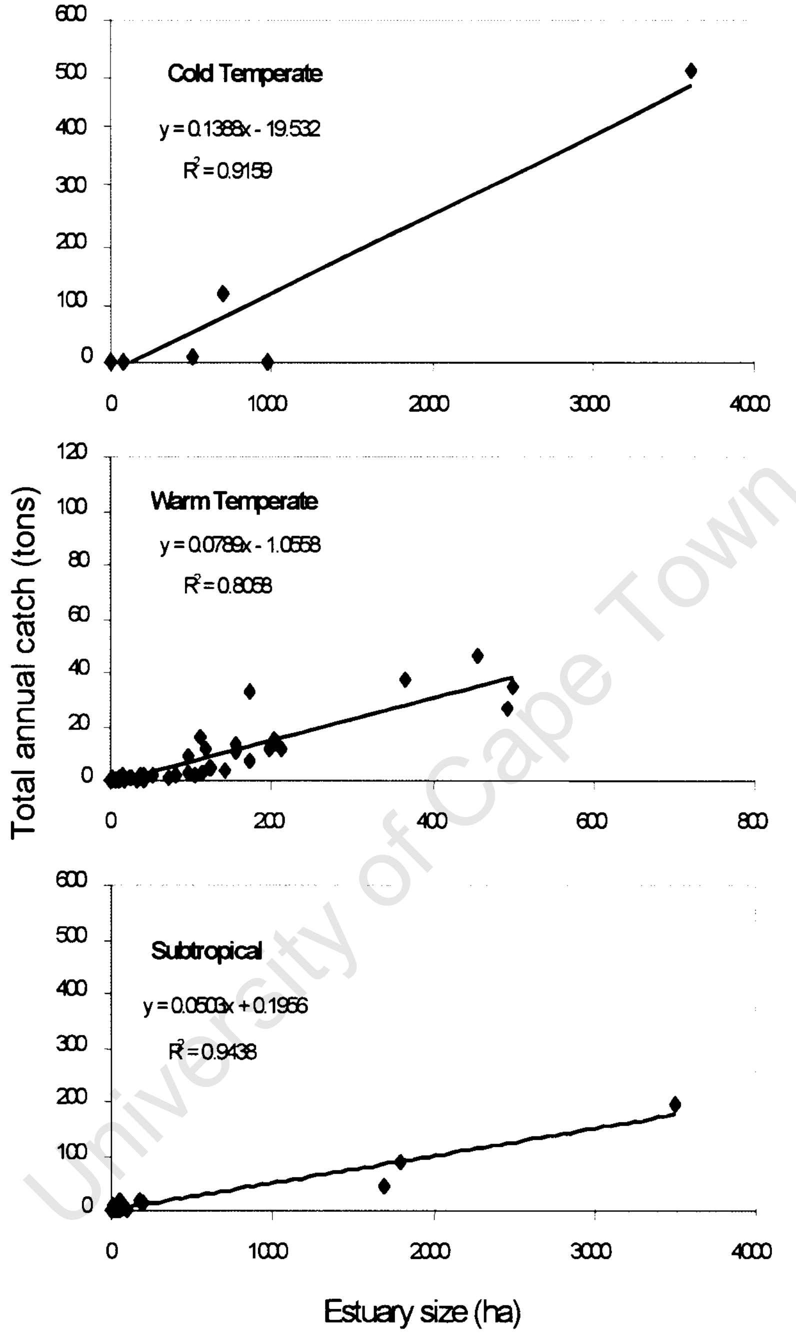


Figure 2.2 Relationships between estuary size and catch in each of the three biogeographical regions of the South African coast.

Finally, both estuarine size (ha) and type (all 5 types) were used to explain catches within the warm temperate and subtropical biogeographical regions using general linear models. Again, these models exclude the three outlying estuaries mentioned above. The models were able to explain 82% and 98% of the variance in catches for the two regions, respectively.

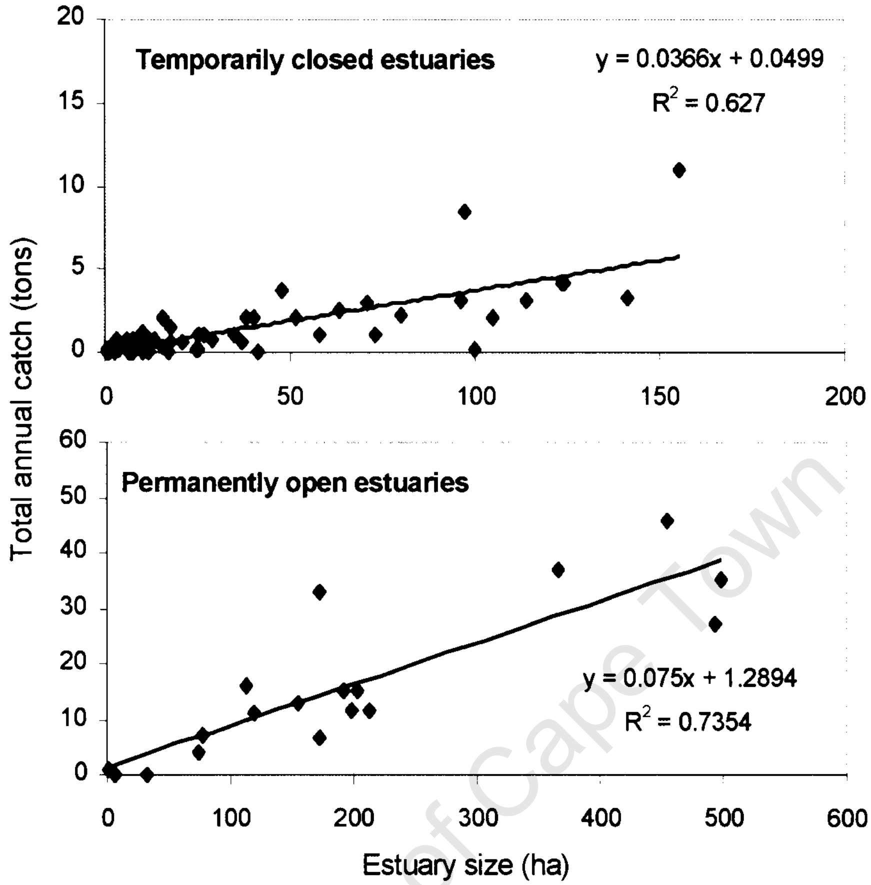


Figure 2.3 Difference in the relationship between estuary size and catch for permanently open and temporarily closed estuaries in the warm temperate and subtropical regions.

Both models were highly significant ($p < 0.001$):

warm temperate region:

Catch (tons) = 0.904 + 0.068*Size + 2.510 (if Permanently open)

subtropical region:

Catch (tons) = -3.461 + 0.055*Size + 8.213 (if Lake) -27.23 (if Bay)
+ 5.605 (if Permanently open) + 10.140 (if River mouth)

Estimated total estuarine catch

These models were applied to the area and type data for the remaining estuaries to estimate total estuarine catches. Existing estimates of catches for 129 estuaries amount to 1700 tons per annum, and the new estimates for the remaining 126 estuaries brings the total to 2482 tons (Table 2.4).

Table 2.4 Estuarine area and estimated annual total catches (tonnes) per fishery for all estuaries in each of five coastal regions in South Africa.

	Estuaries	Ha	Angling	Castnet	Gill-net	Seine-net	Traps	Spear	Total	kg/ha
West	9	5 884	14	2	625	-	-	-	**641**	109
South	52	12 866	410	31	152	12	-	-	**605**	47
East	54	3 764	224	20	52	-	-	-	**296**	78
Transkei	67	2 612	141	13	33	-	-	-	**187**	71
KZN	73	46 811	245	52	297	72	73	16	**755**	16*
TOTAL	**255**	**71 937**	**1034**	**118**	**1159**	**84**	**73**	**16**	**2484**	**35**

* excluding St Lucia, the average yield for KwaZulu-Natal is 58.1kg/ha per annum

Anglers (including castnet activities) and gillnetters account for 93% of the total catch, with total catches being roughly equal for the two groups of fishers. Seine-net and traditional fisheries account for the remainder (Table 2.4).

West coast estuaries have the highest yields per ha (Table 2.4), reflecting the generally high fishery productivity of this region. Indeed, the high overall catch comes from a small number of large estuaries, mainly the Berg and Olifants estuaries. In KwaZulu-Natal, most of the catch is from Kosi and St. Lucia estuaries. On the south coast, Knysna is estimated by the model to have a catch of over 250 tons, but this is likely to be an overestimate.

Estuarine catch composition

Catches within estuaries in South Africa are dominated by harders, most of which are caught on the west coast (Table 2.5). Spotted grunter and dusky kob are the next most important species caught in estuaries, being the main catch of the rest of the country (Table 2.5). These three species make up 69% of the total biomass of fish caught in estuaries. On the west coast, harders make up 86% of catches, and elf make up most of the remaining catch (10%). On the south coast, spotted grunter makes up 45% of catches, harder 18% and white steenbras 10%, and dusky kob makes up 6% of catch weight. On the east coast, catches are dominated by dusky cob (48%) and spotted grunter (31%). Catch composition in Transkei is unknown. In KwaZulu-Natal, catches are dominated by dusky kob (35%), flathead mullet (11%) and spotted grunter (11%), and evenfin pursemouth, Mozambique tilapia, groovy mullet, largescale mullet make up >5% of catch weight.

Table 2.5 Estuarine catch composition by weight and percentage, excluding Transkei catches and traditional fisheries in KwaZulu-Natal.

Species	Common name	Cat.	West Tons	South Tons	East Tons	KZN Tons	TOTAL Tons	%
Liza richardsonii	Harder	IIc	539.79	110.89	17.91	-	668.59	31.52
Pomadasys commersonni	Spotted grunter	IIa	-	270.62	73.51	71.88	416.01	19.61
Argyrosomus japonicus	Dusky kob	IIa	-	36.35	113.31	227.51	377.17	17.78
Mugil cephalus	Flathead mullet	IIa	10.64	13.56	2.16	72.14	98.50	4.64
Pomatomus saltatrix	Elf	IIc	62.58	0.87	1.63	1.47	66.55	3.14
Lithognathus lithognathus	White steenbras	IIa	0.22	60.22	4.47	-	64.92	3.06
Gerres methueni/rappi	Evenfin pursemouth	IIb	-	-	-	50.52	50.52	2.38
Liza dumerilii	Groovy mullet	IIb	-	13.02	0.50	35.07	48.59	2.29
Oreochromis mossambicus	Mozambique tilapia	IV	0.20	-	-	44.11	44.31	2.09
Liza macrolepis	Largescale mullet	IIa	-	-	-	35.20	35.20	1.66
Clarius gariepinus	Sharptooth catfish	IV	-	-	-	28.34	28.34	1.34
Liza tricuspidens	Striped mullet	IIb	-	26.34	1.46	-	27.80	1.31
Lichia amia	Leervis/garrick	IIa	0.79	21.13	4.09	-	26.00	1.23
Rhinobatos annulatus	Lesser guitarfish	III	0.20	22.94	-	-	23.13	1.09
Acanthropagrus berda	Perch/riverbream	IIa	0.63	-	0.67	19.33	20.63	0.97
Elops machnata	Ladyfish/tenpounder	IIa	-	-	7.38	9.36	16.73	0.79
Rhabdosargus holubi	Cape stumpnose	IIa	-	14.26	1.63	-	15.89	0.75
Leiognathus equula	Slimy	IIb	-	-	-	14.25	14.25	0.67
Rhabdosargus sarba	Natal stumpnose	IIb	-	-	-	14.17	14.17	0.67
Trachurus trachurus	Maasbunker	III	12.14	-	-	-	12.14	0.57
Pomadasys hasta/kakaan	Javelin grunter	IIc	-	-	-	10.06	10.06	0.47
Galeichthyes feliceps	Barbel	IIb	1.55	1.62	3.58	-	6.75	0.32
Diplodus sargus	Dassie/blacktail	IIc	-	3.18	0.27	-	3.45	0.16
Lutjanus argentimactulus	River snapper	IIc	-	-	-	3.38	3.38	0.16
Myxus capensis	Freshwater mullet	Vb	-	0.46	-	2.39	2.85	0.13
Rhabdosargus globiceps	White stumpnose	IIc	0.13	2.60	0.11	-	2.84	0.13
Sparodon durbanensis	White musselcracker	III	-	2.60	0.16	-	2.76	0.13
Johnius dussumieri	Mini kob	IIc	-	-	-	2.70	2.70	0.13
Chelidonichthyes capensis	Gurnard	III	0.28	-	2.01	-	2.29	0.11
Carcharhinus leucas	Zambezi shark	IIc	-	-	-	2.17	2.17	0.10
Platycephalus indicus	Bartailed flathead	IIc	-	-	-	2.17	2.17	0.10
Muraenesox bagio	Pike conger	III	-	-	-	1.36	1.36	0.06
Chanos chanos	Milkfish	IIc	-	-	-	1.09	1.09	0.05
Monodactylus falciformis	Cape/Oval moony	IIa	0.06	0.61	0.07	-	0.73	0.03
Caranx ignobilis	Giant kingfish	IIb	-	-	-	0.70	0.70	0.03
Caranx sexfasciatus	Bigeye kingfish	IIb	-	-	-	0.70	0.70	0.03
Caranx melampygus	Bluefin kingfish	IIc	-	-	-	0.70	0.70	0.03
Caranx papuensis	Brassy kingfish	IIc	-	-	-	0.70	0.70	0.03
Diplodus cervinus	Zebra/wildeperd	III	-	0.56	0.07	-	0.62	0.03
Liza alata	Diamond mullet	IIb	-	-	-	0.58	0.58	0.03
Scomberoides lysan	Doublespotted queenfish	IIb	-	0.41	-	-	0.41	0.02
Lithognathus mormyrus	Sand steenbras	III	-	0.41	-	-	0.41	0.02
Thryssa vitrirostris	Orangemouth glassnose	IIb	-	-	-	0.41	0.41	0.02
Gerres acinaces	Smallscale pursemouth	IIb	-	-	-	0.28	0.28	0.01
Megalops cyprinoides	Oxeye tarpon	Vb	-	-	-	0.27	0.27	0.01
Dasyatis chrysonota	Blue stingray	III	0.26	-	-	-	0.26	0.01
Sarpa salpa	Strepie	IIc	-	0.15	0.07	-	0.21	0.01
Mustelus mustelus	Smooth houndshark	III	0.10	-	0.11	-	0.21	0.01
Monodactylus argenteus	Natal/Round moony	IIb	-	-	-	0.15	0.15	0.01
Pomadasys multimaculatum	Cock grunter	III	-	-	-	0.08	0.08	-
Myliobatus aquila	Eagleray	III	0.07	-	-	-	0.07	-
Sphyraena barracuda	Barracuda	IIb	-	-	-	0.05	0.05	-
Sphyraena jello	Pickhandle barracuda	IIc	-	-	-	0.05	0.05	-
Terapon jarbua	Thornfish	IIa	-	-	-	0.02	0.02	-
Glossogobius giuris	Tank goby	IV	-	-	-	0.02	0.02	-
Anguilla bengalensis	African mottled eel	Va	-	-	-	0.02	0.02	-
Anguilla bicolour	Shortfin eel	Va	-	-	-	0.02	0.02	-
Anguilla marmorata	Giant mottled eel	Va	-	-	-	0.02	0.02	-
Anguilla mossambica	Longfin eel	Va	-	-	-	0.02	0.02	-
Spondyliosoma emarginatum	Steentjie	III	0.01	-	-	-	0.01	-
Lutjanus fulviflamma	Dory snapper	IIc	-	-	-	0.01	0.01	-
Ambassis productus	Longspine glassy	Ia	-	-	-	0.01	0.01	-
Ambassis gymnocephalus	Bald glassy	Ib	-	-	-	0.01	0.01	-
Ambassis natalensis	Slender glassy	Ib	-	-	-	0.01	0.01	-
	Total catch (tons)		**629.64**	**602.79**	**235.15**	**653.49**	**2121.07**	

2.3.3 *Estuarine contribution to inshore marine fisheries*

2.3.3.1 Types of fisheries, participation and effort

Recreational shore angling

Most recreational shore angling is by rod and reel, but this sector also includes those fishing from the shore, piers and jetties with handlines. A proportion of these anglers use off-road vehicles to get to less accessible fishing areas. There are an estimated 412 000 regular shore anglers in South Africa (McGrath *et al.* 1997). The majority of recreational anglers come from the upper two quintiles of income earners in South Africa (McGrath *et al.* 1997). Total shore angling effort amounts to approximately 2 778 000 angler days per year, of which 53% is in KwaZulu-Natal (Brouwer *et al.* 1997, McDonald *et al.* 1998, Mann *et al.* 1998).

Recreational boat angling

Recreational boat fishing gear includes both rod and reels and handlines. Boats used range from small dinghies to skiboats of 6-8 m in extent, to the large tuna or striker craft. There are an estimated 12 054 recreational boat anglers, operating from 3 444 boats (McGrath *et al.* 1997), on 92 988 boat-days per year. However, in many cases, the distinction between commercial and recreational boat fishermen is blurred, ranging from purely recreational fishers to those selling some catches to finance boating expenses or to supplement an existing income, to those who fish on a permanent commercial basis.

Recreational spearfishing

Recreational spearfishers operate from boats or swim out from the shore, with spearguns. There is considerable investment in fishing equipment, including wetsuits, fins and other paraphernalia in addition to spearguns. There are an estimated 7000 participants in the recreational spearfishery (Mann *et al* 1997), responsible for about 126 000 spearfishing days per year.

Commercial boat-based linefishing

Boats used in the commercial linefishery range from small dinghies and skiboats to large decked freezer boats that operate to the edge of the continental shelf (Griffiths 2000a). There are approximately 18 533 commercial line fishers operating from 2 581 registered boats (Griffiths & Lamberth 2002), for 380 800 boat-days per year.

Commercial gillnet and beach seine netting

The gear and fishing methods used in these commercial fisheries are similar to those described for the estuarine fisheries. Depending on the area in which they operate, gillnetters are restricted to the use of either two or four 75 m nets of 44-178mm mesh size, but separate permit -holders may join their nets. Gillnet permits are issued exclusively for catching harders and St Joseph sharks *Calorhynchus capensis*, and a maximum of 10 by-catch linefish are allowed per day. All gillnet permits issued for the marine environment are on the west coast, from Yzerfontein northwards (approximately 321 permits), apart from a limited number of permits issued at Hawston on the south coast (currently 3 permits), and occasional experimental fisheries elsewhere. In addition, illegal gillnetting occurs throughout the South African coastline, though mostly on the west and south coasts. There are an estimated 268 illegal gillnets on the west coast, 60 on the south coast, and 120 on the KwaZulu-Natal coast.

Beach-seine permit holders to the west of Walker Bay on the south coast are restricted to nets of 275m long, while on the rest of the south and east coasts they are restricted to 137m, and in KwaZulu-Natal, 100m. Minimum mesh sizes are 14mm in Kwazulu-Natal and 44mm everywhere else. There are 84 beach-seine permits on the west coast, 76 on the south coast, 8 on the east coast and 27 in KwaZulu-Natal. Except for three, the KwaZulu-Natal permits are issued exclusively for pilchards *Sardinops sagax* during the annual sardine run. In addition, there are at least 10 illegal beach-seine nets in use on the south coast, but no estimates have been made for the rest of the country (Lamberth 2000a).

There are approximately 2 700 people who derive some sort of income in the legal inshore net fisheries along the west and south coasts, with a total effort of approximately 32 000 net-days per year. About half of the crew numbers are employed in the beach seine fishery. There is evidence that illegal gillnetting and beach-seining activities have both increased dramatically over the last three years, since the introduction of the Marine Living Resources Act (Act 18 1998).

Overall, it is estimated that there are about 431 000 recreational fishers and well over 21 000 commercial fishers active in the inshore marine environment in South Africa.

2.3.3.2 Inshore Marine Catches

The total inshore marine catch is estimated to be 28 107 tons per year (Table 2.6). Of this 60% is made up by the commercial linefish sector and 23% by the commercial netfishery, the remainder being made up of recreational fisheries.

Table 2.6 Inshore marine catches for different fisheries along different sections of the South African coast. All values are in tonnes per year.

	West	South	East	Transkei	KZN-Natal	Total
Recreational shore angling	115	1 021	1 039	169	662	**3 037**
Recreational boat angling	407	171	236	No data	470	**1 283**
Recreational Spearfishing	19	79 (S & E coast)		No data	108	**123**
Commercial linefishing	10 191	2 848	2 615	110	1335	**17 099**
Commercial net fishing	4 303	1 827	159	No data	192	**6 481**
TOTAL	**15 035**	**5 950**	**4 096**	**279**	**2 747**	**28 107**

Inshore fishery catches on the west coast, which make up 53% of the total inshore fishery catch, are predominantly commercial, whereas recreational catches are comparable to commercial catches in the rest of the country, becoming relatively more important towards KwaZulu-Natal (Table 2.6).

Estuary-associated species in marine catches

Numerous estuary-associated species have been recorded in all types of inshore marine fisheries (Table 2.7). Recreational shore angler catches and commercial gill- and seine-net catches are dominated by estuary-associated species (83% of numbers and 83% of mass, respectively). On the other hand, recreational boat and spearfishers, and commercial boat fishers catch a relatively small proportion of estuary-associated species, which make up about 7% of catches (Table 2.7).

The main estuary-associated species caught by recreational shore anglers are elf and strepie, which together make up over 50% of the catch (Table 2.7). Both of these species are estuary-dependent (category IIc). Numbers of dassie (IIc) and piggy are also significant, making up more than 5% of the catch. Commercial net catches are dominated by harders (75%).

The most important estuary-associated species featured in recreational boat catches is catface rockcod (3%), although this is not an estuary-dependent species (category III). In commercial boat catches, the highly estuary-dependent dusky kob (category IIa) features most importantly, but only makes up 1% of total catch. This low proportion is partly due to the collapsed status of the stock (Griffiths 1997a,b).

Zebra and white musselcracker are the most common estuary-associated species in recreational spearfishing catches, but these each only make up less than 3% of catches. However, these are category III species, and the most common estuarine-dependent species is leervis (1%), which is completely dependent on estuaries for the juvenile phase of its life-cycle.

Table 2.7 Percentage contribution of estuarine associated species to the overall catches in different inshore marine fisheries, and total percentage of estuarine species in catches. Figures are percentage of total biomass in all cases except recreational shore angling, in which data are in numbers of fish.

Species	Common name		Recreational Shore	Recreational Boat	Recreational Spear	Commercial Boat	Commercial Net
Acanthropagrus berda	Perch/riverbream	IIa	0.16	-	-	-	0.08
Argyrosomus japonicus	Dusky kob	IIa	1.73	0.21	-	1.18	0.65
Argyrosomus spp.	Silver and dusky kob	-/IIa	-	0.98	-	4.75	1.02
Elops machnata	Ladyfish/tenpounder	IIa	0.06	-	-	-	0.04
Lichia amia	Leervis/garrick	IIa	0.46	0.06	1.30	-	0.02
Lithognathus lithognathus	White steenbras	IIa	1.40	-	0.01	-	0.82
Liza macrolepis	Largescale mullet	IIa	-	-	-	-	0.18
Mugil cephalus	Flathead/springer mullet	IIa	0.12	-	-	-	0.56
Pomadasys commersonni	Spotted grunter	IIa	1.09	0.04	-	-	0.30
Rhabdosargus holubi	Cape stumpnose	IIa	2.10	0.02	-	-	0.01
Caranx ignobilis	Giant kingfish	IIb	-	0.08	-	-	-
Caranx sexfasciatus	Bigeye kingfish	IIb	-	-	-	-	0.01
Galeichthyes feliceps	Barbel	IIb	0.52	0.05	-	0.01	0.06
Gerres methueni/rappi	Evenfin pursemouth	IIb	-	-	-	-	0.51
Leiognathus equula	Slimy	IIb	-	-	-	-	0.14
Liza alata	Diamond mullet	IIb	-	-	-	-	0.01
Liza dumerilii	Groovy mullet	IIb	-	-	-	-	0.18
Liza tricuspidens	Striped mullet	IIb	1.03	-	-	-	0.07
Rhabdosargus sarba	Natal stumpnose	IIb	0.76	0.08	0.09	-	0.08
Caranx melampygus	Bluefin kingfish	IIc	-	-	-	-	0.01
Caranx papuensis	Brassy kingfish	IIc	-	-	-	-	0.01
Carcharhinus leucas	Zambezi shark	IIc	-	-	-	-	0.02
Chanos chanos	Milkfish	IIc	-	-	-	-	0.01
Diplodus sargus	Dassie/blacktail	IIc	7.64	0.02	0.63	-	0.07
Johnius dussumieri	Mini kob	IIc	-	-	-	-	0.05
Liza richardsonii	Harder	IIc	2.67	-	-	-	74.97
Lutjanus argentimactulus	River snapper	IIc	-	-	-	-	0.03
Platycephalus indicus	Bartailed flathead	IIc	0.02	0.01	-	-	0.02
Pomadasys hasta/kakaan	Javelin grunter	iic	0.02	0.20	-	0.02	-
Pomatomus saltatrix	Elf	IIc	27.18	0.70	-	0.27	0.91
Rhabdosargus globiceps	White stumpnose	IIc	1.40	0.57	-	0.89	0.88
Sarpa salpa	Strepie	IIc	24.30	0.01	-	0.01	0.13
Sillago sihama	Silver sillagio	IIc	0.08	-	-	-	-
Chelidonichthyes capensis	Gurnard	III	0.20	0.04	-	0.02	0.04
Dasyatis chrysonota	Blue stingray	III	0.04	-	-	-	-
Diplodus cervinus	Zebra/wildeperd	III	0.46	0.10	2.47	-	-
Epinephelus andersoni	Catface rockcod	III	0.07	2.93	-	0.03	-
Gymnura natalensis	Butterfly/diamond ray	III	0.02	-	-	-	0.01
Lithognathus mormyrus	Sand steenbras	III	0.93	-	-	-	0.01
Muraenesox bagio	Pike conger	III	-	-	-	-	0.01
Mustelus mustelus	Smooth houndshark	III	0.26	0.16	0.01	-	0.60
Myliobatus aquila	Eagleray	III	0.06	-	-	-	0.03
Otolithes ruber	Snapper kob	III	0.04	0.24	-	0.01	-
Pomadasys olivaceum	Piggy	III	6.10	0.04	-	-	-
Rhinobatos annulatus	Lesser guitarfish	III	0.54	-	-	-	0.03
Sparodon durbanensis	White musselcracker	III	0.47	-	2.41	-	-
Spondyliosoma emarginatum	Steentjie	III	0.43	0.10	-	0.13	0.07
Trachinotus africanus	Southern pompano	III	0.26	-	-	-	-
Trachurus trachurus	Maasbunker	III	0.54	0.15	0.01	0.06	0.34
Myxus capensis	Freshwater mullet	Vb	-	-	-	-	0.02
Total % of estuarine species in catch			**83.14**	**6.79**	**6.93**	**7.40**	**83.03**

The contribution of different categories of estuary-associated species to inshore marine fisheries is summarised for each part of the coast in Table 2.8. Category I species, which are largely resident in estuaries, hardly feature at all in inshore marine catches. Category IIa species, which are entirely dependent on estuaries, generally make up a relatively small percentage of catches, ranging from 1.3% of recreational boat and spear catches to 3.7% of commercial gillnet catches, 5.9% of commercial boat catches and 7.1% of recreational shore catches. However, they do make up high proportions of certain catches in certain regions (Table 2.8). Historically, dusky kob and white steenbras comprised a large proportion of shore angler catches, but overexploitation of these species has led to stock collapses to present levels of 4% and 6% of pristine spawner biomass, respectively (Griffiths 1996,1997, Bennett 1993). The proportion of category IIb species in catches is generally lower than of category IIa species (Table 2.8).

The majority of estuary-associated fish biomass in recreational shore-angling and in commercial gillnet catches is made up of category IIc species, which are species whose juveniles are found mainly in marine environments but also occur in estuaries. Category III species occur in estuaries but are not dependent on them. These make up over 10% of shore-angling catches, 3.8% of recreational boat and 4.9% of recreational spearfishing catches, but are not particularly important in commercial catches (Table 2.8). Category IV species are freshwater species, and thus do not feature in marine catches. Category V species have only been recorded in very small quantities in KwaZulu-Natal, though small quantities are also known to be caught elsewhere. These species are entirely dependent on estuaries, but they are normally caught in rivers, beyond the scope of this study.

2.3.4 *Economic value of estuarine fish*

2.3.4.1 Values considered

All values are considered in terms of value added to the economy (contribution to Gross Domestic Product). Subsistence outputs are not actually recorded as part of GDP, but would be in an ideal world. The value of subsistence fisheries was taken as the gross value of landed catches, based on the market value of fish caught. The values of commercial and recreational fisheries were calculated mainly on the basis of data in McGrath *et al.* (1997). Commercial fishery values include the value added by subsidiary industries. Recreational values include the expenditure by anglers on equipment and travel to fishing sites.

Table 2.8 Percentage contribution of different categories of estuarine associated fish to the inshore marine fisheries in each of the coastal sections. All percentages in terms of biomass except recreational shore angling, in terms of numbers.

		Dependence category									
		Ia	**Ib**	**IIa**	**IIb**	**IIc**	**III**	**IV**	**Va**	**Vb**	**Total**
Recreational shore	West			0.51	0.17	41.26	13.81				55.75
	South			5.31	1.27	58.81	9.13				74.52
	East			9.00	1.64	59.64	18.61				88.98
	Transkei			11.52	1.97	45.97	3.66				63.12
	KZN			5.22	3.98	78.40	3.92				91.52
	Total			**7.12**	**2.30**	**63.31**	**10.41**				**83.14**
Recreational boat	West			0.02	<0.01	0.80	0.10				0.92
	South			7.31	<0.01	3.72	0.77				11.796
	East			0.33	0.24	0.47	1.75				2.80
	Transkei										
	KZN			0.74	0.42	1.84	9.05				12.05
	Total			**1.31**	**0.20**	**1.51**	**3.77**				**6.79**
Recreational spear	West			0.05		0.09	0.09				0.23
	South & east			0.58		0.96	6.74				8.29
	KZN			4.67	0.44		2.78				7.88
	Total			**1.31**	**0.09**	**0.63**	**4.89**				**6.93**
Commercial boat	West			0.09	<0.01	0.80	0.10				0.91
	South			7.31	<0.01	3.72	0.77				11.80
	East			27.45	0.03	0.24	0.15				27.86
	Transkei			8.08	0.91	0.01	0.26				9.26
	KZN			6.13	0.11	0.44	0.82				7.49
	Total			**5.94**	**0.02**	**1.20**	**0.26**				**7.40**
Seine & gillnet	West			1.05	0.04	80.86	1.10				83.06
	South			4.46	0.05	76.03	1.44				81.98
	East			2.16	0.97	96.59	0.01				99.73
	Transkei										
	KZN	<0.01	<0.01	45.46	27.51	4.94	0.70		0.02	0.72	79.37
	Total	**<0.01**	**<0.01**	**3.67**	**1.08**	**77.10**	**1.16**		**0.01**	**0.03**	**83.03**
Species total		1	2	14	15	19	21		4	2	

2.3.4.2 Value of estuarine fisheries

Applying the average per-kg values of the different fisheries to the total catches in each coastal region, the total value of fisheries within South African estuaries is estimated to be about R433 million per year (1997 Rands; Table 2.9). This is based on an estimated total annual catch of 2 482 tons (Table 2.4).

Table 2.9 Estimated annual value (1997 rands) of estuarine fisheries along different stretches of the South African coast.

	West	South	East	Transkei	KZN	TOTAL	%
Angling	5 803 980	169 818 301	92 657 453	58 484 198	101 735 478	**428 499 410**	99
Castnet	6 776	95 821	61 140	38 591	161 392	**363 719**	0.1
Gill-net	1 925 000	466 821	158 510	100 050	913 220	**3 563 601**	0.8
Seine-net	-	36 854	-	-	221 760	**258 614**	0.1
Fish traps	-	-	-	-	224 840	**224 840**	0.1
Spear	-	-	-	-	49 280	**49 280**	<0.1
Total	**7 735 756**	**170 417 798**	**92 877 103**	**58 622 838**	**103 305 970**	**432 959 465**	
%	1.8	39.4	21.5	13.5	23.9		

Ninety-nine percent of this value (nearly R429 million) is the value of recreational angling, while net and traditional fisheries together make up the remaining 1% of value (Table 2.9). This distribution of values among estuarine fishery sectors is very different from the distribution of catches (Table 2.4), which are equally dominated by recreational and gillnet fishing. Furthermore, the estimated value of commercial fisheries (about R3.8 million), derived from marine fishery values, may be slightly overestimated. This is because fish caught in estuaries are generally smaller than in marine catches, which means that catch masses are made up of proportionally more individuals. Smaller fish are of 'lower quality' and do not fetch the same prices per kg as those in the larger size classes.

With over 72 000 anglers in the recreational fishery, compared with some 1350 in the commercial fisheries, these aggregate values (Table 2.9) translate to average values of about R6 000 per recreational angler per year (expenditure), *versus* about R2 800 per commercial fisher (income). The recreational value is realised as income to an unknown number of participants in subsidiary industries.

Thus substantial amounts are spent annually by large numbers of anglers in estuaries, most of whom belong to middle-upper income groups, whereas a relatively few fishers from lower-middle income groups are apparently earning an average annual income well below the poverty line. Indeed, it is increasingly being realised that commercial estuarine fisheries are generally non-viable as sustainable long-term ventures. Prices for estuarine fish are often low, and operating costs are still relatively high, even though they are slightly lower than in the marine environment. The only way these fisheries can be profitable, at least in the short term, is through targeting the more vulnerable linefish species, as fishing solely for mullet and similar species in estuaries is non-profitable (Hutchings & Lamberth 1999, Beckley *et al.* 2000, Kyle 2000a). However, targeting linefish is usually only profitable for a short period until stocks become locally depleted.

Exacerbating this problem is the fact that commercial estuarine fisheries in South Africa are drastically oversubscribed, the large amount of latent effort making the fisheries economically inefficient. The investments in inputs into commercial fisheries in estuaries are often much higher than gross income. For example, gillnet permit holders on the Berg River estuary on average operate at a loss of about R5 600 per annum. It has been estimated that an effort reduction in the region of 60% is required in order to obtain maximum economic yield from this estuarine gillnet fishery (Hutchings & Lamberth 2002b).

Comparatively few people are involved in the traditional fisheries, which are worth just a fraction of the other fisheries, amounting to about R2 300 per fisher per year in terms of subsistence income. Viewing the traditional fisheries in the same economic terms as other fisheries may be somewhat misleading in terms of their importance. It should be noted that these fisheries form an integral part of the survival of communities which rely on them for their protein source. Indeed, such fisheries in tropical Africa commonly contribute a high percentage of household income (Turpie *et al.* 1999b, Turpie 2000b).

A similar type of argument might be made for the commercial fisheries, especially when compared to the recreational fishery. However, on the west coast, where much of the commercial effort takes place, it is evident that the people involved in the fishery are not heavily reliant on the fishery contributing to their income (Hutchings & Lamberth 2002b). On the Berg estuary, none of the fishers interviewed regarded netfishing as their main occupation, 80% of them being employed in other sectors, and the remainder being retired. Indeed, the net fishery contributed over 50% of income for only 10% of the fishers (Hutchings & Lamberth in 2002b).

2.3.5 Estuarine contribution to inshore marine fishery values

The total value of inshore marine fisheries is about R2.4 billion per year (1997 rands; Table 2.10). Approximately 82% of this value is the value of the recreational fisheries (almost all from shore angling), the remaining 18% being commercial value. Similar arguments apply to the disproportionately high value of recreational fisheries in comparison to catch ratios as for the estuarine fisheries. The recreational value, spread among about 431 000 fishers, amounts to an average value (expenditure) of over R4500 per fisher per year, whereas the approximately 21 000 people involved in commercial fisheries gain an average of R20 000 per year (income).

Roughly half of the total inshore marine fishery value (52%) is made up of estuary-associated species (Table 2.10). However, not all of these fish are equally dependent on estuaries.

Table 2.10 Percentage contribution of estuarine associated fishes to the total value of the inshore marine fishing sectors in the different coastal regions, the total annual values of the fisheries, the amount and percentage of total which is comprised of estuary-associated species, and the contribution of estuaries to total fishery values. The latter is calculated on the basis of 100% of the value of Category Ia, Ib, IIa, Va and Vb species, 90% of the value of Category IIb species, and 30% of the value of Category IIc species. Category III species are not included in this value.

	Estuary-associated species categories								Total value	Estuary fish contribution		Value due to estuaries	
	Ia	**Ib**	**IIa**	**IIb**	**IIc**	**III**	**Va**	**Vb**	**R million**	**R million**	**%**	**R million**	**%**
Recreational shore													
West			0.60	0.03	18.05	2.24			105.70	22.12	20.92	6.39	6.0
South			7.29	0.29	38.32	5.75			825.70	426.45	51.65	157.29	19.0
East			16.25	1.13	46.15	21.48			513.00	436.12	85.01	159.63	31.1
Transkei			23.22	0.89	36.65	4.32			87.25	56.78	65.08	30.55	35.0
KZN			11.47	4.46	69.15	5.51			233.29	211.32	90.58	84.50	36.2
Total			**11.42**	**1.09**	**43.05**	**9.74**			**1764.93**	**1152.78**	**65.31**	**438.36**	**25.3**
Recreational boat													
West			0.00	0.00	0.39	0.01			112.06	0.45	0.41	0.13	0.1
South			0.37	0.00	3.77	0.22			14.48	0.63	4.36	0.22	1.5
East				0.02	1.66	2.16			0.88	0.03	3.84	0.00	0.5
KZN					1.08				0.58	0.01	1.08	0.00	0.3
Total			**0.04**	**0.00**	**0.79**	**0.05**			**128.00**	**1.13**	**0.88**	**0.36**	**0.3**
Recreational spear													
West			0.12		0.06	0.12			7.24	0.02	0.30	0.01	0.1
S & E			0.19		0.41	8.28			43.23	3.84	8.88	0.13	0.3
KZN			4.79	0.44		13.15			18.30	3.36	18.38	0.95	5.2
Total			**0.53**	**0.03**	**0.34**	**7.57**			**68.76**	**7.22**	**8.48**	**1.09**	**0.7**
Commercial boat													
West			0.04	0.00	0.78	0.05			188.89	1.66	0.88	0.53	0.3
South			11.09	0.00	2.50	0.20			82.09	11.33	13.80	9.72	11.8
East			36.52	0.01	0.16	0.03			86.00	31.58	36.72	31.45	36.6
KZN			7.09	0.04	0.21	0.99			50.64	4.22	8.33	3.64	7.2
Total			**11.05**	**0.00**	**0.97**	**0.15**			**407.62**	**48.78**	**12.17**	**45.34**	**11.3**
Seine & gillnet													
W.coast			3.89	0.02	72.90	1.86			11.92	9.37	78.67	3.07	25.8
S.coast			10.99	0.01	46.25	2.11			7.49	4.45	59.36	1.86	24.9
E.coast			9.12	0.50	90.04	0.03			0.41	0.41	99.70	0.15	36.6
KZN	0.01	0.01	57.48	2.70	25.15	6.31	0.01	0.01	0.25	0.23	91.64	0.17	67.5
Total	**0.01**	**0.01**	**7.30**	**0.06**	**62.72**	**1.97**	**0.01**	**0.01**	**20.07**	**14.46**	**72.05**	**5.26**	**26.2**
TOTAL									**2389.38**	**1224.37**	**52.3**	**490.40**	**21.3**

Category Ia, Ib, IIa, Va and Vb species are 100% dependent on estuaries to complete their life cycles. Because the juveniles of Category IIb species are largely confined to estuaries, their level of dependence on estuaries was considered to be very high, and was estimated as 90%. The overall numbers of Category IIc species, whose juveniles mainly occur in marine environments, are augmented by the presence of estuarine habitat areas. Estuarine area comprises about 30% of the juvenile habitat available to these species, and those juveniles using estuaries are frequently in better condition than those in marine habitats (De Decker & Bennett 1985). I thus estimate that 30% of the marine catches of Category IIc species can be attributed to estuarine export. Thus adjusting values according to the level of contribution that estuaries make to the catches of species of different categories, the estimated contribution from estuaries to inshore marine fisheries is 21% of the total value, or R490 million per year (Table 2.10). In other words, this value would be lost if estuaries were 'removed' from the coastline.

The relative contribution of estuaries to fisheries varies between types of fisheries and around the coast. The contribution of estuary-dependent species to recreational shore angling values increases from 6% on the west coast to 36% on the KwaZulu-Natal coast. Estuaries contribute 25% of the total value of the recreational shore fishery, whereas they contribute only 0.3% and 0.7% to the value of the recreational boat and spear-fisheries (Table 2.10). Overall, the estuarine contribution to marine recreational fishery values is about R440 million per year. This is 90% of the total estimated estuarine contribution to marine fisheries.

The estuarine contribution to commercial boat fisheries ranges from 0.3% of value on the west coast to a peak of 37% on the east coast, and averages 11% for the whole coastline (Table 2.10).

Estuaries contribute a substantial portion of the value of the gill- and seine-net fisheries, increasing from about 25% on the west and south coasts, to 68% on the KwaZulu-Natal coast. However, as most of the fishery is concentrated on the west coast, the overall contribution is about 26% (Table 2.10).

The overall contribution of estuaries to inshore fishery values is summarised in Table 2.11.

2.3.5.1 Total value of estuarine fish

The total value of estuarine and estuary-dependent fisheries is estimated to be R923.39 million in 1997 Rands (Table 2.12). This is equivalent to R1.594 billion in 2008 rands.

Furthermore, this total estuarine fish value is rather unevenly distributed around the coast, with west coast estuaries contributing less than 2% of the total value. Estuaries along the warm temperate coast have the highest aggregate value, and average per estuary values (Table 2.12). East coast estuaries, in particular are worth over R75 000 per ha per year (1997 rands) in terms of fish production (Table 2.12). However, average values may not be very reliable predictors of individual estuary values, which are related to several factors such as size and mouth status, as well as geographical location.

Table 2.11 Summary of the estimated total contribution of estuaries to the annual value (1997 Rands) of inshore marine fisheries along different stretches of the South African coast, by fishery.

	Estuarine contribution to marine inshore fishery values (million Rands)						
	West	South	East	Transkei	KZN	Total	%
Recreational shore	6.39	157.29	159.63	30.55	84.5	**438.36**	89.4
Recreational boat	0.13	0.22	0		0	**0.35**	0.1
Recreational spear	0.01	0.07	0.07		0.22	**1.09**	0.3
Commercial boat	0.53	9.72	31.45		2.09	**45.34**	9.2
Seine & gillnet	3.07	1.86	0.15		0.17	**5.25**	1.1
Total	**10.13**	**169.16**	**191.30**	**30.55**	**86.26**	**490.40**	
%	2.1	34.5	39.0	6.2	18.2		

2.3.6 *Stock status of estuarine fish species*

Fishing in South Africa is a rapidly-growing activity. It is already evident that the high national fishing effort has taken its toll on fish stocks. This has been quantified in coastal fisheries, where shore-angling catches per unit effort have declined markedly over the past two decades (Bennett & Attwood 1993, Griffiths 2000a), as well as in some estuaries.

In the Swartkops and Sundays estuaries, spotted grunter and dusky kob make up 87% and 90% of angler catches, respectively (Baird *et al.* 1996), indicating a tendency for anglers to concentrate their efforts on particular species, rendering them highly vulnerable to overexploitation. These fears have been confirmed by gillnettling studies in the two estuaries which have indicated a decline in spotted grunter over the past 20 years (Baird *et al.* 1996). Similarly, catch rates of spotted grunter were also found to have declined in Durban Bay estuary over a period of 16 years (Guastella 1994). Moreover, elf was once as abundant as spotted grunter in angler catches in the Swartkops estuary, but has now almost disappeared.

White steenbras, a highly sought-after species, has been depleted both in estuaries and in the marine environment (Bennett 1993, Lamberth 2000c). In the Swartkops estuary, this species formed an important component of catches in 1918, by the 1970s, was reduced to only 3% of anglers catches, and were almost totally absent from catches in the 1990s (Whitfield & Marais 1999).

Table 2.12 Summary of the value of estuarine fisheries and estuary contribution to marine fisheries around different parts of the coast. Values given in 1997 Rands.

	West	South	East	Transkei	KZN	Total
Estuarine fisheries (R million)	7.7	170.4	92.9	58.6	103.3	433.0
Inshore marine (R million)	10.1	169.2	191.3	30.6	89.3	490.4
Total	**17.83**	**339.6**	**284.2**	**89.2**	**192.6**	**923.4**
Number of estuaries	9	52	54	67	73	255
Estuarine area (ha)	5 884	12 866	3 764	2 612	46 811	71 937
Average value/estuary (R million)	2.0	6.5	5.3	1.3	2.6	3.6
Average value/ha (R)	3 030	26 392	75 503	34 131	4 114	12 836

The status of stocks is judged as overexploited, maximally exploited or underexploited on the basis of its current size as a percentage of pristine stock size (or spawner biomass) (Griffiths *et al.* 1999). A maximally exploited stock (one which is exploited close to the maximum sustainable yield) is considered to be at a level of 40-50% of pristine biomass. It should be noted that these judgements assume that current biomass is only a function of harvesting, and that carrying capacity (or maximum stock) has remained constant. In reality, the latter may also be affected by changes in habitat quality, thus also affecting current biomass.

Under the above assumptions, fourteen of the 80 utilised estuary-associated species are considered overexploited (Table 2.13). Of these, elf, dassie, kob, white steenbras, white stumpnose and Natal stumpnose are ranked in the top 30 fish across all inshore sectors in terms of catch, targetting, and the number of people reliant on them (Lamberth & Joubert 1999). The stocks of six of these fourteen species are in a collapsed state, including white steenbras and kob, which are Category IIa species (Table 2.13). A further 27 species, including spotted grunter and leervis, are regarded as maximally or optimally exploited, and are likely to be subject to additional fishing pressure in future.

The remaining 40 species are considered underexploited, as their stocks are at levels greater than 50% of pristine spawner biomass. However, with few exceptions, these are small species such as strepie, flathead mullet and striped mullet, which on a national scale, have limited value to commercial or recreational fishers. Some of them are species which are either at the edge of their range, or have a limited range, with South Africa, but they may be locally important in certain areas, e.g. pursemouths in Kosi Bay.

Table 2.13 The stock status (abundance trend) (A), vulnerability (V), range (R), exploitation level (E) and knowledge (K) of utilized estuarine-associated species in South Africa.

Family	Species	Common name	Cate-gory	CONSERVATION IMPORTANCE A	V	R	E	K
Carcharhinidae	*Carcharhinus leucas*	Zambezi shark	IIc	45	100	0	75	57
Dasyatidae	*Dasyatis chrysonota*	Blue stingray	III	60	0	10	25	71
	Gymnura natalensis	Butterfly/diamond ray	III	60	90	40	50	50
	Himantura uarnak	Honeycomb stingray	III	60	90	0	50	29
Mustelidae	*Mustelus mustelus*	Smooth houndshark	III	55	90	0	100	86
Myliobatidae	*Myliobatus aquila*	Eagleray	III	60	70	0	25	43
Rhinobatidae	*Rhinobatos annulatus*	Lesser guitarfish	III	65	70	10	25	50
Ambassidae	*Ambassis gymnocephalus*	Bald glassy	Ib	55	70	0	0	29
	Ambassis productus	Longspine glassy	Ia	55	70	10	0	29
	Ambassis natalensis	Slender glassy	Ib	55	70	10	0	29
Anguillidae	*Anguilla bengalensis*	African mottled eel	Va	50	100	10	50	50
	Anguilla marmorata	Giant mottled eel	Va	50	100	10	50	50
	Anguilla mossambica	Longfin eel	Va	50	100	10	50	50
	Anguilla bicolor	Shortfin eel	Va	50	100	10	50	50
Ariidae	*Galeichthyes feliceps*	Barbel	IIb	55	100	10	75	71
Belonidae	*Strongylura leiura*	Yellowfin needlefish	IIc	55	70	0	0	21
Carangidae	*Caranx sexfasciatus*	Bigeye kingfish	IIb	55	70	0	25	43
	Caranx melampygus	Bluefin kingfish	IIc	55	70	0	25	21
	Caranx papuensis	Brassy kingfish	IIc	55	70	0	0	21
	Scomberoides lysan	Doublespotted queenfish	IIb	55	70	0	25	7
	Caranx ignobilis	Giant kingfish	IIb	45	80	0	50	50
	Trachurus trachurus	Maasbunker	III	50	70	0	100	79
	Trachinotus africanus	Southern pompano	III	50	70	10	50	21
Chanidae	*Chanos chanos*	Milkfish	IIc	55	80	0	25	43
Charangidae	*Lichia amia*	Leervis/garrick	IIa	50	90	0	75	64
Cichlidae	*Oreochromis mossambicus*	Mozambique tilapia	IV	50	0	10	50	86
Clariidae	*Clarius gariepinus*	Sharptooth catfish	IV	55	0	0	50	86
Elopidae	*Elops machnata*	Ladyfish/tenpounder	IIa	65	100	0	25	36
Engraulidae	*Thryssa vitrirostris*	Orangemouth glassnose	IIb	55	70	0	0	36
Gerreidae	*Gerres methueni/rappi*	Evenfin pursemouth	IIb	55	70	100	50	43
	Gerres acinaces	Smallscale pursemouth	IIb	55	70	0	50	29
Gobiidae	*Glossogobius giuris*	Tank goby	IV	40	70	0	0	36
Haemulidae	*Pomadasys multimaculatum*	Cock grunter	III	45	90	0	50	29
	Pomadasys hasta/kakaan	Javelin grunter	IIc	45	90	0	50	29
	Pomadasys olivaceum	Piggy	III	50	70	0	75	57
	Pomadasys commersonni	Spotted grunter	IIa	40	100	0	100	57
Kuhliidae	*Kuhlia mugil*	Barred flagtail	III	55	0	0	0	29
Leiognathidae	*Leiognathus equula*	Slimy	IIb	55	70	0	0	36
Lutjanidae	*Lutjanus fulviflamma*	Dory snapper	IIc	50	70	0	0	29
	Lutjanus argentimactulus	River snapper	IIc	30	90	0	75	29
Megalopidae	*Megalops cyprinoides*	Oxeye tarpon	Vb	60	90	0	50	14
Monodactylidae	*Monodactylus falciformis*	Cape/Oval moony	IIa	55	70	0	0	36
	Monodactylus argenteus	Natal/Round moony	IIb	55	70	0	0	21
Mugilidae	*Valamugil seheli*	Bluespot mullet	IIc	50	70	0	0	14
	Valamugil buchanani	Bluetail mullet	IIc	50	70	0	25	29
	Liza alata	Diamond mullet	IIb	55	70	0	50	29
	Mugil cephalus	Flathead/springer mullet	IIa	65	90	0	50	50

continued..

Table 2.13 continued.

Family	Species	Common name	Cate-gory	CONSERVATION IMPORTANCE A	V	R	E	K
Mugilidae	*Myxus capensis*	Freshwater mullet	Vb	40	70	40	50	36
	Liza dumerilii	Groovy mullet	IIb	50	70	0	50	36
	Liza richardsonii	Harder	IIc	45	90	10	100	26
	Liza macrolepis	Largescale mullet	IIa	50	70	0	75	29
	Valamugil cunnesius	Longarm mullet	IIa	50	70	0	0	29
	Valamugil robustus	Robust mullet	IIa	50	70	10	0	36
	Liza luciae	St Lucia mullet	IIb	50	70	100	25	14
	Liza tricuspidens	Striped mullet	IIb	65	80	40	50	0
Muraenesocidae	*Muraenesox bagio*	Pike conger	III	55	0	0	0	36
Platycephalidae	*Platycephalus indicus*	Bartailed flathead	IIc	55	70	0	0	36
Pomatomidae	*Pomatomus saltatrix*	Elf	IIc	34	100	0	100	86
Sciaenidae	*Argyrosomus japonicus*	Dusky kob	IIa	4	100	40	100	86
	Johnius dussumieri	Mini kob	IIc	55	90	0	25	29
	Otolithes ruber	Snapper kob	III	60	80	0	50	57
Serranidae	*Epinephelus andersoni*	Catface rockcod	III	13	100	60	100	29
	Epinephelus malabaricus	Malabar rockcod	III	20	100	0	75	14
Sillaginidae	*Sillago sihama*	Silver sillagio	IIc	65	80	0	0	7
Sparidae	*Rhabdosargus holubi*	Cape stumpnose	IIa	40	100	40	75	50
	Diplodus sargus	Dassie/blacktail	IIc	35	100	10	100	57
	Rhabdosargus sarba	Natal stumpnose	IIb	35	100	0	75	50
	Acanthropagrus berda	Perch/riverbream	IIa	35	100	0	75	64
	Lithognathus mormyrus	Sand steenbras	III	20	0	0	25	14
	Spondyliosoma emarginatum	Steentjie	III	70	80	40	100	21
	Sarpa salpa	Strepie	IIc	67	90	20	100	71
	Sparodon durbanensis	White musselcracker	III	30	100	40	100	71
	Lithognathus lithognathus	White steenbras	IIa	6	100	40	100	50
	Rhabdosargus globiceps	White stumpnose	IIc	20	100	20	100	57
	Diplodus cervinus	Zebra/wildeperd	III	35	100	40	100	36
Sphyraenidae	*Sphyraena barracuda*	Barracuda	IIb	50	80	0	50	50
	Sphyraena jello	Pickhandle barracuda	IIc	60	70	0	50	0
Teraponidae	*Terapon jarbua*	Thornfish	IIa	55	70	0	0	29
Triglidae	*Chelidonichthyes capensis*	Gurnard	III	60	80	10	25	50

It is difficult to assess what contributes more to the decline of an estuarine species: estuarine habitat degradation or overexploitation. Estuarine dependence immediately creates a life-history bottleneck for many species, especially when it comes to entering temporarily closed estuaries. In addition to estuarine dependency, sex changes, spawning migrations, predictable aggregations, high age at maturity, longevity, residency and high catchability all contribute to a species vulnerability to overexploitation. For example, white steenbras exhibits seven of these life-history traits, excluding sex change, and is currently at 6% of its pristine spawner biomass, and on the critical list. Half of all species considered have vulnerable life-history characteristics in addition to estuarine dependency, and a quarter of them fall into the most vulnerable category (Table 2.13).

Very few of the species considered are range restricted (Table 2.13). A quarter of species are highly exploited throughout their range (Table 2.13), 23 species are under medium exploitation, and the rest are subject to medium to low exploitation.

On the whole, knowledge of exploited estuarine fish species is poor, with three quarters of species having low knowledge scores up to half the optimum. For most of these species, no comprehensive stock assessments have been done.

2.4 Conclusions

This study has shown that estuaries contribute a significant value to the economy in terms of both estuarine fisheries and their contribution to inshore marine fisheries, with the latter contribution slightly exceeding the value realised within estuaries. Although commercial catches are substantial both within estuaries and in the marine environment, it is recreational fishing activities that contribute most value to the economy, with 22 times as many participants (about half a million vs under 23 000) and realising a value more than 100 times greater per kg of fish caught. Subsistence fisheries are very localised, and involve very small numbers of fishers and low values, but important in the context of their livelihoods.

However, an assessment of the status of estuarine fish stocks suggests that the currently high value of estuarine fish production is probably not sustainable. Dwindling fish stocks will affect catches per unit effort and overall catches, and the value realised from these fisheries may well drop substantially if current trends are maintained. This would have much greater impact on commercial fisheries, upon which many people rely for their livelihoods, particularly in marine fisheries, than on recreational fisheries, which are less sensitive to catch returns. It is clear that sound management practices will need to be put in place in order to sustain these values in future, as well as to ensure the conservation of estuarine biodiversity.

Management strategies chosen for estuarine species may differ depending on socio-economic goals, e.g. whether to secure livelihoods of small-scale commercial fishers, or whether to increase overall contribution to the economy. No doubt, an equitable balance of these goals is required. Nevertheless, any management strategy ultimately has to concentrate on maintaining maximal productivity of resources if benefits are to be sustained in the long term.

Linefish and netfish management is currently undergoing complete revision in order to address these challenges. A linefish management protocol has been developed (Griffiths *et al.* 1999) which requires species-specific management plans. Under the Marine Living Resources Act, estuaries fall within the marine environment, and these management plans include estuarine populations. Apart from the reduction of overall commercial effort, including in estuaries, there has been a substantial revision of bag and size limits for recreational, subsistence and commercial fisheries. With compliance, the effort directed at many of these species is likely to decrease.

Reduced catches in estuaries are needed to secure estuarine contributions to marine inshore fisheries. If current regulations were complied with, this would be achieved, providing the estuarine environments (e.g. freshwater inflows) were also sufficiently protected. In the recreational fishery, a large proportion of landed catches comprise undersized fish, ranging from 90% on the west coast to 50% and 60% on the south and east coasts, respectively (Lamberth 1996, 2000a, Cowley 2000). In other words, catches would be much lower if there was compliance. A reduction in angler pressure would almost certainly serve to increase present abundance of certain species. For example, along the east coast of the Eastern Cape and in KwaZulu-Natal, elf has increased in numbers following increased protection (van der Elst & De Freitas 1987, Garratt & van der Elst 1990). Technically, catches could be reduced without reducing the value of the fishery, as most recreational anglers would still go fishing if they were more strictly policed. It also makes good economic sense to remove all commercial fisheries from estuaries, thereby halving the catch, but only reducing economic contribution by 1%. Commercial fishing in estuaries is predominantly gillnetting, which is unselective, usually with a high by-catch of undersized and immature linefish and other species. These species are already overexploited and this fishing pressure occurs during a particularly vulnerable stage of their life while they are in estuaries. It has already been stressed that these fisheries are seldom viable in the short term and almost never in the long term. By removing commercial fisheries, much greater recruitment will be facilitated into the sea.

Furthermore, subsistence and commercial effort should be excluded from temporarily closed systems, whether large or small, as these stocks are easily overexploited (Pease 1999). The protection of small and closed systems should not be done at the expense of the larger, permanently open systems, however. Protection should be levelled at all estuarine types at a rational scale, as they all support different and valuable fish communities.

Ideally, different fisheries should target different species within the same estuaries. Multi-user fisheries are seldom sustainable. However this is difficult to control, especially those sectors assigned less lucrative species. This is thus a further argument against including commercial fisheries in estuaries. Estuarine exploitation in South Africa should be limited to subsistence and recreational use. However the South African experience is that designated subsistence fishers soon realise the value of their non-target species, and it is hard to prevent them from shifting to these species. This often leads to chaos and user conflict, as has happened in Kosi and St. Lucia (Scotty Kyle, KZN Wildlife personal communication). Subsistence fisheries should be confined to traditional fisheries, and preferably assigned to homogenous communities. In other areas, the *ad hoc* allocation of subsistence rights should rather be addressed by finding alternative livelihoods for the fishers involved.

In general, the protection of estuarine fish resources will also depend on the sound management of activities which affect estuarine environments. Apart from the direct effect on fish stocks, recreational angling involves boat traffic and bait digging, leading to disturbance, trampling and depletion of prey for fish. More importantly, perturbations that occur in the marine environment or catchment may negatively impact on fish populations in estuaries (Whitfield & Marais 1999). In particular, if freshwater requirements of estuaries are not adequately met, the resultant chemical and biophysical changes in the estuarine headwaters and in mouth condition can severely hamper fish recruitment. Indeed, freshwater inputs probably have the most important impact on species distribution, composition and abundance in estuaries. For these reasons it is strongly advocated that a philosophy of ecosystem preservation be used in management policy (Whitfield & Marais 1999) in addition to individual species conservation efforts. Such policies will lead to more rational decisions in terms of all developments which affect estuarine ecology, including development of marinas (which tend to favour ichthyoplankton but not large fish - Cloete 1993).

Thus, in summary, the most sensible overall policy would be to conserve estuarine stocks as nursery and source areas for marine fisheries. This is the most efficient option in terms of maximising resource productivity, economic benefits and biodiversity conservation. Resource productivity in both estuaries and the inshore marine environment can be enhanced by concentrating conservation efforts on estuarine stocks. Stock status can only be improved by reduction of catches. In order to minimise the cost of this, it should be targeted at fisheries which are either low value per unit catch (e.g. estuarine commercial net fisheries), or fisheries whose value is not strongly affected by catch rates (i.e. the recreational fishery, which is much smaller in estuaries than on the open coast). Conserving estuary stocks requires the sound holistic management of estuaries, a spin-off being the improved conservation of all estuarine biodiversity.

CHAPTER 3

3. THE EFFECTS OF ALTERED FRESHWATER INFLOW ON FISH ASSEMBLAGES OF TWO CONTRASTING SOUTH AFRICAN ESTUARIES

3.1 Introduction

The range of benefits and habitats provided by estuaries is considerable, yet fish diversity in estuaries is low compared to marine and freshwater ecosystems, despite estuaries providing services that exceed those of coral reefs, tropical forest and most other ecosystems (Whitfield 1994a, Costanza *et al.* 1997). Benefits provided by estuaries to fish are well documented and include high productivity, low predation, low salinities, and refuge from adverse conditions in the marine environment such as low temperatures or oxygen levels – thus improving body condition, growth and/or survival (de Decker & Bennett 1985, Potter *et al.* 1990, Robins *et al.* 2006).

Whitfield (1996) lists many biotic and abiotic factors influencing the abundance and diversity of estuarine-associated fish, including latitude, seasonality, catchment size, estuary size, salinity gradients, habitat diversity, mouth condition, dissolved oxygen levels, turbidity, food resources, flooding and anthropogenic impacts. The last of these can be direct, such as pollution, dredging, bait collection and fishing; or indirect, such as upstream impoundments, water abstraction and marine fishing. Impoundments trap sediment, reduce freshwater flow and obstruct the upstream migration of catadromous species whereas overexploitation in the marine environment will reduce recruitment of estuarine-associated species into estuaries (Chapter 2). In all, the response of estuarine fish assemblages to environmental and ecological change makes them good indicators of anthropogenic stress (Whitfield & Elliott 2002).

Despite the numerous benefits provided by estuaries, estuarine-associated fish are vulnerable because of their isolation and reliance on local conditions, which can be highly variable (Maitland 1990). Estuarine residents and obligate estuarine-dependent marine species are confined to their systems for all or part of their lifecycles, resulting in many independent or discrete populations each with its own stock characteristics. This may require that juveniles of marine-spawning species return to their natal estuaries. In turn, discreteness or confinement to a single estuary makes entire populations vulnerable to factors such as disease and pollution. Therefore, for a species' survival, the number of discrete populations is more important than the number of individuals (Maitland 1990). Migrations, whether they be of diadromous fish entering or leaving the catchment or of juvenile and larval fish recruiting into the estuary, cannot take place if there are obstructions. Aggregations associated with migration are often predictable, making them susceptible to predation and fishing. Both short- and long-lived species are vulnerable to poor estuarine conditions and exploitation. Large slow-growing, late-maturing species are attractive to fishers and at risk of being caught before they are able to spawn, whereas small short-lived species cannot wait out the years for good spawning conditions. Consequently, estuarine fish populations may be more vulnerable to extinction than their entirely marine counterparts. However, longevity and short life spans may both be adaptations to unstable estuarine environments including erratic freshwater flow (Blaber 2000). Longevity provides a greater chance of a successful spawning whereas brevity of lifecycle allows fish to take advantage of limited windows of opportunity within a year or season.

South Africa has 255 functional estuaries along 3 200 km of coastline stretching from the Orange (Gariep) River on the west coast to Kosi Bay in the east (Turpie *et al.* 2002). The warm-temperate biogeographic region (from Cape Point to Mbashe River) and the subtropical region (northwards of the Mbashe) have 125 and 121 estuaries respectively whereas the arid cool-temperate region (Cape Point to Orange River) is estuary-poor with only nine (Chapter 2). On a broad scale, southern African estuaries have been classified into estuarine lakes, estuarine bays, river mouths and permanently or temporarily open/closed systems (Whitfield 1992). Fewer than 30% are permanently open (Whitfield 2000). On a biogeographical level, low rainfall and runoff coupled with high seawater input and evaporative loss results in high salinities and low turbidity throughout the year in warm-temperate estuaries and during summer in cool-temperate estuaries (Harrison 2004).

Estuarine fish diversity in southern Africa declines as one moves south and westwards with few of the more than 100 species typical of subtropical and tropical estuaries occurring in estuaries on the cool-temperate west coast or warm-temperate southeast coast (Day 1981, Whitfield 1994a, Turpie *et al.* 1999, Whitfield 2005a,b). Fish productivity on the other hand is highest in cool-temperate and lowest in subtropical South African estuaries. Both fish productivity and diversity are higher in permanently open versus temporarily open/closed systems (Chapter 2).

National legislation requires that alterations to freshwater flows take into account the ecological needs of ecosystems (Thompson 2006). This paper focuses on alterations to freshwater flow in terms of their influences on the fish assemblages of two permanently open South African estuaries, the Breede and Olifants, which were selected because of their importance, representation of two biogeographical regions, and the fact that they are already subject to substantial water abstraction and plans are afoot to further alter flows.

The philosophy adopted was to (1) assess the species composition and abundance of fish at the present time, (2) determine their estuarine dependency, (3) measure physical conditions and how they change seasonally, (4) determine how fish respond to these changes and physical conditions, and (5) use this information to assess what fish assemblages would have been like under pristine conditions prior to the alteration of freshwater flows, and how they may change under various future scenarios.

3.2 Study area

3.2.1 Olifants River Estuary

The Olifants/Doring River system has an area of 49 000 km^2 making it the second-largest catchment in South Africa, but because it falls in an arid region it contributes only 2% of the country's mean annual runoff (MAR) (Morant 1984). The Olifants River is approximately 250 km long, and has two of South Africa's oldest large dams, the Clanwilliam and Bulshoek, in its middle reaches. The Doring River runs out of the semi-desert Ceres Karoo and joins the Olifants below the two dams. Both rivers fall within a winter rainfall area.

The Olifants River Estuary flows into the Atlantic Ocean in the cool-temperate Namaqua biogeographical region on the west coast of South Africa. It is approximately 36 km long from the mouth below the fishing village of Papendorp to the Lutzville causeway, which inhibits tidal influence from extending any further upstream (Fig. 3.1a). The surface area of the estuary is approximately 720 ha. The upper reaches 15-36 km from the mouth are narrow, being 20-50 m in width and having water depths averaging 1-3 m. Agriculture is intensive on both banks and fields are often bulldozed to the edge and even into the estuary. The lower 15 km of the estuary widens to approximately 400 m with extensive saltmarsh on either side. Two kilometres from the mouth there is an approximately 2-km-long backwater that originally was a second channel that became blocked with marine sand after a severe storm in 1925 (Morant 1984). The estuary enters the sea between a rocky headland to the north and a large sandy spit to the south. The spit and beach extending 5 km to the south are diamond-mining concessions but have yet to be mined. The Hartebees Kanaal, a shallow rocky channel, bisects the northern headland. The rocky shores, beaches and subtidal areas to the north are mined for diamonds.

The lower 15 km of the estuary supports a gillnet fishery comprised of fishers from the Ebenhaeser/ Olifantsdrift and Papendorp/Viswater communities. There are currently 45 operators although there have been up to 120 in the past. Consequently, the fish fauna and assemblages are likely to have been impacted by fishing, over and above any changes arising from altered habitat or freshwater flows.

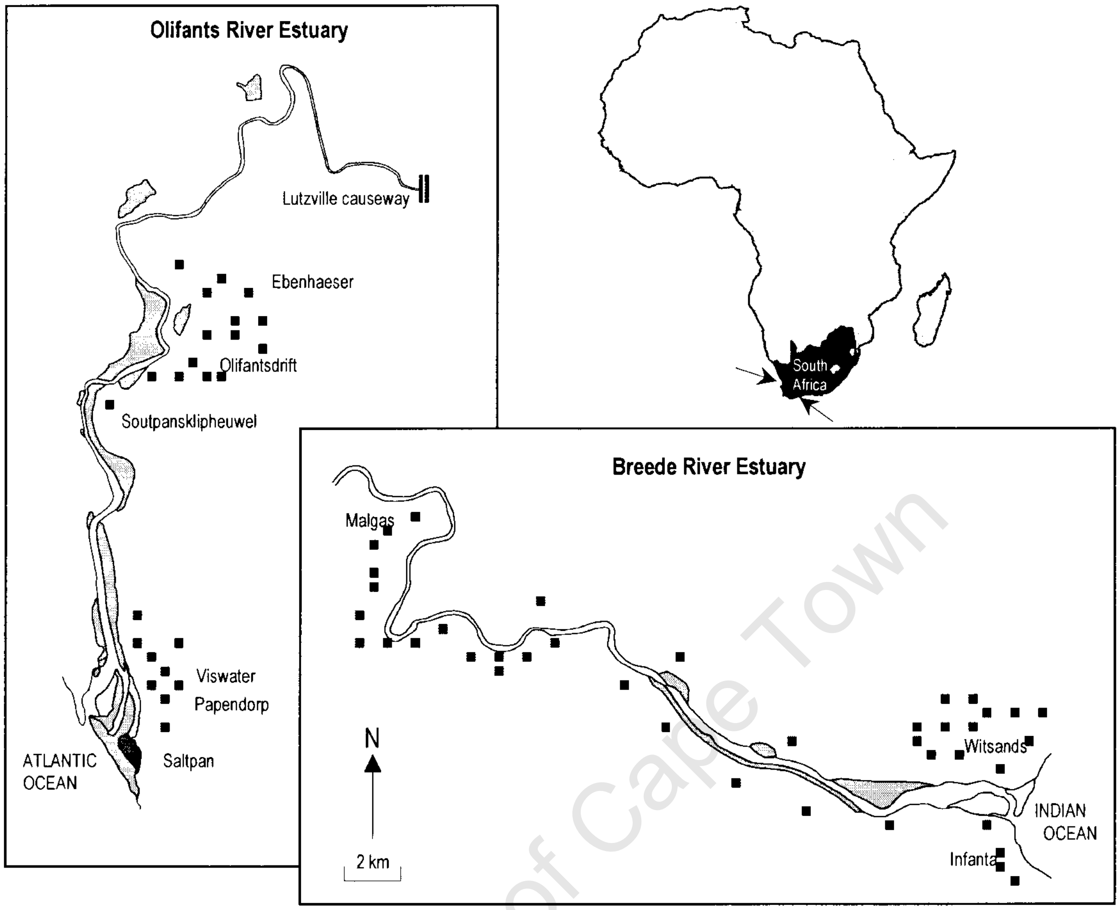


Figure 3.1 Maps of the Olifants and Breede River estuaries showing places mentioned in the text. Shaded areas represent saltmarsh.

3.2.2 Breede River Estuary

The Breede River is 322 km long from its source near Ceres to where it enters the Indian Ocean in Sebastian Bay, and falls within the warm-temperate Agulhas biogeographical region. It drains a catchment of approximately 12 600 km^2 and its estuarine section has a total surface area of 455 ha, extending 50 km upstream to about 10 km beyond the pontoon at Malgas where tidal influence ceases (Fig. 3.1b.) Three large and numerous smaller dams within the catchment have reduced the original MAR reaching the estuary by 42% to the present-day flow of 1 034 x 10^6 m^3 (Taljaard *et al* 2001). Although the estuary falls within the winter/bimodal rainfall transition zone, most of the catchment lies in the winter rainfall area and flows are strongly seasonal with high flows and floods during the winter months.

The Breede Estuary is permanently open, with a mean depth of 4.6 m but there are a limited number of areas up to 17 m deep in the middle and upper reaches. In the 2-km stretch nearest the mouth, an extensive sand-spit running from the northern bank diverts the main channel across to the southern bank where it enters the sea against a wave-cut terrace (Carter 1983). The estuary is highly responsive to freshwater inflows and high flows of 20-95 m^3s^{-1} are able to completely flush and reset the system during a single tidal cycle (Taljaard *et al.* 2001). The water column ranges from well mixed during spring highs to stratified during spring lows and neaps and the river estuarine interface (REI) zone may shift 8-10 km between tides.

3.3 Methods

3.3.1 Fish sampling

Gillnet sampling, which targets the adults and sub-adults of the larger fish species, and seine-nets, which capture juveniles and the smaller fish species, were both employed as means of sampling the fish. Quantitative data on the fish of the Olifants River Estuary were obtained from (1) summer and winter seine and gillnet surveys in February and August 2004, (2) a bimonthly seine and gillnet fishery simulation exercise throughout the southwestern Cape during 1997 – 1999, (3) a gillnet survey in March and August 1995 and (4) monthly catch returns from the commercial gillnet fishery 2003 – 2005 (Marine & Coastal Management (MCM), Netfish System). The 2004 survey entailed sampling every 1-2 km from the mouth to the Lutzville Causeway, approximately 36 km upstream, whereas the 1997–1999 sampling was confined to the lower 8 km of the estuary (Fig. 3.1a). The 1995 survey was confined to the use of gillnets, which were used to obtain samples at 1-km intervals all the way to the Lutzville Causeway.

Quantitative data on the fish of the Breede River Estuary came from (1) summer and winter seine and gillnet surveys in February and August 2000, and (2) the 1997-1999 bimonthly seine and gillnet fishery simulation exercise. The 2000 survey entailed sampling every 1-2 km from the mouth to Malgas approximately 40 km upstream whereas the 1997-1999 sampling was confined to the lower 5 km of the estuary (Fig. 3.1b). Additional information was obtained from published and unpublished literature.

Gillnets used were 30 m in length, 2 m deep, with mesh sizes of 44, 48, 51, 54, 75, 100 and 145 mm. During the 2000 and 2004 surveys they were deployed for approximately one hour at each site whereas during the 1997-1999 sampling they were set and checked on an hourly basis until sufficient fish were caught. Most of the fish caught were cut from the net to prevent injury, identified, measured and released. In both estuaries, night sampling was avoided due to boat traffic, the possibility of net theft, and difficulty in preventing high mortalities through large catches.

Table 3.1 The five major categories of fishes that utilize South African estuaries (after Whitfield 1994)

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

The seine net used was 30 m long, 2 m deep with a mesh size of 10 mm and hauling ropes of 50 m. Depending on the size of the catch, either all fish or sub-samples were identified, measured and, if alive, released. Surface temperature, salinity (portable refractometer) and water clarity (Sechii disc) were measured at each site.

3.3.2 *Categorization of the ichthyofauna*

To categorize fish in terms of their dependency on estuaries the five-category classification scheme originally proposed by Wallace *et al.* (1984) and refined by Whitfield (1994b), based on life-history characteristics (Table 3.1) was adopted.

3.3.3 *Freshwater requirements*

3.3.3.1 The Freshwater Reserve

The National Water Act (Act 36 of 1998) in South Africa recognizes only two water rights: a basic human-needs reserve of 25 litres per person per day (currently being revised to 65 litres) and a freshwater reserve which comprises the ecological water requirements necessary to sustain aquatic ecosystems in a healthy condition. The Act requires that a Freshwater Reserve be determined prior to the authorization of water use for agriculture, urban developments and industry, amongst other things. This stipulation led to the development of methods to determine the ecological water requirements of rivers and estuaries (Adams *et al.* 2002, DWAF 2004a).

Determining a reserve for an estuary includes delineating the geographical boundaries of the estuary and assessing estuarine health by comparing its present state with a hind-cast reference condition using an Estuarine Health Index (Turpie 2002, DWAF 2004a). The Estuarine Health Index comprises an evaluation of habitat health (abiotic variables: hydrology, hydrodynamics, mouth status, water quality, physical habitat alteration) and biological health (biotic variables: microalgae, macrophytes, invertebrates, fish, and birds). Both abiotic and biotic variables are evaluated as the relationships between them are often not well understood and biotic responses to certain abiotic variables can be slow (Turpie 2002). The pristine or reference condition of an estuary usually refers to its ecological status at least 100 years ago before the catchment was altered or any large-scale manipulation of the estuary mouth had taken place. Under the reference condition it is assumed that estuaries would have received 100% of the MAR from their catchments. All hind-casting and forecasting of flow regimes and MAR are derived from modelled hydrology.

The importance of an estuary as an ecosystem is taken from a national rating system and, together with the present health, is used to set the future desired condition (an Ecological Reserve Category) for the estuary. Freshwater is then reserved to maintain the estuary in the desired condition. The reserve (the quantity and quality of freshwater required) is determined by assessing a number of realistic monthly river-flow scenarios, comparing these with data for the present day and evaluating the extent to which abiotic and biotic conditions within an estuary are likely to alter with changes in river inflow. In doing so, the goal is a river flow that allows a reduction in freshwater inflow for human use whilst maintaining the estuary in the desired ecological condition.

3.3.3.2 Hydrology and hydrodynamics

A series of scenarios under different freshwater flows were examined for both the Olifants and Breede estuaries to explore the effects of altered flow rates. These included the reference (pristine) state, present day conditions, and four or five future scenarios spanning both increases and further reductions for the Olifants and a series of reductions of the Breede (Table 3.2).

Hydrological data comprising simulated mean monthly river flows for these scenarios were provided by Ninham Shand Consulting Engineers and covered a 70-year period.

Table 3.2 The percentage reduction in mean annual runoff (MAR) from reference (pristine) conditions under the present-day and future scenarios in the Olifants and Breede River estuaries. There are five and four future scenarios for the Olifants and Breede respectively.

Scenario	**% Reduction in reference MAR**	
	Olifants Estuary	**Breede Estuary**
Present day	34	42
1	25	47
2	31	52
3	43	57
4	50	64
5	60	-

Standard South African hydrological models were used to generate these simulated flows (e.g. Midgley *et al.*, 1994, Pitman 1995).

A consequence of current and future catchment developments is that reductions in baseflow and an increase in the duration of low-flow periods will result in increased salinity as well as a change in salinity distribution in both estuaries. These effects were simulated using the Mike 11 mathematical modelling system, which is an advanced one-dimensional dynamic modelling system for rivers and estuaries that was developed in the 1970s at the Danish Hydraulics Institute and has been applied locally and worldwide in various investigations (CSIR 1993, 1998, 1999; Refsgaard and Knudsen 1996; Slinger *et al.* 1997; Yan *et al.* 1998; DHI 2001). The hydrodynamic and transport dispersion modules of Mike 11 were used to model salinity distribution.

The hydrodynamic model is driven by the tidal variation at the mouth and river flow at the head of the estuary. The hydrodynamic model was calibrated by adjusting the bottom roughness until a satisfactory agreement was reached between simulated and measured water-level variations. The transport dispersion module was used to simulate the effects of the intrusion of seawater on salinities in each estuary based on tidal flows at the mouth and the inflow of freshwater upstream, and was calibrated by adjusting the dispersion coefficients until a satisfactory agreement was reached between the computed and measured salinity concentrations. The model was set up with bathymetric data collected at regular intervals of 0.5 to 1.0 km. Predicted water-level variations in the ocean were used as an open boundary in the marine environment. The model was calibrated using river inflow data, water level data (4 – 5 stations) and salinity data (10 - 20 stations) collected along the length of each estuary over a neap and a spring tide using a YSI 6600 Multi-parameter Environmental Monitoring System. Evaporation was incorporated as an outflow from the model to account for evaporative losses that would have increased salinities.

Based on the measured and modelled results, four abiotic states were identified for the Olifants and Breede estuaries, ranging from freshwater-dominated through balanced to marine-dominated. These states were described in terms of typical flow patterns, tidal variations and salinity distributions. Details of these states are specified in Tables 3.6a,b. In turn, the abiotic states were superimposed on monthly river-flow scenarios to evaluate changes in occurrence (frequency and duration) of the abiotic states under the simulated flow sequences. Results of the numerical modelling were also used to calculate average and maximum salinity penetration during the low-flow period for the various scenarios based on the duration and extent of different salinity regimes (< 10 ‰, 10 – 20 ‰, 20 - 30 ‰, >30 ‰). These results in turn provided the platform from which biotic changes could be hind-cast (for reference conditions) or predicted (for future scenarios). All changes were evaluated in relation to the reference condition.

3.3.3.3 Abiotic states and the ichthyofauna

To predict the response of the fish assemblage in each estuary to future changes in flow, samples were grouped into five salinity ranges. For each abiotic state identified in the two estuaries, fish densities (fish.m^{-2}) were multiplied by the total area of the estuary covered by each salinity range. The total number of fish under each state was the sum of the fish in all the salinity ranges. Densities of exploited fish in the Olifants Estuary were corrected for gillnet fishing effects using catch ratios of fished to non-fished estuaries obtained from Hutchings and Lamberth (2003). For each scenario, "absolute abundance" was the average number of fish summed across all states within a 12-month period. The predicted changes are based on the assumption that all being equal, overall fish abundance will correspond with the shrinking or expansion of the area covered by their preferred salinities under present-day conditions. In reality, many of the species are tolerant of a wider range of salinities and will also respond to changes in habitat availability, prey availability, turbidity and temperature (amongst other factors), and may therefore not conform to the calculated areas.

3.4 Results

3.4.1 Composition of the ichthyofauna

3.4.1.1 Olifants River Estuary

In total, 38 fish species from 30 families have been recorded from the Olifants River Estuary (Day 1981, Morant 1984, Harrison *et al.* 1994, Hutchings & Lamberth 1999 and this study) (Table 3.3).

Table 3.3 A list of all species recorded in the Olifants and Breede River estuaries during this study and after Morant 1984, Day *et al.* 1981, Harrison *et al.* 1994, Hutchings & Lamberth 2002a,b, Ratte 1982, Harrison 1999, Estuarine & Coastal Research Unit CSIR, Carter 1983 and Coetzee & Pool 1991. The species are arranged according to the five major categories of estuarine-dependence as suggested by Whitfield 1994b, Table 3.1.

Family name	Species name	Common name	Dependence category	Olifants Estuary	Breede Estuary
Osteichthyes					
Blenniidae	*Omobranchus woodii*	Kappie blenny	Ia		X
Clupeidae	*Gilchristella aestuaria*	Estuarine roundherring	Ia	X	X
Hemiramphidae	*Hyporhamphus capensis*	Cape halfbeak	Ib		X
Gobiidae	*Psammogobius knysnaensis*	Knysna sand-goby	Ia/Ib	X	X
Atherinidae	*Atherina breviceps*	Cape silverside	Ib	X	X
Clinidae	*Clinus superciliosus*	Super klipvis	Ib	X	X
Gobiidae	*Caffrogobius gilchristi*	Prison goby	Ib	X	X
Gobiidae	*Caffrogobius natalensis*	Baldy	Ib		X
Gobiidae	*Caffrogobius nudiceps*	Barehead goby	Ib	X	X
Gobiidae	*Caffrogobius saldanha*	Commafin goby	Ib	X	X
Syngnathidae	*Syngnathus temminckii*	Pipefish	Ib	X	X
Carangidae	*Lichia amia*	Leervis	IIa	X	X
Elopidae	*Elops machnata*	Ladyfish	IIa		X
Haemulidae	*Pomadasys commersonnii*	Spotted grunter	IIa		X
Monodactylidae	*Monodactylus falciformis*	Cape moony	IIa		X
Mugilidae	*Liza macrolepis*	Largescale mullet	IIa		X
Mugilidae	*Mugil cephalus*	Springer mullet	IIa/Vb	X	
Mugilidae	*Myxus capensis*	Freshwater mullet	IIa/Vb	X	X
Sciaenidae	*Argyrosomus japonicus*	Dusky kob	IIa		X
Sparidae	*Lithognathus lithognathus*	White steenbras	IIa	X	X
Sparidae	*Rhabdosargus holubi*	Cape Stumpnose	IIa		X
Ariidae	*Galeichthyes feliceps*	Barbel	IIb	X	X
Monodactylidae	*Monodactylus argenteus*	Natal moony	IIb		X
Mugilidae	*Liza dumerilii*	Groovy mullet	IIb		X
Mugilidae	*Liza tricuspidens*	Striped mullet	IIb		X
Soleidae	*Heteromycteris capensis*	Cape sole	IIb	X	X
Soleidae	*Solea bleekeri*	Blackhand sole	IIb	X	X
Hemiramphidae	*Hemiramphus far*	Spotted halfbeak	IIc		X
Mugilidae	*Liza richardsonii*	Harder	IIc	X	X
Ophichthidae	*Ophisurus serpens*	Sand snake-eel	IIc	X	
Pomatomidae	*Pomatomus saltatrix*	Elf	IIc	X	X
Sparidae	*Diplodus sargus*	Dassie	IIc		X
Sparidae	*Rhabdosargus globiceps*	White stumpnose	IIc	X	X
Sparidae	*Sarpa salpa*	Strepie	IIc		X
Blenniidae	*Omobranchus banditus*	Bandit blenny	III		X
Carangidae	*Seriola lalandi*	Yellowtail	III		X
Carangidae	*Trachurus trachurus*	Maasbanker	III	X	
Clupeidae	*Sardinops sagax*	Pilchard	III	X	
Dichistiidae	*Dichistius capensis*	Galjoen	III		X
Haemulidae	*Pomadasys olivaceum*	Piggy	III		X

Table 3.3 continued

Family name	Species name	Common name	Dependence category	Olifants Estuary	Breede Estuary
Rachycentridae	*Rachycentron canadum*	Prodigal son	III		X
Sciaenidae	*Argyrosomus coronus*	West coast kob	III	X	
Sciaenidae	*Argyrosomus inodorus*	Silver kob	III	X	
Sciaenidae	*Atractoscion aequidens*	Geelbek	III		X
Sciaenidae	*Otolithes ruber*	Snapper kob	III		X
Sciaenidae	*Umbrina spp.*	Belman	III		X
Siganidae	*Siganus sutor*	Whitespotted rabbitfish	III		X
Soleidae	*Austroglossus microlepis*	West coast sole	III	X	
Sparidae	*Diplodus cervinus*	Wildeperd	III		X
Sparidae	*Lithognathus aureti*	Westcoast steenbras	III	X	
Sparidae	*Lithognathus mormyrus*	Sand steenbras	III		X
Sparidae	*Sparodon durbanensis*	White musselcracker	III		X
Sparidae	*Spondyliosoma emarginatum*	Steentjie	III		X
Stromateoidae	*Stromateus fiatola*	Blue butterfish	III		X
Tetraodontidae	*Amblyrhynchotes honckenii*	Blaasop	III		X
Tetraodontidae	*Chelondon patoca*	Milkspotted blaasop	III		X
Triglidae	*Chelidonichthys capensis*	Cape gurnard	III	X	X
Centrarchidae	*Lepomis macrochirus*	Bluegill sunfish	IV	X	X
Centrarchidae	*Micropterus dolomieu*	Smallmouth bass	IV	X	X
Cichlidae	*Oreochromis mossambicus*	Mozambique tilapia	IV	X	X
Cichlidae	*Tilapia sparrmanii*	Banded tilapia	IV	X	X
Cyprinidae	*Barbus serra*	Sawfin	IV	X	
Cyprinidae	*Cyprinus carpio*	Carp	IV		X
Cyprinidae	*Labeobarbus capensis*	Clanwilliam yellowfish	IV	X	
Galaxiidae	*Galaxias zebratus*	Cape galaxias	IV	X	
Anguillidae	*Anguilla bengalensis*	African mottled eel	Va		X
Anguillidae	*Anguilla marmorata*	Madagascar mottled eel	Va		X
Anguillidae	*Anguilla mossambica*	Longfin eel	Va		X
Chondrichthyes					
Carcharhinidae	*Carcharhinus leucus*	Zambezi shark	IIc		X
Dasyatidae	*Dasyatis chrysonota*	Blue stingray	III	X	X
Dasyatidae	*Gymnura natalensis*	Butterfly ray	III		X
Myliobatidae	*Myliobatis aquila*	Eagle ray	III	X	X
Myliobatidae	*Pteromylaeus bovinus*	Duckbill ray	III		X
Rhinobatidae	*Rhinobatos annulatus*	Lesser guitarfish	III	X	X
Rhinobatidae	*Rhinobatos blochi*	Bluntnose guitarfish	III	X	
Scyliorhinidae	*Haploblepharus pictus*	Dark shyshark	III	X	

Six (16%) are entirely dependent on estuaries to complete their lifecycle (Categories Ia & IIa). Eight breed in estuaries (Categories Ia & Ib) and include the estuarine roundherring *Gilchristella aestuaria*, Cape silverside *Atherina breviceps*, prison goby *Caffrogobius gilchristi*, commafin goby *Caffrogobius saldanha* and longsnout pipefish *Syngnathus temminckii*. Four, white steenbras *Lithognathus lithognathus*, leervis *Lichia amia*, freshwater mullet *Myxus capensis* and flathead mullet *Mugil cephalus* are entirely dependent on estuaries as nursery areas for at least their first year of life (Category IIa). The latter two species may also fall in the facultative catadromous (Vb) category.

Another 7 species (18%) are at least partially dependent on estuaries (Categories IIb & IIc) e.g. harder *Liza richardsonii*, elf *Pomatomus saltatrix*, blackhand sole *Solea bleekeri* and white stumpnose *Rhabdosargus globiceps*. In all, 50% of the fish species recorded from the Olifants Estuary can be regarded as either partially or completely dependent on estuaries for their survival. Most of the remaining species (32%) are marine species e.g. silver kob *Argyrosomus inodorus*, pilchard *Sardinops sagax*, bluntnose guitarfish *Rhinobatos blochi* and eagle ray *Myliobatis aquila*, which occur in estuaries but are not dependent on them (Category III). Finally, the Olifants Estuary supports seven euryhaline freshwater species (Category IV), whose penetration into estuaries is determined by salinity tolerance. These include the endemic, red-data, Clanwilliam yellowfish *Labeobarbus capensis*, sawfin *Barbus serra*, and Cape galaxias *Galaxias zebratus*, as well as the introduced smallmouth bass *Micropterus dolomieu*, bluegill sunfish *Lepomis macrochirus*, banded tilapia *Tilapia sparrmanii* and Mozambique tilapia *Oreochromis mossambicus*. No catadromous species (Category V) have been recorded from the Olifants.

3.4.1.2 Breede River Estuary

An overall total of 59 fish species from 30 families has been recorded from the Breede River Estuary (Day 1981, Ratte 1982, Carter 1983, Coetzee & Pool 1990, Harrison 1999, Hutchings & Lamberth 1999, 2002a,b and this study) (Table 3.3). Of these, 23 (39%) are entirely dependent on estuaries to complete their lifecycle (Categories Ia & IIa). Ten of these are estuarine breeders and include the estuarine round-herring *Gilchristella aestuaria*, kappie blennie *Omobranchus woodii*, Cape halfbeak *Hyporhamphus capensis* and Cape silverside *Atherina breviceps* (Categories Ia & Ib). Nine, including dusky kob *Argyrosomus japonicus*, white steenbras *Lithognathus lithognathus*, leervis *Lichia amia* and spotted grunter *Pomadasys commersonnii* are dependent on estuaries as nursery areas for at least their first year (Category IIa). A further four require estuaries as transit routes between the marine and freshwater environment, namely the obligate catadromous African mottled eel *Anguilla bengalensis labiata*, Madagascan mottled eel *A. marmorata* and longfin eel *A. mossambica* and the facultative catadromous freshwater mullet *Myxus capensis* (Categories Va & Vb). Another 13 species (22%) are at least partially dependent on estuaries e.g. harder *Liza richardsonii*, groovy mullet *Liza dumerilii*, elf

Pomatomus saltatrix and spotted halfbeak *Hemiramphus far* (Categories IIb & IIc). In all, 61% of the fish species recorded from the Breede Estuary are either partially or completely dependent on estuaries for their survival. Most of the remaining species (36%) were marine species, e.g. geelbek *Atractoscion aequidens*, bullray *Myliobatis aquila*, piggy *Pomadasys olivaceum* and musselcracker *Sparodon durbanensis*, which occur in, but are not dependent on estuaries (Category III); two are alien euryhaline freshwater species whose penetration into estuaries is determined by salinity tolerance, namely carp *Cyprinus carpio* and smallmouth bass *Micropterus dolomieu* (Category IV).

3.4.2 Abundance

3.4.2.1 Olifants River Estuary

A total of 247 048 fish representing 21 species from 14 families was caught in 64 seine hauls in the Olifants Estuary during 1997 – 1998 and February and August 2004 (Table 3.4a). A further 567 630 fish representing 13 species from 10 families were recorded in gillnet catches during the 1997 – 1998 and 2004 sampling periods and from 2 700 net-days reported in the 2003 – 2004 catch returns from the commercial gillnet fishery.

Sixty-four seine hauls yielded 247 048 fish or 3 860 fish.haul^{-1} (Table 3.4a). *Liza richardsonii* (55%) and *Gilchristella aestuaria (42%)* dominated numerically, together providing 97% of the total catch. Only two other taxa, *Caffrogobius* spp. and *Atherina breviceps*, provided at least 1% each to the total catch. *Liza richardsonii* occurred in 92% of hauls and *Gilchristella aestuaria* in 68%, *Caffrogobius* spp. (57%), *Syngnathus temminckii* (53%) and *Psammogobius knysnaensis* (43%) occurred in more than 40% of the hauls. *Caffrogobius* spp. were not identified to species level in the field but through otolith characteristics of a selected subsample (Smale *et al.* 1995). *Caffrogobius nudiceps C. saldanha* and *C. gilchristii* respectively contributed 90%, 7% and 3% of the genus.

Gillnet sampling caught a total of 105 fish at an average catch rate of 14 and 5 fish.set-hour^{-1} in summer and winter respectively. Because sampling was limited and catches were low and not considered representative of adult fish in the system, these data were not analysed further and I relied instead on the commercial catch-return data as they were continuous and comprised 2 700 net-days over a 2-year period. Commercial gillnet catches were dominated by *Liza richardsonii* which provided over 98% of the total catch (Table 3.5a). Elf *Pomatomus saltatrix* provided 1% whereas all other species (e.g. *Mugil cephalus* and *Lichia amia*) provided < 1% of the catch. *Liza richardsonii* appeared in 97% of the commercial gillnet catches whereas *P. saltatrix, M. cephalus, Sardinops sagax, Argyrosomus inodorus* and *Lithognathus lithognathus* occurred in 1-10%.

Table 3.4a Species composition and abundance (catch per haul) in 64 seine net samples from the Olifants Estuary during 1997-1998 and 2004. Shading indicates months in which new recruits were recorded.

	Number per haul												Total	%
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	catch	Occurrence
Liza richardsonii	-	753.1	-	-	2282.5	42	-	90.6	-	4445.0	9046.4	-	135 854	92
Gilchristella aestuaria	-	3757.8	-	-	230.0	1.0	-	456.9	-	1970.0	678.7	-	103 224	68
Caffrogobius spp.	-	43.3	-	-	77.5	0.3	-	4.9	-	205.0	122.4	-	3 109	57
Atherina breviceps	-	60.7	-	-	6.3		-	8.7	-	157.5	35.3	-	2 221	36
Psammogobius knysnaensis	-	22.3	-	-	10	7.7	-	3.7	-			-	620	43
Lepomis macrochirus	-	23.3	-	-			-	2.2	-			-	552	15
Syngnathus temminckii	-	10.1	-	-	0.5	10.0	-	2.8	-	0.5	7.7	-	391	53
Clinus superciliosus	-	1.4	-	-	0.3		-	0.8	-	105.0	11.7	-	385	23
Micropterus dolomieu	-	14.9	-	-			-		-			-	328	7
Tilapia sparrmanii	-	7.1	-	-			-	0.2	-			-	159	10
Mugil cephalus	-	7.0	-	-			-		-			-	155	3
Pomatomus saltatrix	-	1.4	-	-			-		-			-	30	13
Rhinobatos blochi	-	0.4	-	-			-		-			-	9	5
Haploblepharus pictus	-	0.1	-	-			-		-	0.5		-	3	5
Chelidonichthys capensis	-	0.1	-	-			-		-			-	2	2
Solea bleekeri	-	0.1	-	-			-	0.1	-			-	2	3
Rhabdosargus globiceps	-		-	-			-		-		0.2	-	2	2
Oreochromis mossambicus	-	0.1	-	-			-		-			-	1	2
Lithognathus lithognathus	-		-	-			-		-		0.1	-	1	2
Total per haul	-	4703	-	-	2607	61	-	571	-	6884	9902	-	247 048	
Number of species	-	17	-	-	7	5	-	10	-	7	6	-	19	

Table 3.4b Species composition and abundance (catch per haul) in bimonthly seine net samples from the Breede Estuary during 1997-2000. Shading indicates months in which new recruits were recorded.

	Number per haul												Total	%
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	catch	Occurrence
Liza richardsonii	14.0	34.4	35.0	-	38.8	-	15.6	30.4	37.1	161.0	60.0	-	2 627	69
Caffrogobius spp.	15.3	21.1	62.3	-	3.2	-	9.2	46.7	5.6	86.0	184.0	-	2 382	68
Atherina breviceps	103.3			-	225.0	-	60.2					-	1 961	4
Gilchristella aestuaria		7.6		-	5.5	-		9.4	1.1	63.0	5.0	-	536	37
Rhabdosargus holubi	39.0	9.3	2.3	-	14.3	-	0.6	11.2	0.9	44.0	28.0	-	808	38
Heteromycteris capensis	6.3	0.7	5.8	-	5.2	-	10.6	1.2	4.4	6.0		-	213	26
Liza dumerilii		1.5		-		-		6.0			8.0	-	198	15
Psammogobius knysnaensis	1.3	0.7	1.8	-	2.0	-	2.6	2.2	4.6			-	147	26
Solea bleekeri	1.0	4.0	1.8	-	0.2	-	2.6	0.3	0.9	1.0	6.0	-	140	35
Syngnathus temminckii		0.3	1.3	-	0.5	-	0.6	1.6	0.1	2.0	2.0	-	65	17
Rhabdosargus globiceps	0.3	0.1	1.5	-	2.0	-	2.0	0.2			22.0	-	57	21
Diplodus sargus	0.3	1.9	1.8	-	0.2	-						-	55	10
Galeichthyes feliceps		1.8	1.3	-	0.5	-						-	52	6
Pomadasys olivaceum		1.5	0.5	-	0.2	-		0.4				-	50	9
Lithognathus lithognathus	7.0	0.4	0.3	-		-		0.1	0.6	1.0	2.0	-	41	14
Mugil cephalus		0.5		-		-		0.7	0.4			-	31	8
Argyrosomus japonicus		0.7		-	1.0	-						-	22	5
Omobranchus woodii	4.0	0.1		-		-				2.0		-	15	4
Monodactylus falciformis		0.4		-		-						-	14	8
Amblyrhynchotes honckenii		0.1		-	0.5	-	0.8	0.1				-	11	8
Hyporhamphus capensis		0.2		-		-		0.1	0.6			-	11	6
Pomatomus saltatrix	0.3	0.2		-	0.3	-	0.2	0.1			1.0	-	11	9
Lichia amia		0.4		-		-						-	9	6
Lithognathus mormyrus	1.0			-	0.7	-						-	7	5
Spondyliosoma emarginatum		0.2		-		-			0.1			-	5	3
Myxus capensis		0.1		-		-		0.1				-	4	3
Pomadasys commersonnii		0.1		-	0.5	-						-	4	3
Clinus superciliosus		0.1		-		-						-	3	1
Myliobatis aquila	0.7	0.1		-		-						-	3	3
Total per haul	194	88	115	-	301	-	105	111	57	366	318	-	9 492	
Number of species	14	27	12	-	18	-	11	18	12	9	10	-	29	

Table 3.5a Species composition and abundance (catch per net-day) in the Olifants Estuary during 2003-2004. The data represents the reported catch of 2 700 net-days from the commercial gillnet fishery.

	Number per net-day												Total catch	% Occurrence
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec		
Liza richardsonii	203.68	183.51	189.73	249.42	235.98	177.84	227.50	195.73	226.90	214.46	144.17	259.78	563 162	97.0
Pomatomus saltatrix	6.57	2.53	2.06	0.67	0.31	0.20	0.184	0.39	1.41	0.64	1.22	2.90	3 557	10.6
Mugil cephalus	0.17	0.17	0.04	0.04	0.02	0.02	0.01	0.39	0.24	0.04	0.33	0.27	410	1.9
Sardinops sagax	0.08	0.06	0.09	0.17		0.01	0.02	0.01	0.09	0.03	0.16	0.06	177	1.5
Argyrosomus inodorus	0.06	0.04	0.05	0.03				0.01	0.04	0.02	0.12	0.05	95	0.7
Rhabdosargus globiceps			0.11	0.12	0.01			0.01			0.04	0.04	68	0.3
Galeichthys feliceps	0.10								0.03	0.07	0.01	0.03	52	0.4
Chelidonichthys capensis	0.06		0.07	0.07	0.02								40	0.2
Lithognathus lithognathus		0.01		0.02	0.01	0.02	0.01	0.02	0.04	0.01			36	0.5
Micropterus dolomieu	0.01		0.01	0.02		0.01	0.01		0.01	0.01	0.01	0.02	22	0.4
Trachurus trachurus				0.01	0.01					0.01			5	0.1
Sole spp.												0.02	4	0.1
Lichia amia				0.01									2	0.1
Total per net-day	207	186	192	251	236	178	228	197	229	215	146	263	567 630	
Number of species	8	6	8	11	7	6	6	7	8	9	8	9	13	
Number of net-days	115	183	172	233	214	215	190	249	311	327	296	199	2 700	

Table 3.5b Species composition and abundance (catch per set-hour) in bimonthly gillnet samples from the Breede Estuary during 1997-2000.

	Number per set-hour												Total catch	% Occurrence
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec		
Liza richardsonii	11.5	4.5	33.8	-	29.9	-	11.5	20.6	12.8	41.2	20.0	-	938	64
Liza dumerilii	0.3	6.0	2.5	-	27.6	-	5.6	1.4		1.6		-	319	33
Pomadasys commersonnii		0.1	0.4	-	1.7	-	4.3	0.6		1.6	0.7	-	63	33
Liza tricuspidens	0.3	0.1	0.3	-	0.6	-	3.3	1.8	0.8	1.6		-	45	21
Lichia amia	1.2	1.8	0.6	-		-			0.8	0.1	1.3	-	32	24
Rhabdosargus holubi		0.8	1.0	-	2.6	-		0.1		0.4	0.3	-	26	21
Argyrosomus japonicus	0.3	0.3		-	1.3	-				0.1	1.7	-	18	12
Mugil cephalus		0.4		-	0.3	-		0.5				-	13	9
Myliobatis aquila	0.5		0.4	-		-	1.0					-	10	10
Galeichthys feliceps				-	1.5	-						-	9	3
Lithognathus lithognathus				-	0.7	-		0.2			0.3	-	7	7
Sarpa salpa			0.5	-		-			0.8			-	5	3
Pomatomus saltatrix				-	0.2	-				1.2		-	4	3
Diplodus sargus			0.2	-	0.5	-						-	4	5
Myxus capensis		0.2		-		-		0.1				-	3	3
Diplodus cervinus	0.3			-	0.1	-						-	2	3
Pteromyleus bovinus	0.2			-		-					0.3	-	2	3
Monodactylus falciformis		0.1		-		-						-	1	2
Dasyatis chrysonota			0.2	-		-						-	1	2
Amblyrhynchotes honckenii				-		-		0.1				-	1	2
Total per set-hour	14	14	40	-	67	-	26	25	15	48	25	-	1 503	
Number of species	8	10	10	-	12	-	5	9	4	8	7	-	20	

Catch size and occurrence of species other than *L. richardsonii* are likely to be underreported, largely due to the fishery targeting *L. richardsonii* and the fact that the landing of species such as *P. saltatrix* is prohibited.

3.4.2.2 Breede River Estuary

In total, 10 995 fish representing 34 species from 20 families were caught during seine and gillnet sampling in the Breede Estuary from September 1997 to August 2000.

Seventy-eight seine hauls yielded 9 492 fish or 122 fish.haul^{-1} (Table 3.4b). *Liza richardsonii* (28%), *Caffrogobius* spp. (25%) and *Atherina breviceps* (21%) dominated numerically, providing 74% of the total catch. A further six species, Cape stumpnose *Rhabdosargus holubi* (9%), *Gilchristella aestuaria* (6%), Cape sole *Heteromycteris capensis* (2%), groovy mullet *Liza dumerilii* (2%), *Psammogobius knysnaensis* (1.5%) and *Solea bleekeri* (1.5%) together contributed 22% towards the remainder of the catch. *Liza richardsonii* and *Caffrogobius* spp. occurred in 68-69% of the hauls whereas *A. breviceps* comprised a few large catches in 4% of the hauls. *Caffrogobius* spp. were again not identified to species level in the field but from otolith identification of a subsample roughly comprised 74% *C. gilchristi*, 15% *C. nudiceps*, 8% *C. natalensis* and 3% *C. saldanha* and *C. agulhensis*.

Gillnet sampling caught a total of 1 503 fish at an average catch rate of 32 fish.set-hour^{-1} (Table 3.5b). Catches were dominated by *Liza richardsonii* (62%) and to a lesser extent *L. dumerilii* (21%) which together with *Pomadasys commersonnii* (4%), striped mullet *Liza tricuspidens* (3%), *Lichia amia* (2%) and *Rhabdosargus holubi* (2%), provided 94% of the total catch. *Liza richardsonii* appeared in 64% of the sets whereas *L. dumerilii* and *P. commersonnii* each occurred in 33%.

3.4.3 Abiotic variables

3.4.3.1 Olifants River Estuary

With the exception of the mouth region there was a marked difference in surface salinities at each sampling site between the summer and winter 2004 surveys (Fig. 3.2). During summer, salinity from the mouth to 4 km upstream ranged from 30 – 35 ‰, whereas in winter it ranged from 20 – 25 ‰. In summer the 10 – 20 ‰ salinity zone spanned 5 – 15 km upstream whereas in winter it was confined to 3 – 4 km from the mouth. In summer the River Estuarine Interface (REI) zone (0 – 10 ‰) extended from 15 km upstream all the way to the Lutzville Causeway where salinity was 2.6 ‰. In winter the REI started 4 km from the mouth and salinities dropped to zero approximately 10 km upstream.

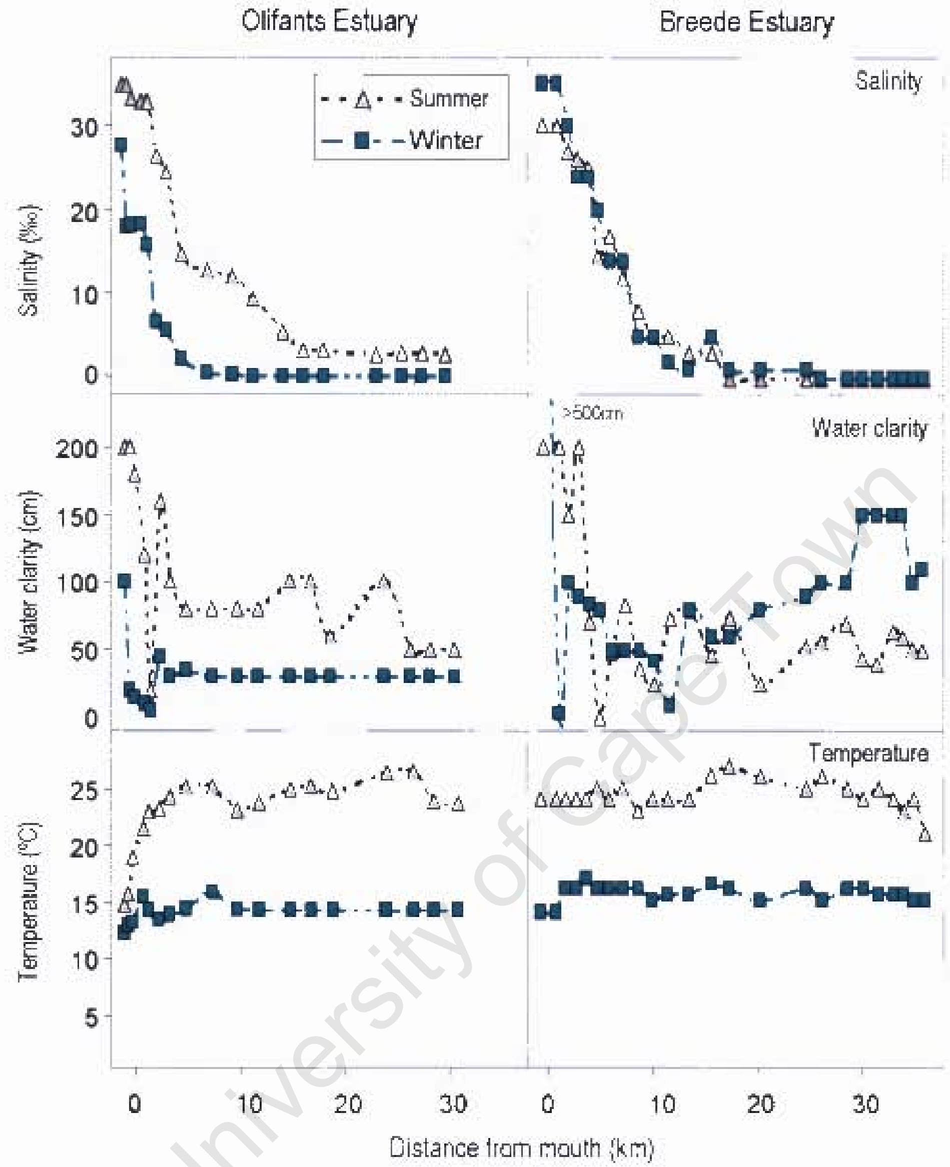


Figure 3.2 Salinity, water clarity and temperature measured at each sampling site during summer (February) and winter (August) on the Olifants River Estuary (2004) and Breede River Estuary (2000).

Water clarity (Secchi disc visibility) at the mouth ranged from more than 200 cm in summer to approximately 100 cm in winter. In both seasons, water clarity dropped approximately 3 km from the mouth, largely due to wind-mixing of fine sediments in the shallow old channel backwater. In summer, water clarity remained fairly constant (80 cm) until 15 km upstream, beyond which it fluctuated according to the presence or absence of dense beds of the pondweed *Potamogeton pectinatus*. During winter, water clarity remained at 40 cm from 5–30 km upstream. Water temperature in summer ranged from 15°C at the mouth to 26°C at the Lutzville Causeway 36 km upstream. In winter, water temperature ranged from 12°C at the mouth to 14°C upstream, the exception being the shallow blind arm near the mouth where it reached 16°C (Fig. 3.2).

3.4.3.2 Breede River Estuary

Surface salinities did not differ much between the summer (February 2000) and winter (August 2000) sampling periods (Fig. 3.2). During winter, salinity from the mouth to 2 km upstream was 35 ‰ compared to 30 ‰ at 0.5 km in summer. In both seasons the 20 ‰ and 10 ‰ boundaries occurred at approximately 6 km and 10 km respectively. In summer, salinity dropped to 0 ‰ at 20 km from the mouth as opposed to 28 km in winter (Fig. 3.2). This is contrary to normal winter-rainfall seasonal patterns where the extent of saline intrusion shrinks or expands in response to high or low flows in winter and summer respectively. Water clarity (Secchi disc visibility) at the mouth ranged from approximately 500 cm in winter to 200 cm in summer. In both seasons, water clarity dropped to below 100 cm approximately 5 km from the mouth. In winter, water clarity increased beyond the 20 km mark whereas in summer it remained <100 cm throughout. Average water temperature in summer was 24.4°C (range = 21-27°C) as opposed to 15.6°C (range = 14-17°C) in winter (Fig. 3.2). In both seasons, temperatures increased gradually from the mouth to the middle reaches followed by a slight decrease 20-40 km upstream.

3.4.4 Seasonality of the ichthyofauna

3.4.4.1 Olifants River Estuary

Catches in the Olifants Estuary were strongly seasonal (Tables 3.4a, 3.5a). The highest and lowest seine catches (9 902 and 61 fish.haul^{-1}) were in spring/early summer (October) and winter (June) respectively (Table 3.4a). The greatest number of species caught (17) was in February, and the lowest (5) in June. *Liza richardsonii* appeared to recruit throughout the year with the highest number of new recruits recorded in the late winter and spring months August and October. Overall, in terms of species, the highest number of new recruits was recorded in summer (February, 8 species) and the lowest in winter (June, 1 species) (Table 3.4a).

Commercial gillnet catches were moderately to strongly seasonal, the highest *cpue* values of 229-263 fish.net-day^{-1} and 236-251 fish.net-day^{-1} being recorded in spring/early summer and autumn respectively (Table 3.5a). The number of species caught was highest in autumn (April, 11 species) and lowest in winter (June/July 6 species).

3.4.4.2 Breede River Estuary

Catches in the Breede Estuary were not strongly seasonal (Tables 3.4b & 3.5b). The highest and lowest seine catches (366 and 57 fish.haul^{-1}) were in the spring months of October and September respectively (Table 3.4b). The greatest number of species caught (27) was in February and the lowest (9) in October. The number of new recruits recorded was highest in the summer months of January-March with seven species recruiting and lowest in the winter months of July-August with three species (Table 3.4b). Gillnet catches were just as erratic with the highest *cpue* (67 fish.set-hour^{-1}) and lowest cpue (14 fish.set-hour^{-1}) being recorded in May and January-February respectively (Table 3.5b). The number of species caught was highest in May (12) and lowest in September (4). Averaging seine catches over the seasons indicated that the highest catches were in spring (Sep-Nov) and autumn (Mar-May) at 247 and 208 fish.haul^{-1} respectively. Seasonal gillnet catches were similar with the greatest *cpue* being in autumn (54 fish.set-hour^{-1}) and spring (29 fish.set-hour^{-1}).

3.4.5 Along-stream distribution of fish

3.4.5.1 Olifants River Estuary

Upstream distribution of the species caught by the gillnet fishery and during the summer and winter seine surveys was largely a reflection of the estuarine-dependence category to which they belong. *Gilchristella aestuaria*, a category Ia estuarine-breeding species, with a preference for the river estuarine interface (REI) zone, showed a downstream shift in distribution and a diminution of numbers during the winter months (Fig. 3.3a). This downstream shift corresponded with the REI zone starting at 4-5 km from the mouth during winter as opposed to 15 km during summer. In summer, category Ib species that have marine and estuarine breeding populations, i.e. *Caffrogobius* spp., *Psammogobius knysnaensis*, *Syngnathus temminckii*, the klipvis *Clinus superciliosus* and *Atherina breviceps*, were largely confined to the lower 12 km of the estuary in salinities of 5-35 ‰. During winter there was a distinct downstream shift and a drop in abundance of nearly all these species (Fig. 3.3a).

Category IIa species that are entirely dependent on estuaries as a juvenile habitat showed various responses between summer and winter. *Lithognathus lithognathus* shifted slightly downstream and increased in abundance during winter (Fig. 3.3b). *Lichia amia* was found up to 20 km from the mouth in summer but only 10 km upstream in winter, and in diminished numbers. *Mugil cephalus* was distributed throughout the estuary in summer with the highest densities 20–35 km upstream as opposed to winter when juveniles were completely absent and the entire population was confined to the lower 20 km (Figs. 3.3 a, b).

Of the partially estuarine-dependent species (categories IIb & IIc), *Solea bleekeri* (Fig 3a), *Rhabdosargus globiceps* and the barbel/white seacatfish *Galeichthyes feliceps* (Fig. 3.3b) were distributed in the lower 15 km during summer and winter but in much lower numbers in the latter season.

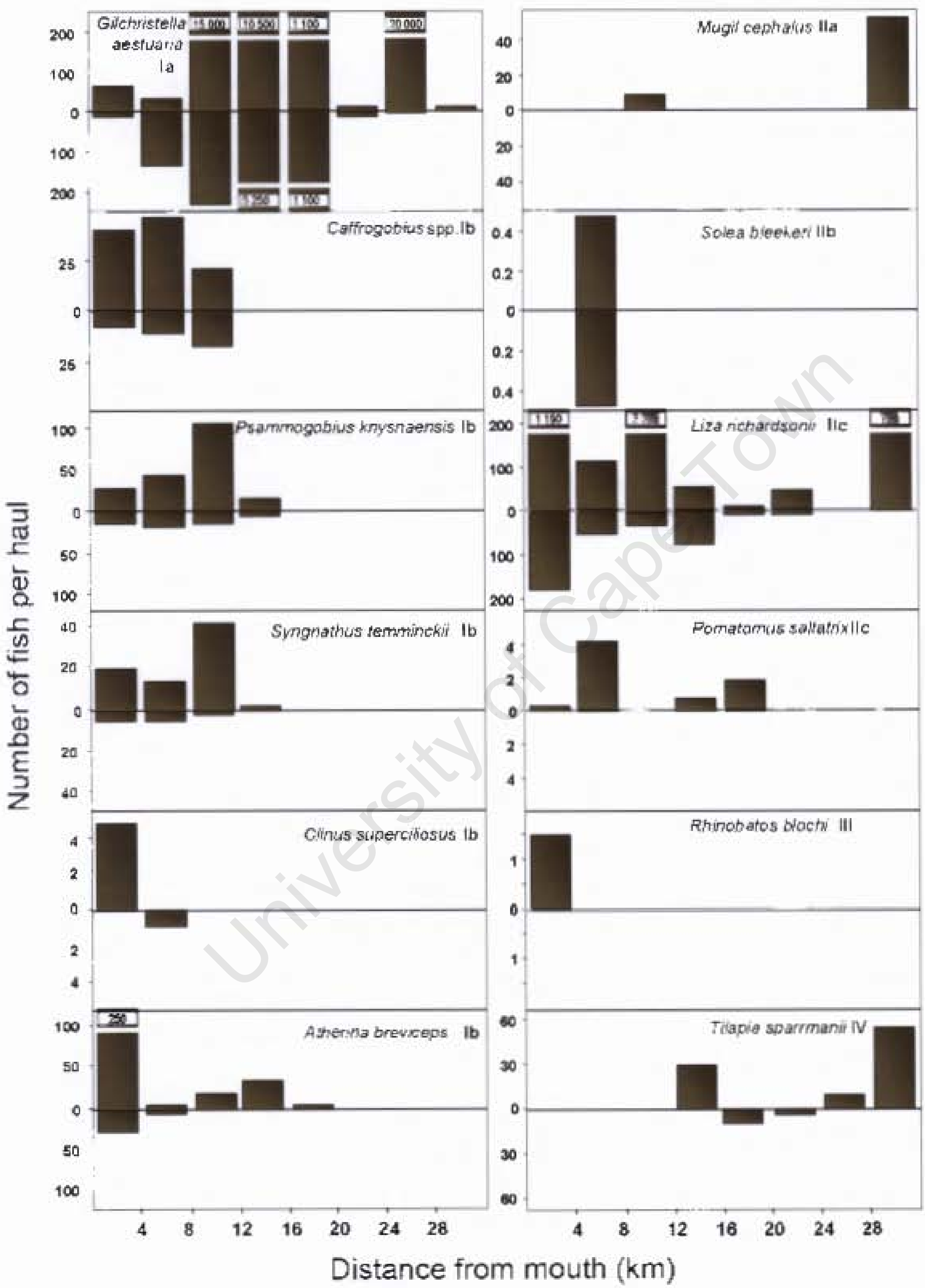


Figure 3.3a Catch per seine haul from the mouth of the Olifants Estuary to 36 km upstream during summer (Feb) and winter (Aug) 2004. Summer catches are shown above, and winter catches below, each axis. Species arranged in order of their estuarine dependence category (Table 3.1).

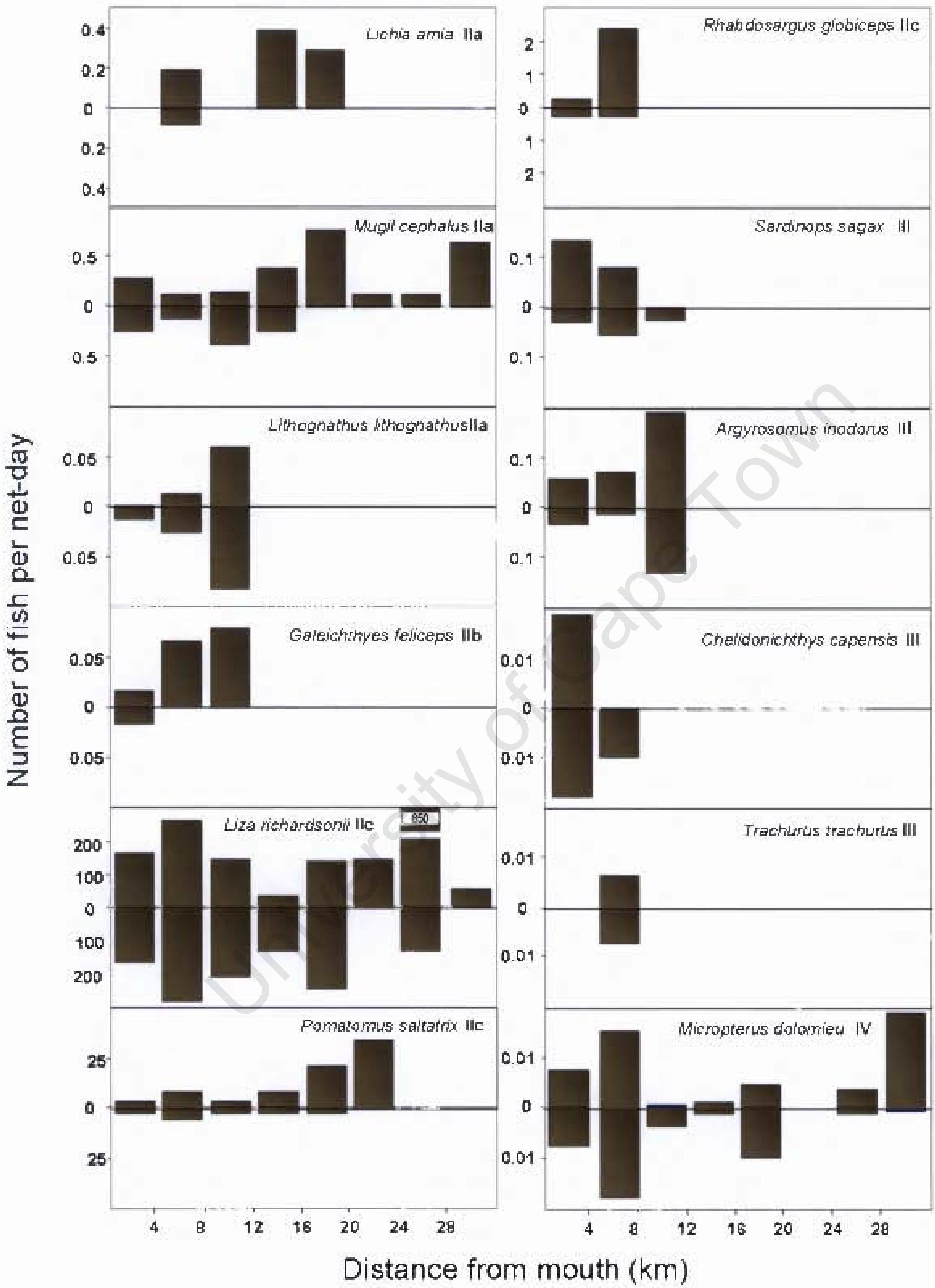


Figure 3.3b Commercial gillnet catch per net-day from the mouth of the Olifants Estuary to 36 km upstream during 2003 - 2004. Summer catches are shown above, and winter catches below, each axis. Species arranged in order of their estuarine dependence category (Table 3.1).

Liza richardsonii (IIc) was spread throughout the estuary during summer but concentrated in the lower 20 km during winter. This species had two peaks of abundance during summer, one in the lower 5-10 km and one 30-35 km upstream, but the latter peak disappeared in winter (Figs 3.3a & 3.3b). *Pomatomus saltatrix* (IIc) occurred from the mouth to 24 km upstream in summer, up to 20 km upstream in winter, but was more abundant in summer with densities gradually increasing upstream (Fig. 3.3b).

Marine species that are not estuarine-dependent (Category III), such as *Rhinobatos blochi* (Fig. 3.3a), *Sardinops sagax, Argyrosomus inodorus* and *Chelidonichthys capensis* (Fig. 3.3b) were confined to the lower 12 km in winter and summer. With the exception of *A. inodorus*, which peaked at 8–12 km in winter and summer, they all decreased in abundance from the mouth upstream. Euryhaline freshwater species (IV) such as *Tilapia sparrmanii* (Fig. 3.3a) and *Micropterus dolomieu* (Fig. 3.3b) were either confined to the upper reaches with low salinities or reached their greatest abundance there, and their modal peak of abundance shifted downstream in winter.

In summary, the majority of completely and partially estuarine-dependent species were most abundant 5-20 km from the mouth in salinities spanning 0-20 ‰ and water clarity < 100 cm. With the exception of *A. inodorus*, marine species that are independent of estuaries occurred most often in the lower 5 km at salinities > 20 ‰, whereas most freshwater-tolerant species were situated further than 15 km from the mouth in salinities of 0-10 ‰.

3.4.5.2 Breede River Estuary

The estuary breeder *Gilchristella aestuaria* (category Ia) was largely confined to the REI zone and showed a shift from 25-40 km upstream during summer to 5-15 km during winter (Fig. 3.4a). Category Ib species that have marine and estuarine breeding populations, i.e. *Hyporhamphus capensis, Syngnathus temminckii, Psammogobius knysnaensis* and *Clinus superciliosus* were largely confined to the lower reaches of the estuary in salinities of 20-35 ‰. The exception in this group was *Caffrogobius* spp., which ranged throughout the estuary during both seasons but with the bulk of the population showing a distinct downstream shift from 10-20 km to 0-10 km from the mouth during winter (Fig. 3.4a).

Category IIa species, entirely dependent on estuaries as a juvenile habitat, showed various responses between summer and winter. *Rhabdosargus holubi* and *Lithognathus lithognathus* showed a downstream shift of approximately 10 km during winter (Fig. 3.4a). *Argyrosomus japonicus* and *Lichia amia* were spread throughout much of the estuary during summer but disappeared from catches during winter, probably a reflection of their overall low abundance rather than an absence from the system (Fig. 3.4a,c). *Mugil cephalus* and *Monodactylus falciformis* were mostly found further than 15 km from the mouth in salinities close to 0 ‰ (Fig. 3.4a,c).

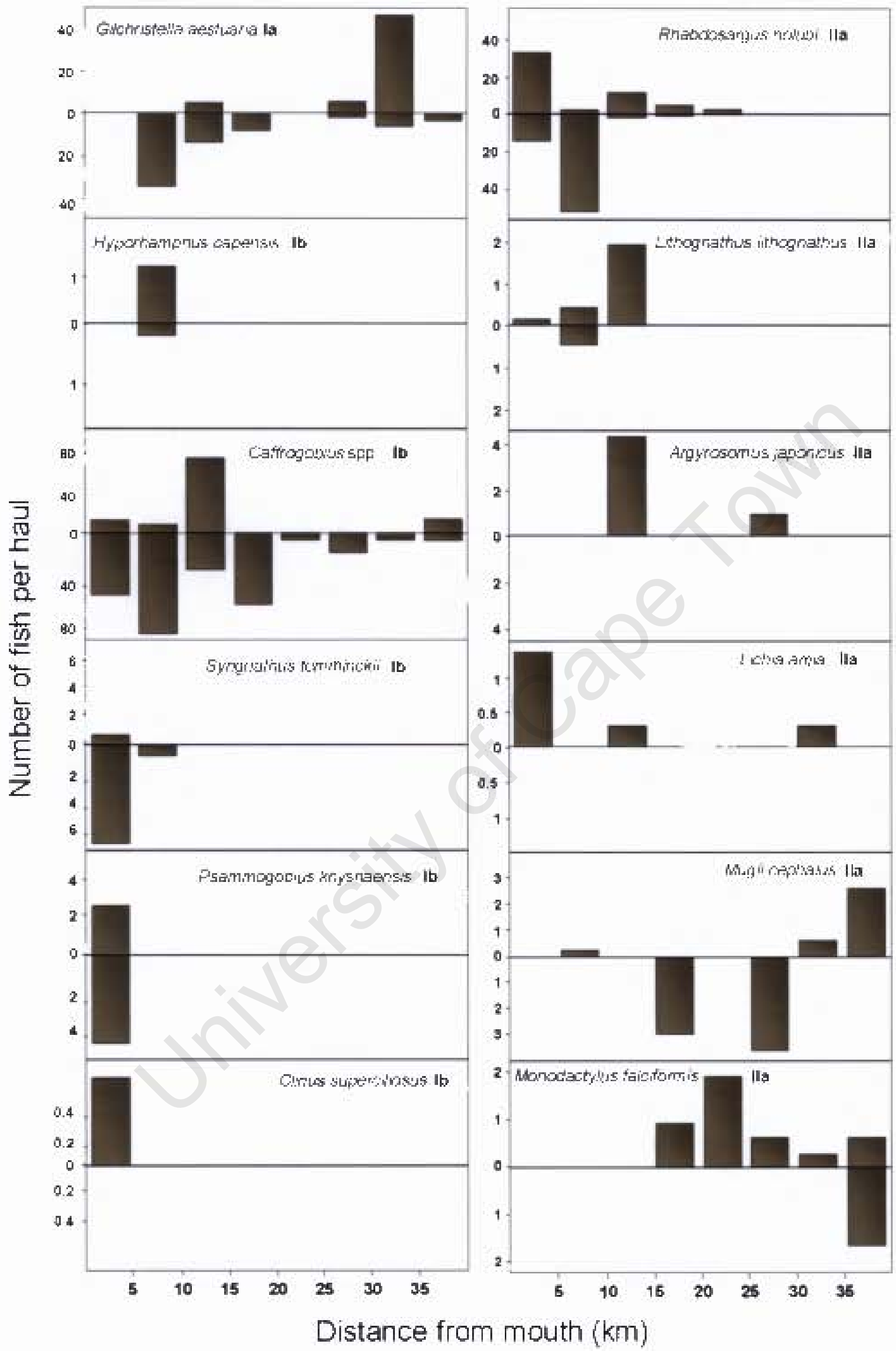


Figure 3.4a Catch per seine haul from the mouth of the Breede Estuary to 40 km upstream during summer (Feb) and winter (Aug) 2000. Summer catches are shown above, and winter catches below, each axis. Species arranged in order of their estuarine dependence category (Table 3.1).

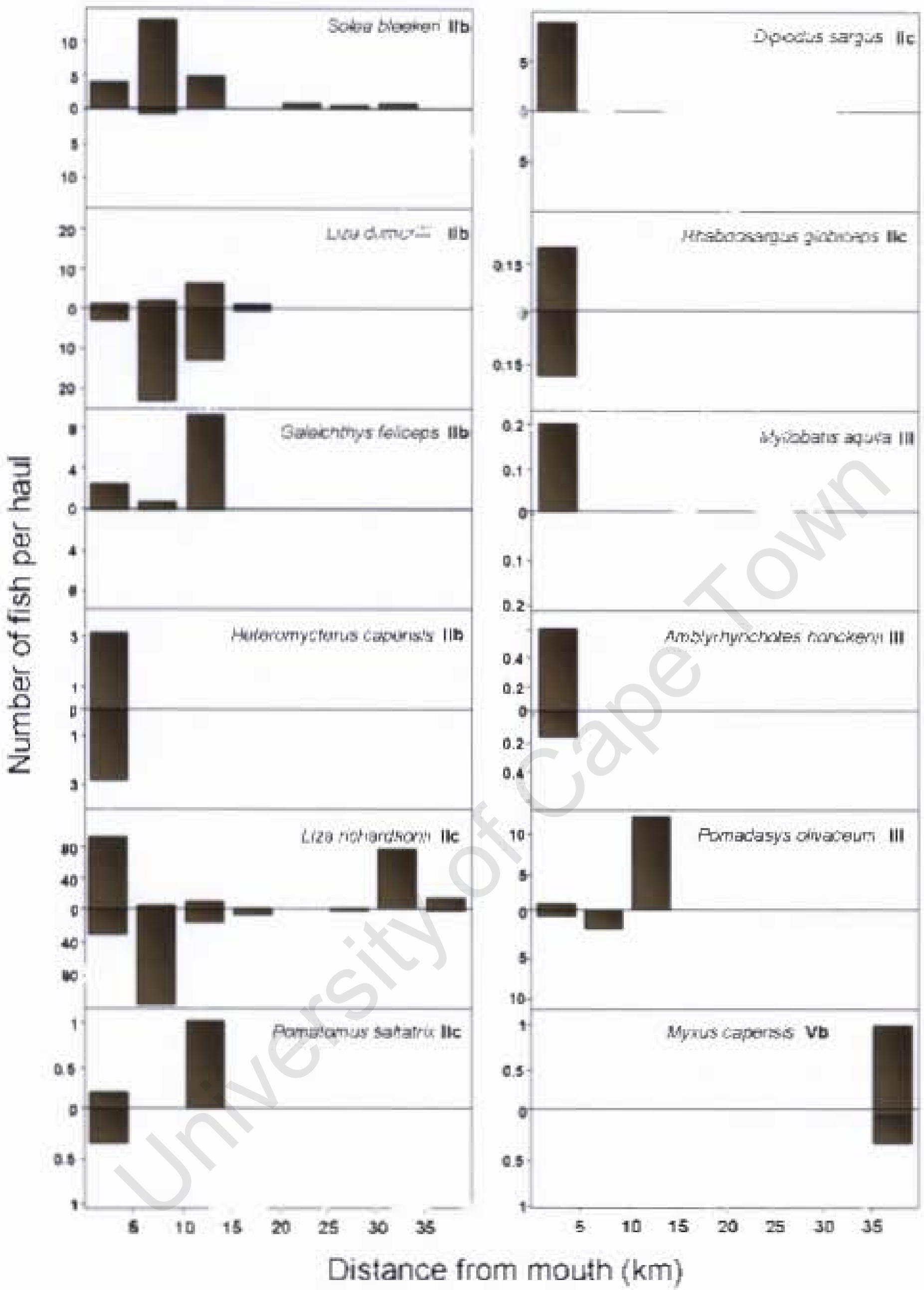


Figure 3.4b Catch per seine haul from the mouth of the Breede Estuary to 40 km upstream during summer (Feb) and winter (Aug) 2000. Summer catches are shown above, and winter catches below, each axis. Species arranged in order of their estuarine dependence category (Table 3.1).

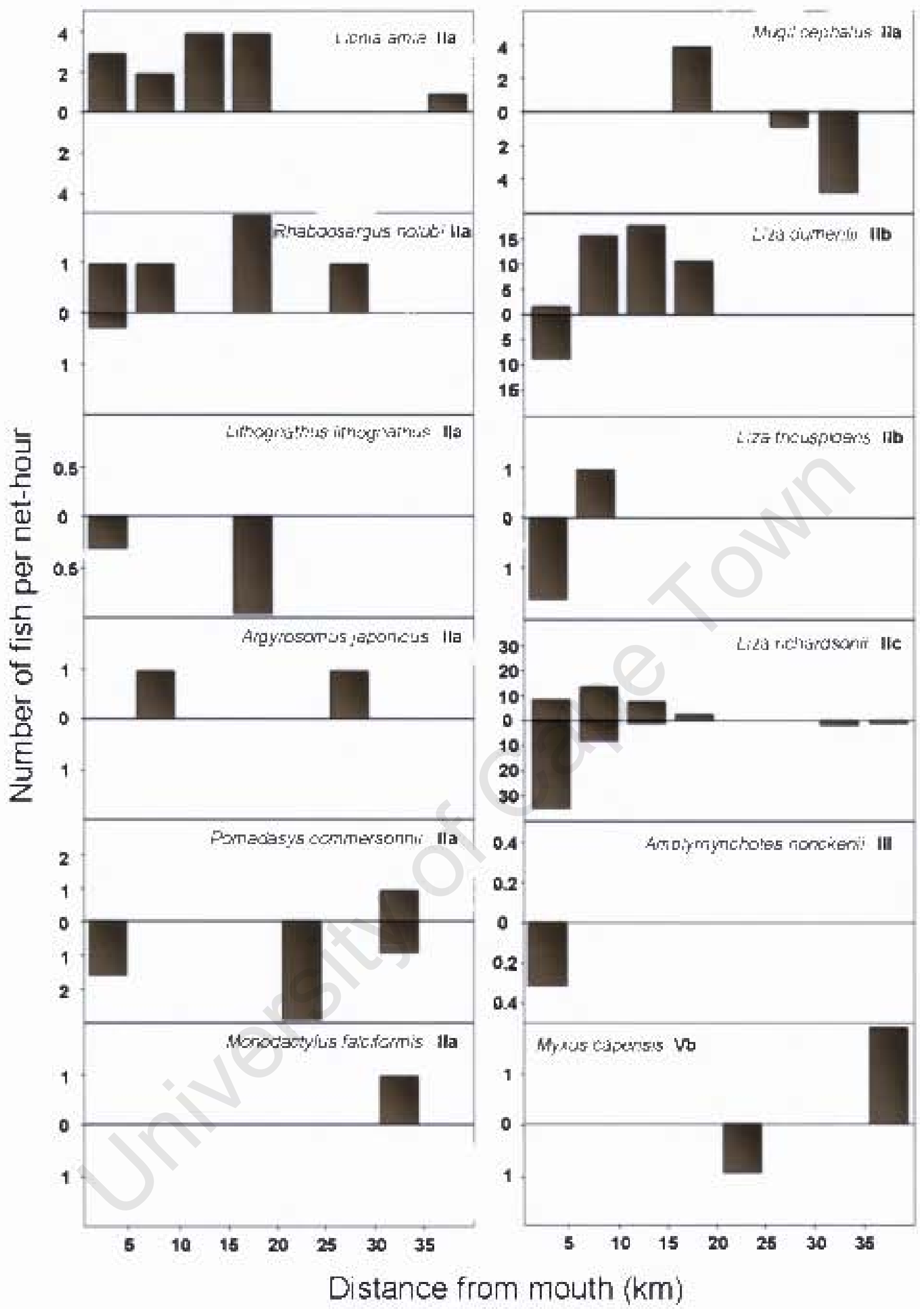


Figure 3.4c Catch per gillnet hour from the mouth of the Breede Estuary to 40 km upstream during summer (Feb) and winter (Aug) 2000. Summer catches are shown above, and winter catches below, each axis. Species arranged in order of their estuarine dependence category (Table 3.1).

Partially estuarine-dependent species (Categories IIb & IIc), such as *Liza richardsonii*, *Liza dumerilii* and *Solea bleekeri* were spread throughout the estuary during summer but concentrated in the lower 10 km or absent during winter (Figs. 3.4b & 3.4c). Similar to the situation in the Olifants Estuary, *L. richardsonii* had two abundance peaks during summer, one in the lower 5 km and one 30-40 km upstream, but the latter peak again disappeared during the winter months (Fig. 3.4b). With the exception of *Pomadasys olivaceum*, which was found 15 km upstream in salinities of less than 10 ‰, all marine species not dependent on estuaries (category III) were confined to the lower 5 km and salinities above 20 ‰ (Fig. 3.4b). The facultative catadromous *Myxus capensis* (Vb) was found above 20 km in 0 ‰ during both seasons (Figs 3.4b & 3.4c) and has also been recorded 100 km upstream shoaling with *Mugil cephalus* (Lamberth 2001).

The majority of completely and partially estuarine-dependent species were most abundant from 5-20 km from the mouth in salinities ranging from 0-20 ‰ and water clarity <100 cm. Marine species that are not dependent on estuaries were recorded most often in the lower 5 km at salinities >20 ‰ whereas most freshwater tolerant and catadromous species occurred further than 20 km from the mouth in salinities of 0-1 ‰.

3.4.6 Effects of altered freshwater flows on abiotic states

3.4.6.1 Olifants River Estuary

Four abiotic states ranging from marine to freshwater dominated were identified in the Olifants Estuary (Table 3.6a). State 1 was marine-dominated with flow less than 2 m^3s^{-1} and a REI zone comprising less than 26% of the estuarine area. States 2 and 3 had saline penetration limited to the middle and lower reaches respectively whereas under the freshwater-dominated State 4 the REI zone covered 60-100% of the total estuarine area.

Under reference conditions the Olifants Estuary would have been more river-dominated than at present: the marine-dominant State 1 never occurred and freshwater-dominated State 4 conditions with average flows greater than 20 m^3s^{-1} would have persisted for at least four months (June - September) every year (Table 3.6a). Under these conditions the REI zone of 0 - 10 ‰ began 0 – 5.4 km from the mouth during spring tidal cycles and extended 36 km upstream. State 2 conditions (2 - 5 m^3s^{-1}) would have dominated during the summer months of December - March and State 3 would have occurred during autumn (April - May) and spring (November – December). Under drought conditions the REI zone would have persisted from 9 km upstream and constituted approximately 140 ha or 34% of the water surface area.

Table 3.6a Summary of the characteristics of the four possible abiotic states, their monthly occurrence and percentage mean annual runoff (MAR) remaining, for the reference, present day and five future flow scenarios in the Olifants River Estuary

	State 1	State 2	State 3	State 4
General description	Marine dominated	Saline penetration extended to middle reaches	Saline penetration limited to lower reaches	Freshwater dominated
Typical flow	< 2 m^3s^{-1}, usually in summer (Zero occurrence under reference)	2-5 m^3s^{-1}, (Summer under reference)	5-20 m^3s^{-1}, (Autumn & spring under reference)	> 20 m^3s^{-1} (Winter under reference)
Mouth condition	Open, slightly constricted	Open	Open	Wide open
Tidal amplitude	0.3 - 1.3 m	0.3 - 1.3 m	0.3 - 1.3 m	0.3 - 1.3 m
REI zone begins (spring tides)	13 - 20 km	9 km	1 - 6 km	0 – 5.4 km
REI area (maximum)	110 - 64 ha	141 ha	201 ha	417 – 252 ha
REI area as% total surface area	26 – 15%	34%	48%	100 – 60%

Scenario	% MAR	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Reference	100	2	2	2	3	3	4	4	4	4	3	3	2
Present	66	1	1	1	1	2	4	4	4	4	3	1	1
1	75	1	1	1	2	3	4	4	4	4	3	2	1
2	69	1	1	1	2	3	4	4	4	3	3	2	1
3	57	1	1	1	1	2	3	4	4	3	2	1	1
4	50	1	1	1	1	1	3	4	4	3	1	1	1
5	40	1	1	1	1	1	2	2	3	3	1	1	1

Table 3.6b Summary of the characteristics of the four possible abiotic states, their monthly occurrence and percentage mean annual runoff (MAR) remaining, for the reference present day and four future flow scenarios in the Breede River Estuary.

	State 1	State 2	State 3	State 4
General description	Marine dominated	Balanced marine and freshwater influence	Freshwater dominated with significant saline intrusion in lower reaches	Strongly freshwater dominated
Typical flow	0.5-3 $m^3.s^{-1}$, <0.5 $m^3 s^{-1}$ may occur in summer (November-April)	3-10 $m^3 s^{-1}$	10-20 $m^3.s^{-1}$ common in autumn & winter	>20 $m^3.s^{-1}$ usually in winter
Mouth condition	Open	Open	Wide open	Wide Open
Tidal amplitude	0.9-1.5 m	0.9-1.5 m	0.9-1.5 m	0.9-1.5 m
REI zone begins (spring tides)	32->50 km	18-32 km	12-18 km	2-10 km
REI area (maximum)	247 – 0 ha	475 – 247 ha	661 – 475 ha	1 168 – 754 ha
REI area as% total surface area	18 – 0%	35 – 18%	48 – 35%	85 – 55%

Scenario	% MAR	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Reference	100	2	2	2	3	4	4	4	4	4	4	4	3
Present	58	1	1	2	2	3	4	4	4	4	4	3	2
1	53	1	1	2	2	2	3	4	4	4	4	3	2
2	48	1	1	1	2	2	3	4	4	4	4	3	2
3	43	1	1	1	1	2	2	3	4	4	4	3	2
4	36	1	1	1	1	1	2	3	4	4	3	2	2

Under present-day conditions the estuary has switched from a freshwater-rich to a marine-dominated system for much of the year. Marine-dominated State 1 conditions, which never occurred under reference conditions, with average flows < 2 m^3s^{-1}, persist for six months of the year (November – April). High-flow State 4 conditions (> 20 m^3s^{-1}) still occur for four months during the winter (June – September) but State 3 conditions (5 - 20 m^3s^{-1}), once characteristic of spring and autumn, now occur only for one month during spring. Under these conditions the winter REI zone of 0 - 10 ‰ still begins at 0 – 5.4 km from the mouth. However, under spring tidal cycles, the summer REI begins at 13 – 20 km as opposed to a maximum of 9 km under reference conditions. Overall, the summer REI may be 55% smaller in extent than it was under reference conditions.

Scenarios 1 and 2 represent a slight increase in flow from the present day, all future scenarios constitute a progressive increase in the duration and extent of marine-dominated relative to reference conditions (Table 3.6a).

3.4.6.2 Breede River Estuary

Four abiotic states were identified for the Breede Estuary (Table 3.6b). Under reference conditions the estuary was more river-dominated than present, with freshwater dominated State 3 and 4 conditions (>10 m^3s^{-1}) persisting for at least nine months (Apr-Dec) every year whereas marine-dominated State 1 conditions would have been absent (Table 3.6b). Under these conditions the REI zone of < 10 ‰ began 2-10 km from the mouth during spring tidal cycles and extended 40-50 km upstream. State 2 (3-10 m^3s^{-1}) conditions with balanced marine and freshwater influence would have dominated during the summer months of January-March. Under drought conditions the REI zone would have persisted from 32 km upstream and been approximately 20 km in extent.

Under present day conditions the estuary is less river-dominated than under pristine conditions but State 3 and 4 conditions with average flows greater than 10 m^3s^{-1} still persist for at least seven months (May-November) every year (Table 3.6b). Under these conditions the REI zone of <10 ‰ begins 12-18 km from the mouth during spring tidal cycles and extends approximately 40 km upstream. State 2 conditions (3-10 m^3s^{-1}) are confined to mostly autumn and December whereas State 1 conditions dominate the summer months of January-February. Overall, present day conditions represent a 42% reduction in MAR.

The future scenarios represent a further reduction in MAR ranging from 47% under the limited development Scenario 1 to 64% under the Le Chasseur Scenario 4 (DWAF 2004b). This will progressively increase marine-domination and curtail freshwater domination.

3.4.7 The effects of altered freshwater flow on fish

Present-day conditions represent 34% and 42% reductions in MAR reaching the Olifants and Breede estuaries respectively. In the Olifants, the first two scenarios will increase freshwater flow from the present circumstance, but still represent a 25–31% reduction in flow from reference conditions. Reductions of 43% can be expected under Scenario 3 and 60% under Scenario 5 with the construction of a large dam. In contrast, numerous proposals exist for the Breede catchment so that increases in freshwater flow are unrealistic and all four future scenarios examined represent a decline in flow, the largest of which would result in reductions of 57% and 64% of the MAR reaching the estuary respectively (Table 3.2)

Under reference conditions the fish assemblage of the Olifants Estuary would have been dominated by category Ia estuarine breeders (37%) and partially estuarine-dependent category IIc species (61%) whereas that of the Breede Estuary would have been dominated by category Ib marine and estuarine breeders (50%) and category IIc species (28%) (Fig. 3.5a, b). Even though overall absolute abundance has changed, the relative contribution of these categories to the fish assemblages of the two estuaries has changed little from reference conditions to the present day. Even under the worst-case scenario with 60% reductions in MAR, relative proportions will change only by 3%.

In the Olifants and Breede, species that breed only in estuaries (Category Ia, e.g. *Gilchristella aestuaria*) have undergone 20% and 15% reductions in numbers from the reference to present day whereas those that have estuarine and marine breeding populations (Category Ib, e.g. *Atherina breviceps*) have increased by 74% and 9% respectively (Fig. 3.5c,d). In the Olifants, category Ia estuarine-breeders will increase slightly to 86–87% of reference with an increase in MAR under the first two future scenarios but will decline to 59% of reference abundance if flow is reduced by 60% relatively to the historical MAR (Fig. 3.5c). Similarly, in the Breede, category Ia fish will decline to 61% of reference abundance once MAR declines by 64% (Fig. 3.5d).

Under present conditions, category IIa obligate estuarine-dependent species such as *Mugil cephalus* and *Lithognathus lithognathus* have declined in abundance to 17% of reference conditions in the Olifants Estuary and are likely to decline to 8% of reference under the maximum 60% reduction in MAR of scenario 5 (Fig. 3.5c). Specifically, *L. lithognathus* and *M. cephalus* have experienced an 80% and 91% decrease from reference to present day and will decline to 17% and 6% of reference under scenario 5 (Fig. 3.6). In contrast to the Olifants, obligate estuarine-dependent fish (category IIa) in the Breede Estuary are 4% more abundant under present day than reference conditions (Fig. 3.5d). Under future scenarios they will experience a 13% increase from reference conditions. However, this is not entirely true for all species within this category.

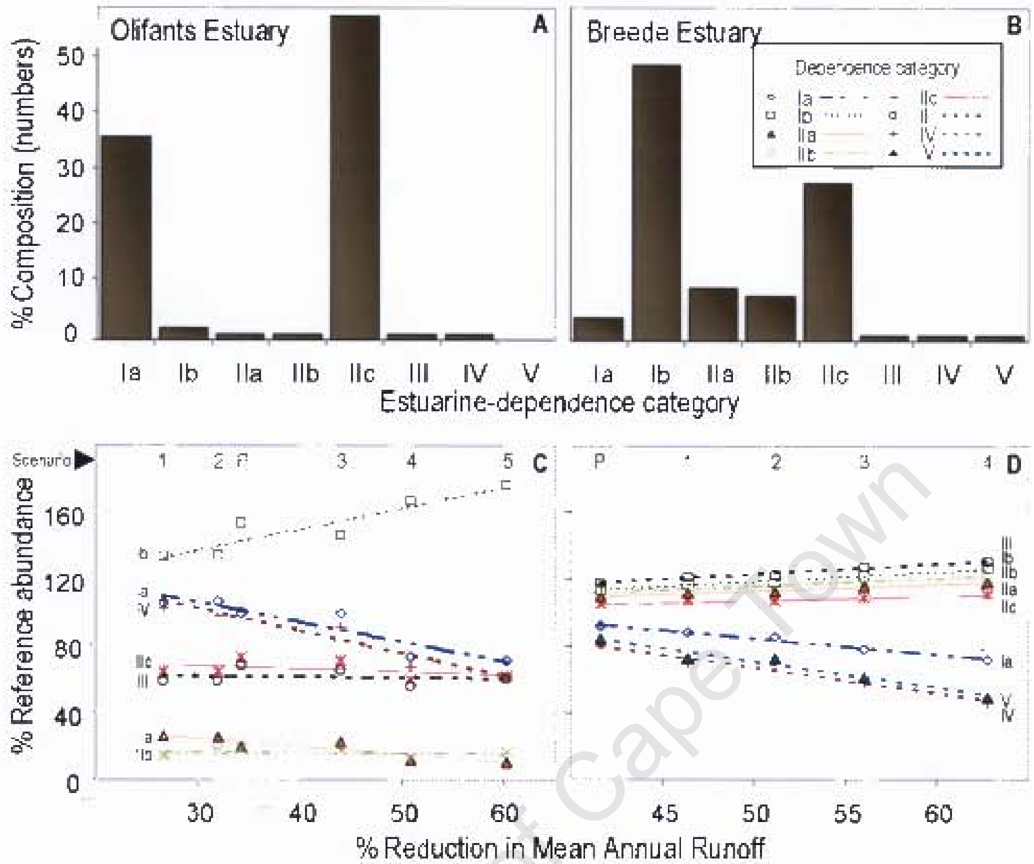


Figure 3.5 Percentage composition of the different estuarine-dependence categories under reference (pristine) conditions (A, B) and the responses of the fish in different estuarine dependence categories to various reductions of MAR from reference conditions under the different flow scenarios in the Olifants River and Breede River estuaries (C, D). Responses are measured as the percentage change relative to pristine abundance. The scenarios are numbered 1-5 and P is the present day. Dependence categories after Whitfield 1994b, Table 3.1.

Four of the seven species will experience a drastic decline from reference conditions to the Le Chasseur scenario with a maximum 64% reduction in MAR (Fig. 3.6). Declines will occur for Cape moony *Monodactylus falciformis* (62%), *Mugil cephalus* (54%), *Argyrosomus japonicus* (49%) and *Pomadasys commersonnii* (34%). Conversely, in this same category, *Lithognathus lithognathus*, *Rhabdosargus holubi* and *Lichia amia* will experience increases in abundance of 20-25% with decreasing flows (Fig. 3.6).

Partially estuarine-dependent category IIb species in the Olifants, represented only by *Solea bleekeri*, have declined to 19% of reference in the present day but, irrespective of increases or decreases in future flows, will not undergo any really discernable changes in abundance (Figs. 3.5c & 3.6).

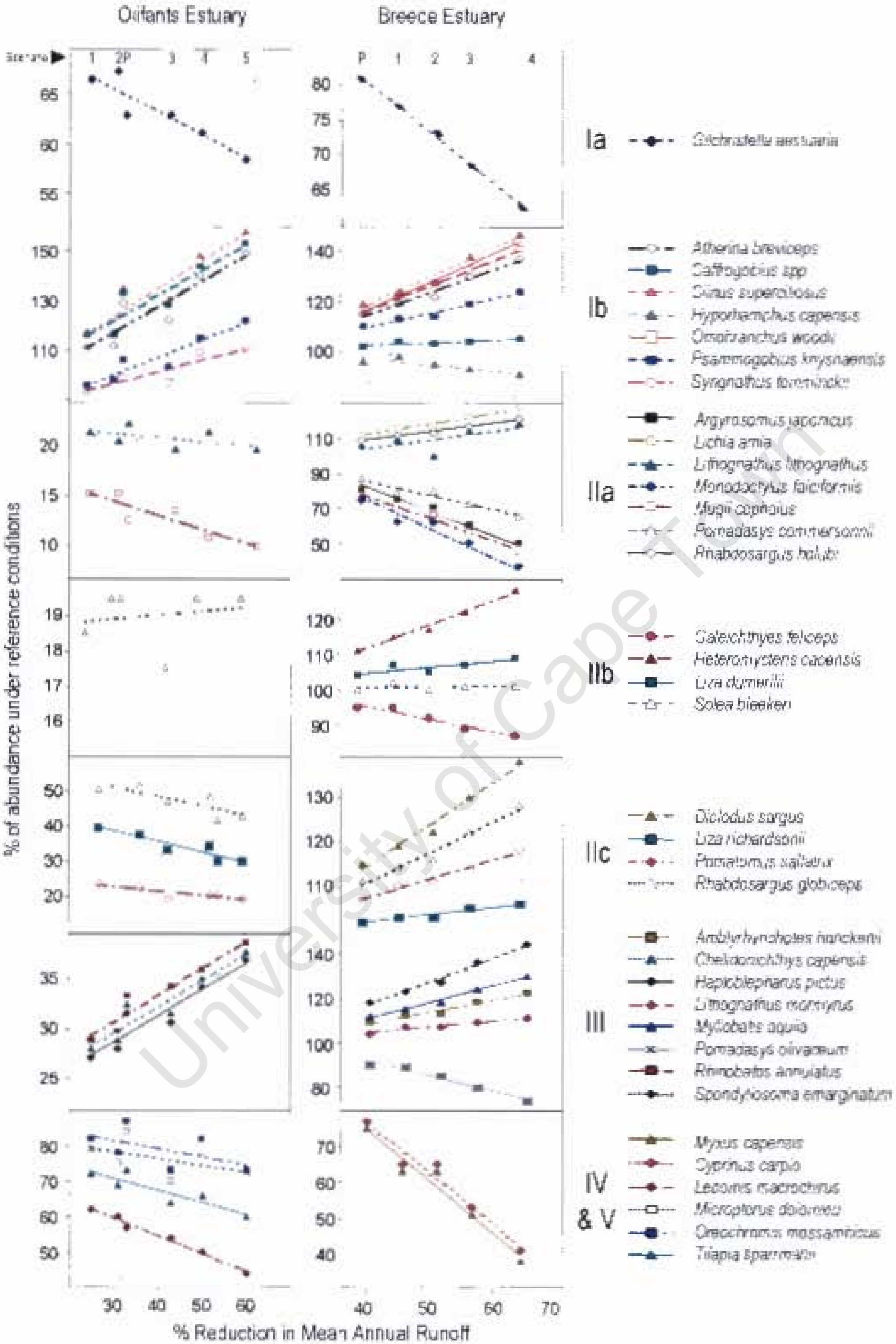


Figure 3.6 Estuarine fish abundance as a percentage of reference (pristine) relative to the reduction in Mean Annual Runoff under present day conditions and for each of the future flow scenarios in the Olifants River and Breede River estuaries. The scenarios are numbered 1-5 and P is the present day. Dependence categories after Whitfield 1994b, Table 3.1.

Category IIb species in the Breede have undergone a 7% increase from reference to the present with a maximum 17% increase predicted for the maximum 64% reduction in MAR (Fig. 3.5d). The increase in abundance of this group is driven by *Heteromycteris capensis* and *Liza dumerilii*; *Galeichthys feliceps* will decline by 13% from reference with a future maximum reduction in MAR whereas *Solea bleekeri* will undergo no real change for any of the future scenarios (Fig. 3.6).

In the Olifants Estuary, partially estuarine-dependent category IIc fish, dominated by *Liza richardsonii*, have populations that are 60% of those under reference conditions (Fig. 3.5c). Increased flows in scenarios 1 and 2 will bring minor improvements, but all three species in this category (*Liza richardsonii*, *Pomatomus saltatrix* and *Rhabdosargus globiceps*) will undergo a further 10% decline from present day under the worst-case scenario 5 that will bring a 60% reduction in MAR (Fig. 3.6). In the Breede Estuary, category IIc species have experienced a small (3%) increase to the present day and are expected to increase to 9% more than reference by Scenario 4 (Fig. 3.5d). Without exception all four fish in this category (*Diplodus sargus*, *Liza richardsonii*, *Pomatomus saltatrix* and *Rhabdosargus globiceps*) in the Breede will increase in abundance with future reductions in flow (Fig. 3.6).

In the Olifants Estuary, marine species that are not estuarine-dependent (category III) have presently been reduced to 57% of their reference abundance (Fig. 3.5c). However, all three species in this category (*Chelidonichthys capensis*, *Haploblepharus pictus* and *Rhinobatos blochii*) will undergo a 5-7% increase in abundance from present day to Scenario 5 involving a 60% reduction in MAR (Fig. 3.6). In the Breede, non estuarine-dependent marine species will undergo the greatest increase in abundance with decreasing flows (Fig. 3.6). At present they are 9% greater in numbers than during reference conditions and are likely to increase to 123% of reference if the 64% reduction in MAR associated with the Le Chasseur scenario is implemented. The exception in this category is *Pomadasys olivaceum* that is likely to decline to 74% of reference in the event of the worst-case scenario.

Category IV freshwater species in the Olifants Estuary, which are dominated by alien species, are likely to decline by 48% with a 60% reduction in MAR (Figs. 3.5c, 3.6). Category IV freshwater fish in the Breede Estuary are also almost entirely introduced species such as carp *Cyprinus carpio* and may decline by 62% with the maximum 64% reduction in MAR (Figs. 3.5d, 3.6). However, the facultative catadromous freshwater mullet *Myxus capensis* (category V) has decreased by 25% from reference to present day conditions and forecast to drop to 38% of reference under the Le Chasseur scenario (Figs. 3.5d, 3.6).

Overall abundance in the Olifants Estuary has decreased by 20% from reference to the present day and will decline to 55% of reference with the 60% reduction in MAR under Scenario 5. Overall, abundance in the Breede Estuary has increased to 106% of the reference level and is likely to increase to 115% of reference with future reductions in flow.

3.5 Discussion

3.5.1 Importance of the two estuaries to fish

Species that breed in estuaries and/or estuarine residents comprise 21% and 17% of the Olifants and Breede Estuary fish fauna as compared to 22-26% for the west–coast Orange and Berg estuaries combined, 25% for all south coast estuaries (Cape Agulhas – Cape St Blaize) and 4-18% for those on the southeast and KwaZulu-Natal coasts (Bennett 1994, Harrison 1999, Lamberth 2003). Including all estuarine breeders, entirely estuarine-dependent species comprise 32% and 39% of the Olifants and Breede Estuary fish fauna, similar to the 26-33% for all west coast estuaries, low compared to 54% for all south-coast estuaries but high compared to the 22% and 9% for estuaries on the southeast and KwaZulu-Natal coasts respectively (Bennett 1994, Harrison 1999, Lamberth 2003). Partially estuarine-dependent species comprise 16% of the Olifants and 22% of the Breede fish fauna, within the 7-29% range of all west coast estuaries and 18-27% for all estuaries from Cape Point to KwaZulu-Natal (Bennett 1994, Harrison 1997, Harrison 1999, Lamberth 2003).

The degree of estuarine dependency may vary within a species among biogeographical regions (Elliott *et al.* 2007). Two species of kob, silver kob *Argyrosomus inodorus* and Angolan kob *A. coronus* are known from the Berg, Olifants and Orange Estuaries, but *A. coronus* has only been caught by anglers in the mouth regions (Lamberth 2003). On the south and east coasts of South Africa the dusky kob (A. *japonicus*) is dependent on estuarine nursery areas whereas *A. inodorus* seldom if ever ventures into estuaries. On the west coast however, *A. inodorus* frequently (and predictably) occurs in the Berg, Olifants and Orange estuaries whereas *A. coronus* is predominantly caught on the beaches immediately adjacent to the mouths of these estuaries, only being recorded in estuaries during low-oxygen conditions in the sea (Lamberth 2003, Chapter 4). Thus, *A. inodorus* may show some degree of estuarine dependence on the west coast of South Africa but not on the south and east coasts. In turn, once outside the northwestern limit of *A. inodorus* in Namibia, *A. coronus* becomes abundant in predominantly open estuaries throughout Angola from the Kunene River to at least the Kwanza River in the north (Lamberth unpublished data, Griffiths & Heemstra 1995)

Marine species that are independent of estuaries comprise a relatively high proportion of the fish recorded in the Olifants (32%) and Breede (36%) estuaries. However, most marine species recorded in the Breede River, e.g. galjoen *Dichistius capensis*, prodigal son *Rachycentron canadum* and geelbek *Atractoscion aequidens*, or in the Olifants Estuary, e.g. pilchard *Sardinops sagax* can be construed as rare vagrants that seldom enter estuaries, their occurrence largely being a result of a strong marine influence in the mouth region of these two permanently open systems. This said, in the Olifants Estuary, silver kob *Argyrosomus inodorus* and west coast steenbras *Lithognathus aureti* do occur in a predictable pattern depending on season and weather conditions, i.e. they are not vagrants that occur there incidently (Lamberth 2003). Overall, although the proportion (and occurrence) of non-estuarine-dependent marine species in the Olifants is high, this is not surprising given that the Olifants Estuary is permanently open and one of the few available warm-water refuges when sea temperatures drop during the summer upwelling season on the west coast.

Catadromous anguillid eel species do not occur in the Olifants or other estuaries on the western seaboard of sub-Saharan Africa whereas four occur on the southeast coast, three in the Breede Estuary (Whitfield 2005b). These comprise one southern African endemic (*Anguilla mossambica*) and three Indo-Pacific species with a common ancestry (Tsukamoto & Aoyama 1998). Although the Indo-Pacific species are distributed throughout the eastern seaboard of Africa, no West African ancestors have dispersed to or speciated on the southern west coast, probably having been inhibited by the development of the Benguela upwelling system, equatorial currents, "poor" climatic conditions and lack of rivers in the southeastern Atlantic (Tesch 2003, Whitfield 2005b).

Based on distributional ranges given by Smith and Heemstra (1986), 21 (55%) of the fish recorded in the Olifants River Estuary and 25 (42%) of those in the Breede Estuary are southern African endemics. At least 12 of these are South African endemics. In terms of the fish importance score outlined in the Resource Directed Measures (RDM) methods for the allocation of freshwater resources, the Olifants Estuary and Breede estuaries have biodiversity and overall importance scores of 99% and 90% respectively, which places both systems within the top quintile of all estuaries in South Africa (Turpie *et al.* 2002). The Olifants is one of only three predominantly open estuaries on the cool-temperate west coast whereas the Breede is one of five permanently open out of a total of eight estuaries from Cape Agulhas to Mossel Bay on the warm-temperate southeast coast (Harrison 1999). The importance of the Olifants lies in its rarity and the fact that it comprises more than 25% of the available estuarine habitat in the cool-temperate region. The Breede is the largest of the estuaries on the warm-temperate south coast and accounts for 43% of the total estuarine area within this region (Turpie *et al.* 2002). Its importance lies in its size and its situation in a region of high endemicity close to the warm-temperate/cool-temperate transition zone between Cape Agulhas and Cape Point (Harrison 1999).

3.5.2 Seasonal patterns

Both the Olifants and Breede samples exhibited high spring and autumn *cpue* values and low winter values, which could be due to a number of factors. False Bay commercial beach-seine catches show a similar pattern, which has been attributed to the shoaling of *Liza richardsonii* and other species during the spring and autumn months, rather than an overall change in abundance (Lamberth *et al.* 1994, 1995a,b). However, even though many species may leave the Olifants and Breede estuaries during the winter months it is unlikely that pre-migration shoaling is entirely the cause of the higher *cpue* values. It is more likely that the higher *cpue* reflects a small change in the total number of fish in the estuary in addition to distributional changes in response to flow or other variables that concentrate fish in certain areas and increase catchability. During autumn and spring, increased flows move fish downstream whereas cool marine waters force fish upstream with the nett result that they become more concentrated in the mid to lower reaches of each estuary. The higher number of species at this time can be attributed to marine species that have entered from the sea in combination with freshwater species that have moved downstream into the estuary.

The Olifants River catchment falls entirely within the winter rainfall zone. Consequently, fish catches and (by inference) abundance in the Olifants Estuary are strongly seasonal. However, it is unlikely that seasonal fluctuations in catches in the Olifants Estuary are as pronounced as they were historically. Reduced flows and the prolonged summer low-flow period as well as the effect of dams on the mainstream will have blurred a once abrupt switch between summer and winter in abundance, along-stream distribution and catchability of different species. In contrast, seasonal fluctuations in catches in the Breede Estuary are not, and probably never were, as pronounced as for the Olifants and other estuaries on the west and southwest coasts (Bennett 1989, Bennett 1994, Lamberth 2003). Reasons include the high physical variability of the system coupled with the fact that the lower Breede falls within a winter/bimodal rainfall transition zone. The intermingling of the rainfall zones adds to the physical variability, ultimately accounting for the relatively high diversity and low abundance of the fish fauna in the Breede compared to estuaries further to the west (Harrison 1999).

3.5.3 *Along-stream distribution*

Along-stream distribution of the species in the Olifants and Breede estuaries during the summer and winter surveys was largely predictable on the grounds of their salinity preferences and the estuarine-dependence categories to which they belong. Category Ia estuary-breeders such as *Gilchristella aestuaria* were most abundant in the REI zone of 0-10 ‰ and extended well beyond the estuary into the freshwater reaches in the summer months. During winter, higher flows and the downstream shift in the REI zone saw this fish become more abundant in the middle and lower reaches. 'Facultative' catadromous species in category Vb such as *Mugil cephalus* extended well into the freshwater reaches of both rivers with this species as well as *Monodactylus falciformis* and *Myxus capensis* having been found up to 100 km upstream in the Breede River (Lamberth 2001). In category IIa, *Pomadasys commersonnii*, a species that occurs in the Breede but not on the west coast, displayed a seasonal response to higher flow contrary to that expected, in that most of the population remaining in the estuary during the winter months appeared to move upstream to 20-40 km from the mouth. In all, many species, especially the larger obligate estuarine-dependent species (IIa) such as *Argyrosomus japonicus* and *Lichia amia* ventured far into freshwater, and have been recorded more than 50 km from the mouth of the Breede Estuary (Coetzee & Pool 1991, Lamberth 2001). *Liza richardsonii*, the numerically dominant species in both the Olifants and Breede estuaries, displayed a similar along-stream distribution in both systems in that it had two peaks of abundance during summer, one in the lower 5 - 10 km and one 25-35 km upstream, with the latter disappearing in winter when the populations shifted downstream.

3.5.4 Links between adjacent estuaries and the sea

Bennett (1994) has argued that the high degree of estuarine-dependence of the fish in the Berg River indicates that estuaries on the west coast are more important as nursery areas and refugia than those on the south and east coasts of South Africa. He further suggests that there is a high reliance of "local" marine fish on the Berg Estuary, implying that any degradation of the estuarine habitat will have worse consequences for fish on the west coast than elsewhere in South Africa. A similar argument can be made for the Olifants Estuary where 48% of the species caught show some degree of estuarine dependency compared to 54% and 39% in the Berg and Orange respectively. The Olifants Estuary is thus of equal importance to the Berg and Orange estuaries as an estuarine habitat for fish. Moreover, the Olifants Estuary is one of only three permanently open estuaries on the west coast of South Africa, together with the Berg River Estuary 125 km southwards and the Orange River Estuary 380 km to the north. The loss or degradation of the Olifants as an estuarine habitat could, in a worst-case scenario, see a reduction in the range of the estuarine-dependent species by 125 km or more if the Olifants represents the western extremity of their distribution. For those fish whose range extends to the Orange River, the loss of the Olifants estuarine habitat could result in stock separation. Either of these two scenarios will ultimately depend on the movement patterns of the species concerned.

In addition, the Olifants is an important nursery area for exploited marine and estuarine species before they recruit into the marine fisheries. This is illustrated by the declines in the *Liza richardsonii* stock and marine gillnet fishery catches on the west coast, which have been directly attributed to recruitment over-fishing in the Olifants and Berg Estuary gillnet fisheries (Hutchings & Lamberth 2003). Closure of the Berg Estuary gillnet fishery has since seen a dramatic recovery of the populations of the target *L. richardsonii* and bycatch species such as *Pomatomus saltatrix* (Hutchings *et al.* 2008).

In the long term, migration of marine and estuarine species up and down the west coast may be facilitated by the Orange, Olifants and Berg Estuaries. Throughout the year, but especially during the summer upwelling months, species such as *Pomatomus saltatrix, Argyrosomus inodorus, Lithognathus lithognathus* and *Lithognathus aureti* tend to be distributed within the warmer-water areas along the west coast (Lamberth 2003). These warm areas are limited and tend to be in shallow bays, estuaries or warm-water plumes in the vicinity of estuary mouths. Hypothetically, the southward distribution of Angolan dusky kob *Argyrosomus coronus* and west coast steenbras *L. aureti*, both non-estuarine marine species, to as far as Langebaan Lagoon, may depend on the availability of warm-water refugia offered by estuary mouths and plumes. Southward movement is most likely during anomalous years when the barrier presented by the Luderitz upwelling cell breaks down or when there is a southwards intrusion of warm water during Benguela Niño years - the nett result being warmer coastal waters (Van der Lingen *et al.* 2006). Once upwelling resumes, populations of these species that have penetrated south will be confined to the limited warm-water areas provided by estuaries and shallow bays. Consequently, a reduction in estuarine flow may influence the distribution of these species by reducing the extent and availability of these refugia. A similar process could facilitate exchange between South African, Namibian and Angolan stocks of *Argyrosomus inodorus, Pomatomus saltatrix* and *Lichia amia*. All three of these species as well as *Lithognathus lithognathus* and *L. aureti*, are important commercial and/or recreational fish in the region.

The Breede Estuary cannot be considered independent of other estuaries in the warm-temperate south coast region, as it comprises only one component of the complexities surrounding the interactions between estuaries and the sea. Besides larval or juvenile recruitment, many species migrate into and out of the estuary as adults, some on a daily basis. Three species, *Argyrosomus japonicus, Pomadasys commersonnii* and *Lichia amia*, which are obliged to spend at least their first year of life in the estuary, are among the most important species in the nearshore and estuarine recreational fisheries (Griffiths & Lamberth 2002). The accessibility of the Breede Estuary and the high catchability of juveniles and sub-adults in it make these species extremely vulnerable to overexploitation.

Juveniles of *Pomadasys commersonnii* recruit into estuaries where they remain until they reach a length of at least 20 cm (Fennessy 2000). Interestingly, although adults are abundant in the Breede Estuary, few 0+ juveniles of this species have been found there or in adjacent estuaries on the south coast (Lamberth unpublished data). There has been a gradual southwest range expansion of this species over the last thirty years or so, with catches changing from rare to frequent in the Breede Estuary. This range expansion may be part of a long-term cycle and/or a response to climatic change. This parallels southeasterly expansions of the ranges of several marine species such as the Westcoast rock lobster *Jasus lalandi* (Tarr *et al.* 1996), anchovy *Engraulis encrasicolus* (Roy *et al.* 2007) and pilchard *Sardinops sagax* (van der Lingen *et al.* 2005), also probably attributable to climate change. Information from tagged and recaptured fish indicates that most *P. commersonnii* remain resident within a particular estuary and adjacent surf-zone and move between the two habitats on a regular basis (Fennessy 2000).

The longest time at liberty for a fish released in the Breede is 5 years, and it was recaptured in the same estuary (Fennessy 2000). There are, however, exceptions to the rule, with one *P. commersonnii* being caught and released in the Breede but recaptured in the Swartkops Estuary 563 km to the east.

Ten percent of the recaptures of *Argyrosomus japonicus* caught and released at Lekkerwater and Koppie Alleen in De Hoop Marine Reserve immediately adjacent to the Breede Estuary have been recaptured in this estuary (Griffiths & Attwood 2005). Time at liberty ranged from 1-5 years. One fish tagged in the Breede as a juvenile was caught seven years later as an adult off Struisbaai (Marc Griffiths unpublished data). In turn, one fish tagged at Stilbaai 50 km away was recaptured 1.5 years later in the Breede Estuary 4 km upstream (van der Elst & Bullen 1991). The fish recaptured in the estuary tend to be the larger individuals of 100 cm or more in length, which indicates a fair degree of adult movement from the adjacent surf-zone into the estuary.

Lichia amia recruit into estuaries as juveniles of 20-40 mm in length and large adults are present in both permanently open and temporarily closed systems (Bennett 1989). One sub-adult tagged in the Breede was caught nearly five years later 1 200 km away on the KwaZulu-Natal coast (Bruce Mann, Oceanographical Research Institute personal communication). On the whole, tagging studies indicate a strong link between the Breede and adjacent estuaries and their surf-zones, emphasising the importance of these estuaries as juvenile as well as adult habitat regionally and countrywide.

3.5.5 Responses to altered freshwater flows

3.5.5.1 Reference conditions

Historically, the Olifants and Breede would both have been freshwater-rich systems with extensive REI zones, and turbidity would have been higher over a greater stretch of each estuary than at present. This would have favoured species such as *Argyrosomus inodorus, A. japonicus* and *Galeichthyes feliceps*, which prefer turbid waters, and *Gilchristella aestuaria*, which adapts easily to either turbid or clear conditions. High turbidity would have excluded *Atherina breviceps*, which is a visual feeder that prefers clear water (Hecht & van der Lingen 1992). Low salinity conditions throughout much of these estuaries would have favoured freshwater-tolerant species such as *Mugil cephalus*, *Myxus capensis* and *Monodactylus falciformis*, although the latter two would have been rare or absent in the Olifants as it is at the edge of their distribution range.

Lower phytoplankton, benthic diatom and zooplankton production would have favoured *Gilchristella aestuaria*, which can rapidly switch feeding behaviour from filter- to selective-feeding (White & Bruton 1983, Talbot & Baird 1985). An abundant supply of detritus from *Phragmites* reed beds in the middle and upper reaches of both systems would have been ideal for partial detritivores such as the mullet species *Mugil cephalus* and *Liza richardsonii*. Benthic burrowers such as the mudprawn (*Upogebia africana*) and sandprawn (*Callianassa kraussi*) would have been restricted to the lower reaches if there was suitable habitat present but densities and productivity would have been lower due to the lower salinities (Teske & Wooldridge 2001). Consequently, adult benthic feeders preying on these two species, such as *Lithognathus lithognathus* and *Rhabdosargus globiceps* would probably have occurred further downstream and in lower densities. In the lower reaches, beds of seagrass *Zostera capensis* would, in the absence of anthropogenic disturbance such as trampling and boat activity, have facilitated a much higher abundance of associated fish such as pipefish *Syngnathus temminckii* and gobies *Caffrogobius* spp.

Overall, the fish assemblages of both estuaries would historically have been dominated by estuarine resident (Ia and Ib) or estuarine-dependent species (IIa, IIb or IIc) that are tolerant of, or prefer, lower salinities (Fig. 3.5). These would have included the estuarine resident *Gilchristella aestuaria*, and the detritivorous Mugilidae such as *Mugil cephalus* and *Liza richardsonii.* Small individuals of the above species would have been preyed on by adults and juveniles of the large picivorous *Lichia amia*, *Pomatomus saltatrix* and *Argyrosomus inodorus* or *A. japonicus,* which are likely to have been the dominant predators in the systems. Juveniles of most estuarine-dependent benthic feeders such as *Lithognathus lithognathus* and *Rhabdosargus globiceps* would have been abundant but the adults are likely to have had a shorter residence time within the system. Indigenous freshwater species such as *Barbus serra* and *Labeobarbus capensis* would be expected to have been abundant in the lower reaches of the Olifants Estuary during the winter months and frequently throughout the year. In the Breede Estuary, at least two of the catadromous anguillid eels would have been the dominant predators in the upper reaches. In both estuaries, marine species that are not estuarine-dependent are likely to have been rare and confined almost entirely to the lower reaches of the estuary. In the Olifants, the abundance of these species would probably have been related to the frequency of upwelling events in the sea, similar to the present day. Overall, the fish assemblages of both estuaries would have been characterised by low diversity and high abundance typical of freshwater-rich systems. The two estuaries would have differed under reference conditions in that the fish assemblage of the Olifants would have been orders of magnitude larger than the Breede whereas the latter would have had a higher diversity. These differences reflect the fact that the Olifants falls within the productive but low-diversity cool-temperate west coast biogeographical region whereas the Breede lies in a warm-temperate region (Emmanuel *et al.* 1992, Turpie *et al.* 2000,2002, Whitfield 2005a,b).

3.5.5.2 Present day and the future

Decision-making surrounding future developments in the Olifants catchment is largely confined to research and debates concerning the sites for a large dam or the raising of the existing Clanwilliam Dam by five or more metres, with the latter being the most likely option (Taljaard et al. 2005). Adherence to the freshwater reserve and committed environmental flow releases from the raised dam should ensure that two of the future scenarios represent a slight increase in the MAR reaching the estuary compared to the present day (Table 3.1). Nevertheless, these two scenarios still represent a 25–31% reduction in flow from reference conditions. Construction of a large dam will result in a 60% reduction in flow. In contrast, in excess of 100 water abstraction and/or storage alternatives or combinations ranging from pipelines to large in-channel and off-channel dams have been proposed for the Breede catchment, the largest of these being the Bromberg and Le Chasseur schemes which would result in reductions of 57% and 64% of the MAR reaching the estuary respectively (Table 3.1). However, even though the two estuaries differ in terms of their likely future development, the nett result will be similar, with both systems experiencing up to a 60% reduction in MAR relative to the reference condition. The existing and proposed reductions in MAR have resulted or will result in both estuaries gradually changing from freshwater-rich to marine-dominated systems. The REI zones will shrink and may even come close to disappearing under drought conditions. In turn, depending on their salinity preferences, the ranges of different species of fish will either shrink or expand. Depending on the persistence of the different states and the life-history characteristics of the species concerned, changes in species composition and abundance may be either short-term or permanent. In all, in each estuary, there is likely to be an irreversible shift away from the fish assemblage as it existed under reference conditions and away from the present-day composition.

Category Ia estuarine breeders were represented solely by *Gilchristella aestuaria* in the Olifants and Breede estuaries. In both systems their declines will be of similar magnitude and will correspond with the shrinking of the REI zone and their preferred salinity range of 0-10 ‰ that will accompany a reduction in flow. Category Ib species will increase due to their being equally at home in the estuarine or marine environment, mostly confined to the middle and lower reaches of the estuary, and having a preference for, or tolerance of, low turbidity. The response of category Ia species to lower flows will be entirely due to the decline in estuarine round-herring *Gilchristella aestuaria* whereas the increase in category Ib species will be due to Cape silverside *Atherina breviceps*, *Caffrogobius* spp. and *Clinus superciliosus* (Fig. 3.6). *G. aestuaria* will respond negatively to a loss of habitat or preferred salinity in the upper reaches of the estuary whereas *A. breviceps*, a visual feeder, will respond positively to a decrease in turbidity and an increase in area covered by their preferred salinity range (20-35 ‰) in the middle and lower reaches.

Obligate estuarine-dependent (category IIa) species in the Olifants Estuary were represented by *Lithognathus lithognathus* and *Mugil cephalus*, which have declined to <20% of reference levels in the present day and could approach extinction in the system with the maximum 60% reduction in flow. In contrast, category IIa species in the Breede Estuary will display a small but positive response to flow reduction. However, the positive response will be largely due to that of a single abundant species, *Rhabdosargus holubi*, and four of the seven species in this category will respond negatively to flow reduction. More importantly, the increases displayed by *Lithognathus lithognathus*, *Lichia amia* and *Rhabdosargus holubi* will be approximately half the magnitude of the declines experienced by *Argyrosomus japonicus*, *Pomadasys commersonii* and other category IIa species. The response of *Lithognathus lithognathus* to declining flow is contradictory being negative in the Olifants and positive in the Breede respectively. In both systems, the benthic-feeding *L. lithognathus* is likely to respond positively to an upstream expansion of the mud and sandflats and an increase in the burrowing mudprawn *Upogebia africana* and sandprawn *Callianassa kraussi* whereas *Lichia amia*, a visual piscivorous predator, will respond positively to reduced turbidity (Cyrus & Blaber 1987, Hecht & van der Lingen 1992). Consequently, in the Olifants Estuary, and in the absence of a gillnet fishery that is currently overexploiting resources, *L. lithognathus* (and *L. amia* for that matter) could have responded in the same way as populations in the Breede and shown a small increase from reference to present day.

The 40% decline in partially estuarine-dependent category IIc fish, dominated by *Liza richardsonii* in the Olifants, is largely due to fishing effects, in the absence of which they could have been more than twice as abundant than under reference conditions. Under the future reductions in MAR reaching the estuary, category IIc fish will continue to decline to 50% of their reference abundance. *L. richardsonii* is the mainstay of the inshore beach-seine and gillnet fisheries along the west coast, including the Olifants gillnet fishery (Hutchings & Lamberth 2002a). Although lower flows from reference to the present have had a positive effect on this species and may to some extent have compensated for the decline due to fishing, future responses to flow reduction are likely to be negative. In addition, they are regarded as overexploited and the local fishers are already struggling to maintain a viable catch. Should this species decline in numbers under the future scenarios, it may see many of the current fishers being forced out of the fishery even before its planned phasing out within the next ten years (DEAT 2006). In addition, the 80% decline from reference abundance and the absence of any discernable recovery of *Pomatomus saltatrix* (IIc) and *Lithognathus lithognathus* (IIa) in the Olifants under any of the future scenarios is a point of concern, as the stocks of these two species are already overexploited and/or collapsed, being at 34% and 6% of pristine respectively (Griffiths & Lamberth 2002). *Liza richardsonii* also dominated the partially estuarine-dependent category IIc In the Breede Estuary which underwent a slight increase in abundance from reference to present day and is expected to increase to 9% of reference with future flow reductions and an expansion of their preferred 20-35‰ salinity range. Also in category IIc, the piscivorous *Pomatomus saltatrix* and invertebrate feeders *Diplodus sargus* and *Rhabdosargus* *globiceps* would have benefited from an increase in water clarity. However, the increase in partially estuarine-dependent species in the Breede from the reference to present day probably falls within natural variability and is slight compared to the reduction in abundance experienced by those in the Olifants.

In the Olifants Estuary, estuarine-independent marine species (category III) have undergone a 43% decrease in abundance from reference but may show a slight 5% recovery with the 60% reduction in freshwater flow and stronger marine influence under Scenario 5. As with the category IIc *Liza richardsonii*, in the absence of fishing, they could have been 77% more abundant in the present day. Slightly contradictory, freshwater may also have played a role with a decline in flow resulting in a reduction in the warm-water plume entering the sea, and a corresponding decline in the number of marine fish encountering it. Similarly, shrinkage of the plume and reduction in the magnitude of olfactory and temperature cues reaching the marine environment are likely to be the main causes of juvenile obligate estuarine-dependent species failing to recruit to the estuary. In the Breede Estuary, estuarine-independent marine species will undergo the greatest increase in abundance with decreasing flows and are likely to increase to 123% of reference with a 64% reduction in MAR and the increasingly marine dominated nature of the system (Fig. 3.5 & 3.6).

Category IV freshwater species in the Olifants and Breede estuaries may decline by 60% or more with a 60% reduction in MAR, but as they are nowadays solely represented by introduced fish such as smallmouth bass *Micropterus dolomieu* and bluegill sunfish *Lepomis macrochirus,* this can be regarded as a positive consequence of reduced flows. However, reduced flows, narrowing of the stream channel and increased salinity will prevent the success of any future initiatives to re-establish indigenous species such as Clanwilliam yellowfish *Labeobarbus capensis* to the upper reaches of the Olifants Estuary. Facultative catadromous (category V) species display a similar response to the freshwater species with the freshwater mullet *Myxus capensis* collapsing to <60% of reference with a 60% reduction in MAR. This species is regarded as vulnerable and in decline throughout its range, largely due to water abstraction and weirs and other obstacles impeding its migration into the freshwater reaches of rivers (Skelton 1993).

3.6 Conclusions

Overall, reduced freshwater flows in the Olifants Estuary are likely to see a reduction in abundance of species that breed only in estuaries, those that are entirely estuarine-dependent, most of those that are partially estuarine-dependent and endemic freshwater species. With the addition of fishing effects, numbers may decline to such an extent that some of these species may completely disappear from the

Olifants Estuary. In the absence of fishing, partially estuarine-dependent and marine species would have increased from reference to the present day with the encroachment of higher salinity further upstream and expansion of available habitat. However, they will decrease in abundance under the future scenarios that are accompanied by shrinkage of the warm-water plume entering the sea, narrowing of the stream channel, and an overall reduction in available habitat. Overall, and assuming an absence of fishing, the Olifants fish community would have experienced a gradual change from a high biomass, low diversity, freshwater-rich system under reference conditions, to a high biomass, medium diversity, marine-dominated system under the present day. Overall abundance has decreased by 20% from reference to present day and will decline to 55% of reference with the 60% reduction in MAR under Scenario 5. Consequently, future reductions in flow are likely to see the Olifants Estuary progressing towards a low biomass, low diversity, marine-dominated system. Furthermore, the shrinking of the REI zone and other estuarine habitat as well as the decline in abundance and diversity of estuarine-dependent fish in the estuary suggests that the refuge offered by the Olifants as well as its nursery function have been severely compromised. Consequently, line and net fisheries inside and outside the estuary will continue to suffer from falling production, and the coastal distribution of some species, especially those endemic to the region, may either split or shrink.

In contrast, reduced freshwater flows in the Breede Estuary are likely to see an overall reduction in the abundance of species that breed only in estuaries, and in freshwater and catadromous species. Partially estuarine-dependent and marine species are likely to increase with encroachment of higher-salinity water further upstream and an expansion of available habitat. Overall, fish abundance in the estuary has increased to 106% of the reference and is likely to increase to 115% of reference with future reductions in flow. Losses of some species with a preference for fresh and brackish water are probable but overall diversity is equally likely to increase with a range expansion of warm-temperate and subtropical marine species westward. In all, the fish assemblage will experience a gradual change from a relatively high diversity low abundance freshwater-rich system under historical flow conditions to a high diversity, high abundance, marine-dominated system, with future reductions in flow. Collectively, entirely estuarine-dependent fish will increase in abundance but some individual important exploited species such as *Argyrosomus japonicus* and *Pomadasys commersonnii* will collapse to 50% of historical numbers with a 64% reduction in MAR. These two species comprise 74% of the total estuarine catch and *A. japonicus*, prior to its collapse to 4% of pristine spawner biomass, once dominated commercial linefish catches in the region.

The severity of past and future flow reduction is much higher for the Olifants than the Breede Estuary. Whereas the fish assemblage of the Olifants Estuary is likely to almost halve in abundance with future reductions in flow, that of the Breede Estuary will undergo an incremental increase. Fish diversity displays a similar pattern, declining in the Olifants and increasing in the Breede. However, the increase in diversity in the Breede is largely due to the intrusion of seawater and more marine species treating the estuary as an arm of the sea rather than an increase in the number of estuarine-dependent species in the system. Overall, whilst both estuaries have undergone similar reductions in flow from the reference to the present day and in the long-term may have to function with less than 40% of historical MAR, the Olifants Estuary is likely to lose much of its estuarine function whereas the Breede Estuary and its fish assemblage appear to be more resilient and likely to persist. This said, the decline in key regionally exploited species in both estuaries will result in a concomitant decline in their estuarine contribution to the productivity of the commercial and recreational fisheries in the adjacent marine environment. Faced with declining catches or loss of estuarine function, management action and mitigatory measures should entail regulating fishers as well as freshwater flow. Singularly addressing either one of these aspects without considering the other is unlikely to lead to any significant recovery or maintenance of estuarine fish assemblages.

CHAPTER 4

4. ESTUARINE REFUGIA AND FISH RESPONSES TO A LARGE ANOXIC "BLACK TIDE" EVENT IN THE ADJACENT MARINE ENVIRONMENT: THE BERG RIVER ESTUARY, SOUTH AFRICA

4.1 Introduction

Estuaries provide refuge to fish from adverse conditions in the marine environment, the most extreme of which may lead to mass mortalities. Globally, fish kills or mass mortalities have several possible causes, including disease, extreme or abrupt changes in temperature, salinity or turbidity, hypoxia or anoxia and harmful algal blooms (e.g. Hanekom *et al.* 1989, Hallegraeff 1995, Whitfield 1995, Cyrus & McLean 1996, Pitcher & Calder 2000, Ward *et al.* 2001). On a long-term geological time scale, volcanic eruptions, earthquakes and meteorite impacts have also been responsible for extirpations of fish, but only in conjunction with shorter-term extreme salinity changes, thermal shock and harmful algal blooms (Zinsmeister 1998). In general, fish kills arising from natural or anthropogenic causes are most frequent and severe in confined habitats such as estuaries, fiords or bays (Heil *et al.* 2001).

The global increase in the frequency and occurrence of harmful algal blooms is, aside from increased awareness, often attributed directly or indirectly to anthropogenic influences such as introductions via ballast water, eutrophication, pollution, the intensification of aquaculture and accelerated climate change (Hallegraeff 1992, 1995, Burkholder *et al.* 1995, Pitcher & Calder 2000). Harmful algal blooms may be either toxic or non-toxic, and their effects may be immediate or manifested in the long term (Pitcher & Calder 2000). Toxic algal blooms poison fish directly or indirectly via bioaccumulation through progressive trophic levels (Kane *et al.* 1998, Pitcher & Calder 2000). Non-toxic blooms cause fish mortalities through anoxia or hydrogen sulphide poisoning arising from algal decay, hypoxia arising from nighttime algal respiration, mechanical damage or blocking of gills and smothering due to the precipitation of dead organic material (e.g. Brown *et al.* 1979, Horstman 1981, Morrison *et al.* 1991, Hallegraeff 1995, Collard & Lugo-Fernández 1999). Both toxic and non-toxic blooms may, especially when recurrent, alter or destroy ecosystems over time (Pitcher & Calder 2000).

Most mass mortalities of fish in southern African estuaries result from a combination of low salinities (<3‰) and low water temperatures (<14°C) whereas most in the sea result directly or indirectly from toxic and non-toxic harmful algal blooms (see Whitfield 1995, Pitcher & Calder 2000 and Cockcroft 2001 for reviews). This said, fish kills along the South African coastline have largely been due to adverse conditions arising in estuaries or their adjacent catchments and more recently due to anthropogenic influences associated with urban areas and mining activity such as eutrophication, increased silt loads, discharge of untreated effluent and ill-conceived flow and estuary mouth manipulation (Morant & Quinn, 1999). In general, fish in the marine environment appear to be less susceptible to adverse conditions than those in the relative confinement of estuaries. The 1988 Orange River floods diluted coastal waters causing mass mortalities of shallow-water invertebrates and kelps (Branch *et al.* 1990). No mortalities of intertidal fish were recorded, probably due to their escape to deeper more saline waters, whereas freshwater fish washed out of the river eventually succumbed to osmotic shock (Morant & O' Callaghan 1990). In comparison, a flood-associated mass mortality of fish in the Sundays estuary on the east coast of South Africa was mostly due to gill clogging by suspended sediments but also due to osmoregulatory stress and reduced dissolved oxygen levels (Whitfield & Paterson 1995). However, estuarine-independent marine species on the Tsitsikamma east coast regularly evade upwelling-induced thermal shock by finding refuge in warmer estuarine waters (Hanekom *et al.* 1989).

Estuaries provide refugia for estuarine-dependent and estuarine-independent marine species. Even so, obligatory estuarine-dependence may be a life-history bottleneck for many fish species as they are generally more vulnerable to physico-chemical stress and fishing within estuaries than would be the case outside estuaries. Therefore, the negative effects resulting from the unstable and unpredictable nature of estuaries need to be outweighed by the benefits of estuarine-dependence, such as the ability to find refuge in estuaries from adverse, sometimes lethal conditions in the sea.

During summer, the prevailing southerly winds along the west coast of South Africa cause upwelling of nutrient-rich bottom water and the development of dense phytoplankton blooms that provide a vital source of food for fish and other marine organisms. These blooms are usually of short duration as they are soon dispersed offshore by the onset of another southerly blow. Towards autumn the southerly winds are less frequent and the blooms may persist for a week or more and sometimes turn the water brown, red, orange, green or purple in colour (Pitcher & Calder 2000). These blooms may be toxic but in most cases are not.

In March 1994, a strong southeasterly followed by a week of windless days facilitated the development of a non-toxic "red tide" in St Helena Bay. Calm conditions persisted and the bloom began to decay, bacterial decomposition reducing oxygen levels in the water and turning the sea black with the production of hydrogen sulphide. Marine life died either from suffocation or hydrogen sulphide poisoning and approximately 1 500 tons of fish were washed up on the shore (Matthews & Pitcher, 1996). The anoxic water extended a short way into the Berg River Estuary and local fishers reported catching fish struggling on the surface in the vicinity of the mouth. Further up the estuary, larger-than-average commercial catches of the southern mullet (*Liza richardsonii*) were reported and fisheries compliance officers had to be reinforced in number to cope with an influx of illegal gillnet fishers.

Fortuitously, an unrelated study addressing altered freshwater flows was carried out in the Berg River Estuary in 1993, the year prior to the low-oxygen event there, provided data before the event that could be compared with data gathered during and after the event in 1994 and 1996 respectively (Bennett 1994), allowing comparison of the species composition, abundance and distribution of the fish assemblage of the Berg River Estuary during these three times. In doing so, it could also be established which fish found refuge in the estuary as a means of escaping the lethal effect of anoxia in the sea. The life history characteristics that allowed particular groups to employ estuaries to escape the low-oxygen 'black tide' event could also be ascertained.

4.2 Methods and study area

The Berg River falls within the cool temperate winter rainfall zone of South Africa. It is 294 km long and drains a catchment of approximately 4 000 km^2 with a mean annual runoff of 693 X 10^6 m^3 (Bennett 1994, Harrison 1997, Morant *et al.* 2001). The Berg River Estuary (32º46'S, 18º09'E), one of only three permanently open estuaries on the west coast, flows into the Atlantic Ocean at Laaiplek in St Helena Bay (Fig. 4.1). The estuary, including floodplain wetland, is approximately 3 615 ha in area and meanders over an extensive floodplain; tidal effects are measurable 69 km upstream (Day 1981, Slinger & Taljaard 1994, Turpie *et al.* 2002). Much of the lower 15 km comprises mudflats and saltmarsh but the final 4 km are dredged to maintain a harbour for purse-seine boats and an entrance to the Port Owen Marina. The original mouth closed with harbour construction and a new mouth was excavated and stabilized with concrete approximately 1 km to the north. In the process, the old channel became a blind-arm that is gradually silting up.

The fish assemblage of the Berg River Estuary was sampled at 32 sites from the mouth to Kersefontein, 40 km upstream (Fig. 4.1), during the summer months of February and March, before (1993), during (1994) and after (1996) a low-oxygen, hydrogen sulphide event that occurred in the adjacent sea. The 1993 sampling was part of a broad multidisciplinary study addressing the freshwater requirements of the Berg River Estuary (Bennett 1994).

Fish were sampled using a 30-m long, 2-m deep, 12-mm stretched-mesh seine-net. Salinity was measured using a handheld refractometer, water clarity with a Sechii disc and temperature with a standard mercury thermometer. Dissolved oxygen (DO) levels were not sampled during 1993 but were measured during 1994 and 1996. During 1994, limited surface and bottom water samples were taken at 5 sites from the mouth to approximately 8 km upstream, whereas in 1996 surface and bottom water samples were taken at all 32 sites. Water samples were analysed for oxygen using the Winkler titration method. All fish caught in each seine haul were identified, counted, and their total lengths measured.

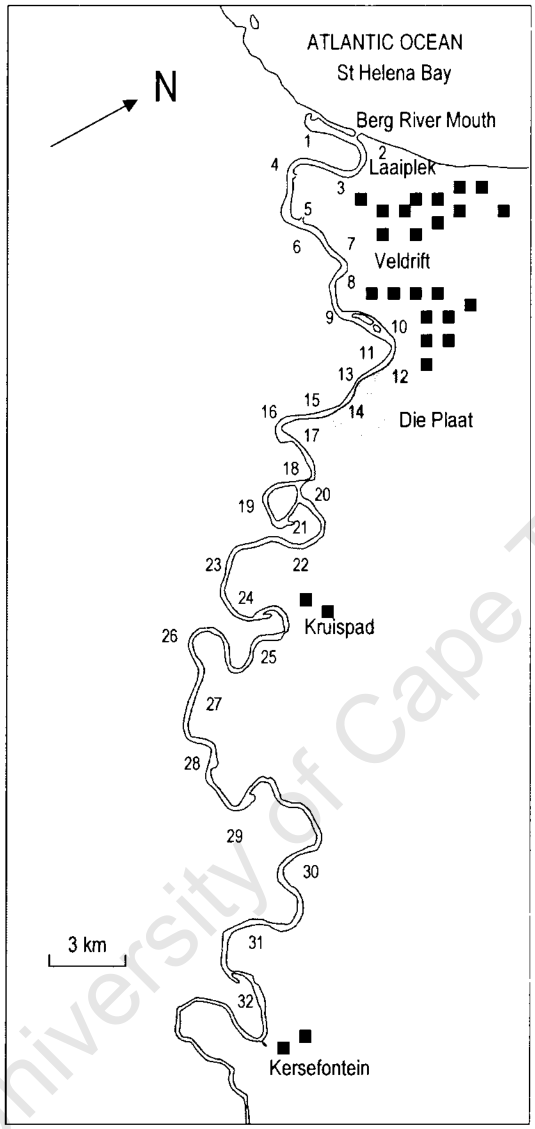


Figure 4.1 Map of the Berg River estuary showing sampling sites and places mentioned in the text.

In the instance of large catches, the haul was sub-sampled and a minimum of 100 fish of each species measured.

Species composition and abundance of fish washed up on the beach adjacent to the Berg Estuary mouth during the low-oxygen event were estimated by walking along ten 25-m long by 2-m wide transects and counting and identifying all fish seen. All fish caught in the estuary or washed up on the beach were categorized in terms of their dependency on estuaries according to the five-category classification scheme originally proposed by Wallace *et al.* (1984) and refined by Whitfield (1994b), based on life-history characteristics (Table 4.1).

Table 4.1 The five major categories of fishes that utilize South African estuaries (After Whitfield 1994)

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

Catch-per-unit-effort data (*cpue*, number of fish per haul) were partitioned among ten 4-km reaches and analysed using Plymouth Marine Laboratories PRIMER statistical analysis software (Clarke & Warwick 2001, Clarke and Gorley, 2006). C*pue* was root-root transformed and similarities between reaches analysed via group average hierarchical clustering using the Bray-Curtis similarity index. The contribution of each species to the average dissimilarity or similarity between reaches within years was determined using SIMPER (similarity percentages) analysis described in Clarke (1993). Analyses of length-frequency data for harders (*Liza richardsonii*) were conducted using STATISTICA version 7.1 (StatSoft, Inc. 2005). Prior to testing for significant differences in length frequencies between 10-km reaches, the data were first tested for homogeneity of variances using Levine's test. Because variances were not equal even after transformation of the data, I used non-parametric Kruskal-Wallis ANOVA by Ranks to explore differences between length-frequency distributions between years within reaches and between reaches within years.

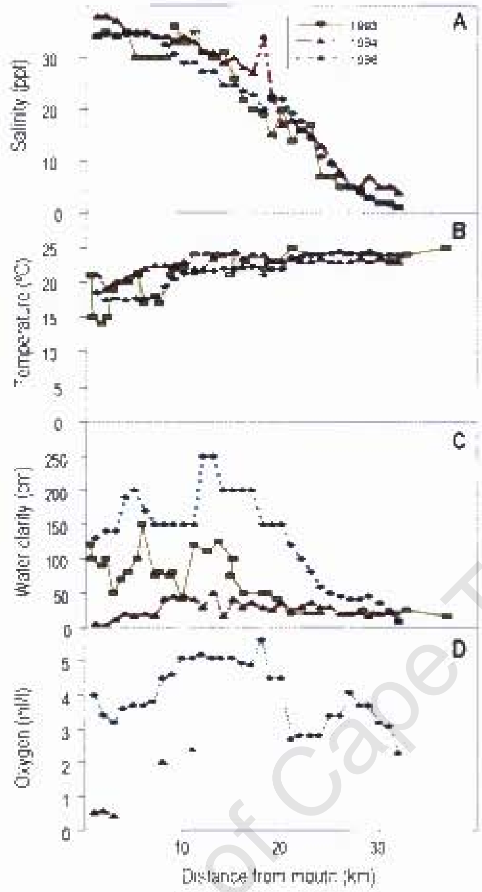


Figure 4.2 Salinity, water temperature, water clarity and oxygen levels measured at each sampling site in the Berg River estuary before (March 1993), during (March 1994), and after a low-oxygen, hydrogen sulphide event in the adjacent sea (February-March 1996). Oxygen concentrations were not measured in 1993.

4.3 Results

4.3.1 Abiotic variables

Salinity before (1993) and after (1996) the low-oxygen event ranged from 34‰ at the mouth of the Berg River Estuary to 1‰ 40 km upstream (Fig. 4.2a). During the event (1994), salinities were slightly elevated and ranged from 38‰ at the mouth to a minimum of 4‰ 40 km upstream. Beyond 10 km from the mouth, water temperature was similar before, during and after the low-oxygen event and ranged from 21-25°C (Fig 4.2b). Water temperatures in the lower 10km during the event were slightly higher with a minimum of 19°C as opposed to minima of 15°C and 17°C before and after the event respectively. Water clarity before and after the low-oxygen event was relatively high and ranged from 120 cm at the mouth to >200 cm in the middle reaches to <10 cm, 40 km upstream (Fig. 4.2c).

During the event water clarity was low throughout the estuary with a minimum of 2 cm (effectively zero) at the mouth to a maximum of 50 cm in the middle reaches. Oxygen levels were not recorded in the sampling trip before the event in 1993. During the event (1994), limited sampling was undertaken up to 10 km from the mouth whereas after the event (1996) oxygen levels were measured at all stations from the mouth to 40 km upstream.

Oxygen levels during the event ranged from 0.44 $ml.l^{-1}$ at the mouth to 2.4 $ml.l^{-1}$ at the 10 km mark. In 1996, after the event levels increased from 3.2 $ml.l^{-1}$ at the mouth to 5.6 $ml.l^{-1}$ in the middle reaches, and then they declined again to 2.3 $ml.l^{-1}$ 40 km upstream (Fig 4.2d).

4.3.2 Fish kill

In total, 57 species of fish representing 38 families were identified washed up on the beach of the open coast adjacent to the Berg River mouth during the low-oxygen event in summer 1994 (Table 4.2). Numerically and by mass, harder *Liza richardsonii* dominated, contributing more than 90% to the fish washed up on the beach.

Eighteen of the species killed had some degree of estuarine dependence (Categories I & II), and all of these (with the exception of the super klipvis *Clinus superciliosus* and the strepie *Sarpa salpa*), were also recorded alive in the Berg Estuary during the low-oxygen event (Table 4.2). No estuarine-independent category III marine species were recorded alive in the estuary during the event despite 39 species in this category being killed and washed ashore (Table 4.2). Notably, all Chondrichthyes fell into this category and conformed to this pattern.

4.3.3 Species composition, abundance & occurrence

Overall, 52 382 fish were caught in 32 seine hauls in the Berg River Estuary during the low-oxygen event; twice the average of the total catches of 29 830 fish and 20 577 fish caught with equal effort before and after the event (Table 4.3).

Harders (*Liza richardsonii*) dominated in all three years but in 1994 during the event this species was 359% more abundant than before and after the event in 1993 and 1996. Catches of a further three species increased substantially during the event. These were the category Ib Knysna sand-goby *Psammogobius knysnaensis* (365%) and category IV introduced freshwater species Mozambique tilapia *Oreochromis mossambicus* (249%) and mosquito fish *Gambusia affinis* (880%). Compared to before and after, catches of seven species were substantially lower or absent during the low-oxygen event.

Table 4.2 Relative abundance and estuarine dependence category of all fish recorded dead on the beach adjacent to the Berg River Estuary mouth during the low oxygen "blacktide" event in the summer month of March 1994. Estuary dependence categories after Whitfield 1994b, Table 4.1.

Family name	Species name	Common name	Dependence category	% abundance	Recorded alive in estuary
Osteichthyes					
Ariidae	*Galeichthyes feliceps*	Barbel/white seacatfish	IIb	0.1-1	√
Atherinidae	*Atherina breviceps*	Cape silverside	Ib	<0.01	√
Blenniidae	*Parablennius cornutus*	Horned blenny	III	<0.01	
Carangidae	*Trachurus trachurus*	Maasbanker	III	<0.01	
Cheilodactylidae	*Chirodactylus brachydactylus*	Twotone fingerfin	III	<0.01	
Clinidae	*Blennophis anguillaris*	Snaky klipfish	III	<0.01	
	Clinus acuminatus	Sad klipfish	III	<0.01	
	Clinus superciliosus	Super klipfish	Ib	<0.01	
	Clinus taurus	Bull klipfish	III	<0.01	
Congiopodidae	*Congiopodus torvus*	Smooth horsefish	III	<0.01	
Cynoglossidae	*Cynoglossus capensis*	Sand tonguefish	III	<0.01	
Dichistidae	*Dichistius capensis*	Galjoen	III	<0.01	
Gempylidae	*Thyrsites atun*	Snoek	III	<0.01	
Gobiesocidae	*Chorisochismus dentex*	Rocksucker	III	<0.01	
Gobiidae	*Caffrogobius caffer*	Banded goby	Ib	<0.01	√
	Caffrogobius gilchristii	Prison goby	Ib	<0.01	√
	Caffrogobius nudiceps	Barehead goby	Ib	<0.01	√
	Caffrogobius saldhana	Commafin goby	Ib	<0.01	√
	Psammogobius knysnaensis	Knysna sand-goby	Ib	<0.01	√
Gonorhynchidae	*Gonorhynchus gonorhynchus*	Beaked sandfish	III	<0.01	
Merlucciidae	*Merluccius capensis*	Hake	III	<0.01	
Mugilidae	*Liza richardsonii*	Harder	IIc	90-95	√
	Mugil cephalus	Flathead mullet	IIa	<0.01	√
Ophichthidae	*Ophisurus serpens*	Sand snake-eel	III	0.01-0.1	
Ophidiidae	*Genypterus capensis*	Kingklip	III	0.1-1	
Pomatomidae	*Pomatomus saltatrix*	Elf	IIc	<0.01	√
Sciaenidae	*Argyrosomus coronus*	Angolan dusky kob	IIc	<0.01	√
	Argyrosomus inodorus	Silver kob	IIc	<0.01	√
	Atractoscion aequidens	Geelbek	III	<0.01	
Scorpaenidae	*Helicolenus dactylopterus*	Jacopever	III	<0.01	
Soleidae	*Austroglossus microlepis*	West coast sole	III	0.01-0.1	
Sparidae	*Argyrozona argyrozona*	Silverfish	III	<0.01	
	Diplodus capensis	Blacktail	IIc	<0.01	√
	Lithognathus lithognathus	White steenbras	IIa	<0.01	√
	Pachymetopon blochii	Hottentot	III	0.01-0.1	
	Pterogymnus laniarius	Panga	III	<0.01	
	Rhabdosargus globiceps	White stumpnose	IIc	0.01-0.1	√
	Sarpa salpa	Strepie	IIc	<0.01	
Stromateidae	*Stromateus fiatola*	blue butterfish	III	<0.01	
Syngnathidae	*Syngnathus temminckii*	Longsnout pipefish	Ib	<0.01	√
Tetraodontidae	*Amblyrhynchotes honckenii*	Blaasop	III	<0.01	
Triglidae	*Chelidonichthys capensis*	Cape gurnard	III	0.01-0.1	
Chondrichthyes					
Callorhinchidae	*Callorhinchus capensis*	St Joseph shark	III	0.01-1	
Dasyatidae	*Dasyatis chrysonota*	Blue stingray	III	0.01-1	
Hexanchidae	*Notorynchus cepedianus*	Spotted sevengill shark	III	0.01-1	
Myliobatidae	*Myliobatis aquila*	Eagle ray	III	0.01-1	
Narkidae	*Narke capensis*	Onefin electric ray	III	<0.01	
Rajidae	*Raja alba*	Spearnose skate	III	<0.01	
	Raja straeleni	Biscuit skate	III	<0.01	
Rhinobatidae	*Rhinobatos annulatus*	Lesser guitarfish	III	0.01-1	
Scyliorhinidae	*Hapolblepharus edwardsii*	Puffadder shyshark	III	0.01-1	
	Hapolblepharus pictus	Dark shyshark	III	0.01-1	
	Poroderma africanum	Pyjama shark	III	0.01-1	
Squalidae	*Squalus acanthias*	Spotted spiny dogfish	III	0.01-1	
Torpedinidae	*Torpedo nobiliana*	South coast torpedo	III	<0.01	
Triakidae	*Mustelus mustelus*	Smooth-hound shark	III	<0.01	
Pteraspidomorphi					
Myxinidae	*Eptatretus hexatrema*	Sixgill hagfish	III	0.01-1	

Table 4.3 Catch composition by number, 1994 catches as a percentage of the 1993 and 1996 mean and percentage occurrence (proportion of hauls containing each species) for all fish caught in 96 seine hauls during the summers of 1993, 1994 and 1996 from the mouth to 40 km upstream in the Berg River Estuary. Species arranged in descending order of abundance during the 1994 low-oxygen event. Estuary dependence categories after Whitfield 1994b, Table 4.1)

		Dependence category	Number of fish			1994 as % 1993 & 1996	% Occurrence		
			1993	1994	1996		1993	1994	1996
Liza richardsonii	Harder	IIc	14037	40336	8455	359	94	91	94
Gilchristella aestuaria	Estuarine roundherring	Ia	5817	5337	7931	78	91	53	88
Atherina breviceps	Cape silverside	Ib	4027	2424	684	103	84	81	63
Caffrogobius nudiceps	Bareheaded goby	Ib	4761	1740	2121	51	78	66	88
Oreochromis mossambicus	Mozambique tilapia	IV	302	1217	674	249	31	53	31
Psammogobius knysnaensis	Knysna sandgoby	Ib	300	1069	286	365	53	59	59
Syngnathus temminckii	Longsnout pipefish	Ib	118	126	259	67	44	28	50
Galeichthyes feliceps	Barbel	IIb		58		-		3	
Pomatomus saltatrix	Elf	IIc	20	35	68	80	16	31	16
Gambusia affinis	Mosquito fish	IV	1	22	4	880	3	22	6
Solea bleekeri	Blackhand sole	IIb	7	9	26	55	9	13	22
Cyprinus carpio	Carp	IV	24	7	32	25	25	6	31
Rhabdosargus globiceps	White stumpnose	IIc		1	7	29		3	3
Micropterus dolomieu	Smallmouth bass	IV	30	1	21	4	25	3	13
Clinus superciliosus	Super klipvis	Ib	238				16		
Rhinobatos annulatus	Lesser sandshark	III	7				9		
Mugil cephalus	Flathead mullet	IIa	139				25		
Lichia amia	Leervis/garrick	IIa	2		3		6		6
Lithognathus lithognathus	White steenbras	IIa			5				6
Chaetodon marleyi	Doublesash butterflyfish	III			1				3
	Total		**29830**	**52382**	**20577**	**208**			

These were the category Ib barehead goby *Caffrogobius nudiceps* and super klipvis *Clinus superciliosus*, which can breed in estuaries; the obligate estuarine-dependent category IIa flathead mullet *Mugil cephalus* and leervis *Lichia amia;* the category III estuarine-independent lesser sandshark *Rhinobatos annulatus*; and the introduced freshwater category IV carp *Cyprinus carpio* and smallmouth bass *Micropterus dolomieu*. In addition, *C. superciliosus*, *R. annulatus* and *M. cephalus* were abundant prior to the event in 1994 but disappeared entirely from catches during the event and remained absent in 1996. Two estuarine breeders, namely the category Ia estuarine roundherring *Gilchristella aestuaria* and category Ib longsnout pipefish *Syngnathus temminckii* as well as the partially estuarine-dependent category IIb blackhand sole *Solea bleekeri* and category IIc elf *Pomatomus saltatrix* were more abundant after, than before or during the low-oxygen event. However, Cape silversides *Atherina breviceps*, also a category Ib estuarine breeder, experienced a 40% decline during the event followed by a further decline in 1996 to less than 20% of 1993 pre-event numbers (Table 4.3).

4.3.4 Composition and abundance of fish in beach-seines

Sixteen species of fish were caught in beach-seine hauls before and after, and 14 during the low-oxygen event (Table 4.3). Seven species, *Liza richardsonii, Gilchristella aestuaria, Caffrogobius nudiceps, Syngnathus temminckii, Cyprinus carpio, Micropterus dolomieu* and *Lichia amia* occurred in fewer hauls in 1994 during the low-oxygen event than before or after the event in 1993 and 1996 (Table 4.3). Three species, *Oreochromis mossambicus, Gambusia affinis* and *Pomatomus saltatrix* occurred more frequently during than before or after the event. *Psammogobius knysnaensis* and *Solea bleekeri* occurred in more hauls during and after than before the event. Barbel (*Galeichthyes feliceps*) only occurred during, white stumpnose (*Rhabdosargus globiceps*) occurred during and after, and two species, white steenbras (*Lithognathus lithognathus*) and doublesash butterflyfish (*Chaetodon marleyi*) only occurred in 1996 after the event (Table 4.3).

4.3.5 Distribution of fish in the estuary

Cluster-analysis of seine catch-per-haul before, during and after the low-oxygen event showed three distinct groupings of fish roughly corresponding to the lower (0-16 km), middle (17-32 km) and upper (33-40 km) reaches of the estuary and salinity ranges of 35-20‰, 20-5‰ and 5-0‰ respectively (Fig. 4.3). Before and after the event the samples formed groups at the 60-65% level of similarity whereas during the event they grouped out at the 68-80% level (Fig. 4.3). SIMPER analysis of these groupings revealed that the average dissimilarities between reaches were similar before and after the low-oxygen event but lower during the event in 1994: before and after the event dissimilarities were 40.7-41.2% between the lower and middle, 72.2-74.5% between the lower and upper, and 55.0-56.5% between the middle and upper reaches; during the event, the respective values were 34.5%, 50.3% and 39.3%.

In all comparisons, six or fewer species accounted for 60-80% of the dissimilarity between reaches. In all years, the species contributing more than 90% of the similarity in the lower reaches were *Liza richardsonii*, *Caffrogobius nudiceps*, *Atherina breviceps* and *Gilchristella aestuaria*, with the additions of *Syngnathus temminckii* and *Psammogobius knysnaensis* before and after the low-oxygen event. Similarly, the middle reaches were characterised by these species but with an additional contribution by the freshwater category IV *Oreochromis mossambicus* and facultative catadromous category IIa/Vb *Mugil cephalus*. The upper reaches were characterised by the estuarine breeder *Gilchristella aestuaria* and the freshwater species *Oreochromis mossambicus*, *Micropterus dolomieu*, *Gambusia affinis* and *Cyprinus carpio*.

The along-stream distribution of selected species before, during and after the low-oxygen event, are shown in Figures 4.4a & b. During the low-oxygen event in 1994, five estuarine-dependent species

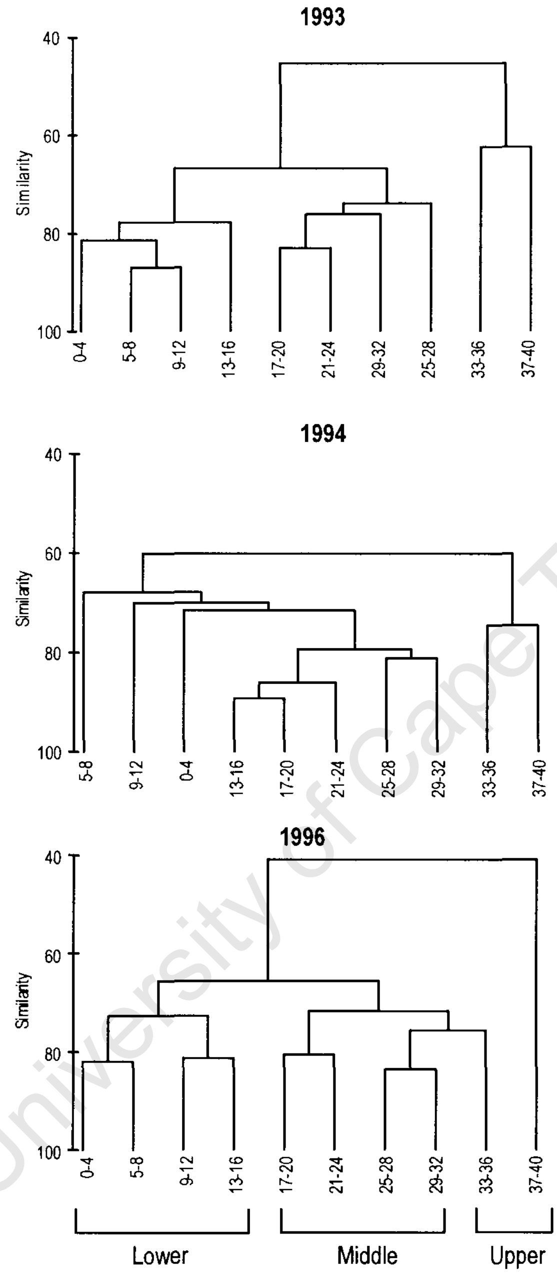


Figure 4.3 Bray-Curtis similarity of catch-per-unit-effort (fish per seine-haul) between reaches (kilometres from the mouth) in the Berg River Estuary before (1993), during (1994), and after (1996) a low-oxygen, hydrogen sulphide event that occurred in the adjacent sea.

(Categories I & II), namely *Atherina breviceps, Caffrogobius nudiceps, Psammogobius knysnaensis, Syngnathus temminckii* and *Pomatomus saltatrix* extended their range 5-15 km upstream.

In 1996, after the event, all of these reverted to their pre-event distribution although a substantial proportion of the *Syngnathus temminckii* population remained upstream. Three species, *Clinus superciliosus, Rhinobatos annulatus* and *Mugil cephalus* disappeared completely from catches in 1994

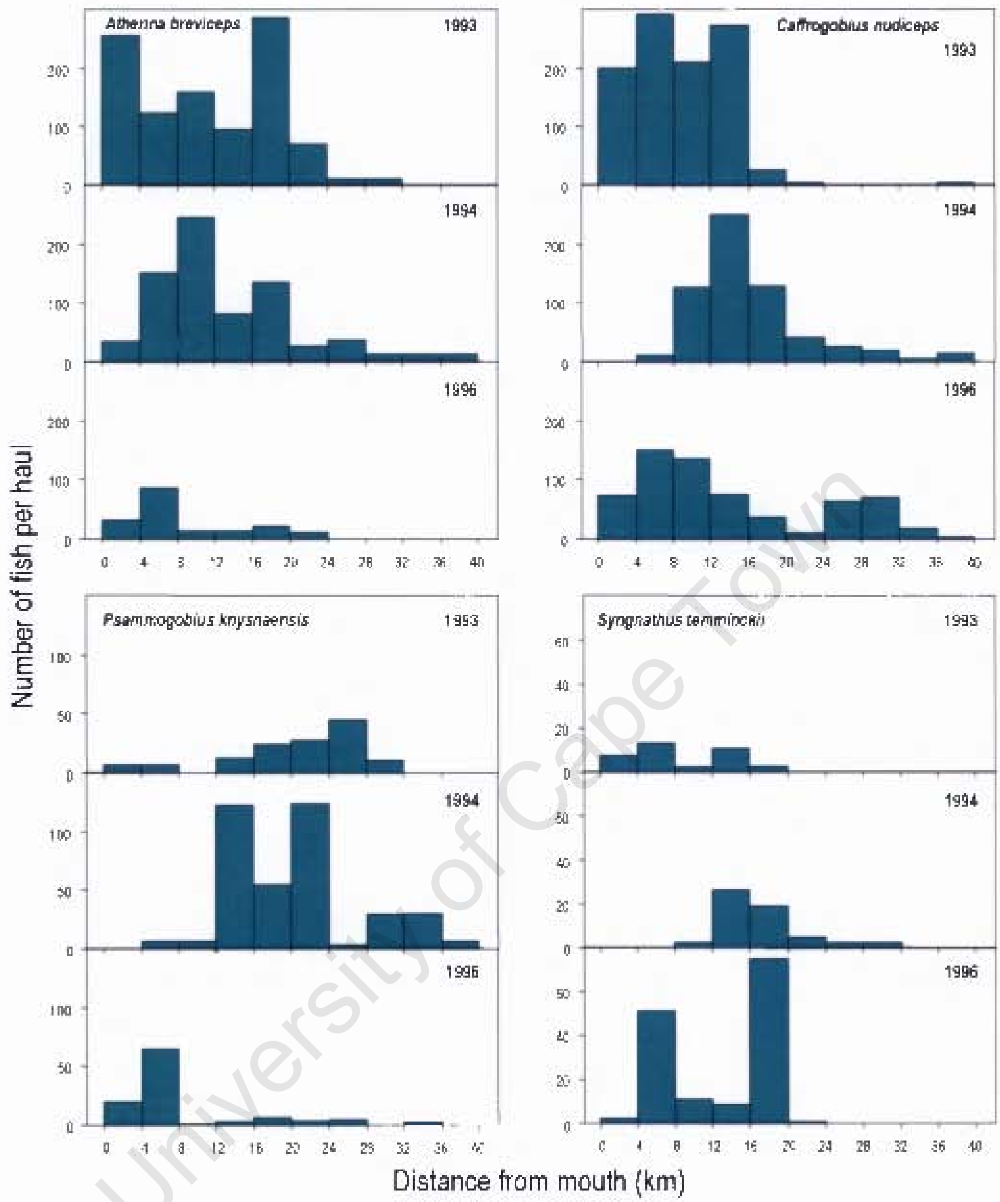


Figure 4.4a Catch per seine haul in the Berg River Estuary in relation to distance upstream, before (1993), during (1994), and after (1996) a low-oxygen hydrogen sulphide event that occurred in the adjacent sea.

and had not reappeared by 1996. The modal distribution of the freshwater *Oreochromis mossambicus* shifted upstream during the low-oxygen event and downstream after the event but its range extended further downstream during the event into near-anoxic waters 2 km from the mouth (Fig 4.4b). Of the other freshwater fish in the estuary, *Cyprinus carpio* and *Micropterus dolomieu* responded similarly to the estuarine species by decreasing in abundance and retracting their downstream distribution during the event (Table 4.3). However, *Gambusia affinis* increased in abundance and extended downstream (Table 4.3). Their distribution is not illustrated as their abundances were low.

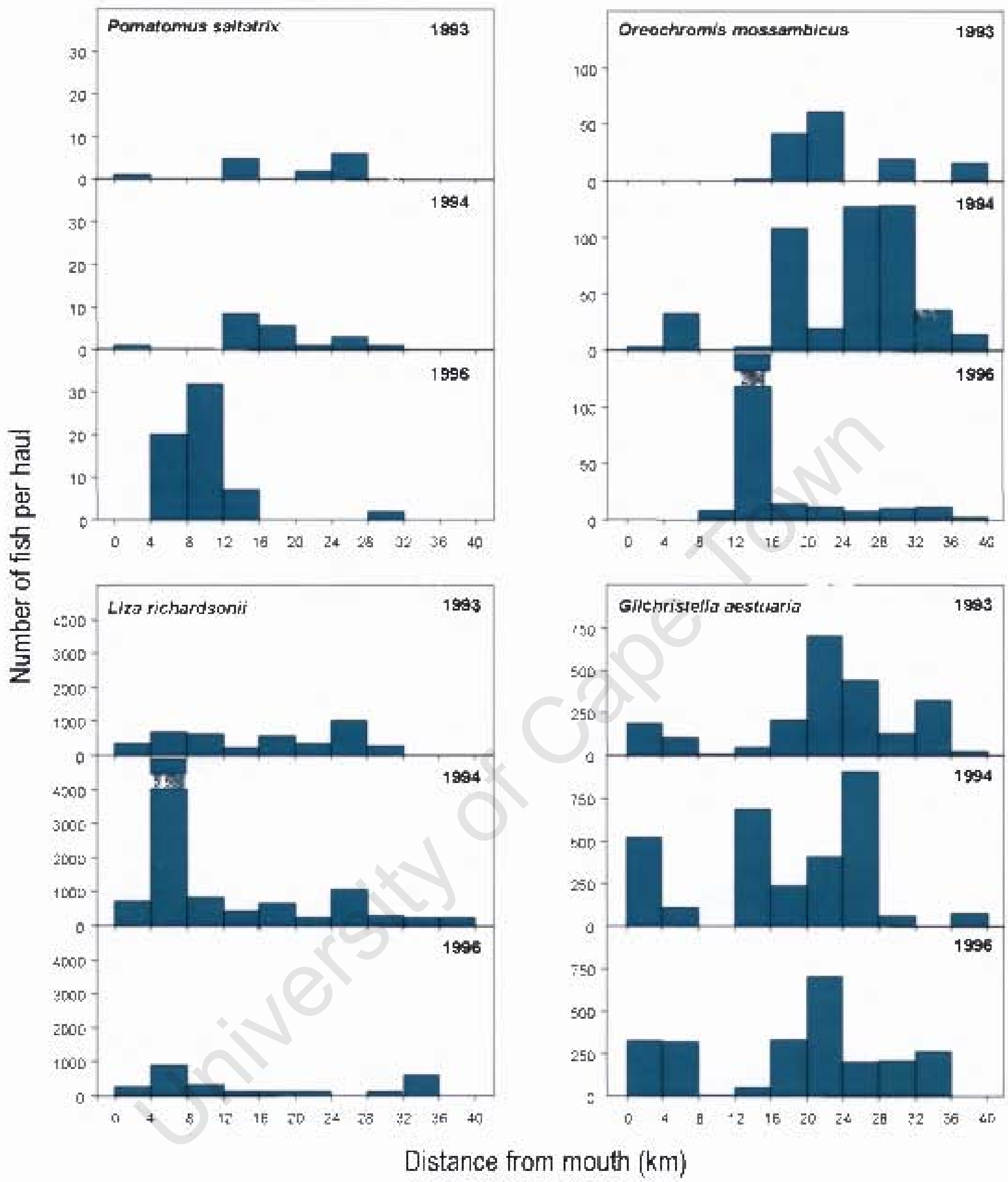


Figure 4.4b Catch per seine haul in the Berg River Estuary in relation to distance upstream, before (1993), during (1994), and after (1996) a low-oxygen, hydrogen sulphide event that occurred in the adjacent sea

Liza richardsonii did not markedly alter its upstream distribution among years, but its *cpue* in the lower reaches was a lot higher during than before or after the low-oxygen event. The along-stream catch-distribution of *Gilchristella aestuaria* remained fairly constant over all three years (Fig 4.4b).

Table 4.4 Nonparametric Kruskal-Wallis ANOVA by Ranks test results of multiple comparisons of harder (*Liza richardsonii*) length-frequency distributions within years among reaches (0-10, 11-20, 21-30 and 31-40 km upstream) and within reaches among years (1993, 1994 and 1996) in the Berg River Estuary. Significant differences between reaches indicated by + and non-significant differences by n.s., shaded areas represent irrelevant comparisons that were not tested.

Year Reach	1993 0-10	1993 11-20	1993 21-30	1993 31-40	1994 0-10	1994 11-20	1994 21-30	1994 31-40	1996 0-10	1996 11-20	1996 21-30	1996 31-40
1993 0-10												
1993 11-20	+											
1993 21-30	+	+										
1993 31-40	n.s.	n.s	+									
1994 0-10	+											
1994 11-20		+			+							
1994 21-30			+		n.s.	+						
1994 31-40				+	n.s.	n.s.	n.s.					
1996 0-10	n.s.				+							
1996 11-20		+				+			n.s.			
1996 21-30			n.s.				+		+	+		
1996 31-40				+				-	n.s.	n.s.	+	

4.3.6 Size composition

Liza richardsonii was the only species caught in sufficient numbers and throughout the estuary to provide a meaningful comparison of fish size distributions among reaches (Fig 4.5). Overall within years, there was a significant increase in fish size from the mouth to 30 km upstream (Kruskal-Wallis ANOVA by Ranks test, $p<0.05$, Table 4.4, Fig 4.5). Comparisons among years showed significant increases in fish size within each reach during the low-oxygen event (Table 4.4). For further illustration, the data for *L. richardsonii* were grouped into small fish (<120 mm) and large fish (>120 mm). Before and after the low-oxygen event in 1994, both small and large fish were mostly in the lower 12 km of the estuary (Fig 4.6). During the event, the proportion of small fish in the lower reaches increased to more than 80% whereas most of the large fish moved up to 30 km upstream.

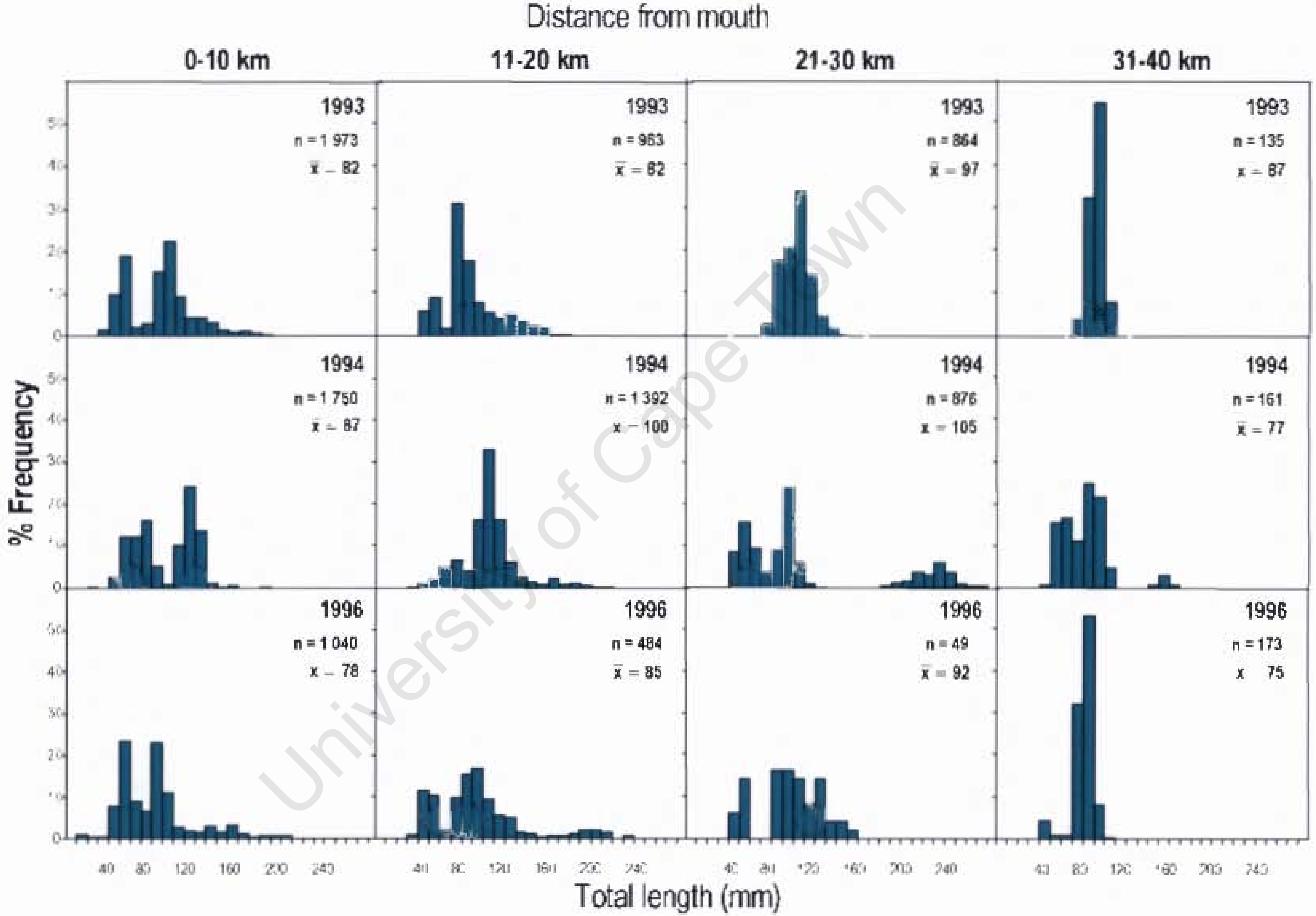


Figure 4.5 Length-frequency distributions of harders (*Liza richardsonii*) in four 10-km reaches from the mouth of the Berg River estuary to 40 km upstream, before (March 1993), during (March1994) and after (February-March 1996) a low-oxygen, hydrogen sulphide event that occurred in the adjacent sea.

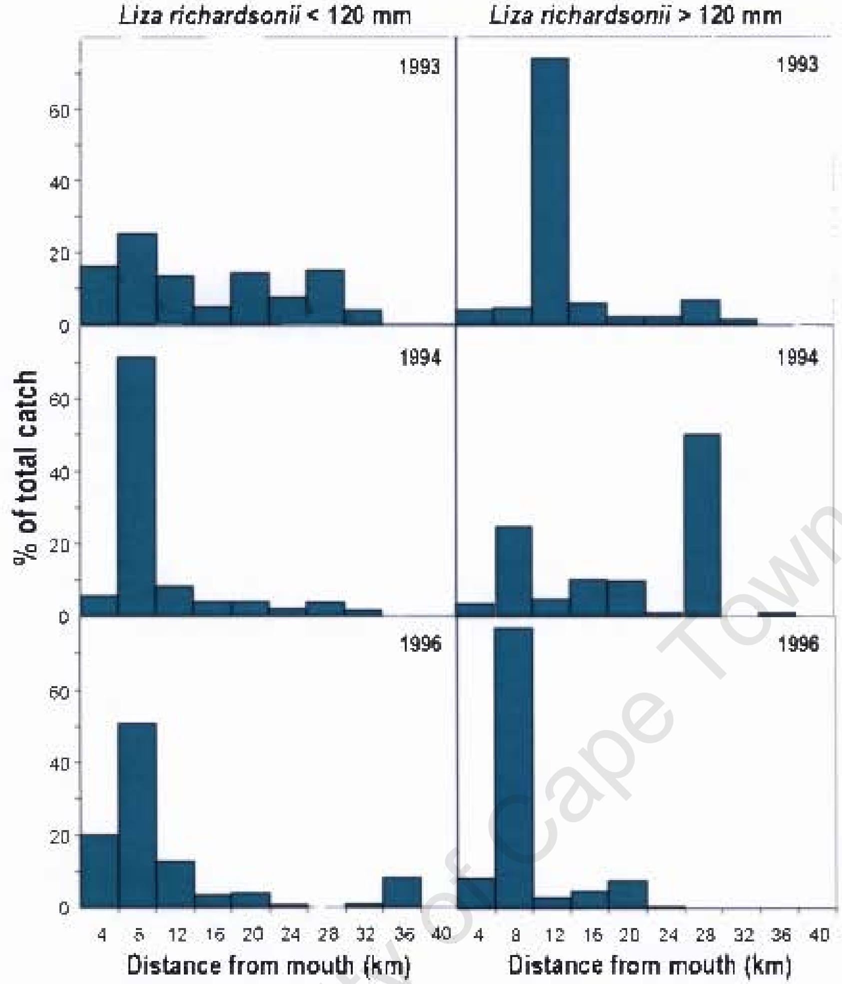


Figure 4.6 Percentage of the total catch of small (<120 mm) and large (>120 mm) harders (*Liza richardsonii*) from the mouth of the Berg River estuary to 40 km upstream, before (March 1993), during (March1994) and after (February-March 1996) a low-oxygen, hydrogen sulphide event that occurred in the adjacent sea.

4.4 Discussion

Although numerous, the benefits provided by estuaries are available only to those fish that are tolerant of the relatively harsh conditions there (Blaber 1981). Of the 57 species of fish washed up on the adjacent shoreline, 16 were recorded alive in the Berg River Estuary during the low-oxygen event, all of which had some degree of estuarine association. Only two estuarine-associated species, *Clinus superciliosus* and *Sarpa salpa*, were stranded on the beach but not recorded in the estuary during the event, but both have been previously recorded in the estuary (Bennett 1994). Not one estuarine-independent fish was found alive in the estuary during the event.

There could be three reasons for the differences in the ability of estuarine–dependent and estuarine-independent species to capitalise on estuaries as a refuge. First, estuarine-independent fish may have succumbed more quickly to low-oxygen conditions, diminishing their potential to escape. All the fish seen entering the Berg Estuary during the event were observed breathing at the surface, which may have prolonged their survival sufficiently to have escaped upstream. Surface respiration has been shown to be a specific adaptation to hypoxia amongst fishes in potentially anoxic estuarine and freshwater habitats (Kramer 1983). Estuarine-independent species may lack this ability. Second, estuarine-independent species may shun estuaries because of physical stresses to which dependent species are tolerant. Notable was the absence of all Chondrichthyes from the estuary, despite the presence of 14 species among those recorded on the beach adjacent to the estuary. Their absence from the estuary presumably reflects their being predominantly benthic species and isosmotic to seawater and compared to estuarine-dependent teleosts, relatively slow at adjusting to lower salinities (Brix 2002). Third, species that are independent of estuaries may lack the capacity to detect cues that lead dependent species into estuaries, such as salinity, temperature, turbidity or chemical gradients (Whitfield 1998, Costa *et al* .2002).

Not all estuarine-associated fish survived to escape into the Berg Estuary during the low-oxygen event, as evidenced by the fact that individuals of 18 of these species were recorded dead on the adjacent shoreline. In fact, 90% of the estimated 1 500 t of dead fish washed ashore comprised the partially estuarine-dependent *Liza richardsonii*. Distance from the mouth is likely to have played a role in their mortality, as only those sufficiently close to the mouth of the estuary are likely to have had the opportunity to escape into the estuary before succumbing. Estuarine-dependent species employ physico-chemical gradients to detect and move into estuaries (Whitfield 1998, Costa *et al* .2002). However, for two reasons, conditions at the time of the low-oxygen event would have conspired to weaken normal gradients. First, river flow at the time was lower than usual (DWAF flow gauging station G1H031-A01, Misverstand). Second, there were anomalous weather conditions associated with the event. Due to a prolonged upwelling quiescent phase (Mathews and Pitcher 1996), surface waters had warmed up and sea temperature at the mouth of the estuary was 2-4°C higher than during the sampling periods before or after the low-oxygen event, water at the mouth was slightly hypersaline at 38‰, and clarity was zero due to the sulphides. Thus, gradients between the sea and the estuary that fish could potentially have followed into the estuary were either weakened (temperature) or reversed (salinity and water clarity). Oxygen levels were effectively zero at the mouth and remained below the 3.5 $ml.l^{-1}$ threshold at which most estuarine biota become stressed (Brearly 2005) for at least the first 10 km upstream. However, they were above the lethal zero levels experienced in the adjacent sea.

From the estuarine seine catches, overall fish density in the Berg River Estuary underwent a twofold increase during the low-oxygen event. This was most likely due to a combination of fish escaping into the estuary from the sea and those already in the system being herded together upstream because of the intrusion of anoxic water in the lower reaches. The greatest contributor to the overall increase in density was the category IIc *Liza richardsonii* which comprised 77% of the total catch during the event, compared to 47% and 41% before and after respectively. Only three other species, the estuarine-dependent *Psammogobius knysnaensis* (Ib) and freshwater *Oreochromis mossambicus* and *Gambusia affinis* (IV) increased substantially during the event but even so, together only contributed 4% to overall numbers. *P. knysnaensis* breeds in the estuarine and marine environment and at least some of its increase in abundance would have been due to escape from adverse conditions in the adjacent surf-zone into the estuary.

The three- to eight-fold increase in abundance and percentage occurrence of the two freshwater species *O. mossambicus* and *G. affinis* had to have been caused by fish moving downstream from the freshwater reaches above the zone sampled. *Oreochromis mossambicus* is tolerant of a wide range of conditions and is euryhaline and eurythermal almost to the extreme. It survives in salinities of 0-100‰ and has been recorded in temperatures of up to 42°C (Whitfield 1998). It is also opportunistic in "taking advantage" of degraded habitats from which other fish have been excluded. The optimum temperature range for *O. mossambicus* is 20-35 °C whereas its tolerance to lower temperatures is positively correlated with brackish water (Whitfield 1998). It may have opportunistically and immediately extended its distribution 10 km downstream once water quality deteriorated in the lower reaches of the Berg Estuary during the event.

Seven species recorded in the Berg Estuary were substantially less abundant or absent during the low-oxygen event. In normal years, one of these, *Caffrogobius nudiceps* (Ib), had the bulk of its estuarine population in the lower 12 km whereas two, *Clinus superciliosus* (Ib) and *Rhinobatos annulatus* (III) were confined to the lower 3 km (Bennett 1994). All three are benthic species and would have been the first to encounter the intrusion of low-oxygen water into the estuary. All three are tolerant of salinities lower than the 20‰ of the middle reaches so would not have found low salinities a barrier to escaping upstream (Whitfield 1998). Therefore, the lower numbers of *C. nudiceps* and complete absence of *C. superciliosus* and *R. annulatus* during the low-oxygen event may have been a combination of their benthic nature, relatively restricted distribution in the lower reaches and the speed at which the low oxygen water entered the estuary. Benthic fish are the first to succumb when oxygen levels fall (Franks & Dodds 1997). Of the other four species, catches of *Lichia amia* (IIa) were too low before and after the event to draw any conclusions whereas catches of the facultative catadromous *Mugil cephalus* (Vb) and freshwater *Cyprinus carpio* and *Micropterus dolomieu* (IV) are likely to have been low because these fish could have swum further upstream beyond the reaches sampled.

Two estuarine breeders, *Gilchristella aestuaria* (Ia) and *Syngnathus temminckii* (Ib), were more abundant after the low-oxygen event whereas one, *Atherina breviceps* (Ib) was less abundant. The cause is unknown, but it can be speculated that the increase in *S. temminckii* was due to an increase in algal (*Cladophera* & *Enteromorpha* spp.) and eelgrass (*Zostera capensis*) habitat observed in 1996. *A. breviceps* shares the water column and same trophic level as *G. aestuaria*, but is less catholic in its diet and less versatile in feeding behaviour, as *G. aestuaria* can switch from filter to selective feeding depending on water clarity and prey availability (White & Bruton 1983, Hecht & van der Lingen 1992). Therefore, under adverse conditions, *G. aestuaria* tends to out-compete *A. breviceps*. This species would also have been severely depleted in both its favoured habitats, the nearshore marine and lower reaches of the estuary.

The fish assemblage of the Berg River Estuary can be divided into three separate groupings roughly corresponding to the lower (0-16km), middle (17-32) and upper (33-40km) reaches of the estuary. In all three years, dissimilarities between reaches were due to species being more abundant in their preferred habitat as opposed to their presence or absence in particular reaches. In normal years (1994 & 1996) the lower reaches were characterised by the estuarine-dependence category I & II *Liza richardsonii, Caffrogobius nudiceps, Atherina breviceps, Gilchristella aestuaria, Syngnathus temminckii* and *Psammogobius knysnaensis*, but the latter two species made a much lesser contribution during the low-oxygen event. In all years, all of these species were also representative of the middle reaches, albeit in different numbers, and were mixed with the facultative catadromous *Mugil cephalus* (IIa/Vb) and freshwater *Oreochromis mossambicus* (IV) as is typical of these reaches in most West Coast estuaries, (Bennett 1994, Harrison 1997). The fish assemblage of the upper reaches was also typical of most West Coast estuaries and characterised by the estuarine breeder *G aestuaria* (Ia) and the freshwater (IV) *O. mossambicus*, *Micropterus dolomieu*, *Gambusia affinis* and *Cyprinus carpio*.

During the low-oxygen event the fish grouping in the lower reaches broke down to some extent as fish moved in from the sea and/or shifted from the lower reaches into the middle and upper reaches. Before and after the event the fish groupings were more distinct, with a Bray-Curtis similarity level of 60-65%, whereas during the event they were more similar, grouping at the 68-80% level. Fish dispersal throughout the estuary during the event was likely to have been a response to adverse conditions in the sea and lower reaches, coupled with a density-dependent response to overcrowding. The overall result was a blurring of the boundaries with average dissimilarities in the fish assemblages among reaches dropping from 40-75% before, to 35-50% during the low-oxygen event, and then rising again to 40-75% after.

The overall 5-15 km upstream shift in the distribution of at least five species (*A. breviceps, C. nudiceps, P. knysnaensis, S. temminckii,* and *P. saltatrix*) during the low-oxygen event suggests that these fish were responding to the poor conditions in the sea and lower reaches of the Berg Estuary. This said, during the event, *P. saltatrix* was seen predating on concentrations of small fish struggling at the surface in the lower reaches, which suggests that far from being stressed, those within the estuary were taking advantage of unusually abundant and easily-caught prey. Of the five species above, *Syngnathus temminckii* did not revert to its pre-event distribution in 1996 but retained its extended range from during the event and regained that lost during the event in the lower reaches.

In all three years there was a significant upstream increase in the size of *Liza richardsonii*. There are at least three possible explanations. First, larger fish swim faster and may disperse further upstream as a result. Second, they would have been in the estuary longer and had a greater chance of finding their way further upstream than small newly recruited juveniles. Third, they may be more tolerant of low salinities. If 1996 represents normal conditions (and previous work suggests it did; Harrison 2004), oxygen levels in the lower 5 km and middle to upper 20-40 km of the Berg Estuary are often below the mean 3.5 $ml.l^{-1}$ level at which estuarine fish become stressed (Brearly 2005). Oxygen levels are often good indicators of fish distribution and different species and age classes may be distributed along oxygen gradients according to their specific tolerances and responses (Costa *et al.* 2002). There was also a significant increase in fish size within reaches during the low-oxygen event, which indicates that large fish swam further upstream than small fish. Before and after the low-oxygen event, the greatest densities of large and small fish were in the lower 4-8 km of the Berg Estuary. During the event, small fish were still concentrated in the lower 4-8 km, specifically at the front between estuarine and anoxic marine water. Some succumbed to suffocation at each tidal push. The highest densities of large fish were more than 20 km upstream from the mouth. The differential ability of large and small fish to escape low oxygen conditions has been shown in studies elsewhere, for example with small 0-group sole *Solea solea* (Koutsikopoulos *et al.* 1989). In general, larval and juvenile fish rely more on passive movement and are less successful than active strong-swimming adults at escaping adverse conditions such as low oxygen levels.

4.5 Conclusions

This paper presents clear but circumstantial evidence that marine fish can secure refuge in estuaries at times when marine conditions become stressful or lethal. This capacity is, however, limited to those species that are classed as being "estuarine-dependent". Estuarine-dependence includes the ability or pre-adaptation to locate and secure refuge in estuaries. This is borne out by the observation that no estuarine-independent species found refuge in the Berg River Estuary during the low-oxygen event, despite being in close proximity to the mouth. Movement of estuarine-dependent species into the estuary was likely to have been along olfactory and/or oxygen gradients as other potential cues such as gradients in temperature, salinity and turbidity were either reversed or severely weakened during the event.

The fact that no estuarine-independent species were recorded in the estuary indicates either that they died before reaching the estuary or lacked the capacity to locate it.

Fish densities doubled in the Berg River Estuary during the event due to fish escaping into the estuary from the sea, coupled with their being herded together by the tidal intrusion of low-oxygen water into the lower reaches of the estuary. In turn, there was an overall upstream shift in the distribution of fish in the estuary during the event. Most returned to their original distribution after the event, although a few did not. Based on species composition and abundance, the fish assemblages of the Berg River Estuary can in normal years be broadly grouped into those of the lower, middle and upper reaches. The escape of fish into the estuary and the movement of many upstream during the low-oxygen event resulted in this pattern being temporarily disrupted.

Large fish, being stronger swimmers, were able to escape further upstream, whereas small fish remained concentrated in the lower reaches and would have been more susceptible to mortalities with the intrusion of low-oxygen water each floodtide.

The differences in fish assemblage structure during, as opposed to before and after, the low-oxygen event, may arguably be attributed to seasonality or interannual variation. However, sampling was confined within the same month and season before, during and after the event, whereas the argument against interannual variabllity being the driver is supported by there being no statistical diffrenece between the fish assemblages before and after the event.

The extent of the low-oxygen, hydrogen sulphide event was more than 50 km along the coast and 10 km out to sea (Danie Van Zyl, Marine & Coastal Management, personal communication). The situation of the Berg River close to the centre of the event clearly provided a refuge for estuarine–dependent species to escape and, by implication, would have aided subsequent recovery of the fish assemblages and fisheries adjacent to the estuary.

CHAPTER 5

5. THE IMPLICATIONS OF ALTERED FRESHWATER INFLOWS FOR THE COMMERCIAL LINEFISHERY ON THE THUKELA BANKS, KWAZULU-NATAL, SOUTH AFRICA.

5.1 Introduction

River flows influence marine fish and fisheries directly and indirectly through the export of nutrients, sediment and detritus (Houde & Rutherford 1993, Gillanders and Kingsford 2002, Robins *et al.* 2005). Nutrient supply stimulates production of phytoplankton and zooplankton and, ultimately, the larval, juvenile and adult fish that depend on them as food sources (Morgan et al. 2005). Detritus may be broken down into useful nutrients, serve as a substrate for microorganisms or be consumed directly by detritivorous fish and invertebrates (Whitfield 1998, Blaber 2000). Sediment export replenishes nearshore habitats that are continuously eroded by oceanic currents and provides a refuge for many fish by increasing turbidity (Cyrus & Blaber 1992, Uotani *et al.* 1994, Halim *et al.* 1995). Turbidity also tends to increase the catchability of many species, especially the 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 moving into and out of the estuarine environment (Whitfield 1998). The strength of these cues will ultimately dictate how many individuals of these species recruit into marine fisheries. From a fisheries perspective, altered freshwater flows and consequent variations in 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 (Binet *et al.* 1995, Loneragan and Bunn 1999, Chapter 2).

A catchment-derived nutrient supply is especially important in oligotrophic nearshore waters such as the Thukela Banks off KwaZulu-Natal in South Africa, where nutrient supply from upwelling events is limited. More specifically, nutrient export from the largest of the local rivers, the Thukela, is likely to be greater than elsewhere in KwaZulu-Natal for two reasons. First, this river provides approximately 40% of the regional annual river volume. Second, the estuary is river dominatedit and has a small estuarine area (and is hence classified as a river mouth), and consequently will export most of its nutrients whereas in 'true' estuarine systems such as St Lucia most of the nutrients are incorporated into estuarine phytoplankton production before they reach the marine environment (Whitfield 1992, Turpie *et al.* 2002, DWAF 2004c). The Thukela also supplies the bulk of the terrigenous sediment reaching the adjacent marine banks: approximately 10^7 metric tons per year (Flemming & 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 would favour penaeid prawns and flatfish species, but be detrimental to filter-feeding invertebrates 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. Because the Thukela Estuary is a river mouth, it is relatively unimportant as a nursery area and alterations to its freshwater flow are unlikely to be of consequence to the eventual recruitment of estuarine-dependent species into the marine fisheries. However, the opposite may be the case for the Thukela Banks, where freshwater flows are likely to provide cues for spawning and the recruitment of juveniles that utilise the banks as a nursery area.

Numerous future developments, ranging in magnitude from local water abstraction to large dams and inter-basin transfer schemes, have been proposed for the Thukela River and its tributaries (DWAF 2004c). South African water law governs decisions about such developments and the National Water Act of 1998 requires that, for any given water resource, sufficient water be set aside to provide for basic human needs and the protection and maintenance of aquatic ecosystems (Republic of South Africa 1998, Thompson 2006). The quantity and quality of water set aside is referred to as the 'Reserve', further divided into 'basic human needs' and 'ecological' components. In protecting aquatic systems, the Ecological Reserve is aimed at securing ecologically sustainable use of the water (Thompson 2006). Establishing the basic human needs and ecosystem requirements of a water resource entails following strict guidelines and is referred to as a Reserve Determination. Methods have been developed for determining the Ecological Reserve of rivers and estuaries but not the adjacent marine environment (Taljaard *et al.* 2003, Van Ballegooyen *et. al.* 2005).

The sheer magnitude of some of the envisaged developments in the Thukela catchment required a robust Reserve Determination for the river and estuary to steer decisions (DWAF 2004c). Nine most-likely future scenarios have been identified; six comprising minor increases, one the *status quo,* one a moderate (16%) reduction and one a worst case scenario constituting a 44% reduction in flow volume (DWAF 2004c). This done, the point has been raised that there are also concerns that freshwater runoff has implications for the marine environment, particularly the prawn-trawl and linefisheries. These may not be easy to quantify because runoff will be one amongst many environmental and anthropogenic factors influencing their catches, but the focus of this paper is to address the relationship between runoff and linefish.

In terms of participation and catch, the commercial and recreational linefishery is the most important fishery in KwaZulu-Natal, accounting for 40% of the landed mass. At the time of this study the commercial linefishery comprised approximately 100 boats and 600 crew, at least half of which fished on the Thukela Banks (Penney *et al.* 1999). Typical of many subtropical fisheries, the commercial linefishery has a diverse catch of approximately 140 species, although fewer than 15 of these contribute more than 90% of the landed mass (Penney *et al.* 1999, Turpie *et al.* 2000, Jones *et al.* 2002). These 15 have a variety of life-history strategies and span reef-dwelling Serranidae, shoaling Sparidae and pelagic Scombridae. Few are, however, estuarine-dependent or have any other known affinity for freshwater (Griffiths & Lamberth 2002, Chapter 2). This said, anecdotal local fishing lore suggests that catches of at least one of these species, king mackerel *Scomberomorus commerson*, reflect the magnitude of the previous year's rainfall (Govender 1992).

This paper examines two long-term data series, one constituting data on catchment flow and the other catch-and-effort data from the linefishery. The flow data comprise 17 years of monthly volumes from the 17 major catchments that discharge into the sea along the length of the Thukela Banks. Correspondingly, the linefishery data comprise monthly catch-and-effort data for more than 100 species over the same 17-year period. An exploratory and correlative approach was taken, using a combination of spectral analysis and general linear models (GLMs). Spectral analysis helped to identify reoccurring patterns shared by the two time series, whereas GLMs measured the intensity of the relationships between flow and catch.

Short and long-term flow and catch relationships were examined with lags and cycles ranging from months to years. Some relationships were obviously auto-correlative whereas others were real. For example, spurious relationships existed where strong correlations were related to climate and rainfall, rather than being catchment-related. To avoid this problem, detailed analysis was restricted to about 20 species for which there were substantial continuous catch data over the entire time series. Real and spurious relationships were examined more specifically by detailed analyses of king mackerel *Scomberomorus commerson*, squaretail kob *Argyrosomus thorpei* and slinger *Chrysoblephus puniceus*, spanning relationships that ranged from short-term 1-12 month seasonal patterns and fluctuations in catchability, to long-term inter-annual variability and survival.

5.2 Materials and methods

5.2.1 Study area

KwaZulu-Natal spans both the subtropical Natal and the tropical Delagoa biogeographic provinces on the east coast of South Africa (Emmanuel *et al.* 1992, Sink *et al.* 2006). The Thukela Banks, comprising much of the Natal Bight, stretches approximately 150 km along the coastline to the north of Durban and is approximately 50 km at its widest point at the edge of the continental shelf (Fig. 5.1). For the purpose of this study, the entire shelf region from Durban to the Mozambique border was considered to fall within the range of the Thukela Bank linefishery. Seventeen catchments of any consequence, providing over 90% of the mean annual runoff, enter the sea in this region. Of these, the Thukela, Mfolozi and Mgeni rivers systems are the largest (Fig. 5.1).

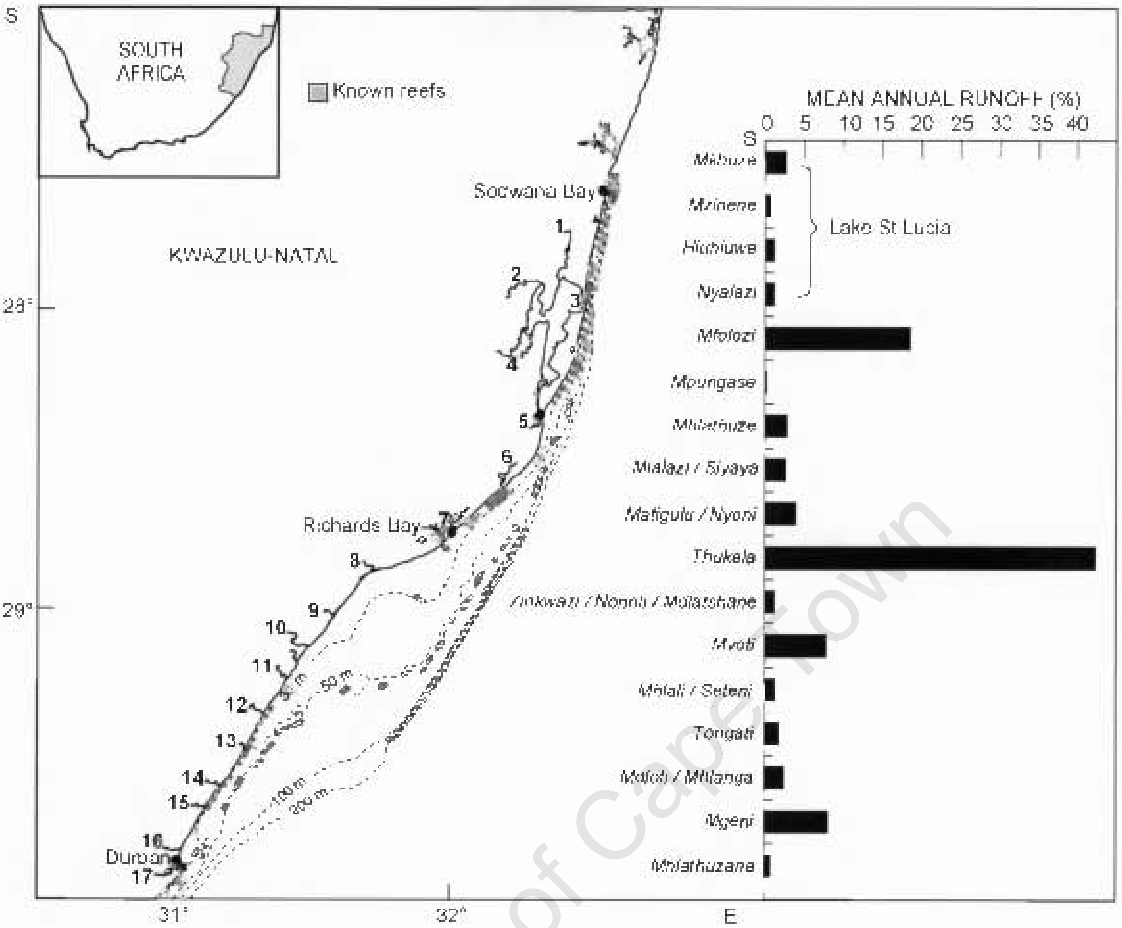


Figure 5.1 Map of KwaZulu-Natal to the north of Durban showing the major river catchments, their contribution to mean annual runoff (MAR) and the continental shelf to the 200m depth contour. The Thukela Banks fall within the area where the continental shelf widens known as the Natal Bight. The 17 rivers shown provide over 90% of the MAR entering the sea in the study area. Numbering from north to south corresponds to the ordering of the rivers shown on the right.

5.2.2 *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 1900s when 10 boats operated there (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 rapidly expanded the fishery as the coast became more accessible and the fishery more affordable for recreational fishers and more lucrative for commercial fishers. Participation and effort peaked at approximately 10 000 fishers in 1995, with 140 and 2 000 boats registered in the commercial and recreational sectors respectively. Since then, declining catch rates coupled with the opening up of fisheries in Mozambique has resulted in a substantial decrease in the number of boats operating in KwaZulu-Natal. By 2001, approximately 100 boats employing 600 crew operated in the KwaZulu-Natal commercial linefishery. Effort was 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 Banks.

5.2.3 *Catch and flow data*

Exploratory analyses of the relationships between monthly river-flow volumes and commercial linefish catches on the Thukela Banks were performed using Spectral Analysis and General Linear Models (GLMs). The information available comprised 17 years of monthly commercial catch-per-unit-effort (*cpue*) data (1985-2001) for 140 species from the National Marine Linefish System (NMLS, Marine and Coastal Management, Department of Environmental Affairs and Tourism, South Africa), and monthly flow data for the same period from seventeen catchments to the north of Durban (DWAF, 2004c).

Spectral analyses were conducted on the catch and flow time-series to explore cyclical patterns of data (StatSoft, Inc. 2005). The analysis proceeds by decomposing the cyclical components of a time series (flow & *cpue*) into a few underlying sinusoidal (sine and cosine) functions of particular wavelengths and differing frequencies that may be assessed in terms of their dominance or strength. For the time-series under consideration, spectral analysis identified the seasonal fluctuations of different lengths whereas in most other techniques the length of the seasonal component is usually known (or fixed) *a priori* and included in one or other theoretical model of moving averages or autocorrelations (Jenkins and Watts 1968, Shumway 1988, Wei 1989). One approach is to treat the observed time-series and the sine functions of all possible frequencies as the respective dependent and independent variables of a linear multiple regression:

$$x_t = a_0 + \Sigma[a_k \times \cos(\lambda_k \times t) + b_k \times \sin(\lambda_k \times t)] \quad \text{(for k = 1 to q different sine and cosine functions)}$$

where λ is the frequency in radians per unit time and a_k and b_k are regression coefficients that indicate the strength of the correlation (StatSoft, Inc. 2005). If a large correlation (sine or cosine coefficient) is identified, it can be concluded that there is a strong periodicity of the respective frequency (or period) in the data.

To better understand the underlying relation between two sets of time series, I also used cross-spectral analysis, which uncovers the correlations between two series at different frequencies (periods) based on their individual cycles. Briefly, cross-spectral analysis is an extension of Single Spectrum (Fourier) Analysis to the simultaneous analysis of two series. Both analyses were conducted with *STATISTICA*, version 7.1 (StatSoft, Inc. 2005).

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. General Linear Models differ from multiple regression models in terms of the number of dependent variables that can be analysed and by allowing for linear transformations or linear combinations of multiple dependent variables. They also differ from multiple regression models in being able to provide a solution for the normal equation when the dependant variables are not linearly independent. One can summarize the advantages of GLMs in two ways: 1. The random component can be something other than normal, 2. It is possible to model a function of the mean. The GLM models were used to quantify the links between the time series. These analyses were also conducted with *STATISTICA* version 7.1 (StatSoft, Inc. 2005).

For the GLMs the only species examined were those for which catches had been reported in more than 50 months over the 17-year period, and lags corresponding to the highest spectral densities were applied to each catchment separately. The responses of king mackerel *Scomberomorus commerson*, squaretail kob *Argyrosomus thorpei* and slinger *Chrysoblephus puniceus* are discussed separately and in more detail as exemplars of the patterns emerging.

5.3 Results

5.3.1 Catch composition

Over the period 1985-2001, 140 species, 60 of which can be regarded as important, were caught by the KZN linefishery, and approximately 1 235 tons were landed annually (Table 5.1). The recreational and commercial sectors were responsible for 62% and 38% of the value of this catch respectively. Some 90% of the catch, was however, contributed by 15 species. Of the commercial and recreational catches, slinger *Chrysoblephus puniceus,* (3.8 & 31.1% respectively), king mackerel *Scomberomorus commerson*, (33.2 & 3.4%), geelbek *Atractoscion aequidens*, (3.3 & 15.0%), yellowfin tuna *Thunnus albacares*, (18.8 &1.3%), santer *Cheimerius nufar*, (2.4 & 8.2%) and squaretail kob *Argyrosomus thorpei*, (3.9 & 7.2%) were the most important (Table 5.1).

The recreational and commercial sectors differed in that *S. commerson* (33%) and *T. albacares* (19%) provided the bulk of the recreational catch, whereas *C. puniceus* (31%) and *A. aequidens* (15%) were the most important commercial species. Overall, recreational fishers tended to target the pelagic gamefish species, whereas the commercial fishers concentrated on the higher-value reef and shoaling species.

Chrysoblephus puniceus was commercially caught in equal numbers throughout KZN comprising 31% and 36% of the overall KZN and the Thukela Banks commercial linefish catches respectively (Table 5.1).

Table 5.1 Mean annual catch and economic contribution of the 25 most important taxa captured by the recreational and commercial boat-based linefishery in KwaZulu-Natal for the years 1985-2001. Stock statuses, depending on available data, are the ratios of present versus historic spawner biomass per recruit (SBPR current), catch per unit effort (cpue) or catch composition, all expressed as percentages. Economic values include value added and all contributions by subsidiary industries (after McGrath *et al.* 1997 and Lamberth & Joubert 1999). South African Rand equivalent to US$ 0.13 in 2007. Stock status after Mann 2000 and Griffiths & Lamberth 2002.

Species	Common name	Stock status % pristine	KZN Recreational boat % catch	KZN Recreational boat Value Rands (M)	KZN Commercial boat % catch	KZN Commercial boat Value Rands (M)	Thukela banks commercial boat % catch	Thukela banks commercial boat % KZN catch
Chrysoblephus puniceus	Slinger	14	3.81	1.79	31.11	7.82	35.60	43.53
Scomberomorus commerson	King mackerel	33	33.24	15.58	3.44	1.15	5.08	56.17
Atractoscion aequidens	Geelbek	5	3.28	1.54	15.02	5.03	3.88	9.82
Thunnus albacares	Yellowfin tuna	30	18.88	8.85	1.29	0.14	0.08	2.48
Cheimerius nufar	Soldier/santer	30	2.41	1.13	8.23	1.03	11.52	53.25
Argyrosomus thorpei	Squaretail kob	17	3.96	1.85	7.24	2.42	15.08	79.29
Serranidae spp.	Rockcods				7.09	2.77	9.63	51.71
Argyrosomus spp.	Kob				6.05	2.03	7.16	45.05
Epinephelus andersoni	Catface rockcod	13	8.25	3.75	0.59	0.23	0.51	32.81
Chrysoblephus anglicus	Englishman	10	1.44	0.68	4.53	1.52	1.06	8.93
Polysteganus coeruleopunctatus	Blueskin	55			5.17	1.73	4.28	31.46
Euthynnus affinis	Eastern little tuna	50	6.24	2.92	0.11	0.03	0.02	5.59
Scomberomorus plurilineatus	Queen mackerel	50	2.89	0.94	0.53	0.18	1.04	75.06
Polyprion americanus	Wreckfish	55			1.73	0.67	0.06	1.30
Polysteganus praeorbitalis	Scotsman	10	0.82	0.38	1.15	0.39	0.17	5.78
Istiophorus platypterus	Sailfish	55	1.93	0.91	0.04	0.01	0.03	26.87
Coryphaena hippurus	Dolphinfish/dorado	60	0.92	0.43	0.56	0.19	0.41	28.06
Caranx sem	Blacktip kingfish	60	1.54	0.72	0.01	0.01	0.00	4.27
Cymatoceps nasutus	Poenskop	15			0.78	0.33	0.74	36.16
Pomatomus saltatrix	Elf / shad	34	1.24	0.56	0.03	0.01	0.01	17.84
Pomadasys kaakan	Javelin grunter	45	0.55	0.26	0.36	0.05	0.38	40.02
Scomber japonicus	Mackerel	50	0.56	0.26	0.33	0.02	0.05	6.14
Lethrinidae spp.	Emperors				0.62	0.16	0.28	17.24
Otolithes ruber	Snapper kob	60	0.67	0.31	0.18	0.05	0.00	0.33
Epinephelus albomarginatus	White-edged rockcod	10	0.34	0.14	0.29	0.11	0.04	5.30
	Other (102 species)		12.47	3.86	3.06	0.81	1.98	9.27
	Total		470 t (38%)	47 (62%)	765 t (62%)	29 (38%)	291 t	38%

Catch composition to the north and south of Durban differed largely due to the bulk of the *Argyrosomus thorpei* catch being taken to the north on the Thukela Banks where it provided 15% as opposed to 7% of the overall commercial catch (Table 5.1). *Atractoscion aequidens* provided 15% of the overall commercial linefish catch but less than 4% of the Thukela Banks catch to the north of Durban.

5.3.2 Catchment flows

During the time series September 1980 to October 2001, the 17 catchments analysed had a total mean annual runoff (MAR) of $5\times10^9 m^3$, 42% of which was contributed by the Thukela (Fig. 5.1). The Mfolozi (19%), Mvoti (8%) and Mgeni (8%) also contributed substantial proportions of the MAR whereas the remaining catchments provided less than 4% each (Fig. 5.1). Even collectively, the four rivers flowing into St Lucia only provided 5% of the MAR. In most years, this volume of freshwater seldom reaches the sea as it first has to inundate the 40 000 ha extent of the lake system (Turpie *et al.* 2002). The Thukela, despite providing much of the MAR, sometimes closes to the sea and may experience zero flow in the winter dry season. During the study period, monthly flow from the Thukela varied from zero to a maximum of $1\ 227\times10^6 m^3$ during the 1984 wet season. In all, the Thukela, Mfolozi, Mlalazi, Matigulu, Mhlali, Mdloti, Mgeni and St Lucia (Mkhuze, Mzinene, Hluhluwe & Nyalazi) made significant contributions ($p<0.05$) towards the relationship between flow and catch. These systems provided 85% of the mean annual runoff in KZN.

5.3.3 Spectral Analysis

The *cpue* of at least 13 taxa either responded to flow or followed the same pattern as flow (Table 5.2). The strongest cross-spectral densities were coupled with annual or seasonal patterns with a periodicity of 11-12 months. These short-term cycles had lagged responses ranging from almost zero for *Chrysoblephus puniceus* to 10.4-11.4 months for *Cheimerius nufar* and *S. commerson*. Some taxa (e.g. *S. commerson* and serranids spp.) showed a second cycle of repeatability through a range of 1.5-8 years. The cross-spectral densities of these long-term periods were (with the exception of *A. thorpei*), much weaker than those for the shorter 11-12 month period (Table 5.2). The relationships between flows and catches for two species, *C. puniceus* and *A. thorpei*, both displayed two long-term periods. Further, the long-term responses to flow of six species - Poenskop *Cymatoceps nasutus*, Serranidae (Mostly *Epinephelus andersoni* & *E. rivulatus*), sea-catfish *Galeichthys feliceps*, *C. puniceus* and *A. thorpei* - all corresponded to their ages-at-first-capture (Table 5.2). The short-term response of *S. commerson*, represented by a lag of 10-11 months, corresponded with this species' age-at-first-capture of just under a year.

Table 5.2 Age at first capture and results of spectral analysis and general linear models (GLMs) using 17 years (1985-2001) of monthly volumes from 17 catchments and commercial linefish *cpue* of selected species as the independent and dependent variables respectively. The short-term responses are mostly seasonal and all recur within a 12-month period as opposed to the long-term where the periods differ. Consequently, lags are shown for the short-term and periods for the long-term. Age at first capture after Mann 2000. Familial or generic names are given where fishers have reported catches but failed to distinguish between them at the species level

			Spectral analysis				General linear models	
			Short-term		Long-term			
Species	Common name	Age at 1st capture (yrs)	Cross spectral density	Lag (months)	Cross spectral density	Period (years)	Multiple R^2	P
Argyrosomus spp.	Kob (50/50 dusky & squaretail)	1.5 (dusky)	17.82	4.6		none	0.209	n.s.
Scomberomorus commerson	King mackerel	< 1	15.57	10.4	5.51	6-8	0.418	< 0.001
Scomberomorus plurilineatus	Queen mackerel	unknown	14.28	7.1		none	0.084	n.s.
Cymatoceps nasutus	Poenskop	8	10.53	4.1	4.91	8	0.586	< 0.001
Pomadasys kaakan	Javelin grunter	unknown	9.65	1.5	5.96	8	0.198	n.s.
Serranidae spp.	Rockcods (catface & halfmoon)	2.5	9.54	1.1	4.80	2.7	0.461	< 0.001
Chrysoblephus puniceus	Slinger	1-2	8.08	0.02	3.10	1.5 & 6-8	0.338	< 0.001
Argyrosomus thorpei	Squaretail kob	3.7	7.50	4.2	7.78	3.5 & 6-8	0.281	< 0.008
Cheimerius nufar	Soldier/santer	1-2	7.30	11.4		none	0.271	< 0.015
Galeichthys feliceps	Sea catfish	9	5.48	5.4	3.58	8	0.321	< 0.001
Sparidae spp.	Redfish (70% slinger, 10% santer)	1-2					0.667	< 0.001
Epinephelus marginatus	Yellowbelly rockcod	2.9					0.495	< 0.001
Polyamblyodon germanum	German	unknown					0.477	< 0.001
Porcostoma dentata	Dane	unknown					0.417	< 0.001
Polysteganus undulosus	Seventy four	4					0.349	< 0.001
Coryphaena hippurus	Dolphinfish/dorado	< 1					0.345	< 0.001
Chrysoblephus cristiceps	Dageraad	5-9					0.238	n.s.
Polysteganus coeruleopunctatus	Blueskin	1					0.229	n.s.
Chrysoblephus anglicus	Englishman	unknown					0.217	n.s.
Atractoscion aequidens	Geelbek	2					0.186	n.s.
Epinephelus andersoni	Catface rockcod	2.5					0.120	n.s.
Lethrinidae spp.	Emperors	unknown					0.084	n.s.
Pristipomoides filamentosus	Rosy jobfish	unknown					0.070	n.s.

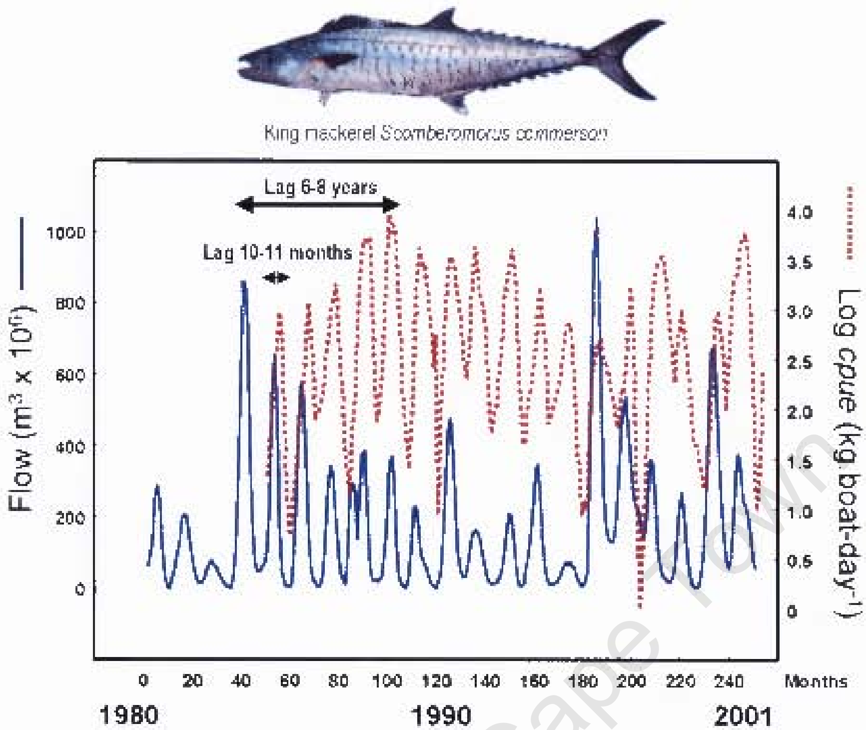


Figure 5.2 Time series of monthly volumes from the Thukela River and monthly catch-per-unit-effort of king mackerel *Scomberomorus commerson* by the commercial boat-based linefishery operating on the Thukela Banks for the period 1985-2001.

The relationships between flow volumes and linefish landings were exemplified by the time series of *S. commerson*, *A. thorpei* and *C. puniceus* catches and monthly volumes from the Thukela River (Figs. 5.2 – 5.4). For *S. commerson*, short-term 10-11 month lags were graphically evident between flow and catches (Fig 5.2). In addition, although the response was lagged, catch magnitude appeared to vary with that of flow. In turn, long-term 6-8 year periods corresponded with the response of *S. commerson* to wet-flow and drought low-flow cycles (Fig. 5.2). The relationship between *Argyrosomus thorpei* and flow was obscured by the long-term decline in catches and eventual stock collapse to 17% of pristine (Fig. 5.3, Table 5.1). Nevertheless, catches of this species exhibited a short-term lagged response of 4 months, a 3.5 year period corresponding to age-at-first-capture and, similar to *S. commerson*, a long-term 6-8 year period corresponding to wet and drought years (Fig. 5.3, Table 5.2). The short-term response of *Chrysoblephus puniceus* to flow was positive and immediate with no lags (Table 5.2, Fig. 5.4). In addition, there was a 1.5-year period related to age-at-first-capture as well as a 6-8 year period of catches fluctuating with wet and dry cycles (Table 5.2, Fig. 5.4).

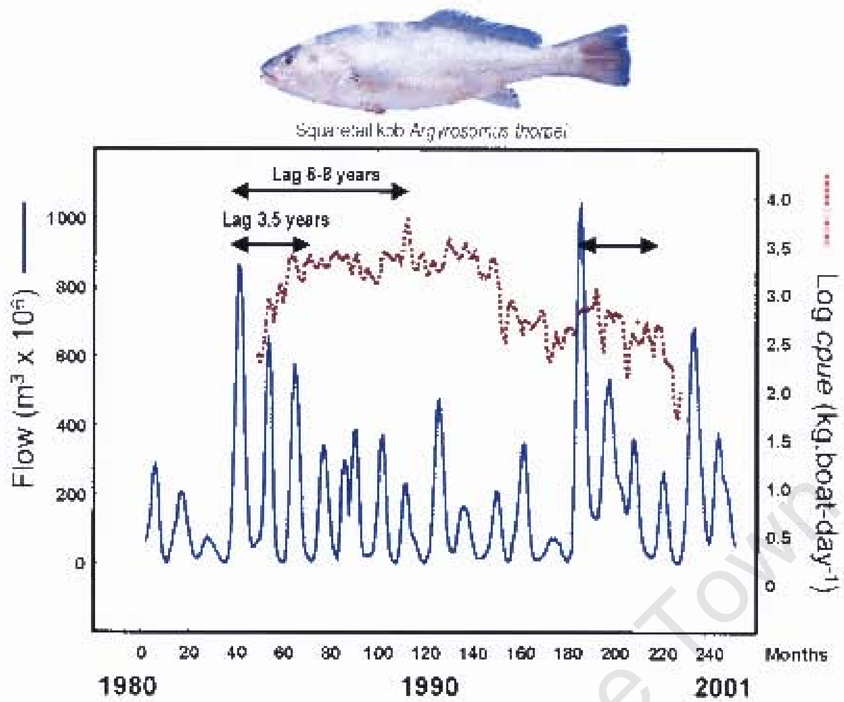


Figure 5.3 Time series of monthly volumes from the Thukela River and monthly catch-per-unit-effort of squaretail kob *Argyrosomus thorpei* by the commercial boat-based linefishery operating on the Thukela Banks for the period 1985-2001.

5.3.4 *General Linear Models*

The GLMs indicated significant relationships between the *cpue* of 13 of the selected taxa and the total combined monthly flow volumes of the Thukela, Mfolozi, Mlalazi, Matigulu, Mdlali, Mdloti, Mgeni and St Lucia (Mkhuze, Mzinene, Hluhluwe & Nyalazi) (Table 5.2). Depending on the species and intensity of their respective cross-spectral densities, lags used ranged from zero to 96 months. The strongest relationships were between flow and *cpue* of "redfish" (*Chrysoblephus puniceus* & *Cheimerius nufar*) and *Cymatoceps nasutus*, for which respectively 67% and 59% of the variability in catch could be explained by flow. Flow also explained 40-50% of the variation in catch of dane *Porcostoma dentata*, german *Polyamblyodon germanum*, king mackerel *S. commerson* and yellowbelly rockcod *Epinephelus marginatus*, catface rockcod *Epinephelus andersoni* and halfmoon rockcod *Epinephelus rivulatus*. The significant relationship that *E. andersoni* had with flow was as a group under the Serranidae including *E. rivulatus* not as an individual species (Table 5.2). Similarly, the relationships that *C. puniceus* and *C. nufar* had with flow were much more robust when catches of the two species were grouped together.

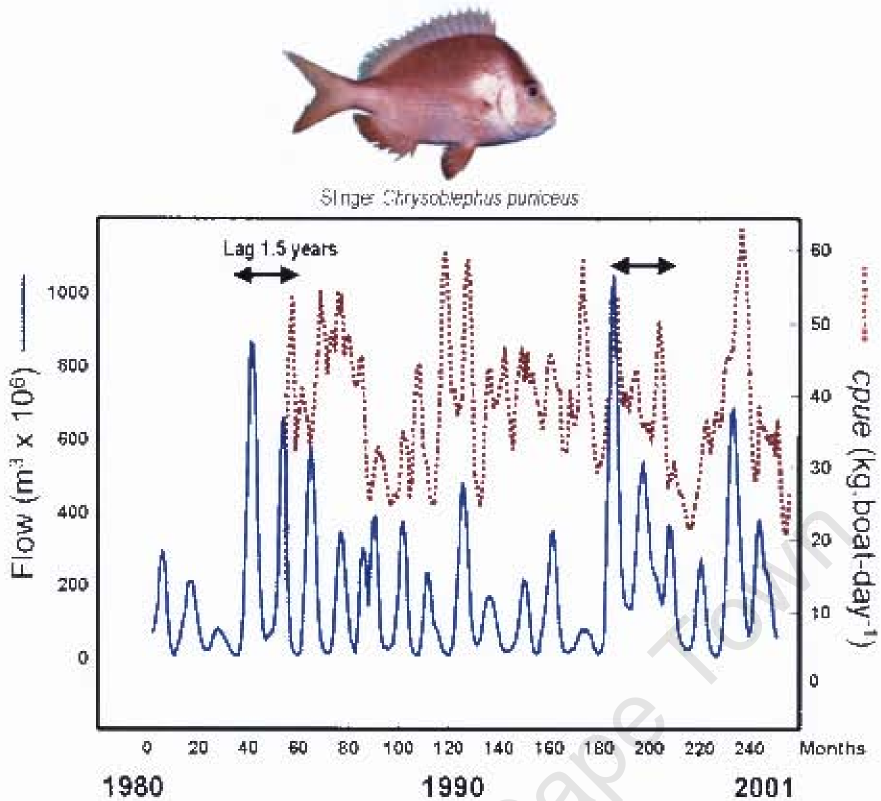


Figure 5.4 Time series of monthly volumes from the Thukela River and monthly catch-per-unit-effort of slinger *Chrysoblephus puniceus* by the commercial boat-based linefishery operating on the Thukela Banks for the period 1985-2001.

Weak and strong relationships are best illustrated by a comparison of the cross-correlation functions between flow and catches of *S. commerson* and *C. nufar* (Fig. 5.5). Whereas the *S. commerson* relationship with flow displayed a strong pattern of synchronicity beyond the confidence interval around 10-14 months, *C. nufar* was asynchronous and remained largely within the confidence limits.

5.4 Discussion

Correlations between environmental conditions and recruitment are seldom regarded as useful predictive tools largely due to the low incidence of verification on retesting (Myers 1998). Those that are successful have been tested over multiple populations and/or on populations that lie at the limit of the species range where abiotic, density-independent factors are relatively more important and easier to understand (Myers 1998). This study fulfils most of these requirements, addressing multiple populations, albeit of different species, the most important of which are close to the limits of their distribution (Turpie *et al.* 2000).

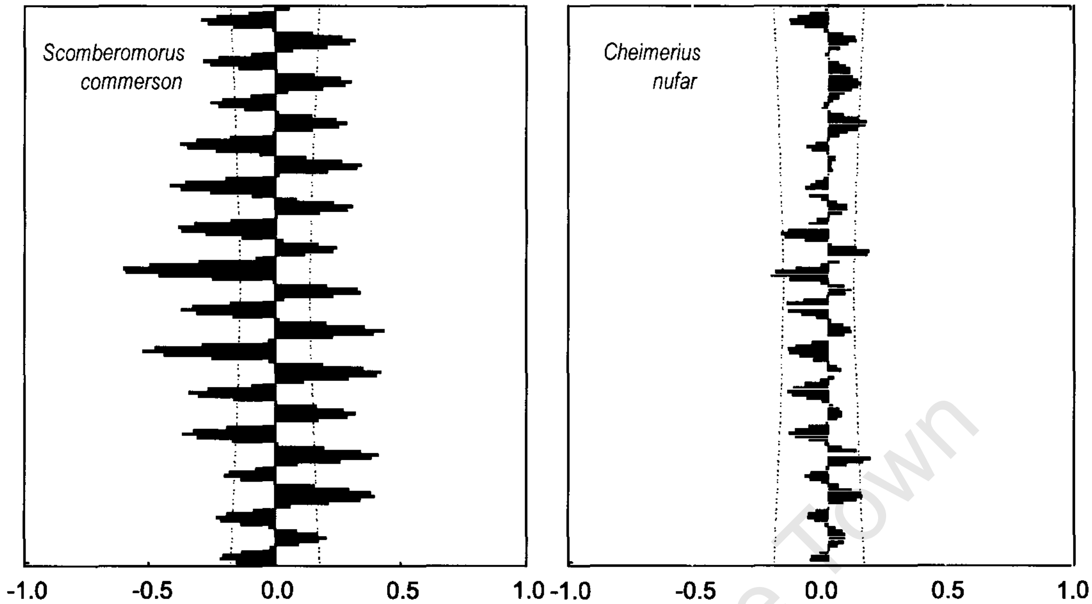


Figure 5.5 A comparison of the cross-correlation functions of flow versus the lagged running means of the catches of *Scomberomorus commerson* and *Cheimerius nufar.* Dashed lines indicate the confidence limits.

5.4.1 The linefishery

Chrysoblephus puniceus was uniformly important to the commercial linefishery throughout KZN providing 31-35% of the catch (Table 5.1). In other respects, the catch composition of the commercial fishery to the north of Durban and on the Thukela Banks differed from that in the south, with *Argyrosomus thorpei* rather than *Atractoscion aequidens* being the second-most dominant species (Table 5.1). A. *aequidens* migrates from the cooler south and east coasts to southern KZN in winter where it spawns in spring (Griffiths and Hecht 1995). Most are caught on the KZN south coast during winter. In contrast, *A. thorpei* appears to be resident in soft-sediment areas in water less than 50 m deep, such as the Thukela Banks where 80% of the KZN commercial catch is taken (Fennessy 1994). In all, 38% of the total commercial linefish catch in KZN comes from north of Durban, mostly from the Thukela Banks.

In terms of mass, the KZN commercial linefishery provides only 7.2% of the national catch. However, KZN falls within the subtropical biogeographical region at the southernmost range of many species. Consequently, for most of these fish, e.g. *C. puniceus, S. commerson* and *A. thorpei,* the KZN linefishery provides the bulk of the South African catch. 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 (Govender *et al.* 2000).

The combined recreational and commercial KZN boat-based linefishery contributes approximately R76 million to the Gross Geographic Product (GGP) of the province annually (Table 5.1). *Scomberomorus commerson* (22%), *C. puniceus* (13%) and *T. albacares* (12%) are the most important species economically, but *A. aequidens*, Serranidae and kobs (mostly *A. thorpei*) are also important, each contributing about 9% (R5 million) to the total value of the fishery. Considered alone, the Thukela Banks component of the commercial and recreational sectors contribute about 38% (R28 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. Indeed, to satisfy local demand, KZN imports fish from the other coastal provinces and from other southern African countries such as Mozambique, Tanzania and Angola (Jack Walsh, Spray Fishing personal communication). Of further 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.

5.4.2 Catch-flow relationships

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 for which such relationships have been detected (Griffiths 2000a, Demetriades *et al.* 2000) 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 (Griffiths & Lamberth 2002, Chapter 2). However, for at least 13 species, despite these sources of noise, there were significant relationships between flow and catch, some of which are likely to be 'real' in the sense of being cause-and-effect-relationships, whereas others are probably the result of catches responding to other environmental variables (e.g. water temperature, current directions), which follow similar seasonal patterns to rainfall and flow.

With the exception of santer *Cheimerius nufar* and queen mackerel *Scomberomorus plurilineatus*, species having a significant relationship with flow exhibited both short and long-term responses. The long-term responses or periods were as long as eight years and had much weaker cross-spectral densities. The most likely cause of this is that the cumulative impact of such variables as recruitment and mortality of different year-classes, and consequently the noise, is expected to be much greater over the long term.

The short-term responses of 11-12 months are likely to be primarily driven by a combination of nutrient and sediment input from the catchments leading to increased primary production and food availability, coupled with changes in 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 (Binet *et al.* 1995, Loneragan & Bunn 1999, Blaber 2000). Conversely, adverse weather conditions at the time of high flows could have reduced the efficiency of fishing in particular areas, causing the fleet to move elsewhere to catch different species. Changes in the behaviour of fishers could thus easily result in false positive or negative correlations, as catches of some species would appear to increase or decrease in response to flow, whereas in reality fisher behaviour is driving the change in catch.

The short-term patterns displayed by *C. puniceus*, javelin grunter *Pomadasys kaakan* and Serranidae with a lag of <1-2 months (Table 5.2) are likely to be an immediate response to an increase in turbidity, or the availability of prey items attracted to an increase in turbidity, which would together promote aggregations and/or catchability of these fish. The aggregations would persist with a consequent increase in food supply. In turn, the delay between nutrient input, increased productivity and eventual food/prey availability could explain the four-month lag between flow events and catches of *A. thorpei*, dusky kob *Argyrosomus japonicus* and *C. nasutus*. 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 (Buxton & Clarke 1989). *Cpue* of *S. commerson* and *C. nufar* responded 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 suggests that the lag could represent recruitment into the fishery after the previous years' wet season provided suitable conditions or cues for successful spawning and egg, larval and juvenile survival (Coetzee & Baird 1981, Govender 1992).

Longer-term responses to flow, with periods of 6-8 years, were evident for *P. kaakan*, *S. commerson*, *C. nasutus*, *G. feliceps, C. puniceus* and *A. thorpei*. For these species, it appears that the catches are fluctuating according to long-term wet and dry cycles, catches being higher following wet years. The age-at-first-capture (and 50% sexual maturity) of *C. nasutus* and *G. feliceps* ranges between 8 and 9 years, which hints that the life history of these two species may be adapted to optimise the benefits of wet cycles. In addition, *G. feliceps* is an estuarine-dependent, paternalistic mouth brooder that migrates into estuaries and turbid inshore waters during the mouth-brooding phase (Tilney 1990). Access to estuaries (especially temporarily open systems), and consequently breeding success, is likely to be greater during wet years. This said, longevity alone could be an adaptation to prolonged periods of negative stress punctuated by infrequent good years conducive to breeding success.

Analysis of flow and the *cpue* of Serranidae, *C. puniceus* and *A. thorpei* revealed periods that more or less corresponded with their age-at-first-capture into the fishery. The age-at-first-capture of 3.7 years for *A. thorpei* corresponds with a catch versus flow period of 3.5 years (Table 5.2). The age-at-first-capture of 2.5 years for the Serranidae (mostly *E. andersoni* and *E. rivulatus*) corresponds well with a period of 2.7 years, whereas that of *C. puniceus* (1-2 years) falls within the catch versus flow period of 1.5 years. Although the cross spectral densities for all three were weak, there appeared to be a long-term relationship between flow events and *cpue,* with wet years providing suitable conditions for spawning and survival and eventual later recruitment into the fishery. The weak cross-spectral densities are to be expected, given the cumulative impact of fishery effects and environmental factors other than flow on catches.

Overall, with the exception of *S. commerson*, the strongest relationships were for reef species that show a high degree of residency and are unlikely to move much in response to environmental changes. *A. thorpei* and *C. nufar*, although resident, are nomadic within the confines of the Thukela Banks. This may partially explain why only 28% of the variation in their catches could be attributed to flow. The same probably holds for the migratory *P. undulosus* and nomadic *A. feliceps* for which respectively only 35 and 32% of the variation in catch could be explained by flow (Garrat 1988, Tilney 1990).

5.4.3 Freshwater reserves and catches

The freshwater Reserve Determination for the Thukela catchment yielded nine possible future scenarios (DWAF 2004c). Apart from the status quo, six represented slight incremental increases (0.1%) whereas two, including the maximum development or "worst case" scenario would see a 16-44% reduction in present-day flow volume (Table 5.3). To predict changes in fish catches under these scenarios, all flows but those of the Thukela were kept constant. Not surprisingly, the predicted catches under the Reserve scenarios 1-7 did not differ much from the present day, varying from no change for *Porcostoma dentata* and *Scomberomorus commerson* to a maximum of 0.9% for *C. puniceus* (Table 5.3). *Chrysoblephus puniceus*, *Argyrosomus thorpei*, *Coryphaena hippurus*, serranid spp. and *Cheimerius nufar* responded positively, whereas *Cymatoceps nasutus*, *Galeichthys feliceps*, *Polyamblyodon germanum*, *Polysteganus undulosus* and *Epinephelus marginatus* responded negatively to an increase in Thukela flow volume. The decrease in catches of the latter species was unexpected but small and ultimately trivial. Catches of *S. commerson*, known to increase in response to good rainfall 11-12 months previously, showed no response to any of the future Thukela flow scenarios (Govender 1992, Table 5.3). This, coupled with the results from the spectral analysis illustrates that although *S. commerson* is strongly responsive to rainfall and terrestrial runoff within the tropical and subtropical biogeographical regions, this response does not necessarily extend to individual river systems.

Table 5.3 Predicted catch as a percentage of the present-day catch for the eight freshwater Reserve scenarios for the Thukela River catchment using General Linear Models. Scenarios 1-7 were combined due to their similarity and collectively represent a 0-1% increase in flow volumes. Flows used were the average monthly volumes (m³) from each system. Flows for all systems other than the Thukela were kept constant for each scenario.

	Percentage present day catch		
Scenarios	1-7	8	Worst case
% Present-day Thukela flow volume	100.97	83.5	56.2
Chrysoblephus puniceus	100.90	86.30	63.64
Argyrosomus thorpei	100.68	89.60	72.39
Coryphaena hippurus	100.46	93.08	81.64
Serranidae spp. (50/50 *Epinephelus andersoni* & *E. rivulatus*	100.06	99.12	97.68
Cheimerius nufar	100.06	99.14	97.72
Porcostoma dentata	100.00	99.98	99.94
Scomberomorus commerson	100.00	100.00	100.00
Cymatoceps nasutus	99.96	100.64	101.69
Galeichthys feliceps	99.93	101.05	102.78
Polyamblyodon germanum	99.93	101.10	102.91
Polysteganus undulosus	99.89	101.64	104.34
Epinephelus marginatus	99.89	101.72	104.55

In all, this species is illustrative of how some predicted catches under the different Reserve scenarios using GLMs, appear counterintuitive to the patterns identified through the spectral analysis.

Three species, *Chrysoblephus puniceus* (14%), *Argyrosomus thorpei* (11%) and *Coryphaena. hippurus* (7%) are likely to experience a substantial decline in catch under scenario 8 (Table 5.3). *Chrysoblephus puniceus* and *A. thorpei* are the two most-important species in the fishery, and provided 50% of the landed mass of the Thukela Banks commercial linefishery. Under scenario 8, the decline in catches of these two species would result in a 20 t (7%) drop in the total annual catch from the Banks. The decline in catch of *C. hippurus* is unlikely to have much impact on the fishery as it currently provides <1% of the landed mass. However, similar to *S. commerson*, reductions in rainfall and flow may impact on its regional abundance because elsewhere in the world it is known to undertake pre-spawning migrations to higher latitudes during spring and summer to spawn inshore, and eggs, larvae and juveniles have been found on the Thukela Banks (Oxenford and Hunte 1987, Connell 2007). The underlying cause of the relationship between flow and the catch of this species is unknown but could encompass spawning cues, flotsam under which juveniles shelter and production and food availability (Oxenford and Hunte 1986). Overall, the response of *C. hippurus* is more likely to be cued by regional rainfall throughout its eastern Africa distribution rather than indirectly through flow from the Thukela or other catchments in KZN.

Under the "worst-case" scenario, catches of *C. puniceus, A. thorpei* and *C. hippurus* are forecast to decline by 36, 28 and 18% respectively (Table 5.3). This equates to a 50 t (17%) reduction in the total landed catch of the commercial linefishery from the Thukela Banks (Table 5.1). Similar to scenario 8, reductions in flow may alter the distribution and abundance of *C. hippurus*, but these changes are unlikely to have much impact on the viability of the commercial linefishery. Catches of the Serranidae and *C. nufar* will undergo a 2% decline. On the other hand, predicted catches of *C. nasutus*, *G. feliceps*, *P. germanum, P. undulosus* and *E. marginatus* will be 1-5% greater than present day. These are all likely to be an artefact of an immediate drop in *cpue* usually experienced at the time of high flows (0 lag) when rain and sea conditions make fishing difficult. Consequently, a modelled 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 Banks commercial linefishery. This would be largely due to the two main target species of the fishery, *C. puniceus* and *A. thorpei*, exhibiting the strongest negative responses to a decline in river flow. Increased catches of those species responding positively to a reduction in flow are trivial, probably within normal variability and unlikely to compensate for those lost. Most of the species that may increase either occur naturally in low abundance, and/or have already been fished down to such an extent that attainment of sufficient increases in *cpue* to offset losses is highly unlikely.

5.4.4 Responses of individual species

Consideration of three species constituting the bulk of the catch and for which more detailed information exists casts light on the likely mechanisms in operation.

5.4.4.1 King mackerel *Scomberomorus commerson*

Scomberomorus commerson is a widespread Indo-Pacific species with a southern African stock extending from Mozambique into KwaZulu-Natal waters through to Mossel Bay on the south coast of South Africa (Govender 1992,1995, Heemstra & Heemstra 2004). 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 < 2 years of age (Govender 1992,1995). It is the most important species in the KZN recreational boat fishery where it provides 33% of the catch, although it makes up only 3% of the commercial linefish catch (Table 5.1). However, the Thukela Banks commercial linefishery constitutes 56% of the national catch of this species.

Scomberomorus commerson appear to respond to flow with a lag of 10.4 months and to follow the wet and dry cycles with a period of 6-8 years (Table 5.2, Fig. 5.2). Using GLMs, the correlation between monthly flows and catch was significant although only 42% of the variation in catch was explained by flow. The predicted absence of any change in catch with reduced flows of the Thukela (Table 5.3) was at firsthand counterintuitive, given the negative response expected from the spectral analysis and from what could be inferred from Figure 5.2. However, considering that this species had a significant relationship with the combined flows from all catchments and not that of the Thukela alone, then the absence of any response to flow reductions in the Thukela specifically becomes understandable.

The apparent 10.4 month response of *S. commerson* to higher flows as well as the correlation of catches with the Thukela and other systems in KZN are likely to be artefacts reflecting responses of this species to conditions in Mozambique rather than in KZN. High rainfalls and the input of freshwater into the marine environment off Mozambique where *S. commerson* breeds will provide good conditions for spawning and larval survival there (Nzioka 1991). This is likely to result in good catches when this fast-growing fish recruits into the fishery in KZN one year later (Govender 1992). Ultimately, good catches in KZN will rely on flows in Mozambique, not KZN, and the correlation between flows and catch in KZN is likely to be a by-product of the two regions falling within the same biogeographical zone and experiencing a similar rainfall pattern. This would also explain the low r^2 value obtained for this species.

In the medium-term, within a particular season, any enhanced production associated with higher flows in KZN could influence catches as *S. commerson* migrates south and moves onto the Thukela Banks in response to increased prey availability. In the short-term (0 lag), the weather and fishing conditions associated with higher flows could see a decline in *cpue*. This may be an additional reason why the predicted response of *S. commerson* to flow reduction was relatively weak even when all the catchments were considered. 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.

5.4.4.2 Squaretail kob *Argyrosomus thorpei*

Argyrosomus thorpei is endemic to southern Africa with a range extending from Mozambique to Algoa Bay in the southeastern Cape of South Africa (Heemstra & Heemstra 2004). It is fairly resident in particular areas with the adults associated with rocky reefs and the juveniles with soft sediments in water < 50 m deep (Fennessy 1994). Age-at-first-capture is 3.7 years (Van der Elst *et al.* 1990). The bulk of the national catch (99%) is landed in KZN, where *Argyrosomus thorpei* provides 4 and 7% of the recreational and commercial linefish catches respectively (Table 5.1). On the Thukela Banks it is the second most important species and provides 15% of the commercial catch. It also comprises a significant proportion of the bycatch in the prawn trawl fishery (Fennessy 1994). Historically, *A. thorpei* 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).

Argyrosomus thorpei responded to flow with a lag of 4.2 months, and *cpue* followed the wet and dry cycles with a period of 6-8 years (Table 5.2, Fig 5.3). Catches also exhibited a response to flow with a period of 3.5 years that corresponds to the age-at-first-capture of 3.7 years (Van der Elst *et al.* 1990). Using GLMs, the response to flow was significant but weak with only 28% of the variation in catch being explained by flow.

In the short-term (0 lag), the negative response of *A. thorpei cpue* to higher flows was probably due to deteriorating fishing conditions at the time and/or due to fisher behaviour with the fleet fishing elsewhere for more lucrative catches. A positive short-term response to increased flow occurred at a 4-month lag and may be due to nutrient input, production and an increase in prey availability. It may also partially be due to fishers targeting this species where there is a known increase in availability or catchability.

Spawning of *A. thorpei* occurs from June-September on the Thukela Banks (Van der Elst *et al.* 1990, Denton & Van der Elst 1987). 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 the time 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 the collapse of the stock that has occurred over the last 10 years or more (Fennessy 1994).

Overall, despite the noise, flow from the Thukela River and other KZN catchments, especially the Mfolozi and St Lucia appears to have a significant impact on the catch of *A. thorpei* with a reduction in catch of 28% predicted under the worst-case scenario.

5.4.4.3 Slinger *Chrysoblephus puniceus*

Chrysoblephus puniceus is a protogynous hermaphroditic reef-dwelling sparid endemic to the eastern coast of Africa from southern Mozambique to KZN and northern Transkei (Garratt 1985). Adult *C. puniceus* > 4 years old are fairly sedentary whereas younger fish may migrate northwards from KZN to Mozambique (Punt *et al.* 1993, Buxton 1992). Juveniles and adults are abundant on reefs from the 12-100m depth contours (Garratt 1984). Age at first capture is between 1-2 years, corresponding to the age attained at its minimum size of 250 mm, whereas age at 50% maturity is 3 years (Garratt *et al.* 1993). *Chrysoblephus puniceus* is the most important species in the KZN commercial linefishery with nearly half of the catch being taken to the north of Durban on the Thukela Banks (Table 5.1). However, reductions in mean size, skewed sex ratios and a spawner-biomass-per-recruit ratio of 14-16% of pristine are indicative of a collapsed stock (Punt *et al.* 1993, Garratt *et al* 1993).

Chrysoblephus puniceus cpue exhibited longer-term cycles of 1.5 and 6-8 years corresponding to age-at-first capture and wet and drought cycles respectively (Garratt *et al.* 1993, Table 5.2, Fig. 5.4). Similar to *A. thorpei*, the cross-spectral densities were high and the relationships significant, with flow explaining 34% of the variation in catch. In contrast to most other linefish species, the minimum size and consequently age-at-first-capture of *C. puniceus* is set at approximately half the age at 50% maturity. The fact that the flow response of *C. puniceus* corresponds to the "artificially set" 1.5 year age-at-first-capture and not the 3.5 year age at 50% maturity strengthens the argument that the relationship with flow (or related environmental variables) is real and not an artefact of the species' life-history characteristics.

In the short-term, the response of *C. puniceus* to flow was positive and instantaneous with zero-lag (Table 5.2, Fig 5.4). This may be a result of a change in fleet behaviour with weather conditions causing fishers to move elsewhere. However, there is no evidence, anecdotal or otherwise, to substantiate this line of argument. In all, catches were strongly seasonal and patterns markedly similar to those of flow (Fig. 5.4).

5.5 Conclusions

This study is correlative and as such can be used to infer cause-and-effect but not test it. Indeed, it is difficult to conceive a definitive test of cause-and-effect given the nature of the system. Moreover, catches are potentially influenced by at least four things - a causal effect of local river flow on fish abundance, the behaviour of fish, conditions outside the region (particularly in Mozambique), and the behaviour of fishers. Nevertheless, strong patterns emerged from the analysis, including some striking correlations between age-at-first-capture and the long-term periods between flow and catch (Fig 5.6).

Emerging from this study, the responses of linefish catches to changes in freshwater flow entering the sea in the vicinity of the Thukela Banks fell into four broad categories:

(a) Apparent negative responses to reduced flow, that are most likely due to rainfall patterns throughout the subtropical and tropical biogeographical regions rather than local flow rates. This is exemplified by *S. commerson*, which responds to flow but is reliant on flow volumes entering the sea in its spawning grounds off Mozambique and Tanzania to the north.

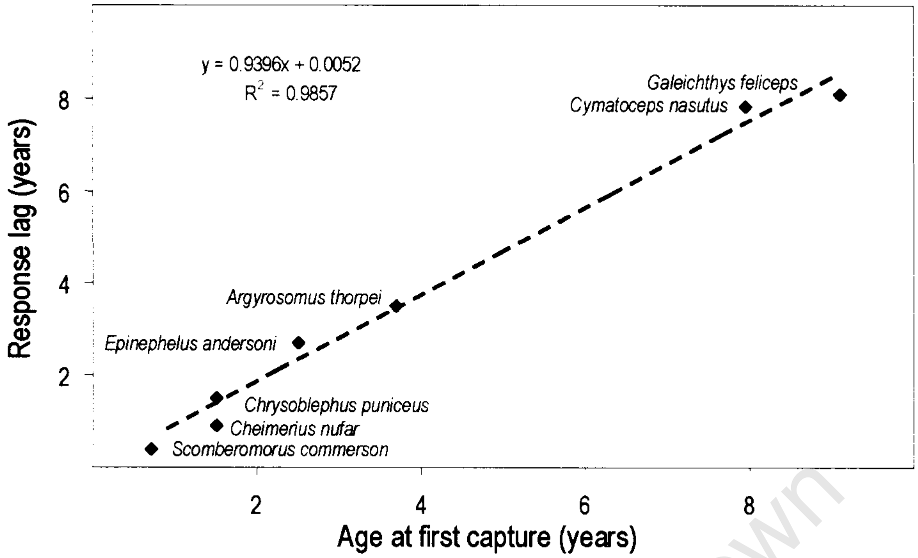


Figure 5.6 Age-at-first-capture versus fish response time to freshwater flow for species that displayed significant relationships between flow and catch. (In most cases, due to minimum sizes being set at the age and size at 50% maturity, age-at-first-capture corresponds to that at 50% maturity.)

The responses of this species to flow from the Thukela and other catchments in KwaZulu-Natal range from non-existent to weak.

(b) Negative responses to local reduced flows that are real. For example, reduced flow from KwaZulu-Natal catchments will result in reduced catches of both *Argyrosomus thorpei* and *Chrysoblephus puniceus*. Responses of these species to the Thukela River flow were strong, reflecting the fact that it is the largest catchment, providing more than 40% of the runoff into the sea.

(c) Cases of zero or negligible response, either positive or negative, to changes in flow. Examples are *Porcostoma dentata* and *Pomadasys kaakan*, which exhibited no response to changes in flow in KwaZulu-Natal or in the entire subtropical region. However, the lack of response may be an artefact of the fact that catches are low and reporting correspondingly poor. The trend throughout this analysis has been that frequently-caught species providing the bulk of the catch are by default those providing the better data and exhibiting significant relationships with flow.

(d) Situations where flow reduction has a positive effect on catches, e.g. seventy-four *Polysteganus undulosus* and yellowbelly rockcod *Epinephelus marginatus*. Correlations like these are likely to be less due to ecological drivers than to various aspects of fleet behaviour. This is especially true with regards to *P. undulosus*, for which stock collapse led to a moratorium on catches in 1998. The cessation of the targeting and reported catches of this species roughly coincided with a wet period, leading to an artificial negative relationship between flow and catch. In turn, both *P. undulosus* and *E. marginatus*, although relatively strongly correlated with overall flow, exhibited no response, lagged or otherwise, using spectral analysis. In any case, even if the ecological effects are real, the increases are relatively small and will not offset the losses of other species.

In short, the responses of many of the linefish species to changes in flow are real and significant, albeit for different reasons. The responses to local reductions in freshwater flow are predominantly negative and associated with predicted declines in catches. Positive responses to flow reduction are limited to a few species, are negligible in magnitude and are unlikely to compensate for losses of other species. In South Africa, remedial measures aimed at rebuilding linefish stocks are almost exclusively confined to changing fisher behaviour and limiting fishing effort. If the stocks of many are to be successfully rebuilt, management plans will have to deviate from the traditional path by incorporating environmental variables, including freshwater flow. Specifically, the influence of the Thukela and other KZN catchments must be taken into consideration.

These findings have much greater generality than the particular systems I investigated. First, they expand current ideas about the ways in which river flows influence marine fish. The relationship between river flow and estuarine-dependent fish is well established (Gillanders & Kingsford 2002), but this work strongly indicates that some commercially important open-sea species that are not estuarine-dependent are also influenced by flow rates. Secondly, this in turn requires a rethink about the application of national laws. Much thought has gone into the Ecological Reserve required for rivers and estuaries, but these findings demand that the needs of open-sea marine systems also be incorporated.

OVERVIEW AND SYNTHESIS

OVERVIEW AND SYNTHESIS

Priority species

Studies that categorise species according to their conservation status often fall short in their implementation by not accounting for the impacts on, or the response of, people who benefit from, or exploit, the resource under consideration. This is especially true in multispecies fisheries where personnel and funding limitations often create a dilemma over which species should be the first to receive management and research attention. In Chapter 1 I used Multi-Criteria Decision Analysis to prioritize 176 South African linefish species on the basis of a number of criteria indicating conservation and socio-economic importance. Conservation criteria were abundance trend, level of knowledge, vulnerability, range and relative level of exploitation throughout that range. Sectoral criteria were total catch, degree of targeting, number of participants and the economic value of each species. The scores given to each species on the basis of each of these criteria were summed to examine each fish's importance from three points of view: (1) conservation, (2) each fishery sector separately and combined and (3) the overall combined conservation and sectorial importance. Different weight sets were used in the weighted summation of the scores, and results examined for sensitivity. The results were reasonably insensitive to changes in weights. Relative scores within each of the fishery sectors were dominated by two or three species. Consequently, the scores separating the remaining species from each other were small. This meant that in many cases even when the rank of species changed by a number of places with a different weight set, the differences in score were slight. On the whole, the top-ranked fish included the most important species in each sector, in each biogeographical region and in terms of conservation. The separate and overall rankings should assist the development of broadly acceptable management strategies for different fish.

The relative scores within each of the fishery sectors were dominated by two or three species with the scores separating the remaining species being small. The top-ranked species in the recreational shore fishery was the elf *Pomatomus saltatrix*. This is not surprising considering that it provides >50% of the catch and is considered overexploited at 34% of pristine spawner biomass (Govender 1997). With the exception of snoek *Thyrsites atun* and strepie *Sarpa salpa*, the stocks of all fish in the overall top thirty were either overexploited or collapsed. This increases confidence in the prioritisation exercise and the appropriateness of the conservation criteria. It also supports the almost obvious conclusion that the most sought-after species are also those in the most perilous state and that any inherent resilience in any of their populations has already been negated by extreme fishing pressure. Musick (1999) has criticised the IUCN approach to selecting species for conservation on the grounds that (1) standardised quantitative risk criteria are too inflexible in predicting extinction risk across all phyla, and (2) the criteria do not account for the vast array of life-history parameters and other ecological features that contribute to the vulnerability of different taxa. Applying the IUCN criteria to exploited fish species is even more suspect as stock thresholds regarded by fisheries managers as optimum are classed as indicators of high extinction risk by these criteria. The MCDA approach of Chapter 1 used similar criteria to those of the American Fisheries Society (Musick 1999) and included rarity, endemicity, limited range and population decline, and yields a more valid and workable categorisation of species.

The merits of the MCDA approach to assessing exploited South African fish species are illustrated by the appearance of the small-bodied strepie *Sarpa salpa*, spotted grunter *Pomadasys olivaceum* and harder *Liza richardsonii* within the top 30 of the recreational list, associated with a substantial and growing subsistence component within this sector. Until recently, although subsistence fisheries have been given attention from a socio-political perspective, the perception has been that these fisheries had little impact on the low value fish resources that they targeted. The prioritisation exercise has shown that subsistence fishing activities along the South African coastline are important from a socio-economic perspective as well as for their impacts on resources, and that the species targeted warrant top priority in terms of research, conservation and management. However, from a research and management perspective, it would be prudent to merge the subsistence component with the recreational or commercial fisheries, as the species targeted by the three groups are similar. To formally recognise a distinct subsistence component appears to perpetuate the economic inefficiency and inherent poverty associated with these fisheries.

What has been demonstrated is that most species with a high priority from a conservation point of view, such as white steenbras *Lithognathus lithognathus*, dusky kob *Argyrosomus japonicus*, slinger *Chrysoblephus puniceus* and white stumpnose *Rhabdosargus globiceps*, are also important from a sector perspective. These species need the most urgent stock assessments and management plans. However, despite their precarious state, fishing on these species cannot be barred because of socio-economic and political ramifications. Also evident, is that in addition to standard stock assessments, ecologically linked life-history characteristics such as habitat requirements and estuarine-dependence also need to be considered when devising management plans for individual species.

Distinct-population-segments (DPSs) may be used to describe any recognizably isolated population segment, stock or yearclass. Although Chapter 2 highlights the difficulty of assessing distinct-population-segments (DPSs) in developing countries where few have been identified, estuarine fish assemblages are an exception and comprise many known DPSs, albeit mostly of unexploited species. For the exploited fish species, identifiable DPSs are mostly confined to those that have an obligatory estuarine-dependent juvenile phase in their lifecycle. These DPSs apply to the juvenile components across all estuaries not to individual systems, as lack of knowledge makes it difficult to define those within any particular estuary. In South Africa, the few exploited estuarine fish species for which DPSs can be broadly defined (e.g. the juvenile components of the obligate estuarine dependent *Argyrosomus japonicus* and *Lithognathus lithognathus*), are listed within the top ten in terms of conservation and sector importance. At the scale of biogeographical region, DPSs (i.e. stocks) have been identified and managed accordingly for some of the high priority species. Two of these, dusky kob *Argyrosomus japonicus* and silver kob *A. inodorus*, have different bag and size limits in different bioregions and between estuaries and the sea (Anon 2005).

Priorities change. Historical catch and effort strongly influence the current priority status of most of the exploited fish species listed. Overexploitation increases their conservation status but diminishes their sectoral importance once catches fall below a viable level. For example, obligate estuarine-dependent species are a small proportion (6-7%) of the catches of the recreational shore and commercial beach-seine and gillnet fisheries as well as the commercial and recreational boat fisheries. Historically, prior to the collapse of stocks such as *A. japonicus* and *L. lithognathus* the importance of these species to the inshore fisheries was much greater. Nowadays, the more versatile and adaptable partially estuarine-dependent species comprise the bulk of the shore-based and estuarine catches, and the commercial and recreational boat fisheries have almost lost the obligate estuarine-dependent and reef-fish components of their catches, which are now dominated by nomadic shoaling species such as snoek *Thyrsites atun* and yellowtail *Seriola lalandi*. Consequently, the relative importance of the different species groups has changed and the similarities between catches of the shore-based and boat fisheries are much less than they were historically. However, the conservation priorities of most of these species are now greater. This said, the shore-based recreational angling and commercial beach-seine and gillnet fisheries are enhanced or sustained by the estuarine contribution of partially estuarine-dependent species such as harders *Liza richardsonii* and elf *Pomatomus saltatrix* to their catches.

Estuarine production and value

Of the top 30 most important species across all inshore commercial and recreational fishery sectors, half have some degree of estuarine association. From a biogeographical aspect 7 of the 30 priority exploited fish species on the cool temperate west coast have some degree of estuarine-dependence, and in the warm temperate south and east coasts and subtropical KwaZulu-Natal (KZN), 12 of the top 30 species are estuarine-dependent (Chapter 1). In KZN the top six species are estuarine-dependent. From a diversity perspective the importance of estuarine-dependent species and, consequently, estuaries to nearshore fisheries increases as one moves eastwards, whereas from a productivity perspective their importance increases westwards from the largely oligotrophic waters of KZN to the upwelling-fed nutrient-rich waters of the west coast (Chapter 2). Approximately 160 species of fish occur in South African estuaries, of which about 80 are exploited. Similar to the nearshore fisheries, catches of estuarine-associated fish reflect the increase in diversity as one moves eastwards from the cool temperate west coast (19 species) to the subtropical and tropical biogeographical regions in KZN (71 species).

There are 255 functional estuaries along the South African coastline. Existing catch data for 129 of these were reviewed and the relationships between fish catch and estuarine size, type and biogeographical region analysed using simple and multivariate models. The best predictive models were obtained by analysing data separately for each biogeographical region. Estuary size alone explained over 80% of the variation in catch in the warm temperate region and over 90% of the variation in catch in the cool temperate and subtropical regions. Further analysis of the two main estuarine types, i.e. permanently open and temporarily open/closed estuaries, revealed a steeper regression slope of catch versus estuarine size and therefore higher productivity for the permanently open systems. Both estuarine size (ha) and type (5 types) were used to explain catches within the warm temperate and subtropical regions using general linear models. The models were able to explain 82 % and 98 % of the variance in catches for the two regions respectively and both were significant ($p<0.001$).

This said, the relationships used by the analysis were linear, when in reality they are unlikely to be so. To support this, fishery production in subtropical KZN was estimated at 16 $kg.ha^{-1}.yr^{-1}$ if Lake St Lucia was included but jumped to 58 $kg.ha^{-1}.yr^{-1}$ if it was excluded. The reason for this is that St Lucia, with a size of approximately 40 000 ha, is by far the largest estuarine system in South Africa with most others being small (<150 ha) or medium (<500 ha) in size. Consequently, there are no intermediate estuaries between 5 000 ha and 40 000 ha to complete the curve. At the lower end of the curve, the relationship between estuarine size and production is close to linear but is likely to flatten out once some critical estuarine size is reached and available fish or fishing effort become diluted. This assumption can only be tested by expanding the study eastwards and westwards into other African countries where estuaries of intermediate size exist.

The models were applied to estuarine type and size data for all 246 estuaries in the warm temperate and subtropical regions and a total catch of 1 840 tons per annum was estimated. Including the cool temperate region, the total estuarine catch in South Africa was estimated at 2 480 tons per annum. Fifty percent of the estuarine catch was attributed to the commercial seine and gillnet fisheries, 46 % to recreational angling and 4 % to the traditional trap and spear fisheries. Total catch value was R433 million per year of which 99 % could be attributed to recreational angling. Estuarine contribution to the inshore marine fisheries was estimated at approximately R490 million per year with estuarine-dependent species comprising 83% of the catch of the recreational shore and commercial seine and gillnet fisheries and only 7% of the catch of the recreational spearfishery and commercial and recreational boat fisheries. Total value of estuarine and estuary-dependent fisheries was estimated to be R1.127 billion per annum (R1.594 billion in 2008 rands).

The total estuarine catch in South Africa is fairly evenly split between recreational and commercial with only a small contribution by the traditional fisheries. However, 99% of the catch value can be attributed to the recreational component, which suggests that it would make good management sense to remove commercial fisheries from estuaries in South Africa, thereby halving the catch but only losing 1% of the value. This management measure would also provide a better guarantee of recruitment success to the commercial fishers in the sea (Hutchings & Lamberth 2003, Hutchings *et al.* 2008). In turn, on a national scale, there is no valid reason to reduce numbers of traditional fishers, but rather to maintain the status quo and to secure the livelihoods of existing fishers by protecting them from new participants. Further, reduced estuarine catches are needed to secure the estuarine contribution to the shore-based and nearshore marine fisheries. Compliance with existing legislation would go a long way to achieving this if the estuarine environment, especially its freshwater requirements, were also protected. The most sound overall policy would be to conserve estuaries as nursery and source areas for marine fisheries as this would be the most efficient option in terms of maximising resource productivity, economic benefits and biodiversity conservation.

Contrasting cool temperate and warm temperate estuaries

The spatial and temporal distribution of exploited fish species within estuaries is confounded by their being fished down or by their naturally low numbers. Overall, species that are partially estuarine-dependent are likely to benefit most from estuaries as they can move back and forth, capitalising on good conditions in estuaries and the sea. Conditions are always likely to be better in one than the other. These species are also those more likely to escape adverse conditions in estuaries or the sea, as unlike estuarine breeders and obligatory estuarine-dependent fish they are not compelled to spend all or part of their lifecycle in estuaries.

In general, partially estuarine-dependent species (category IIb & IIc marine opportunists) comprise a fairly constant proportion of estuarine fish assemblages throughout South Africa whereas the proportion of entirely estuarine-dependent species (Ia, IIa & Va) is highest on the south coast, fairly high on the west coast and low in KZN. This parallels the southward increase in endemism of marine and estuarine species (Turpie *et al.* 1999). The southward increase in endemism amongst estuarine species is likely a combination of the relative isolation due to estuarine-dependency lending itself to speciation and endemism, and the fact that there is a greater diversity of estuarine-independent marine and freshwater species in sub-Saharan estuaries as one moves northwards (Whitfield 2005b). The fact that the west coast of South Africa has few estuaries is likely to result in even further isolation of estuarine-dependent species there. The high level of endemism in the Olifants and Breede specifically, may also be due to the relatively close proximity of these two estuaries to the warm/cool temperate transition zone (Chapter 3).

Estuarine-independent marine species comprise a high proportion of the Breede and Olifants fish assemblages and those of most other permanently open estuaries (*ca* 30-40%), most likely an artefact of their permanently open nature and the strong marine influence at their mouths. However, on the west coast some marine species (e.g. *Argyrosomus inodorus*), which are estuarine-independent and seldom if ever enter estuaries on the south and east coast, may have some degree of estuarine-dependence there. This is most likely the result of estuaries providing warm-water refugia, which are limited on the west coast. In turn, the fact that there are few available estuaries on the arid west coast may lead to either an increase or decrease in estuarine–dependency within a species. An increase in the degree of estuarine dependence would be driven by the requirement for some limited variable such as warm water accompanied by selection for the ability to find it by homing in on estuarine cues. Alternatively, the lack of estuaries could lead to a decrease in the degree of estuarine-dependency due to the constraints it puts on the life-histories of some species. An example of this is the Knysna sandgoby *Psammogobius knysnaensis* which is almost, if not entirely, an estuarine breeder on the east coast, but a partially estuarine-dependent fish on the south and west coasts. On the west coast, the scarcity of estuaries means that the bulk of its population exists in the surf-zone.

One of the remarkable features arising from the comparison of the Breede and Olifants estuaries is their similarity in terms of estuarine functioning, fish assemblages and responses to changes in freshwater flow. Differences in their fish assemblages are confined to the absence of catadromous eels in the Olifants and other west coast estuaries and a greater diversity of estuarine-independent fish in the Breede and other estuaries on the warm temperate south coast. However, the Olifants comprises 30% of the available estuarine habitat on the cool temperate west coast, being one of only three predominantly open estuaries there and supports a fisheries production output of approximately 109 $kg.ha^{-1}.yr^{-1}$, as opposed to the Breede which comprises 4% of the estuarine area on the warm temperate south coast and is one of 20 permanently open estuaries there, and has a fisheries production of 47 $kg.ha^{-1}.yr^{-1}$. This supports the observation that the loss of the Olifants would have a much greater impact on fish production and diversity than the loss of similar sized estuaries such as the Breede in the warm and subtropical biogeographical regions.

Overall, the differences between the Olifants and Breede and their respective fish assemblages are probably currently a lot less than they were historically, as reduced freshwater flows have dampened variability and the seasonal signal in the Olifants and its fish assemblage, whereas the Breede has always had a much higher flow variability and weak seasonal response in its fish assemblage due to its catchment falling within the winter/bimodal rainfall transition zone. In turn, because the Breede falls within this transition zone, responses of the fish assemblage to flow reduction will depend on where in the catchment flow is removed. Flow removed from the part of the catchment receiving bimodal rainfall is likely to reduce flow variability within the estuary thereby inducing a clearer seasonal response in the fish assemblage whereas flow reduced from the winter rainfall zone is likely to weaken the seasonal signal of the assemblage even further.

Estuaries may help maintain the stock integrity of important exploited fish, especially on the west coast of South Africa where loss of the Olifants or the Berg and Orange estuaries could result in stock separation or range reduction of estuarine-dependent species. This is not confined to obligate estuarine-dependent species, as there is evidence showing the dramatic recovery of the populations of the partially estuarine–dependent *Liza richardsonii* and *Pomatomus saltatrix* following the closure of the gillnet fishery in the Berg River Estuary (Hutchings *et al.* 2008). There is also the untested hypothesis that west coast estuaries provide warm-water refugia from stresses associated with upwelling (such as periodic hypoxia), thereby facilitating the (mono-directional) southward dispersal and maintaining links between the stocks of important linefish species such as *Argyrosomus inodorus*, *Lithognathus aureti* and *Pomatomus saltatrix* that are shared with countries to the north. Similarly, there appears to have been a southward movement of some estuarine-dependent species on the east coast (e.g. *Pomadasys commersonii*) over the last 30 years or more (Lamberth unpublished data) and the Breede and similar estuaries may provide sheltered warm-water refugia during upwelling and storm events on that coast. However, unlike the west coast, there is substantial suitable warm-water surf-zone habitat on the south and east coasts.

Reduced freshwater flows in the cool temperate Olifants Estuary are likely to see a reduction in abundance of species that breed only in estuaries, those that are entirely estuarine-dependent, and freshwater species. With the addition of fishing effects, numbers may decline to such an extent that some of these species may completely disappear from the Olifants Estuary. In the absence of fishing, partially estuarine dependent and marine species would have increased from the historical reference situation to the present day with the encroachment of higher salinity further upstream and expansion of available habitat. However, they will decrease in abundance under future developments in the catchment which are accompanied by shrinking of the warm water plume entering the sea, narrowing of the stream channel and an overall reduction in available habitat. Overall, in the absence of fishing, the fish community has experienced a gradual change from a high-biomass, low-diversity, freshwater-rich system under reference conditions, to a high-biomass, medium-diversity, marine-dominated system under the present day. Overall abundance has decreased by 20% from reference to present day and thereafter will gradually decline to 55% of reference with the predicted future 60% reduction in mean annual runoff (MAR). Consequently, future reductions in flow are likely to see the Olifants Estuary progressing towards a low-biomass, low-diversity, marine-dominated system.

In contrast, reduced freshwater flows in the Breede Estuary are likely to see an overall reduction in the abundance of species that breed only in estuaries, and in freshwater and catadromous species. Collectively, entirely estuarine-dependent fish should increase in abundance, but considered individually, some important exploited species such as *Argyrosomus japonicus* and *Pomadasys commersonnii* will collapse to 50% of historical numbers once there has been a 64% reduction in MAR. Partially estuarine-dependent and marine species are likely to increase with the encroachment of higher salinity water further upstream and the expansion of available habitat. Overall, present-day fish abundance in the estuary has increased by 6% from the reference situation and is likely to increase to 115% of reference with future reductions in flow. There are likely to be some species with a preference for fresh and brackish water lost from the system but overall diversity is equally likely to increase with the range expansion of warm temperate and subtropical marine species westward. In all, the fish assemblage will experience a gradual change from a relatively high-diversity low-abundance freshwater-rich system under historical flow conditions to a high-diversity, high-abundance, marine-dominated system with future reductions in flow.

Estuarine refugia

Estuaries provide refugia from a plethora of adverse conditions in the marine environment. Fish can find refuge in estuaries provided that they are open to the sea. Chapter 4 provides clear evidence that marine fish found refuge in the Berg River Estuary during a lethal low-oxygen event in the sea. However, this escape was limited to those species that are classed as being "estuarine-dependent". By inference, estuarine-dependence includes the ability or pre-adaptation to locate and secure refuge in estuaries. This is borne out by the observation that no estuarine-independent species seen dead on the adjacent shoreline managed to find refuge in the Berg River Estuary during the low-oxygen event, despite being in close proximity to the mouth. Movement of estuarine-dependent species into the estuary was likely to have been along olfactory and/or oxygen gradients as other potential cues such as gradients in temperature, salinity and turbidity were either reversed or severely weakened during the event.

Fish densities doubled in the Berg River Estuary during the low-oxygen event due to fish escaping into the estuary from the sea, coupled with their being herded together by tidal intrusion of low-oxygen water into the lower reaches of the estuary. In turn, there was an overall upstream shift in the distribution of fish in the estuary during the event. Most species returned to their original distribution after the event, although a few did not. Based on species composition and abundance, the fish assemblages of the

Berg River Estuary can in normal years be broadly grouped into those of the lower, middle and upper reaches. The escape of fish into the estuary and the movement of many upstream during the low-oxygen event resulted in this pattern being temporarily disrupted. Larger individuals of the most abundant species in the system, *Liza richardsonii,* being stronger swimmers, were able to escape further upstream, whereas small fish remained concentrated in the lower reaches and would have been more susceptible to mortalities with the intrusion of low-oxygen water on each floodtide.

Nearshore fish assemblages on the west coast have ample refugia from predation and competition in the surf-zone. However, refuge from large-scale environmental perturbations in the marine environment such as hypoxia, thermal stress and harmful algal blooms is limited to only three estuaries and a few small shallow bays. When conditions become lethal, the Berg, as well as the other two predominantly open estuaries on the arid west coast of South Africa, the Olifants and Orange, are likely to be crucial in the recovery of the fish assemblages and fisheries of their adjacent shorelines.

Freshwater flows and estuarine-independent marine fisheries

The influences of rainfall and freshwater flow are not restricted to estuaries, their catchments and the terrestrial environment nor are they restricted to estuarine-associated fish species. In Chapter 5 I explore the consequences of seasonal and interannual differences in riverine flow rate for entirely marine species. The commercial and recreational boat-based marine linefishery is the largest fishery in KwaZulu-Natal on the east coast of South Africa, accounting for 1 200t (40%) of the total landed mass there. The Thukela Banks is the most important fishing area stretching approximately 150 km along the coastline and 50 km at its widest point to the edge of the continental shelf. Numerous developments ranging from dams to interbasin transfer schemes either exist or have been proposed for the Thukela River, which is the largest of 17 catchments entering the sea in the region and provides over 40% of the mean annual runoff.

Exploratory analyses of the relationships between monthly flows and catch-per-unit-effort (cpue) were performed using spectral analysis and general linear models on a data set comprising 17 years of monthly commercial catch and effort data for 140 species and monthly flow data from 17 catchments. Catchments having a significant influence on catches were those providing the bulk (75%) of the runoff volume reaching the sea. Significant relationships ($p<0.05$) existed between flow and the catches of 14 species, which provided over 90% of the total linefish catch on the Thukela Bank. Time lags between flow events (wet and drought periods) and changes in catch-per unit effort corresponded in many cases to age at 50% maturity and/or first capture of the species concerned. Under a future maximum-development scenario, corresponding to a 44% reduction in flow from the Thukela River, catches of slinger *Chrysoblephus puniceus* and squaretail kob *Argyrosomus thorpei* were forecast to decline by

36% and 28% respectively. These two species currently provide over 50% of the landed mass on the Thukela Banks. Some species will respond positively to a reduction in flow, but increases in their catches will be negligible, falling within natural variability, and unlikely to compensate for losses incurred by species that respond negatively. Most of the species that will benefit either occur naturally in low abundances and/or have already been fished down to such an extent that sufficient increase in cpue to offset losses of other species is unlikely to occur.

Response of fish and fisheries to climate change

There are a plethora of potential impacts of global climate change on estuaries and the nearshore. (Midgley *et al.* 2005, Clark 2006). Changes in precipitation and runoff are likely to result in the modification of seawater intrusion into estuaries, changes in the frequency and duration of mouth closure, altered nutrient inputs, decreases in the dilution and/or flushing of pollutants and changes in the magnitude and frequency of floods and sediment deposition/erosion cycles. Estuaries and the nearshore will also be impacted by rising temperatures, sea level rise, changes in ocean circulation patterns and an increase in the frequency and intensity of coastal storms. All of these variables will have an impact on the distribution, species composition and abundance of fish assemblages and the fisheries that rely upon them.

All of the chapters in this thesis provide tools that may be effective in measuring the impacts of climate change. Prioritisation of exploited fish species provides a useful management tool in that changes in conservation priority status can be used as a measure of fish response to fishing, climate change and other environmental and anthropogenic influences. Measuring estuarine fisheries production and economic value helps guide management in setting conservation goals and selecting suitable mitigatory measures for the protection or recovery of nearshore and estuarine fish populations, stocks and fisheries. Measuring and modelling salinity and fish distribution in estuaries provides an indication of gauging past and future impact of changes in freshwater flow on fish assemblages. Altered freshwater flows resulting from increases in abstraction or changes in precipitation are a direct consequence of climate change as are increases in the frequency and duration of large-scale harmful alagal blooms and hypoxic or anoxic events in the sea. Monitoring terrestrial runoff and marine fish catch provides a useful indicator and predictor of the magnitude and direction of future changes in flow, ecosystem functioning, fish stocks and fisheries.

Synopsis

Overall, the multi-species, multi-user nature of nearshore and estuarine fisheries coupled with personnel and funding limitations requires that research, conservation and management be directed at priority species. Multi-Criteria Decision Analysis provides a robust approach to prioritise fish species allowing them to be grouped into various levels of action amongst other, frequency of stock assessments, bag limits and sector exclusivity. The approach also accounts for the 'precautionary principle' as it includes level of knowledge as a criterion. The MCDA approach highlights the necessity of deviating from traditional management paths confined to biological stock assessment and re-evaluation, to include criteria that indicate conservation, sector and socio-economic importance. Also evident is that fishery management measures often fall short in that they do not take cognisance of the effects of environmental variables and perturbations on fish stocks, assemblages and populations.

Apart from fishing, one of the most obvious factors currently influencing the distribution and abundance of fish is altered freshwater flow. Estuarine fish assemblages respond to changes in salinity and other environmental variables that are ultimately linked to changes in flow. Altered freshwater flows in South African estuaries have seen a gradual parallel decline in estuarine fishery productivity, nursery function and recruitment of estuarine-associated fish into the marine environment and fisheries. Added to this, evidence from the Thukela Banks fisheries suggests that even marine species that are independent of estuaries are highly responsive to flow and that traditional management measures aimed at mitigating declining catches will fail unless the freshwater flow requirements of marine ecosystems and fishes are taken into account.

Overall, this thesis has made several contributions to our knowledge and management of fisheries, particularly in the context of estuaries, including (1) the development of methods to prioritise species for management attention; (2) an assessment of estuarine fisheries production and economic value; (3) estimation of the consequences of altered freshwater flows into two important estuaries, the Olifants and Breede Estuaries, for the ichthyofauna; (4) a case history of the employment of the Berg River Estuary by estuarine-associated fish species as a refuge from lethal hypoxic marine conditions, and (5) demonstration of the importance of freshwater flows for marine species that are entirely independent of estuaries. All five approaches have expanded our knowledge of fish biology and ecology in southern Africa and demand fresh approaches for their management.

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