AN INVESTIGATION OF THE ICHTHYOFAUNAL BY-CATCH OF THE TUGELA BANK PRAWN TRAWLERS

by

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Submitted in partial fulfillment of the

requirements for the degree of

Master of Science

in the

Oceanographic Research Institute

Biology Department

University of Natal

1994

PREFACE

The work in this thesis was carried out at the Oceanographic Research Institute in Durban, under the supervision of Professor A.J. de Freitas (Director) and Mr R.P. van der Elst (deputy Director).

This study represents original work by the author and has not been submitted in any other form to another University. Where use was made of the work or research samples of others it has been duly acknowledged in the text.

ACKNOWLEDGEMENTS

This study was jointly funded by the South African Association for Marine Biological Research, the Sea Fisheries Research Fund and British Petroleum. I am extremely grateful to them for making this possible.

I would also personally like to thank the following people:

Jack Walsh (Director) and Ian Cameron of Natal Ocean Trawling, who were very co-operative in making arrangements for me to spend time onboard the trawlers. To all the skippers and crews with whom I spent many hours, including Nils, Barry, Grant, Gavin - many thanks for the company and providing me with a great experience.

The Natal Sharks Board, for providing (sometimes hairy!) transport to and from the trawlers - in particular Mike Anderson-Reade, Paul McMullen, Brendan O'Leary and Pete Streicher. Also thanks to Geremy Cliff for supplying sea temperature data.

Professor John Field and Carlos Villacastin of the University of Cape Town, for assistance and advice in running the multivariate analysis programs.

Doctors Alan Connell, Richard Kilburn and Malcolm Smale with assistance in species identification.

To the staff at ORI who helped with various aspects, particularly my supervisors Tony and Rudy for their constructive comments; Anesh for clarifying some mathematical mists; Michelle for patient typesetting; Shelley for some very able histology and database assistance; Nat for assisting with the diagrams; Pat and Bruce (M) for comments on various parts of the manuscript and the field team (Nuno, Tim and Derek) for rescuing me when marooned.

Finally, I would like to thank my wife, Merril, for putting up with a great deal of overtime at a time when I was needed at home.

ABSTRACT

The by-catch of penaeid prawn trawlers operating on the Tugela Bank of Natal was analysed at irregular intervals for a period of three years, from May 1989 to June 1992. This was primarily in response to claims by linefishermen that trawlers were catching and discarding juvenile linefish species.

Catch and effort data were recorded from 159 trawls, and catch composition data from 110 trawls, over a depth range of 20 to 45 meters. A total of 108 teleost species were identified in the by-catch, six of which comprised 80 percent of overall teleost abundance by number. Many of these fish were small-sized shoaling species, which increased their vulnerability to trawlers, and the majority were considered to be estuarine-associated. Multivariate analysis of samples showed there to be significant differences in relative abundance of species by season and depth.

Annual average by-catch and discarded quantities were estimated at 400 and 315 tonnes respectively. Discard:retained catch ratios ranged from 4.25 (± 1.19) : 1 to 15.48 (± 3.86) : 1 for shallow (20-33 meters) and deep (33-45 meters) trawls respectively. Only one important linefish, the squaretail kob, *Argyrosomus thorpei*, occurred in prawn trawl catches. These fish were spawned four to six months prior to being caught and appeared to use the Tugela Bank as a nursery area. They were seasonally abundant, occurring mostly from January to March. During these months trawling effort was generally low, as the prawns had not yet migrated offshore in quantity. Per-recruit analyses showed that the removal of these age 0 fish by trawlers reduced yield-per-recruit and spawning biomass-per-recruit values for the *A. thorpei* fishery.

Aspects of the biology of three common sciaenids occurring in trawl catches, *Johnius dussumieri*, *J. amblycephalus* and *Otolithes ruber*, were investigated. Most of the fish examined were juveniles which utilised the Tugela Bank as a nursery area, owing to the existence of suitable food, and the turbid waters afforded them protection from predators. Standard biological data, such as length frequencies, length-weight relationships and size at 50% maturity are presented.

Based on the data collected and the analyses presented here, management recommendations are presented, which include the improvement of the collection of catch and effort data for the Tugela Bank prawn trawlers; communication of the results of this study to prawn trawler operators in order to encourage the reduction of trawling effort early in the year; consideration to be given to the re-surveying of Tugela Bank ichthyofaunal by-catch in the future in order to assess potential long-term effects of trawling in the area.

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INTRODUCTION

Background

Fisheries for penaeid prawns are amongst the most lucrative in monetary terms, but also the most wasteful with respect to under-utilisation of resources (Allsopp, 1982; Saila, 1983; Somers, 1990). Penaeid prawns are members of the Superfamily Penaeoidae, distinguished by having an estuarine phase of development, hence their occurrence in shelf waters (de Freitas, 1989). There is a high diversity and abundance of other organisms found on continental shelves (Van der Elst, 1988) including fish, brachyurans, molluscs and turtles, and the largely indiscriminate nature of demersal or bottom trawling results in the capture of these organisms as a "by-catch" (Wassenberg and Hill, 1990; Poiner, 1990).

By-catch can be defined as any part of the catch which is caught incidentally to the target species i.e. the species at which effort is being directed (Saila, 1983). In many prawn fisheries, most of the by-catch is discarded as it is not marketable, or would occupy storage space needed for the more valuable target species (Sheridan *et al*, 1984; Harris and Poiner, 1991). Thus the discarded catch is that component of the by-catch which is not used in any way. It is common practice to estimate discarded catch quantities from a discarded : retained catch ratio (Samuel, 1981; Pelgrom and Sulemane, 1982; Poiner *et al,* 1990). Using a conservative ratio of 5 : 1 (Allsopp, 1982) related to global penaeid prawn landings of 1.3 million metric tonnes in 1989 (FAO, 1991), an estimated 6.5 million mt of by-catch was discarded in that year. Discarding practices vary considerably - in artisanal fisheries in Mozambique, much of the by-catch is retained (personal observation), whereas in commercial fisheries in the Gulf of Mexico, most of the by-catch is discarded (Slavin, 1982).

Annual global landings of penaeid prawns are valued at about 13 billion US dollars, with most fisheries already fully exploited and no increases in world production expected (Anon., 1984). The rapid growth rate and high fecundity of penaeids enables them to withstand high fishing pressure (Anon., 1984), which implies that these fisheries will endure, despite the wasteful harvesting techniques. Recently, increasing attention has been focussed on by-catch issues. Reasons for this can be grouped into three categories:

-1- Concern over wasteful harvesting, given the increasing demands on limited resources. The global maximum attainable catch (marine species) is estimated to be 100 million mt (FAO, 1990). Total catch by world marine fisheries in 1991 was approximately 84 million mt (FAO, 1991). Demand is expected to exceed supply by the year 2000 (Slavin, 1982), so alternative sources of fish protein need to be found. Unless new stocks are discovered, the onus will fall on aquaculture or improved utilisation of existing resources to provide the shortfall.

-2- The impact of trawling on other fisheries. These may be direct effects by removal of species important to commercial, artisanal or recreational fisheries, or indirectly via substratum modification or altered predator-prey relationships (Nepgen, 1982; Young and Sainsbury, 1985; Timmons *et al*, 1989; Van Beek *et al,* 1989; Hutchings, 1990; Penney, 1991).

-3- Increasing public antagonism, particularly in First World countries, to activities that are perceived to be environmentally damaging. The by-catch of the Gulf of Mexico prawn fishery, for example, is increasingly becoming a political issue (Hinman, 1991; Murray *et al,* 1992; Perra, 1992).

In South Africa, there are only limited possibilities for penaeid prawn trawling, owing to the narrow width of the continental shelf and the paucity of nursery areas (de Freitas, 1989). A small bait fishery operates in the St Lucia estuary, harvesting mostly immature white prawn, *Penaeus indicus*, which migrate offshore in order to spawn. A Durban-based trawling company harvests this species on a seasonal basis, on an area of the continental shelf known as the Tugela Bank. There is also an active linefishing community in the area, comprising recreational and commercial skiboats, as well as shore anglers. These fishermen often observe the prawn trawlers operating close inshore, and are aware that these trawlers discard fish at sea. The fishermen believe the trawlers to be at least partly responsible for declining linefish catches, as reported in Garratt and Van der Elst (1990), and voice their concern at government level and at management meetings (e.g. Natal Parks Board Coastal Fisheries Liaison meeting, Oceanographic Research Institute, Durban: March 1990). This study was therefore initiated in March 1989 in order to address these issues and to resolve the apparent resource user conflict.

Objectives

The objectives of the study were defined as follows:

1. To describe the ichthyofauna trawled on the Tugela Bank in terms of relative abundance, diversity, seasonality and distribution of species in the catch.

2. To assess the potential impact of prawn trawlers on linefish stocks in the area.

3. To describe aspects of the biology of key teleost species occurring in trawled catches on the Tugela Bank.

STUDY AREA

The Tugela Bank trawl grounds are situated between four and eighteen kilometres (km) off the Matikulu river mouth (29°06'36"S, 31°36'48"E) on the Natal North coast (Figure 1). The continental shelf is at its widest in this area, with the shelf break occurring about 50 km offshore. The coastline between St Lucia in the north and Durban in the south is indented, forming the Natal Bight (Lutjeharms *et al*, 1989), which forces the south-flowing Agulhas current further from the coast. The hydrodynamics of the area are thus dominated by wave action, as opposed to the current-dominated coastline north of St Lucia and south of Durban (Flemming and Hay, 1988). This Bight in the coastline is therefore of great importance in influencing aspects of inshore shelf circulation such as upwelling (Lutejeharms *et al*, 1989) and current reversals (Schumann, 1982). These in turn affect dispersion and recruitment of local marine organisms, some of which are the targets of line, trawl and land-based fisheries.

The trawl grounds, situated approximately at the midpoint of the Bight, coincide closely with a depocentre of mud originating from the fluvial discharges of the numerous rivers in the area (McCormick *et al*, 1992). The Tugela river alone has an annual estimated sediment discharge of 5.6 million m^3, much of which is deposited in pulses of high concentration and because of the high wave energies on the shelf, this mud probably settles out in the centre of closed eddy systems. Apart from a small area off the mouth of the St Lucia estuary, no other regions of the Natal coast show high concentrations of mud, hence the concentration of penaeids in these areas and particularly on the Tugela Bank. The mud itself is browner and softer than that occurring further offshore, which has a much lower clay content. The remainder of the shelf sediments are composed predominantly of sand. This description of the Natal shelf and particularly the Tugela Bank area can be found in more detail in Flemming and Hay, (1988).

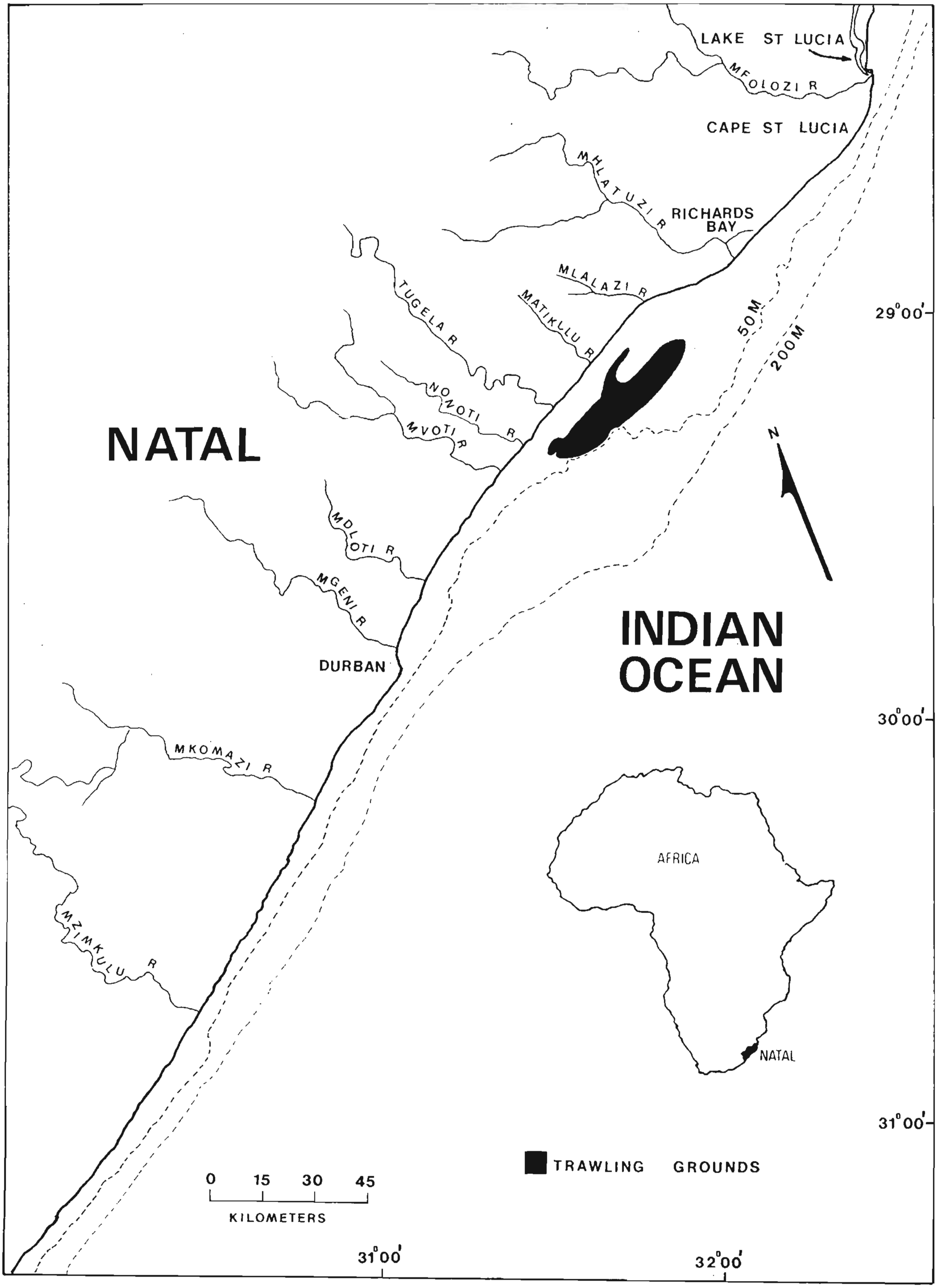

Figure 1: Location of the Tugela Bank prawn trawling grounds.

The trawl grounds cover an area of approximately 200 km^2, with the inshore boundary of the trawl grounds being demarcated by untrawlable terrain. Navigational charts of the area do not show obvious reef and these obstructions to trawlers are therefore probably in the form of low relief outcrops of beachrock (Ramsay, pers. comm.)*. The offshore boundary for trawling is less well defined, probably being restricted by the preference of penaeids for depths of less than 50 meters (de Freitas, 1989), with actual trawled depths ranging from 20 to 45 meters.

Probably because of the high-energy coastline, Natal shelf waters are generally well mixed as regards temperature and salinities (Schumann, 1982). Average salinity for the Tugela area is 35.3 $^{\circ}/_{\circ\circ}$, with little seasonal variation (Grundlingh, pers. comm.)*, although episodic reductions may occur during flooding. Monthly mean sea surface temperatures recorded by the Natal Sharks Board at Sinkwazi (Figure 1) from 1982 to 1991 ranged from 20 to 24.4°C, while individual surface temperatures recorded onboard the trawlers ranged from 19.5 to 25.5°C. As a result of the concentrations of sediment in suspension and the strong mixing processes, the water is always discoloured to a greater or lesser degree. North-easterly and southerly winds predominate, the latter particularly later in the year (Hunter, 1988). These can attain speeds of 35 and 60 knots respectively, and thus contribute to the high energies of the Natal coast.

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DESCRIPTION OF THE TUGELA BANK PRAWN TRAWL FISHERY

The existence of trawlable penaeid stocks off the Tugela river mouth was established as early as 1921, during the Fisheries and Marine Biological Survey by the S.S. Pickle, commissioned by the Fisheries Survey Committee of the Department of Mines and Industries. Few other references to surveys in the area can be found until 1964, when the Fisheries Development Corporation commissioned an exploration, subsequent to which permits for commercial prawn trawling were issued to two companies (Division of Sea Fisheries Annual Report no.34, 1966). Trawling took place sporadically until 1976, when two vessels began more regular trawling. Currently only five vessels are permitted within a seven nautical mile offshore limit, although this was increased to eight when local trawlers were prevented from trawling in Mozambique (1983-1984).

Only one Durban-based company, Natal Ocean Trawling, currently operates on the Tugela Bank. Trawling for non-penaeids, such as the knife prawn, *Haliporoides triarthrus vniroi*, also occurs in much deeper water on the continental slope. There are no quotas imposed on either the inshore (Tugela) or the deep water fisheries. The gross annual landed value of the Tugela Bank component of the catch was approximately R 2.2 million in 1992. Fleet maintenance and operating costs are high, as the trawlers are fairly old, and trawling in the open sea exerts considerable strain on equipment. The vessels used are currently all steel stern trawlers, with overall lengths ranging from 24 to 33 meters and generate between 500 and 610 hp. All are equipped with echo sounders and Dekka navigators and are currently being upgraded with computerised Global Positioning Systems and track plotters. They can remain at sea for up to three weeks, depending on their fuel and water capacity, and carry between 15 and 18 crew, with five officers and up to seven deckhands.

The gear used on the Tugela Bank, as for most commercial penaeid fisheries, is the otter trawl. The following is a description of a generalised trawl as used by the local trawlers (Figure 2). The horizontal opening of the trawl mouth is maintained by two rectangular doors or otter boards, which are rigged so that the forward motion of the boat causes them to veer apart, thus spreading the net. These doors may be steel or wooden, and dimensions vary according to the size of the trawl net. The vertical opening is maintained by attaching floats to the headline and weighting the footrope, either with chain or by binding it with manila rope. The panels of mesh making up the trawl are also cut so as to promote lifting of the headrope, causing it to "balloon", thereby increasing the height of the trawl opening.

Trawl speed is critical in maintaining the opening of the trawl and can be combined with tuning of the gear to maximise spread. Trawl sizes vary, with footrope lengths ranging from 45 to 25 meters. Mesh sizes range from 70 mm in the wings, tapering to 38 mm in the codend. Although there are no mesh restrictions on this fishery, there is a current trend by the fishermen to use 50 mm mesh in the codend. A "tickler" chain may be attached just forward of the footrope in order to cause the prawns to jump as the net approaches, thus ensuring they end up in the mouth of the trawl. The headrope is rigged ahead of the footrope so as to prevent prawns from jumping or swimming over the net. Since 1989, three boats have been converted from single trawls to boom-operated twin trawls, as were used when fishing commenced in the 1960s. This is a system developed for the Gulf of Mexico prawn fishery and is being used with great success in Australia, providing greater coverage of the sea bed and reducing fuel consumption.

Retained prawn catch is graded by size category, packed into two kilogramme (kg) cartons and blast frozen within an hour of being caught. Ninety percent of the prawns caught are white prawns, *Penaeus indicus*, with lesser quantities of *Metapenaeus monoceros*, *Penaeus monodon*, *Penaeus japonicus* and *Penaeus semisulcatus*. Other trawled organisms which are packed for marketing include crabs (*Portunus sanguinolinta*), cephalopods (*Loligo duvauceli*, *Sepiella cyanea*) and several fish species. Fishing takes place mostly from March to September, commencing once the prawns have recruited to the trawl grounds. Trawling takes place on a 24 hour basis as there is little variation in day/night catch rates. Trawl speeds are between two and three knots and drag duration averages four hours, with night trawls generally being of longer duration in order to let the crew rest.

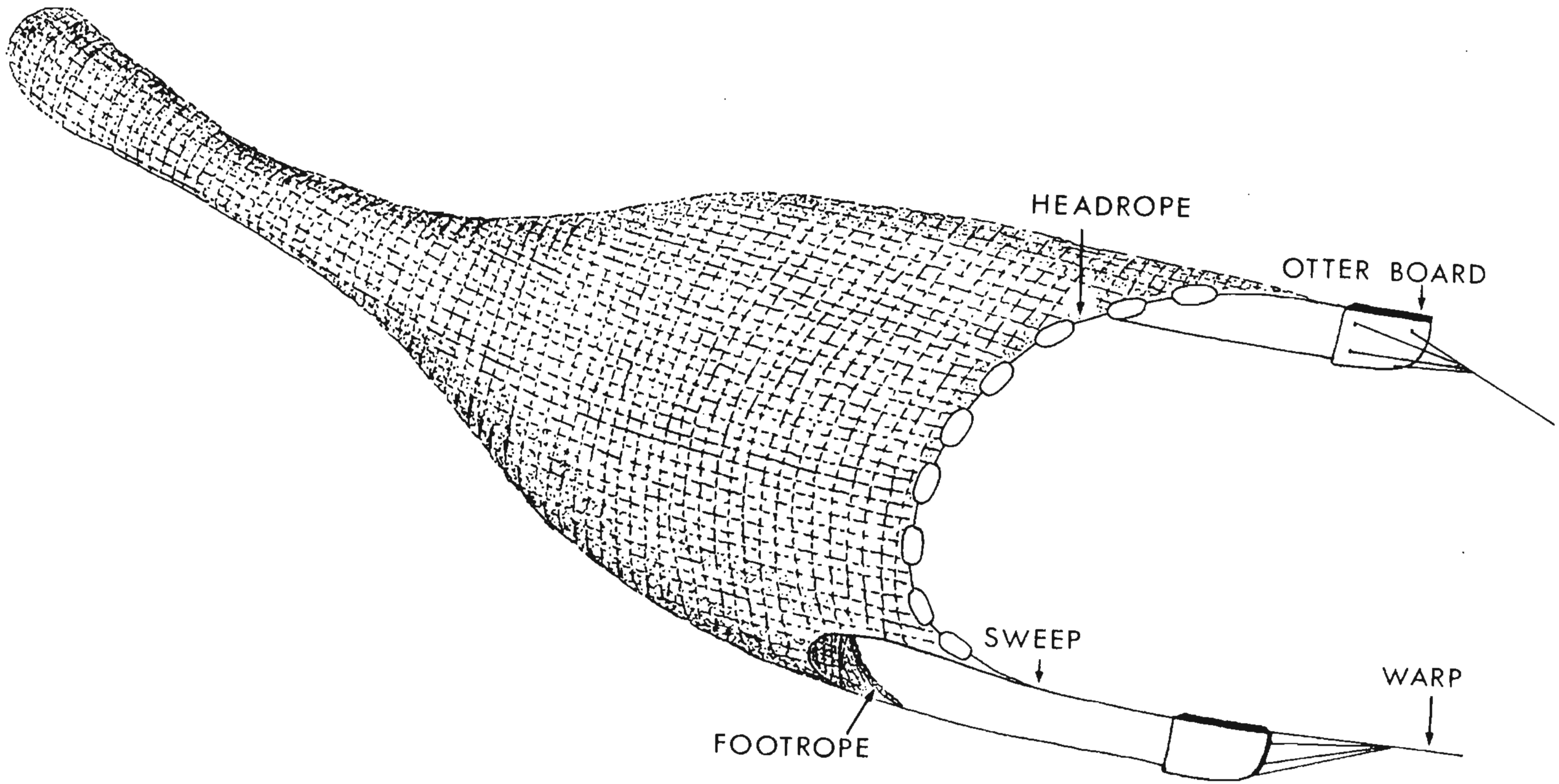

Figure 2: Diagram of a generalised otter trawl.

OVERALL SAMPLING APPROACH

General

In April 1989, an initial five day trip on a Tugela Bank trawler was undertaken in order to become familiar with the trawling process and also to design a sampling programme which would provide the data necessary to meet the objectives outlined above. Because of the lengthy duration of fishing trips, transport to and from the trawlers was effected by various means, but mostly via a rubber duck skippered by Oceanographic Research Institute field staff and via a skiboat manned by members of the Natal Sharks Board. Rendezvoux with trawlers was hampered by weather conditions and poor radio communications, which at times necessitated the abandonment of sampling trips. This was particular so during the early (January and February) and late months (August to October) of the year. During these months, trawlers would only fish intermittently, literally "waiting for the prawns to appear". Poor catches would result in trawlers moving to the deep water knife prawn grounds after two or three days, where catches were generally more consistent. The commercial nature of the trawling operation therefore also disrupted regular sampling efforts.

Sampling procedure

Fish by-catch species composition data were collected from commercial prawn trawls between 29°05' and 29°18' S and 31°30' and 31°55' E, from May 1989 to June 1992. An attempt was made to collect samples at monthly intervals during trips of between one to seven days duration. Depth, position and time of day were noted for each sampled trawl, with trawl duration recorded as the period from winch stopped to winch started. Sea surface temperatures were recorded by the Natal Sharks Board between the Tugela and Nonoti rivers (Study area, Figure 1) and were assumed to be representative of the nearby sampled area. Catch and effort data for trawlers and commercial skiboat operators were obtained from logbooks submitted by the skippers to the Directorate of Sea Fisheries. Recreational catch data was obtained from the National Marine Linefish Data System.

Sampling of an individual trawl proceeded as follows: Once the trawl catch was released into the sorting pen, the crew removed the crustacean and cephalopod components, following which a random half crate sample (about 12 kg) of the remaining by-catch was taken by means of a shovel from several areas in the pen. The crate was frozen on board for later determination of catch composition. An attempt was made to collect samples from several depths for each month. Once the sample had been taken, the crew were allowed to remove fish for packing, following which, the remaining by-catch was placed in crates, which were counted before being discarded. The occurrence of elasmobranchs in the catch was not documented in detail, as many of these survive the trawling process and are returned to the water alive. For the purposes of this thesis, therefore, the term fish will refer to teleosts.

Processing of collected samples included a breakdown of the half-crate sample by species weight and number for all taxa and recording of biological data (length, weight, sex, gonad stage and stomach contents) for the three commonest fish species (see Chapter 3 for details of collection of biological data). Species were identified according to Smith and Heemstra (1986).

Efforts to randomise the selection of trawlers for each sampling trip were not always successful, as there was often only one trawler operating, or accommodation was not available on other vessels. A total of seven vessels were eventually sampled, during 65 sea-days, over the three year sampling period. The most common gear types were single or double otter trawls, with foot ropes ranging from 25 to 53 meters. Mesh size in the codend was 38 mm (stretched) throughout the study. Monthly sampling was not always possible owing to the constraints imposed by the weather and the commercial nature of the trawling operation outlined above. A total of 23 out of a possible 38 months were sampled, with December being the only month for which a sample was not obtained. The number of samples collected per trip ranged from four to ten. Similarly, it was not always possible to obtain samples from the full range of depths every month, since the trawlers concentrated their efforts where prawn catches were greatest: early in the season, the prawns tended to be more numerous in shallower water (20-33 meters), while later in the season, prawn catches were greater in deeper water (33-45 meters).

CHAPTER 1

Distribution and seasonality of ichthyofauna associated with commercial prawn trawl catches on the Tugela Bank of Natal, South Africa.

1.1 Introduction

The sub-tropical waters of the Natal coast harbour a great variety of invertebrate and vertebrate species (see for example Cohen, 1973; Smith, 1980; Branch and Branch, 1981). Existing knowledge of the marine fauna of Natal is largely based on intertidal surveys, linefish catches and diving surveys, with few trawl surveys having been done. The investigation of Tugela Bank commercial prawn trawler by-catch therefore provided an opportunity to characterise the ichthyofauna of a unique region of the Natal shelf (Study Area, this thesis). Furthermore, data on seasonality and distribution of trawlable fish species will be of importance should it be necessary to implement measures to reduce by-catch quantities. These data are also of value for work on the identification and description of hitherto unexploited fish stocks on the Natal shelf (Fennessy, 1990).

1.2 Methods

Sampling

Samples were collected according to the procedure outlined in the section entitled "Overall sampling approach". An effort was made to collect at least one sample per trawled depth category (Table 1.1) for each month of the year.

Data analysis

A multivariate approach was decided upon, owing to the discontinuous nature of data collection (see sampling approach in the introductory chapter) and the proven sensitivity of this method in discriminating between samples in time and space (Warwick and Clarke, 1991). The approach is that followed by Field *et al*, (1982), i.e. analysis of the species composition data first, "letting the species tell their story" and then a search for explanations for the observed groupings. This constitutes an *a posteriori* approach to explaining the station groupings (Clarke, 1993).

Clustering of fauna: Dendrograms were produced by hierarchical agglomerative clustering (using group average linkage) of all samples, based on Bray-Curtis dissimilarity measures calculated on root-root transformed abundance data, following Field *et al*, (1982). Only species contributing more than two percent to the similarity measures were used.

The Bray-Curtis measure of dissimilarity (δjk) is:

$$\delta jk = 100 \left(1 - \frac{\Sigma_{pi=1} \mid y_{ij} - y_{ik} \mid}{\Sigma_{pi=1} (y_{ij} + y_{ik})} \right) \qquad (1)$$

where y_{ij} = abundance of species i in sample j

and y_{ik} = abundance of species i in sample k

Ordination of fauna: Two-dimensional plots were produced by non-metric multi-dimensional (MDS) scaling of samples and species, based on Bray-Curtis similarities using root-root transformed abundance data. The MDS constructs a map of the samples, in which distances between samples reflect differences/similarities in species composition. The MDS operates by means of an algorithm which attempts to minimise, by iteration, the difference between sample rankings in the plot and the dissimilarity matrix. The extent to which the two disagree is measured by a stress coefficient, with low values indicating a satisfactory representation of the data (Clarke, 1993).

Species responsible for holding groups together and for separating groups:

The species characterising the observed groups and those which were responsible for determining the groupings were identified by the SIMPER (percent similarities) procedure, whereby the contribution of each species to the similarity measures **within** sample groups (S_i) and the dissimilarity measures **between** sample groups (δ_i) is determined respectively. The ratio of the average S_i and δ_i, for each species, to their respective standard deviations, is a measure of a particular species' importance in holding sample groups together, or separating them (Clarke, 1993).

Relation of faunistic groups to the environment:

Using the same similarity matrix, the ordinations are replotted using the environmental data (season, depth and time of day) collected for each station, i.e. the environmental data are superimposed on the species ordinations. Thereafter, stations are stratified according to the environmental variables (season, depth, day/night), irrespective of how they were grouped according to species composition, and a non-parametric equivalent of MANOVA (known as ANOSIM) is used to test for the interactive effects of these variables. The ANOSIM procedure tests the null hypothesis that differences **among** strata are no greater than differences **between** strata. Values of the R statistic produced range from 0 (no differences) to 1 (differences among strata greater than those within strata). A randomisation test is used to test the null hypothesis by sampling randomly from the full set of permutations to give the null distribution of the statistic R. If the true calculated value of R lies in the tail of this distribution, the null hypothesis is rejected (Clarke, 1993).

All the above programmes were developed by Dr K.R. Clarke, Dr R.M. Warwick and M.R. Carr at Plymouth Marine Laboratory, United Kingdom, and were run on a 386 IBM personal computer at the Zoology department, University of Cape Town.

1.3 Results

General

A total of 110 samples were collected, representing 2.1 percent of all trawls done during the study period. Difficulties were experienced in obtaining regular monthly samples over all depth ranges, owing to the commercial nature of the fishery. Based on sea surface temperatures, two seasons can be defined: a "warm" season (December to April) and a "cool" season (May to November), with the dividing line being the overall mean for the last ten years i.e. 21.98°C (Figure 1.1).

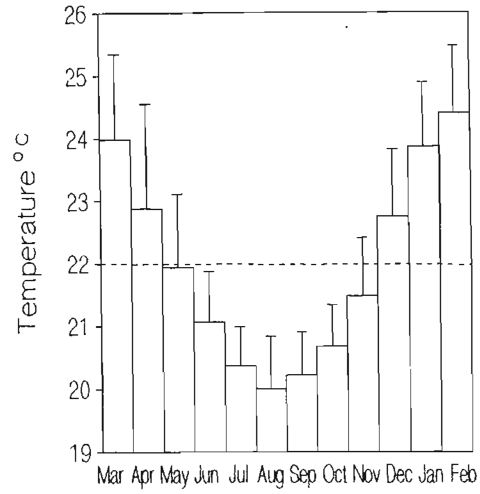

Figure 1.1: **Mean sea surface temperatures (plus 1 std. deviation) collected on the Natal North coast from 1980 - 1990 (Natal Sharks Board - unpublished data).**

Limited CTD data from research cruises in the area indicated that temperature and salinity were respectively isothermal and isohaline for sampled depths (Beckley*, pers. comm.). Salinity does not change significantly with season (Grundlingh*, pers. comm.), although there may be localised effects when river flow rates are high (Demetriades, 1991). The range of depths trawled was grouped into three categories (Table 1.1), with overlap of some trawls done between 20 - 41 meters.

Table 1.1: **Sampled depths from 110 Tugela Bank prawn trawls (May 1989-June 1992).**

Trawl depths	Category	No. of samples
20 - 24 meters	Shallow	33
20 - 28 m	"	4
20 - 33 m	Medium	22
20 - 41 m	"	3
28 - 33 m	"	16
33 - 45 m	Deep	19
37 - 45 m	"	13

Overall catch composition

A total sample weight of 961 kg, comprising 40160 fish, from a total estimated catch of 1200 tonnes was collected during the 37 month sampling period. A list of common trawl-associated species is presented in Appendix 1. Teleost species were always the largest component of the by-catch by number and weight. A total of 108 teleost species were recorded, with one undescribed species yet to be confirmed.

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Seven species occurred in 90% or more of all trawls (Table 1.2), and can be considered ubiquitous in the area. Overall relative abundance of the six most common species is presented in Figure 1.2. No clear trends in abundance are apparent, although these may be obscured by the irregularity of sampling in time and space.

Table 1.2: Overall relative abundance of common by-catch teleost species from 110 Tugela Bank commercial prawn trawls (May 1989 - June 1992). * denotes ubiquitous species.

Species	Common names	% of trawls	No. of individuals	% by no.	Cumul. %
Johnius dussumieri	Small kob	99*	8665	21.6	21.6
Johnius amblycephalus	Bellfish	99*	8033	20.0	41.6
Otolithes ruber	Snapper kob	99*	5752	14.3	55.9
Trichiurus lepturus	Cutlass fish	97*	4366	10.9	66.8
Atrobucca nibe	Longfin kob	90*	3139	7.8	74.6
Thryssa vitrirostris	Orangemouth glassnose	90*	2246	5.6	80.2
Lagocephalus guentheri	Blackback puffer	66	976	2.4	82.6
Drepane longimanus	Concertina-fish	71	917	2.3	84.9
Cynoglossus attenuatus	Fourline tonguefish	94*	907	2.3	87.2
Cynoglossus lida	Roughscale tonguefish	61	702	1.7	88.9
Argyrosomus thorpei	Squaretail kob	44	603	1.5	90.4
Pomadasys olivaceum	Piggy	47	395	1.0	91.4
Polydactylus sextarius	Sixfinger threadfin	77	374	.9	92.3
Pellona ditchela	Indian pellona	37	351	.9	93.2
Saurida undosquamis	Largescale lizardfish	55	275	.7	93.9
Carangoides malabaricus	Malabar kingfish	27	246	.6	94.5
Lagocephalus inermis	Smoothback puffer	60	239	.6	95.1
Solea bleekeri	Blackhand sole	51	204	.5	95.6
Gazza minuta	Toothed soapy	37	184	.5	96.1
Upeneus vittatus	Yellowbanded goatfish	29	176	.4	96.5
Secutor ruconius	Slender soapy	23	148	.4	96.9
Cociella sp	Spotfin flathead	52	135	.3	97.2
Ariomma indica	Indian driftfish	28	125	.3	97.5
Uroconger lepturus	Longtail conger	21	99	.2	97.7

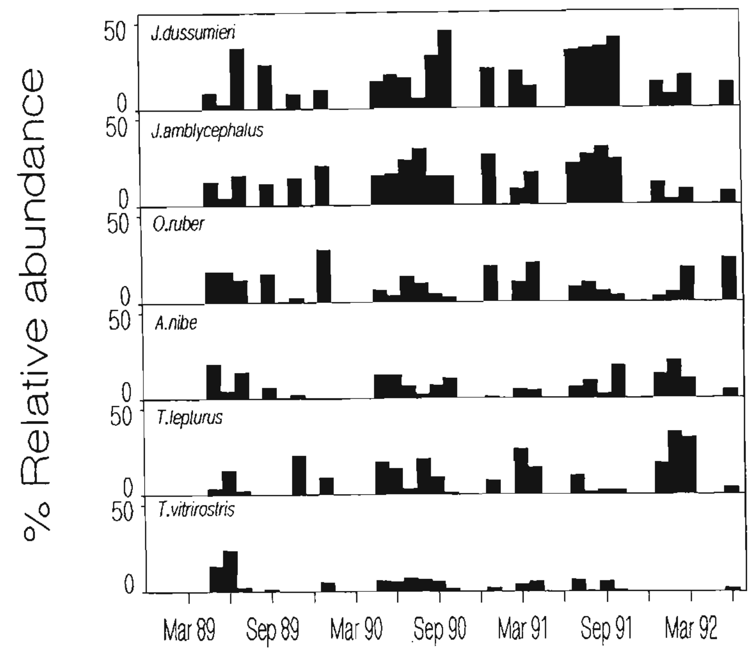

Figure 1.2: **Monthly relative abundance (by % number) of the six commonest Tugela Bank prawn trawler by-catch fish species (May 1989 - June 1992).**

Clustering and ordination of fauna

Classification of all samples in a dendrogram produces four poorly separated groups (I - IV), and two small heterogeneous clusters (a and b) comprising 11 samples (Figure 1.3). Inspection of the raw data matrix revealed that the isolation of the latter is apparently due to the paucity of species (in samples from group a), or lack of the commonest species in group b. All samples fuse at the 52% level, indicating high intergroup similarity. The lack of clear separation of the groups implies that the patterns of species abundance among groups are similar, so an ordination was done in order to examine the patterns further. The MDS ordination plots samples as points separated on the basis of their ranks in the dissimilarity matrix, i.e. the more dissimilar two samples are, the further apart they will appear in the plot. The 2-dimensional ordination produced four poorly separated groups which correspond fairly closely to the dendrogram groupings (Figure 1.4), albeit with some anomalies (Table 1.3). The discontinuous clusters in the dendrogram (a and b) ordinate as outliers, indicating their differences from the other samples (see above).

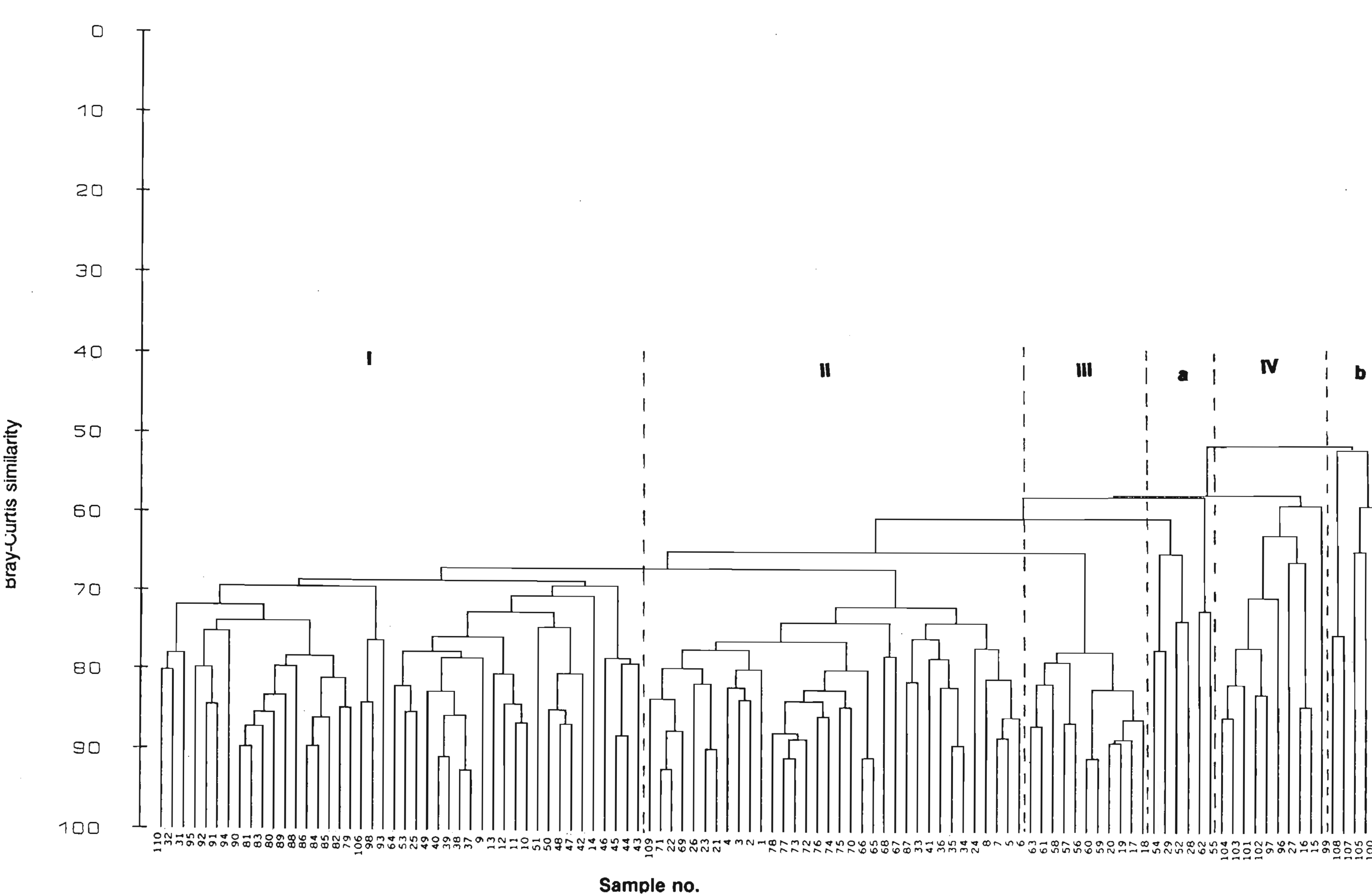

Figure 1.3: Dendrogram of 110 Tugela Bank prawn trawler by-catch samples from group-average clustering based on Bray-Curtis similarities and root-root transformed abundance of fish species.

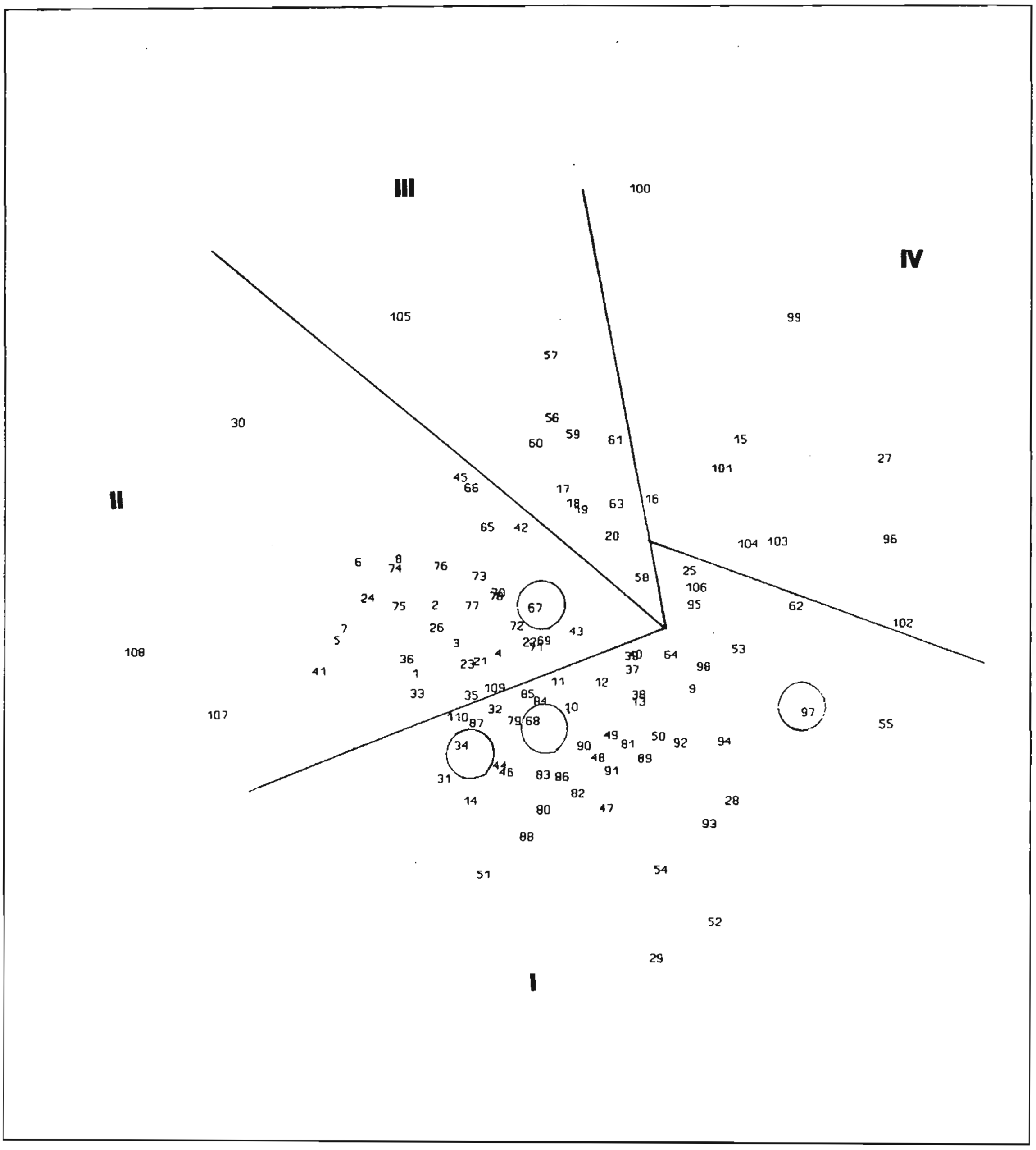

Figure 1.4: Ordination of 110 Tugela Bank prawn trawler by-catch samples based on Bray-Curtis similarities and root-root transformed abundance of fish species. (Stress = .243). Circled numbers = anomalous samples (Table 3).

The stress value for the 2-dimensional plot presented is relatively high (0.243), and Clarke (1993) advocates caution when interpreting plots with stress values greater than 0.2. A 3-dimensional MDS has a lower stress coefficient of 0.18, which indicates that the data would be better represented in higher dimensions. The computer package on which the programme was run was not able to produce 3-dimensional plots, so the 2-dimensional plot has been used.

Table 1.3: Grouping of 110 Tugela Bank prawn trawl by-catch samples, derived by classification and ordination.

Group	Sample no.	Anomalous samples *
I (n=44)	9-14, 25, 31-32, 37-40, 42-51, 53, 64, 79-86, 88-95, 98, 106, 110	-
II (n=34)	1-8, 21-24, 26, 33-36, 41, 65-78, 87, 109	34, 67, 68
III (n=11)	17-20, 56-61, 63	-
IV (n=10)	15-16, 27, 96-97, 99, 101-104	97
a	28, 29, 52, 54, 55, 62	
b	30, 100, 105, 107, 108	

* Samples in dendrogram groups that do not correspond to the ordination groups.

Species responsible for holding groups together

Having established the groups, it was necessary to identify the species characterising them, by means of the SIMPER procedure. The greater the abundance of a species (i) in a group of samples, the greater its contribution to the within-group similarity (S_i). The species is characteristic of the group if it has consistent abundance throughout the group, with low associated standard deviation (SD). The ratio $\bar{S}_i/SD(S_i)$ grades these characteristic species i.e. the higher the ratio, the more typical that species is of a group and the more consistently it contributes to the within-group similarity. Table 1.4 presents these ratios and cumulative percentage similarities contributed by species occurring in groups I to IV.

Table 1.4: **By-catch fish species contributing strongly to average within-group similarity measures, based on the ratio $\bar{S}_i/SD(S_i)$. Cumulative percent contribution to similarity measures also shown. Cutoff is at a ratio level of 1.**

Group I	**Ratio**	**Cum. %**
Johnius amblycephalus	5.6	13.8
Atrobucca nibe	4.8	24.2
Otolithes ruber	4.6	34.4
Johnius dussumieri	4.4	48.4
Cynoglossus attenuatus	3.6	54.8
Thryssa vitrirostris	2.3	61.7
Trichiurus lepturus	2.0	69.1
Polydactylus sextarius	1.6	73.6
Drepane longimanus	1.5	78.4
Pomadasys olivaceum	1.2	82.4
	62.17*	**(7.54)**

Group II	**Ratio**	**Cum. %**
Otolithes ruber	7.5	11.6
Cynoglossus attenatus	6.2	18.3
Johnius amblycephalus	5.8	29.0
Thryssa vitrirostris	5.6	38.1
Lagocephalus guentheri	4.6	43.8
Trichiurus lepturus	3.7	55.3
Johnius dussumieri	3.0	64.4
Drepane longimanus	2.2	70.7
Atrobucca nibe	2.1	77.9
Cynoglossus lida	1.1	81.3
	67.59*	**(6.50)**

Group III	**Ratio**	**Cum. %**
Otolithes ruber	11.0	15.4
Argyrosomus thorpei	10.7	26.5
Johnius amblycephalus	9.3	42.4
Johnius dussumieri	7.7	54.3
Trichiurus lepturus	3.3	63.3
Thryssa vitrirostris	3.1	70.1
Lagocephalus guentheri	2.0	75.3
Cynoglossus attenuatus	2.0	81.0
Cynoglossus lida	1.9	86.6
Polydactylus sextarius	1.3	90.3
Pomadasys olivaceum	1.0	93.1
	71.83*	**(5.67)**

Group IV	**Ratio**	**Cum. %**
Otolithes ruber	6.9	11.2
Cynoglossus attenuatus	6.2	20.5
Argyrosomus thorpei	3.5	30.6
Atrobucca nibe	3.1	42.2
Trichiurus lepturus	2.9	54.0
Johnius amblycephalus	1.9	61.5
Cociella sp	1.9	67.3
Johnius dussumieri	1.8	76.0
Polydactylus sextarius	1.8	83.0
Saurida undosquamis	1.2	87.7
	58.71*	**(8.51)**

* Average percentage within-group similarities (standard deviation in brackets)

In all four groups, 10 or fewer species account for 80% of the contribution to the similarity measures, and all or most of these species are common to each group. Four species (*Otolithes ruber*, *Johnius amblycephalus*, *Johnius dussumieri*, and *Trichiurus lepturus*) occur at high levels in all four groups, between them accounting for 39 - 52 % of the cumulative percentage contribution to the similarity measure. Three species (*Atrobucca nibe*, *Thryssa vitrirostris* and *Cynoglossus attenuatus*) occur at fairly high levels in three groups, and all seven species have high $\bar{S}_i/SD(S_i)$ ratios i.e. all contribute strongly to within-group similarities. These seven are the ubiquitous species referred to above. This dominance of a few species in all samples, despite root-root transformation of abundance, accounts for the clustering of samples in a single large group.

Species responsible for separating groups

Similarly, the ratio $\bar{\delta}_i / SD\ (\delta_i)$, where δ_i is the contribution of species i to the mean **dissimilarity** measure **between** all intergroup sample pairs, identifies those species that contribute most to the inter-group dissimilarities i.e. distinguishes the groups from each other. These species, with their percentage contribution to total inter-group dissimilarity, are listed in Table 1.5.

Table 1.5: By-catch fish species contributing strongly to between group dissimilarity measures, based on the ratio $\bar{\delta}_i / SD\ (\delta_i)$. Only species with a ratio of $\geq$ 1.5 in at least one inter-group comparison shown. Cumulative percent contribution to dissimilarity measures also shown.

Group I x II	**Ratio**	**Cum.%**
Lagocephalus guentheri	1.7	5.2
Pomadasys olivaceum	1.5	9.0
Trichiurus lepturus	1.4	12.7
Johnius dussumieri	1.4	16.4
Otolithes ruber	1.4	19.1
Saurida undosquamis	1.4	22.2
Cynoglossus lida	1.3	25.9
Lagocephalus inermis	1.3	28.7
Johnius amblycephalus	1.3	31.1
Solea bleekeri	1.2	33.8

Group I x III		
Atrobucca nibe	2.3	7.4
Argyrosomus thorpei	2.1	13.8
Drepane longimanus	1.7	18.4
Pomadasys olivaceum	1.7	22.6
Saurida undosquamis	1.6	26.1
Otolithes ruber	1.6	29.6
Lagocephalus guentheri	1.5	33.4
Cynoglossus lida	1.4	37.6
Johnius dussumieri	1.4	40.6
Trichiurus lepturus	1.3	44.0

Group I x IV		
Thryssa vitrirostris	2.1	5.6
Johnius amblycephalus	1.7	11.4
Drepane longimanus	1.7	16.0
Argyrosomus thorpei	1.6	20.4
Johnius dussumieri	1.6	26.0
Pseudorhombus arsius	1.4	29.3
Atrobucca nibe	1.4	32.1
Otolithes ruber	1.4	34.7
Pomadasys olivaceum	1.3	38.7
Trichiurus lepturus	1.3	42.2

Group II x III	**Ratio**	**Cum.%**
Argyrosomus thorpei	3.9	8.7
Drepane longimanus	2.2	15.2
Atrobucca nibe	1.8	22.0
Thryssa vitrirostris	1.5	25.3
Trichiurus lepturus	1.4	28.5
Johnius amblycephalus	1.4	31.5
Solea bleekeri	1.3	34.5
Lagocephalus guentheri	1.3	37.3
Gazza minuta	1.2	40.4
Johnius dussumieri	1.2	43.0

Group II x IV		
Thryssa vitrirostris	3.2	7.1
Otolithes ruber	2.4	10.8
Drepane longimanus	2.3	16.3
Argyrosumus thorpei	2.3	21.5
Lagocephalus guentheri	1.4	26.6
Johnius amblycephalus	1.5	30.8
Cynoglossus lida	1.5	34.5
Pseudorhombus arsius	1.4	37.7
Saurida undosquamis	1.4	40.8
Atrobucca nibe	1.3	43.6

Group III x IV		
Otolithes ruber	4.6	5.7
Thryssa vitrirostris	2.1	11.4
Johnius amblycephalus	2.0	18.7
Atrobucca nibe	1.8	25.5
Cynoglossus lida	1.7	30.6
Saurida undosquamis	1.7	34.9
Argyrosomus thorpei	1.7	37.5
Lagocephalus guentheri	1.6	41.6
Pseudorhombus arsius	1.4	45.3
Trichiurus lepturus	1.4	48.5

Species which are important in discriminating between two groups are listed in decreasing importance, and species important in discriminating between group categories (depth or season) will be high on the list of between-category group comparisons. In all between-group comparisons, the cumulative contributions to dissimilarity are low, indicating that many species all contribute a little to inter-group dissimilarity. This also accounts for the low average inter-group dissimilarities (Table 1.6).

Table 1.6: Matrix of average inter-group dissimilarity measures for by-catch sample groups (corresponding standard deviations in brackets).

Group	I	II	III	IV
I		(6.04)	(6.81)	(8.28)
II	40.34		(5.99)	(7.94)
III	40.69	43.53		(8.26)
IV	52.15	49.06	48.73	

Despite considerable overlap of species' occurrence from group to group, some trends in distribution can be identified. *O. ruber*, has a relatively high ratio and is therefore important in distinguishing groups III and IV (Table 1.5), despite being typical of these groups (Table 1.4). This apparent anomaly is due to it's **consistent** occurrence in these two groups, but with generally higher abundance in group III. *A. thorpei* is important in distinguishing groups II and III on the basis of it's importance in characterising the latter group (Table 1.4). In this way, the characteristic or distinguishing species can be determined for each group or group comparison.

Relation of faunistic groups to the environment

Examination of the environmental variables recorded for each station revealed that the clustering of samples is attributable to season and depth. To clarify this, samples were re-plotted using physical parameters collected for each trawl i.e. depth (Figure 1.5), season (Figure 1.6) and time of day (Figure 1.7). Based on the depth plot and corresponding sample data, groups I and IV are categorised as comprising medium/deep samples, while groups II and III comprise shallow/medium samples. Samples collected at 20-24 meters show the best separation, and there is a general gradient of increasing depth from left to right. There is a dichotomy in the plot of seasonal data, with "warm" samples ordinating in the upper right-hand quadrant. Groups I and II are therefore categorised as cool, and groups III and IV are warm. The plot of samples according to time of day (Figure 1.7) shows no obvious separation, and so it is assumed that day/night effects on sample groupings are negligible.

The possible influence of the three environmental variables (season, depth, day/night) on species distribution patterns was further examined by the ANOSIM statistical procedure. Currently only one and two-way tests are available, so the three-factor problem has been tested as three two-way tests (Table 1.7).

Table 1.7: Two-way cross factor ANOSIM (analysis of similarity) of by-catch sample groups.

	Factor 1 Depth	Factor 2 Season	Factor 3 Day/night
Level 1	Shallow	Cool	Day
Level 2	Medium	Warm	Night
Level 3	Deep		

a) Test for season against levels of depth: R = 0.505 (P <.01)
Test for depth against levels of season: R = 0.407 (P <.01)

b) Test for day/night against levels of season: R = 0.103 (P <.05)
Test for season against levels of day/night: R = 0.119 (P <.05)

c) Test for day/night against levels of depth: R = 0.188 (P <.05)
Test for depth against levels of day/night: R = 0.229 (P <.01)

The conclusions are:

a) The fish by-catch community changes highly significantly with depth, irrespective of season, and with season, irrespective of depth.

b) There is a slightly significant difference in the fish by-catch community between day and night irrespective of season and with season, irrespective of whether the trawl was by day or night.

c) There is a highly significant effect of depth on the fish by-catch community composition irrespective of day/night, and a slightly significant difference between day/night by-catch, irrespective of depth.

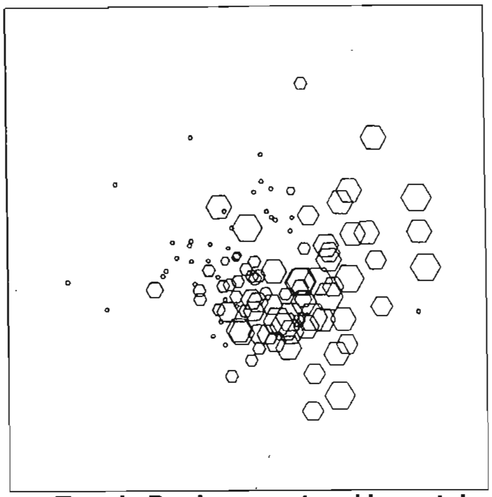

Figure 1.5: Ordination of 110 Tugela Bank prawn trawl by-catch samples based on Bray-Curtis similarities and root-root transformed abundance of fish species. Samples depicted as hexagons with superimposed depth data. Increasing depth denoted by increasing symbol size.

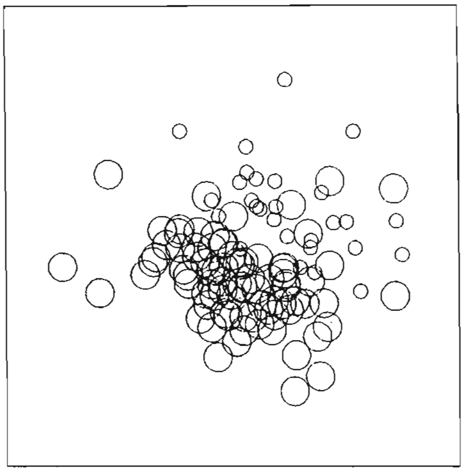

Figure 1.6: Ordination of 110 Tugela Bank prawn trawl by-catch samples based on Bray-Curtis similarities and root-root transformed abundance of fish species. Samples depicted as circles with superimposed seasonal data. Large circles denote cool season samples, small circles denote warm season samples.

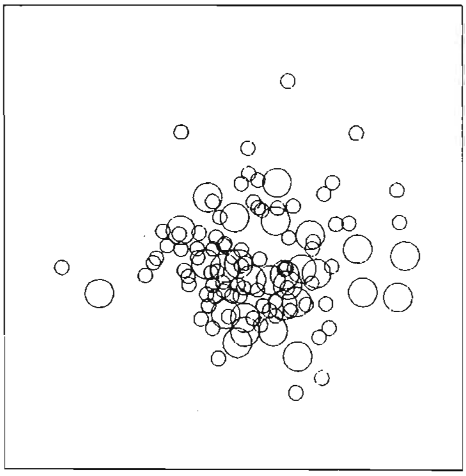

Figure 1.7: Ordination of 110 Tugela Bank prawn trawl by-catch samples based on Bray-Curtis similarities and root-root transformed abundance of fish species. Samples depicted as circles with superimposed seasonal data. Large circles denote night samples, small circles denote day samples.

The significant changes found using the above ANOSIM randomisation test on the ranked Bray-Curtis similarity matrix confirm statistically the trends suggested by the ordination diagrams upon which environmental factors have been superimposed (Figs. 6-8), with clear differences related to depth and season but only slight differences related to day/night.

Having confirmed the categorisation of groups by season and depth, the species chiefly responsible for characterising and distinguishing the groups (Tables 1.4 and 1.5) can also be categorised according to these environmental criteria. The five commonest species that occur in all or virtually all trawls (Table 1.2), obviously occur in all four categories, but still exhibit some distributional preferences. *J. dussumieri* favours warmer, shallow water on the Tugela Bank, a phenomenon which agrees with the recorded estuarine habits of this species (van der Elst, 1988), while *J. amblycephalus* is less common in deep waters during warmer months. *O. ruber* occurs commonly in all depth/seasonal combinations, but is not as abundant in deeper water during cooler months. *T. lepturus* shows little seasonal or depth preference and *C. attenuatus* is less common in shallow, warm water. *A. nibe* is more common in deeper water on the Tugela Bank, which agrees with occurrence of this species in trawls on the continental shelf break (pers obs). *T. vitrirostris* is more numerous during cool months, as is *D. longimanus*. *A. thorpei* shows strong seasonality, occurring mostly in warmer months at all depths. Neither *P. olivaceum* nor *P. sextarius* exhibit strong depth or seasonal trends, while *L. guentheri* is mostly found in shallow trawls.

1.4 Discussion

The above results indicate a considerable ichthyofaunal species diversity on the Tugela Bank trawl grounds. This is in common with penaeid fisheries world-wide. A few species dominate the Tugela by-catch by number and weight, which also commonly occurs in other penaeid fisheries. In the Arabian Gulf, for example, over 200 by-catch species have been identified, with as few as two species comprising up to 48 percent of the by-catch at times (Grantham, 1980). Maharaj and Recksiek (1991) found that six fish species made up 75-80% of prawn trawl by-catch in the Gulf of Paria, Trinidad, while Blaber *et al* (1990) recorded 10 fish species out of a total of 237 as comprising 62% of the biomass associated with prawns in the Gulf of Carpentaria, Australia.

The Tugela Bank trawler by-catch comprises mostly demersal or semi-demersal species, with the engraulid, *T. vitrirostris*, being the only pelagic species contributing significantly to abundance. Many of the species recorded in the by-catch also occur in estuaries. As is typical for soft substratum species, most Tugela Bank by-catch fish are silver in colour as opposed to the varied colours found in reef-associated fish. Many are shoaling species, which, together with their small size, accounts for their vulnerability to trawlers.

The turbidity of the water and slow trawling speed (average 2.5 knots) probably account for the infrequent occurrence and poor capture rates of pelagic species. Most of the fish occurring in the Tugela Bank by-catch are Indo-Pacific species, and are probably approaching the southern limits of their range. Several are endemic to the southwestern region of the Indo-Pacific, including *A. thorpei*, *C. attenuatus* and *S. bleekeri* (Smith, 1980). Most have been recorded in demersal trawls at lower latitudes on the East coast of Africa e.g. Maputo Bay in Mozambique (de Freitas, (1984) and personal observation; Sofala Bank in Mozambique (Brinca *et al*, 1984) and in Tanzania (Bianchi, 1985). The frequent incidence of Sciaenidae in Tugela Bank trawl catches (four of the seven ubiquitous species) agrees with the reported common occurrence of this family on coastlines close to river mouths (Trewavas, 1977). Frequently, therefore, sciaenids are a numerically dominant family in the by-catch of prawn fisheries, to the extent that they are considered "indicators" of penaeid fishing grounds (Pauly and Neal, 1985).

Season and depth have been demonstrated as important factors governing occurrence of fish species. The ANOSIM procedures used in this study indicate that season and depth are significant factors in distinguishing Tugela Bank by-catch sample groups. This is also reflected in the ordination of samples with environmental data superimposed, with shallower samples occurring in the left quadrant (Figure 1.6) and "warm" samples concentrating in the upper right quadrant of the plot (Figure 1.6). Some species exhibit strong seasonal trends, such as *A. thorpei*, which is more abundant in warm months, and *D. longimanus*, which is more abundant in cool months. Inspection of the original monthly sampling data revealed that there is an increase in numbers of *A. thorpei* in the by-catch during January to March, while numbers of *D. longimanus* are greater during April to October. The former spawns in winter, the latter in spring (Smith and Heemstra, 1986; van der Elst, 1988b), with the recruits probably becoming vulnerable to the trawl gear at different times of the year. The seasonal trends in abundance of these two Tugela Bank by-catch species are therefore ascribed to spawning pulses rather than direct environmental influence on species presence and absence. The other sciaenids, *O. ruber*, *J. dussumieri* and *J. amblycephalus* all demonstrate seasonal and depth preferences, but, having protracted spawning seasons (Chapter 3, this thesis), these trends are more difficult to interpret. There is some evidence of resource partitioning in these three species (Chapter 3, this thesis), but this requires further investigation. Two other commonly occurring species, such as *P. olivaceum* and *T. lepturus*, show low seasonal and depth preferences. These species have a reported cosmopolitan distribution (Smith and Heemstra, 1986; van der Elst, 1988b) and appear to tolerate a variety of temperatures and depth. Two species known to be seasonally abundant on the Natal coast, *P. saltatrix* and *S. ocellatus*, do occur in Tugela Bank trawl catches, but not consistently enough to be important in forming sample groupings. It is possible that their pelagic lifestyle means they are not vulnerable to prawn trawls, or they are not abundant on the prawn grounds.

In conclusion, many of the Tugela Bank by-catch fish species can generally be considered resident in the region, with the major species exhibiting seasonal and distributional (depth) trends. Most are juveniles, and probably aggregate in the area for two reasons. Firstly, stomach content analysis of the major species has shown that the Tugela Bank is a source of various suitable prey items for small fish, including non-commercial penaeid species such as *Parapenaeopsis acclivirostris* (Chapter 3, this thesis). Secondly, the water on the Bank is turbid virtually throughout the year owing to the numerous river outlets nearby and therefore offers the juveniles protection from predation. This is a strategy also favoured by fish associated with estuaries, these areas also functioning as nurseries because of high turbidities and a good food supply (Blaber and Blaber, 1980). Most of the Tugela Bank fish species are found in estuaries, and therefore, even if not dependant on them, can be considered estuarine-associated.

CHAPTER 2

The impact of commercial prawn trawlers on linefish of the north coast of Natal.

2.1 Introduction

Most of the world's penaeid prawn fisheries are situated in shelf waters in order to harvest the adult prawns which have moved from their estuarine nurseries to the marine environment in order to spawn. Penaeids are therefore often found in shallow, inshore, tropical or sub-tropical waters, where there is a high abundance and diversity of other organisms. The most common gear used to catch these prawns is the otter trawl (Vendeville, 1990), which is largely indiscriminate in it's operation. As a result there is often a "by-catch" of demersal organisms which are associated with the prawns. Some of this may be retained, but in many fisheries the majority of the by-catch, most of which is killed by the trawling process, is discarded owing to low marketability. By-catch is therefore any organism caught incidentally to the target species, whereas the discards are that component of the by-catch which are not used in any way. The discarding of this so-called "trash" fish by prawn trawlers is increasingly being investigated in all oceans, as evidenced by the numbers of publications dealing with this issue (Bello, 1987; Wassenberg and Hill, 1989; Isaksen *et al,* 1992; Robin, 1992).

An issue which is of particular concern is the catching of species which are the targets of other types of fisheries (GMFMC, 1989; Vaughan, 1991; Kennelly, 1993). In South Africa, the greatly increased pressure on declining linefish stocks (Garratt and Van der Elst, 1990) has recently resulted in the identification of potential resource user conflicts in both the Cape Province (Penney, 1991; Griffiths, 1993) and in Natal. One of these stems from the perception, by particularly ski-boat operators on the Natal north coast, that the Tugela Bank prawn trawlers are removing juvenile linefish (Mercer, 1991; Barrass, 1992). Initial investigation identified the commercially important squaretail kob, *Argyrosomus thorpei*, as occurring in trawler by-catch (Fennessy, 1990) and therefore in order to investigate this apparent resource user conflict, a more detailed study on the by-catch of the Tugela Bank trawlers was initiated.

2.2 Methods

Sampling:

Samples were collected according to the procedure outlined in the section entitled "Overall sampling approach". Attempts were made to collect at least one sample per trawled depth category for each month of the year (Table 2.4). Retained and discarded catch quantities were recorded for all observed trawls. Retained catch weights were estimated from the packed weight of each catch category e.g. prawn, crab, fish, etc. Discarded catch quantities were estimated from the product of number of crates discarded and average crate weight. Fleet catch and effort data for trawlers and commercial skiboat operators were obtained from logbooks submitted by the skippers to the Directorate of Sea Fisheries. Recreational linefish catch data were obtained from the National Marine Linefish Data System reports.

Data analysis

Catch rates

The catchability of individual fish species was assumed to be the same for all lengths of trawl footropes. Catch rates were standardised as kilogrammes per trawl hour (kg/hr). Annual by-catch estimates were derived from the product of monthly by-catch rates (kg/hr) and fleet effort in hours. The following factors were identified as possibly affecting the calculation of catch rates: gear size, day/night effects, season, depth, weather and fishing efficiency/skill.

1) Gear - controlled experiments to test for the effects of gear size (footrope length) on catch rates were not possible owing to the commercial nature of the fishing operation. *A posteriori* testing was carried out as follows: mean by-catch catch rates (kg/hour) for each gear size were tested over four months during the main prawn trawling season over a restricted range of depths, by Spearman's rank correlation (Table 2.1). The correlation between gear size and catch rate was positive ($r=0.5$), but not significantly so ($p = .221$). Furthermore, the majority of trawling is done with trawls having footropes of between 33 and 37 meters, so gear size was disregarded when calculating by-catch rates. It is likely that the correlation

between catch rate and gear type is not simply affected by the dimensions of the trawl, but also by structural modifications. These include the use of tickler chains and varying the lengths of sweep cables between the doors and the net. These modifications were not consistently applied while trawling, so their effects could not be quantified, but it is believed that the catch composition and average by-catch rates presented are representative of this fishery.

Table 2.1: By-catch rates of Tugela Bank prawn trawl gears, from April to July (1989 - 1992), at depths of 20 to 33 meters.

Footrope (m)	By-catch (kg/hr)	Std. Dev.	No. of Trawls
25	15.72	3.23	4
30	14.62	3.35	10
33	37.62	11.32	4
35	27.87	17.38	32
36	24.05	13.3	37
37	26.56	17.03	14
53	34.6	23.66	6

2) Day/night effects - Controlled testing for temporal effects on by-catch rates was not possible. Results of Mann-Whitney rank sum testing of day and night by-catch catch rates, over short periods at a restricted range of depths, indicated that daylight by-catch rates are higher (Table 2.2). However, since trawling occurs over the whole 24 hour period, it was assumed that an overall average by-catch rate would account for day-night effects.

Table 2.2: Mann-Whitney rank sum test of differences between day and night by-catch rates (* denotes significance at the 95 % level).

Month	Depth (m)	Mean catch rate kg/hour		Z statistic	No. of trawls
		Day	Night		
April	20 - 33	35.37	21.8	-2.0*	21
June	20 - 33	25.45	17.15	-1.33	15
July	20 - 33	35.65	16.63	-2.8*	18
September	33 - 45	37.34	31.62	-0.45	14

3) Season and depth - Initial inspection of the data revealed differences in catch rates by season and depth. By-catch rate estimates were therefore lumped by month (over all three years) and depth (shallow, 20-33 meters and deep, 33-45 meters). Monthly lumping ensured that there was an estimate for virtually every month and depth category over the year, while grouping of estimates by depth simplified interpretation of skipper's drag sheet entries.

4) Weather and fishing skill - The effect of these on catch rates could not be evaluated with the available data and were therefore discounted.

By-catch : retained prawn catch ratios

The ratio of by-catch to retained prawn catch quantities provides an alternative method for estimating total by-catch (Campos, 1981; Samuel, 1981; Maharaj and Recksiek, 1991). However, the distribution of these ratios was skewed, particularly for trawls in shallower depths (Figure 2.1). Transformations of the form $\log(x)$, $\log(x+1)$ and $\sqrt{\sqrt{(x)}}$ were attempted in order to normalise the data distribution, but without success, so a jacknife procedure was utilised. This is a robust procedure which serves to reduce the bias of ratio estimates (Pauly, 1984; Neter *et al*, 1988), as follows:

1) From n observations, n standard deviations are obtained, each time omitting one sample. The sample standard deviation is denoted by s_{-i}.

2) Next, n pseudovalues (J_i) are calculated, based on the full sample standard deviation (s) and s_{-i}:

$$J_i = ns - (n - 1)s_{-i} \quad i = 1,2,...,n \qquad (1)$$

3) The n pseudovalues are then treated as a sample i.e. a jacknife mean $(\bar{J})$, standard deviation (S_J) and estimate of standard deviation of the jacknife mean $(S\{\bar{J}\})$, are calculated.

4) The jacknife confidence limits are calculated by:

$$\bar{J} \pm t\,(S\{\bar{J}\}) \qquad (2)$$

Since the pseudovalues are treated as if they are a random sample from a normal population, the t distribution is used, with n-1 degrees of freedom.

Jacknife ratios of by-catch : prawn catch and discarded catch : prawn catch were calculated for two depth categories (shallow and deep) over the whole sampling period, excluding the months of October to December when trawling effort is zero or minimal. Trawls with nil prawn catch were not used. Monthly ratios were not calculated owing to the paucity of samples in some months, particularly for deeper trawls (Table 2.4). These ratios were applied to fleet catches at the relevant depths in order to obtain additional estimates of by-catch and discarded catch quantities.

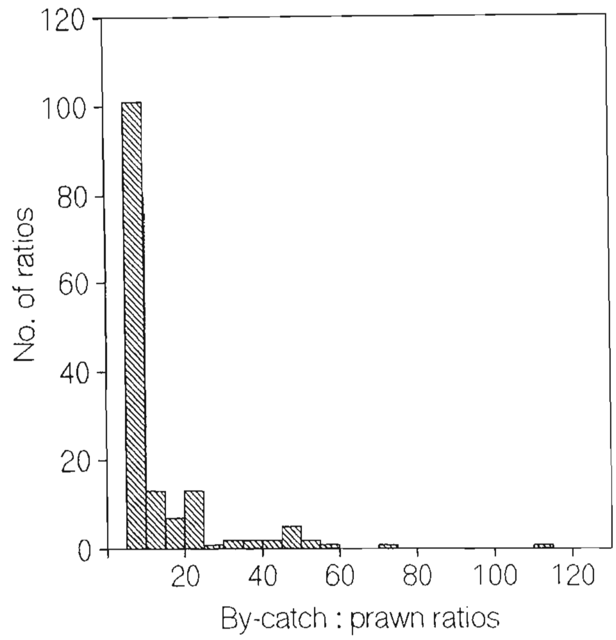

Figure 2.1: **Plot of by-catch : prawn catch ratios (by weight) from 152 Tugela Bank prawn trawls (May 1989-June 1992).**

Estimates of numbers of linefish in by-catch

The term linefish as used here refers to all fish species which are caught by means of a fishing line. Investigation of by-catch species composition revealed that only one important linefish species, the squaretail kob, *Argyrosomus thorpei*, occurred in quantities greater than one percent by number (Table 2.7), so estimates of numbers were restricted to this species. Average monthly catch rates of *A. thorpei* in numbers per hour were estimated from the product of numbers of fish (per sample) and by-catch quantity, divided by trawl duration in hours. This assumes a linear relationship between numbers of fish caught and the number of trawl hours (Gutherz and Pellegrin, 1988). Annual estimates of numbers of fish caught by trawlers were derived from the product of monthly catch rates and monthly fleet effort in hours.

Per-recruit analyses

Comparison of numbers and weights of *A. thorpei* caught by prawn trawlers and skiboaters are not, in themselves, an efficient method to assess whether the former fishery is affecting catches of the latter. Therefore, a yield-per-recruit approach (Beverton and Holt, 1957) was used. This method is often used by fisheries managers to determine the optimal age (or size) of capture of a species (Pauly, 1984). The rationale behind this method is that three factors control the biomass of a fish stock: recruitment, growth and mortality. In an exploited (fished) stock, mortality can be divided into two components: natural mortality (predation, disease, abiotic factors) and fishing mortality (loss of biomass due to fishing). A choice often faced by fisheries managers is how long to let the fish grow in order to maximise growth, but also to minimise losses over time due to natural mortality. The Beverton and Holt model expresses this trade-off in terms of yield-per-recruit (YPR) i.e. the average catch in weight of each fish recruited to the fishery.

In particular, the YPR model describes the change in biomass (due to natural and fishing mortality) of a cohort of fish following recruitment, where biomass is the product of the numbers of individuals and their mean mass (Butterworth *et al*, 1989) and a cohort is defined as a single year class of fish i.e. all born in the same year (Pauly, 1984). The Beverton and Holt (1957) model assumes that the yield from a cohort over its whole lifetime is equal to yield of the whole population in a single year, under steady state conditions i.e. recruitment, growth, mortality and age-at-first-capture are constant.

In terms of the interaction of the two fisheries: the Tugela Bank prawn fishery which catches *A. thorpei* indirectly and the skiboat linefishery directed at the same species, a per-recruit model was used to assess the effect of removal of fish by the former on the yield-per-recruit of the total stock. Assuming knife-edge selection (i.e. no fish are caught below their age at-first-capture; above this age they are equally available to the fishing gear), yield-per-recruit was derived as follows:

$$YPR = \sum_{t_c}^{10} N_t . W_t . \frac{F_t}{Z_t}(1 - e^{-Z_t}) \qquad (3)$$

where YPR = yield-per-recruit

t_c = age-at-first-capture (in years)

N_t = no. of fish in the cohort at age t

W_t = average fish weight at age t (in grams)

and

$$F_t = S_t^T F + S_t^L F$$
$$Z_t = F_t + M \qquad (4)$$

where F_t = combined fishing mortality of both fisheries

S_t^T = fishing selectivity of trawlers at age t

S_t^L = fishing selectivity of skiboats at age t

Z_t = instantaneous total mortality at age t

F_t = instantaneous fishing mortality at age t

M = instantaneous natural mortality

The contribution of each fishery to combined fishing mortality (F_t) was varied by changing the selectivity coefficients (S_t^x) in equation (4): the trawl fishery either caught no *A. thorpei* or only caught age 0 fish, while the skiboat fishery only caught fish of age 3 and above. For the purposes of the model, the maximum age of *A. thorpei* was assumed to be 10 years. These assumptions are in keeping with the observed age structure of catches in both fisheries (pers. obs. and Govender*, pers. comm.).

* Anesh Govender, Oceanographic Research Institute, PO Box 10712, Marine Parade, 4056.

Total mortality (Z) was estimated as 0.9 year^{-1} from the slope of the descending limb of the catch curve (Van der Elst *et al*, 1990). Natural mortality (M) was estimated from the Pauly (1980) equation:

$$\log M = -0.0066 - 0.279\log L\infty + 0.6543\log K + 0.4634\log T \qquad (5)$$

where T = annual mean sea temperature (°C)

and L∞ and K are as defined below. Estimates of L∞ and K for *A. thorpei* were obtained from Van der Elst *et al* (1990) and T was estimated from sea surface temperatures collected by the Natal Sharks Board at Sinkwazi. The number of fish in the cohort at age t (N_t) was obtained from:

$$N_t = R.e^{-Zt} \qquad (6)$$

where R is the initial number of recruits in the cohort and for this analysis was set at unity (one). The average fish weight at age t (W_t) is obtained from the Von Bertalanffy equation:

$$W_t = a.(L\infty.(1 - e^{k(t-t_0)}))^b \qquad (7)$$

where a and b = parameters of the length-weight relationship (**W (grams) = a.l(mm)^b** - Ricker, 1975)

L∞ = asymptotic length i.e. the mean total length the fish stock would reach if it grew indefinitely (Pauly, 1984)

k = a growth constant (the rate at which fish length approaches L∞)

t_0 = the theoretical age at "zero" length

As well as affecting overall biomass, fishing also affects the **spawning** biomass of the stock i.e. that component which is sexually mature and reproduces (Sissenwine and Sheperd, 1987). If fishing mortality is sufficiently high, spawning biomass may be severely depleted, leading to possible recruitment failure (Butterworth *et al*, 1989). Spawning biomass-per-recruit (SBPR) was estimated by:

$$SBPR = \sum_{t_m}^{10} N_t.W_t \qquad (8)$$

where t_m = age at 50% maturity (the age at which 50% of the fish reach maturity - Beverton and Holt, 1957) and N_t and W_t are as defined previously.

The yield-per-recruit (YPR) and spawning biomass-per-recruit (SBPR) equations (3 and 8) were incorporated into a model which produced per-recruit estimates for varying age-at-first capture, instantaneous natural mortality and instantaneous fishing mortality. Estimated values of input parameters to the model are summarised in Table 2.3. The sensitivity of the model to some of these parameters was tested by varying the values of $L\infty$, K, T, M and F.

Table 2.3: Input parameter values to the per-recruit model for the assessment of the impact of Tugela Bank trawlers on skiboat catches of *A. thorpei*.

Parameter	Value	Source
a	2×10^{-6}	Van der Elst *et al*, 1990
b	2.89	"
T	22 °C	Natal Sharks Board, unpublished data
$L\infty$	518.3 mm	Van der Elst *et al*, 1990
K	0.286 yr^{-1}	"
t_0	-1.46 yr	"
S_t^I	age 3+ years	Govender, unpublished data
S_t^T	age 0 years	Fennessy, unpublished data
M	0.32 yr^{-1}	This study
t_m	2.1 yr	Van der Elst *et al*, 1990

2.3 Results

Overall catch composition and effort

Catch and effort data were recorded from 159 trawls, and 110 catch composition samples were taken, representing 1.9 and 1.3 percent respectively of commercial trawls during the 38 month sampling period. Although trawled depths ranged from 20 to 41 meters, most effort is concentrated at shallower depths, particularly during the first half of the year when prawns occur closer inshore. This is reflected in the skewed distribution of collected samples (Table 2.4). For this reason, and because catch rates vary with depth (Figure 2.2), trawls were classified as either shallow (20-33m) or deep (33-45m). A total sample weight of 961 kilogrammes, comprising 40160 individual fish was collected. Fish constituted an average of 74 percent of the by-catch by weight. A total of 108 teleost species was recorded, with seven occurring in 90 percent or more of all trawls (Table 1.2, Chapter 1).

Table 2.4: **Sampling effort (May 1989 - June 1992) and total fleet effort (January 1989-December 1992 - from Sea Fisheries drag sheets) for Tugela Bank prawn trawlers.**

	No. of samples		No. of commercial trawl hours	
	Shallow	Deep	Shallow	Deep
January	14	4	1898	73
February	1	11	2419	237
March	3	1	3721	520
April	23	-	4079	1226
May	10	1	6496	906
June	29	1	4488	623
July	32	2	871	1598
August	3	7	1050	2656
September	4	10	623	1572
October	-	1	265	65
November	1	1	104	13
December	-	-	75	26
TOTAL	120	39	26089	9514

Catch rates

Mean by-catch rates, lumped by depth and month are presented in Figure 2.2. It is apparent that greater quantities are caught in deeper waters during January to August, with similar rates for all depths in September. The rates from October to December are possibly partially biased as they are based on only three trawls. However, very little trawling occurs during these months (Table 2.4), so only the months from January to September were used for estimating catch quantities.

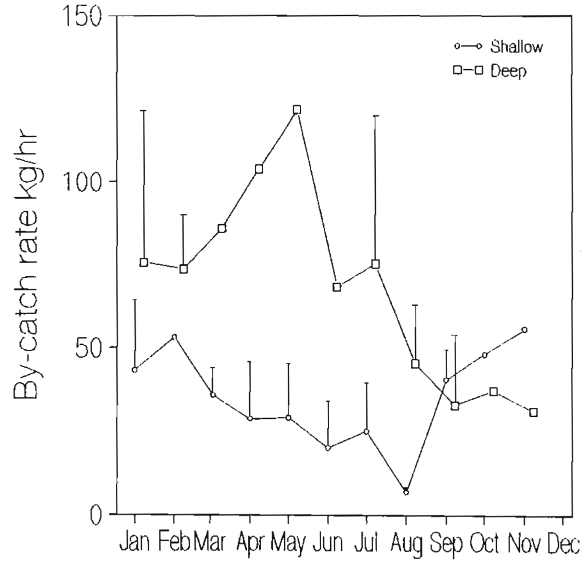

Figure 2.2: **Average monthly by-catch rates (plus 1 std. deviation) for 152 Tugela Bank prawn trawls (May 1989-June 1992).**

The mean monthly by-catch rate estimates were used to obtain estimates of monthly by-catch quantities, derived from the product of monthly mean by-catch rates and fleet effort (Table 2.5). Fleet effort is derived from the Sea Fisheries Research Institute (SFRI) drag and landing sheets. By-catch rates for April (deep) and October (shallow) were taken as the average of March and May, and September and November, respectively, as there was no sample data available for these months. Fleet effort values (and hence by-catch estimates) are probably underestimated by between 7 and 28 percent because of missing landing sheets. By-catch estimates have therefore been adjusted by the percentage difference between SFRI estimates of landings and actual landed catches for each year (from the trawling companies records). This provides the only means of estimating the discrepancy between actual and recorded effort.

By-catch : retained prawn catch

Of the total of 159 trawls for which catch data existed, four trawls had nil prawn catch and three occured during October or November. Of the remaining 152 trawls, 115 occured in shallow depths, 37 in deeper water. Jacknife ratios and corresponding confidence intervals are presented in Table 2.6 along with retained prawn catches obtained from available logbook data, in order to derive by-catch and discard estimates. Confidence intervals for ratios based on deep trawl catches were considerably reduced by the omission of a possible anomalous trawl ratio. Omission of this ratio reduced the by-catch ratio confidence intervals from ± 14.09 to ± 3.29, and the discard ratio intervals from ± 14.0 to ± 3.86. Again, by-catch and discard quantities are probably underestimated by between 7 and 28 percent because of the discrepancy between landed catch records and have been adjusted accordingly.

Table 2.5: Estimated by-catch quantities (1989-1992) from Tugela Bank prawn trawlers, based on the product of by-catch rates and fleet effort (S = shallow and D = deep trawls).

	Depth	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
By-catch rates (kg/hr)	S	43.3	53.2	35.8	28.9	29.2	20.2	25.1	7.0	40.5	-
	D	75.7	73.7	85.9	104.0	122.0	68.0	75.0	45.0	32.0	-
1989 Fleet effort (hrs)	S	1107	1575	1971	1978	1783	949	101	503	524	10491
	D	6	172	31	31	503	71	505	524	123	1966
Derived by-catch (kg)	S	47900	83743	70463	57184	52010	19122	2533	3496	21243	357694
	D	454	12680	2664	3223	61361	4856	38052	23784	4052	151125
Total by-catch 1989											508819
Adjusted by-catch 1989(+ 3%)											**524084**
1990 Fleet effort (hrs)	S	589	413	667	739	1225	1373	310	232	40	5588
	D	7	0	153	715	63	16	210	974	290	2428
Derived by-catch (kg)	S	25486	21949	23845	21364	35733	27666	7775	1612	1622	167052
	D	530	0	13146	74331	7685	1094	15824	44210	9553	166372
Total by-catch											333424
Adjusted by-catch 1990 (+ 28%)											**426782**
1991 Fleet effort (hrs)	S	52	267	361	284	1428	1376	460	82	9	4317
	D	0	65	284	434	310	297	455	808	873	3524
Derived by-catch (kg)	S	2233	14175	12913	8205	41643	27726	11537	568	349	131616
	D	0	4755	24384	45150	37768	20294	34284	36693	28753	235007
Total by-catch											366623
Adjusted by-catch 1991 (+ 7%)											**392287**
1992 Fleet effort (hrs)	S	151	165	722	1078	2060	790	0	233	50	5249
	D	60	0	52	46	30	100	428	350	286	1352
Derived by-catch (kg)	S	6512	8773	25812	31165	60090	15919	0	1619	2027	151917
	D	4554	0	4468	4782	3672	6840	32250	15887	9421	81873
Total by-catch											233790
Adjusted by-catch 1992 (+ 8%)											**252493**

Table 2.6: **Annual prawn catches (from drag sheets), jacknife ratios and derived estimates of by-catch and discarded catch (in kg). (S) and (D) denote shallow and deep trawls respectively.**

	1989	1990	1991	1992
Logbook prawn catch (S)	95145	82611	59461	68803
Logbbook prawn catch (D)	16127	26058	37391	12327
Jacknife ratios	**By-catch : prawn**		**Discard : prawn**	
Shallow	4.60 ± 1.25 : 1		4.25 ± 1.19 : 1	
Deep	17.13 ± 3.29 : 1		15.48 ± 3.86 : 1	
Derived by-catch				
Shallow	437667	380010	273521	316494
Deep	276256	446373	640508	211162
Total	713923	826383	914029	527656
Adjusted total	**735341**	**1057770**	**978011**	**569868**
Derived discards				
Shallow	404366	351097	252709	292413
Deep	249646	403378	578813	190822
Total	654012	754475	831522	483235
Adjusted total	**673632**	**965728**	**889729**	**521894**

Linefish species in the by-catch

From the data collected by the National Marine Linefish System (NMLS) on the Natal North coast (NMLS Data Reports; Guastella and Van der Elst, 1992; Pilfold and Pampallis, 1993), it is apparent that proportions of linefish in trawls are not high (Table 2.7). Only one important linefish species, the squaretail kob, *Argyrosomus thorpei*, occurs in trawler fish by-catch in quantities greater than 0.2 percent by number (Table 2.7). Of the 101 catch composition samples collected between January to September, only 43 contained squaretail kob. Of these, 22 were collected in January and February, indicating changes in seasonal abundance (Figure 2.3). The resulting disparity in catch rates of *A. thorpei* necessitated utilisation of monthly rates (Table 2.8). Again, because of the discrepancy between records of landed catches, fleet effort and hence numbers of *A. thorpei* are probably underestimated by between 7 and 28 percent. Most of these fish are between 110 and 150 millimetres in length (average weight 40 grams) and are much smaller than those caught by linefishermen (Figure 2.4).

Table 2.7: Common linefish catches on the Natal North coast. (Data source: National Marine Linefish System Data Reports, 1986-1991.) * denotes occurring at < 0.2%.

Species	Commercial Ski-boat (% by weight)	Recreational Ski-boat (% by no.)	Shore Angling (% by no.)	Trawl (% by no.)
Chrysoblephus puniceus	29	8	-	-
Scomberomorus spp	9	32	-	-
Argyrosomus thorpei	22	8	*	1.5
Epinephelus spp	9	11	*	*
Cheimerius nufar	11	4	-	-
Argyrosomus hololepidotus	4	8	3	*
Polysteganus coeruleopunctatus	2	*	-	-
Pomadasys spp (not *P.olivaceum*)	*	2	3	*
Chrysoblephus anglicus	2	1	-	-
Pomatomus saltatrix	*	4	55	*
Atractoscion aequidens	2	1	-	-
Otolithes ruber	*	3	*	14
Sarpa salpa	-	-	20	-
Rhabdosargus sarba	-	-	4	-
Diplodus sargus	*	*	4	-
Total	90	82	89	

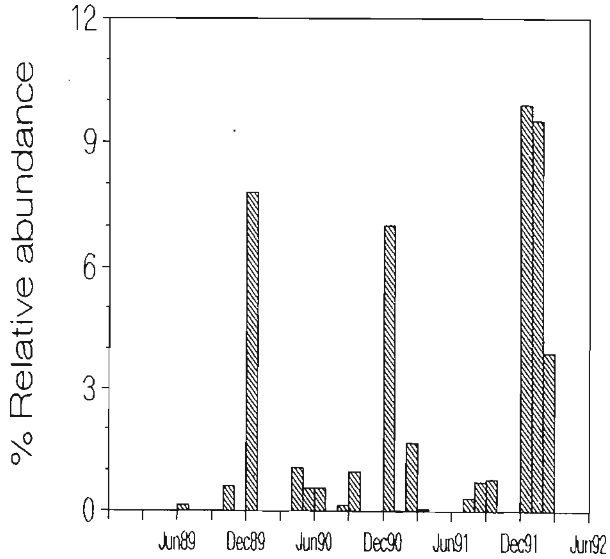

Figure 2.3: Monthly abundance (as a relative percentage by number of the total number of fish) of *A. thorpei* in Tugela Bank prawn trawler by-catch.

Table 2.8: **Average monthly catch rates (standard deviation in brackets) and estimated numbers of *A. thorpei* caught by Tugela Bank prawn trawlers (1989-1992).**

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
Avg. no. A. thorpei trawled/hour	93.4 (50.4)	104.2 (90.6)	30.4 (43.4)	0.5 (1.5)	20.8 (51.1)	1.2 (3.4)	2.2 (5.5)	1.5 (3.9)	0.3 (0.6)	
1989										
Fleet effort (hours)	1113	1747	2002	2009	2286	1020	606	1027	647	12457
Derived no's	103954	182037	60861	1005	47549	1224	1333	1541	194	399698
Adjusted no's (+ 3%)										**411688**
1990										
Fleet effort (hours)	596	413	820	1452	1288	1389	520	1206	330	8016
Derived no's	55666	43035	24928	726	26790	1667	1144	1809	99	155864
Adjusted no's (+ 28%)										**199506**
1991										
Fleet effort (hours)	52	332	645	718	1738	1673	915	890	892	7841
Derived no's	4857	34594	19608	359	36150	2008	2013	1335	268	101192
Adjusted no's (+ 7%)										**108275**
1992										
Fleet effort (hours)	211	165	774	1124	2090	890	428	583	336	6601
Derived no's	19707	17193	23530	562	43472	1068	942	875	101	107449
Adjusted no's (+ 8%)										**116045**
Average annual numbers of A. thorpei caught (std. deviation in brackets)										**208878 (141373)**

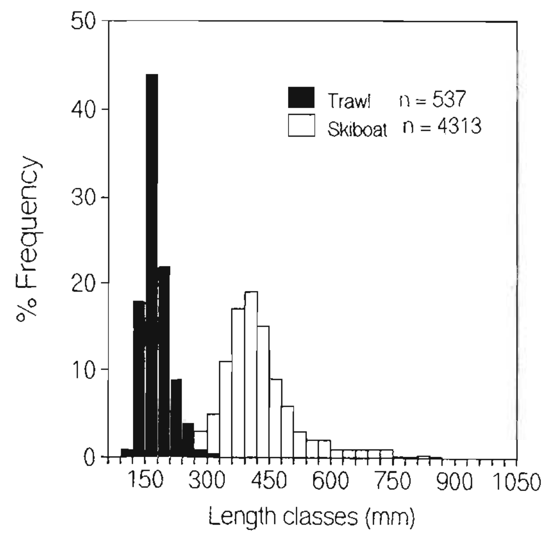

Figure 2.4: **Frequency distributions of *A. thorpei* in Tugela Bank trawler by-catch (1989-1992) and commercial skiboat catches (1985-1988).**

Per-recruit analyses

Yield-per-recruit (YPR) and spawning biomass-per-recruit (SBPR) increased for all selected parameter values when trawlers did not catch *A. thorpei* (Table 2.9). Combination of parameters #1 utilises current estimates of L_∞, K, M and F (Van der Elst *et al*, 1990); #2 utilises a hypothetical value of L_∞ based on observed large specimens (pers. obs.) with an associated reduction in natural mortality M (from Pauly, 1980); #3 utilises a hypothetical growth rate (K) with an associated higher M; #4 utilises a hypothetical M value and #5-7 utilise various values of F (fishing mortality).

Table 2.9: **Input parameters to the per-recruit model (equations 3 and 8) and relative percentage change in values of yield-per-recruit (YPR) and spawning biomass-per-recruit (SBPR). Fixed parameters used were: S_t^1 = 3 years; t_m = 2.1 years.**

#	Non-fixed model parameters				% increase in YPR if no trawling for *A. thorpei*	% of pristine SBPR remaining if:	
	L_∞ (mm)	K (yr^{-1})	M (yr^{-1})	Total F (yr^{-1})		Skiboats "only"	Trawlers + skiboats fishing
1	518.3	.286	.32	.6	63	37	21
2	1000	.286	.27	.65	73	32	17
3	518.3	.5	.46	.46	19	58	37
4	518.3	.286	.6	.32	11	69	51
5	518.3	.286	.32	.5	50	41	25
6	518.3	.286	.32	.4	38	47	31
7	518.3	.286	.32	.3	28	54	40

The model is sensitive to F and M, shown by the relative change in per-recruit values as a result of varying these parameter estimates. The #1 M value of 0.32 $year^{-1}$ is close to that obtained for similar-sized sciaenids (Pauly, 1980) and is fairly insensitive to input values of L_∞ and T (for *A. thorpei*) in Pauly's equation (8) (Table 2.10). It is therefore assumed to be a reasonable estimate. The estimated L_∞ used here is low compared to the observed maximum size for this species (± 1200 mm), but is representative for the sizes in the Natal fishery (Van der Elst *et al*, 1990).

The estimate of total mortality derived from the slope of the descending limb of the catch curve (Z = 0.92 $year^{-1}$ - Van der Elst *et al*, 1990), is based on three assumptions: constant recruitment; minimal emigration and immigration; and no trends in selectivity over the size range of the catch. The latter two assumptions are probably violated for *A. thorpei*, as these fish are thought to undertake local migrations (Denton and Van der Elst, 1987) and most fish caught in Natal are under 600 mm in length (Van der Elst *et al*, 1990). The value of Z is therefore probably over-estimated. Assuming an M value of 0.32 year^{-1}, current values of F for *A. thorpei* therefore probably range between 0.3 and 0.6 year^{-1}.

Table 2.10: Instantaneous natural mortality estimates for *A. thorpei* based on equation 8 (K = 0.286 year^{-1}).

Temperature (°C)	L∞ (mm)	M (year^{-1})
19	518.3	.30
22	518.3	.32
25	518.3	.34
22	1000	.27

2.4 Discussion

Overall catch composition and effort

Although prawn trawling on the Natal coast is on a small scale relative to similar operations in many other regions of the world, this study shows that there are several features in common, including the target species, *Penaeus indicus*, by-catch genera and the gear which is utilised (Brinca *et al*, 1984; Pauly, 1987; Harris and Poiner, 1991). Typical of penaeid trawls catches is the dominance of a few species in the by-catch (Saila, 1983). In the Tugela Bank trawls, six teleost species comprise 80 percent of the total catch by number (Table 1.2). Of these, four belong to the family Sciaenidae, members of which are common in penaeid trawl catches in several countries (Lowe-McConnell, 1966; Brinca *et al*, 1984; Sheridan *et al*, 1984; Pauly, 1987; Wenner and Sedberry, 1989). The six commonest fish species in the Tugela Bank by-catch can be considered ubiquitous in the area, being recorded in all sampled months (January to November) and depths. Many of the by-catch fish are demersal or semi-demersal shoaling species and this, together with their small size, accounts for their vulnerability to the trawl gear. The high turbidity of the water and slow trawling speeds probably accounts for the low abundance of pelagic species in trawls, as reflected by their poor capture rates.

Fleet effort is variable from year to year, and from month to month (Table 2.5), owing to the seasonal abundance of the target species, *Penaeus indicus*. In some years, prawns appear on the Bank in viable quantities in January, while in other years, they only occur in late March (skipper's logbooks and personal observation). Although the relationship between the offshore migration of penaeids and rainfall/river flow rates is not fully understood, there is evidence of some correlation (Demetriades, 1990), which could possibly account for the variable appearance of the prawns on the Tugela Bank, and hence variable effort.

From the analyses performed, average annual by-catch quantities for the Tugela Bank prawn fleet from 1989 to 1992 are between 252 and 524 tonnes (based on by-catch rates, Table 2.5) and between 569 and 1057 tonnes (based on by-catch ratios, Table 2.6). These estimates should be treated with caution as limited data necessitated the lumping of catch rate and ratio estimates. The estimates of the amount of trawling effort and partitioning into shallow and deep trawls are reliant on the logbooks which are filled in by skippers. In many cases these are inaccurately completed. It should be noted that by-catch estimates obtained by means of by-catch : prawn ratios, although commonly used, are generally only accepted as first estimates (Campos, 1981; Mathews and Samuel, 1989a), because biases may arise despite the jacknife procedure. For example, high ratios obtained in January and February 1992 when prawn catches were poor, resulted in inflated by-catch estimates when prawns were abundant.

Estimates based on catch and effort data tend to be more reliable (Mathews and Samuel, 1989a). Assuming that the obtained catch rates are representative of overall fleet rates, an average annual estimate of 400 tonnes of by-catch is more likely. Using the same estimation procedures, the corresponding quantities of annual discarded catch are estimated to be between 219 and 437 tonnes (based on discard rate estimates) and between 522 and 966 tonnes (based on discard : prawn catch ratios, Table 2.6), with an annual average estimate of 315 tonnes likely to be more reliable. The difference between the by-catch and discarded catch quantities is made up by retained by-catch of marketable fish, crabs and cephalopods. Actual catches of these are not recorded precisely by skippers, and are therefore difficult to confirm. Available information indicates that the estimates of retained by-catch obtained in this study are too high (Ian Cameron, pers. comm.)*, which could also imply overestimation of by-catch rates and quantities. Estimates of by-catch quantities recorded in other penaeid prawn fisheries are considerably higher. In Kuwait, Mathews and Samuel (1989b) estimated average annual discards of 21 000 tonnes in Kuwait, at an average ratio of 14.3:1, while Williams (1986) estimated annual by-catch quantities to be 4 800 tonnes at a ratio of 6:1 in the Torres Strait, Australia. In the Gulf of Mexico, annual by-catch is estimated at 500 000 tonnes, at an average by-catch:prawn ratio of 10:1 (Nichols, 1990), and Maharaj and Recksiek (1991) obtained an annual by-catch estimate of 1 594 tonnes based on a by-catch:prawn ratio of 14.7:1 and an annual prawn catch of 108 tonnes in the Gulf of Paria, Trinidad.

Almost three quarters of the Tugela Bank by-catch comprises fish i.e. 300 tonnes per year, most of which is discarded. These fish are killed as a result of crushing as the trawl is hauled, and also by the effects of barotrauma. Large flocks of terns (*Sterna* spp.), albatrosses (*Diomedea* spp.) and, in winter, Cape gannets (*Morus capensis*), often follow the trawlers, scavenging the discarded fish from the surface, and sharks (*Carcharhinus* spp.) are often observed feeding as well. Hill and Wassenberg (1990) found that sinking by-catch from prawn trawlers is eaten by numerous teleost families in Torres Strait, Australia. Discards also feature strongly in the diet of benthic scavengers such as crabs (Wassenberg and Hill, 1987), and since prawns are omnivorous (de Freitas, 1989), it is likely that they also feed on trawler discards (Sheridan *et al*, 1984). Ecological implications of this redistribution of demersal organic material are unknown, although there is evidence that removal of prawn predators such as teleosts by trawling may lead to increased catches of prawns (Pauly and Palomares, 1987; Brewer *et al*, 1989), and that a reduction in discards may result in reduced prawn catches (Sheridan *et al*, 1984).

The Tugela Bank has only been fished regularly since 1976, prior to which trawling was inconsistent (de Freitas, 1989). The fishing grounds are therefore relatively new, and few historical data exist. Surveys in the 1920s (von Bonde, 1928), the 1960s (Heydorn, 1966-1968) and 1970s (Champion, pers. comm.)*

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reported many of the common species currently occurring in trawl catches, but no quantitative data are available. Evidence for long-term changes in faunal community structure as a result of trawling has been found elsewhere (Young and Sainsbury, 1985; Pauly, 1987; Harris and Poiner, 1991), and it is possible that similar effects may occur in this fishery in the long term. However, the level of fishing effort on the Tugela Bank is low. Only five trawlers are permitted inside seven nautical miles of the coast at any one time. To date, the maximum number observed on the Bank has been three (pers. obs.). Furthermore, the seasonality of the target species, *P. indicus*, results in the majority of trawling occurring during only nine months of the year (Table 2.4). Furthermore, the trawlers are not restricted to fishing on the Tugela Bank, as they can also target deep water knife prawns (*Haliporoides triarthrus vnirio*). The trawlers therefore operate where catches are best, which serves to reduce effort on the inshore penaeids.

The nature of the trawl ground may also reduce the accessibility of fish to trawlers: the trawlable area is irregularly shaped (Study area: Figure 1), indicating areas unsuitable for trawl gear. Although obstructions are not apparent on echosounders, skippers know from experience that the ground is rough, and avoid these areas (pers. obs.). These irregularities of the sea bottom may be low relief outcrops of beachrock (see Study Area) i.e. not reef *per se*, but sufficient to prevent trawling, and which may form areas of natural protection (harvest refugia) from trawling for demersal organisms.

Catches of linefish

Concern has been expressed locally regarding the impact of the prawn trawlers on linefish. Analysis of catches by three sectors of the fishing community shows that there is minimal overlap of trawl by-catch species and those targeted by linefishermen, primarily because the respective fishing grounds are spatially distinct. Skiboat operators fish either on reef (for demersal fish) or in the pelagic zone (for game fish), and rock and surf anglers concentrate on the shoreline. None of these three areas are suitable for penaeid prawns, which favour muddy or sandy areas (de Freitas, 1984).

One linefish species which does occur in trawl catches, the squaretail kob, *Argyrosomus thorpei*, is assuming increasing importance in commercial linefish catches as stocks of reef fish such as the sparids decline (Garratt and Van der Elst, 1990). *A. thorpei* are seasonally abundant on the Tugela Bank, with numbers in trawl catches at a maximum during the first three months of each year (Figure 2.3). Stomach content analysis of these fish indicates that they are utilising the Tugela Bank as a nursery area, there being suitable crustacean prey in quantity (pers. obs.). As they grow in size, these fish move to flat reefs and pinnacles in deeper water, where there is an increased proportion of teleost prey in their diet (Van der Elst *et al*, 1990). From the size of these trawled fish (Figure 2.4), and knowledge of their spawning season (Van der Elst *et al*, 1990) they are age 0 fish, probably spawned four to six months earlier.

Based on the estimates obtained (Table 2.8), the Tugela Bank trawlers caught an average of 209 000 squaretail kob per year, from 1989 to 1992. The accuracy of these estimates is probably low, owing to gaps in the data. The large range of these estimates is due to the variablity of fishing effort. This is particularly the case for the low estimated catch numbers during 1991 and 1992, when trawling effort was low in January and February (Table 2.5). In 1989, however, trawling effort was high in January and February, as prawns were present in viable quantities. Based on estimated numbers of *A. thorpei* caught by the trawlers and an average fish weight of 40 grams, 33 tonnes of this species were caught by trawlers from 1989 to 1992. The reported commercial linefish catch of squaretail kob for 1989 to 1992 on the North coast was 378 tonnes (National Marine Linefish System (NMLS) data reports, 1989-1992) and recreational catches were about 12 tonnes for the same period (NMLS data reports, 1989-1992). The trawl fishery therefore removes less than ten percent by weight of total line catches of this species.

However, the per-recruit model utilised shows that removal of these young-of-the-year fish has considerable impact on yield-per-recruit (YPR) and spawning biomass-per-recruit (SBPR) for the whole fishery, for a wide range of input parameter values (Table 2.9). Even assuming high values of natural mortality M (as reported for age 0 fish (Laevastu and Favorite, 1988; Robin, 1992)), YPR and particularly SBPR are increased if the trawlers do not catch squaretail kob. Assuming the estimated value of M (0.32 $year^{-1}$) is close to the actual M, a recommended management strategy which sets F = M (Gulland, 1970) results in a SBPR value of 50 percent of the unfished level - if there is no trawling for *A. thorpei* (Table 2.9). This (F_{SB50}) strategy, i.e. of setting a fishing mortality such that spawning biomass-per-recruit will not drop below this 50 percent level, is an often-stated management goal (Butterworth *et al*, 1989). It is designed to prevent spawning biomass from dropping below a critical level, which in turn could affect recruitment. Recently, however, Clark (1991) suggested that an F value which would reduce SBPR to 35 percent of its unfished level would provide high yields from demersal fish without threatening recruitment.

Given that the current F for the squaretail kob fishery (trawlers and skiboats combined) is 0.6 $year^{-1}$, the model showed that spawning biomass-per-recruit is currently 21 percent of the unfished (pristine) level (Table 2.9). The model also showed that YPR would increase by 63 percent and SBPR would increase to 37 percent of the unfished level if the trawlers did not catch age 0 squaretail kob. Even assuming F = 0.6 $year^{-1}$ to be over-estimated, reduced levels of F show improved YPR and SBPR in the absence of trawling for *A. thorpei*. There would therefore appear to be merit in reducing trawling effort during the first two months of the year, when the abundance of *A. thorpei* is relatively high and catches of prawns are generally low. A simple risk-analysis of this situation lends further support for this proposition (Figure 2.5). Based on total hourly running expenses (per trawler) of about R 270.00 and an ex-vessel price of R 27.00 per kg of prawns (Ian Cameron, pers. comm.)*, the economic profitability break-even point is 10 kg of prawns trawled per hour. This accounts for the concentration of trawling effort from March to September. Delaying the commencement of trawling would have the effect of reducing the trawling component of fishing mortality for squaretail kob. This would increase the yield-per-recruit and spawning biomass-per-recruit of the fishery and should lead to greater yields to the skiboat fishery. Trawlers may benefit by optimising their cost-benefit ratio and may further benefit from increased catch weights of prawns as a result of the longer growth period of prawns before harvesting. There is evidence to support this latter proposal (Somers, 1990; Condrey, 1991), although this would need to be confirmed for local penaeids.

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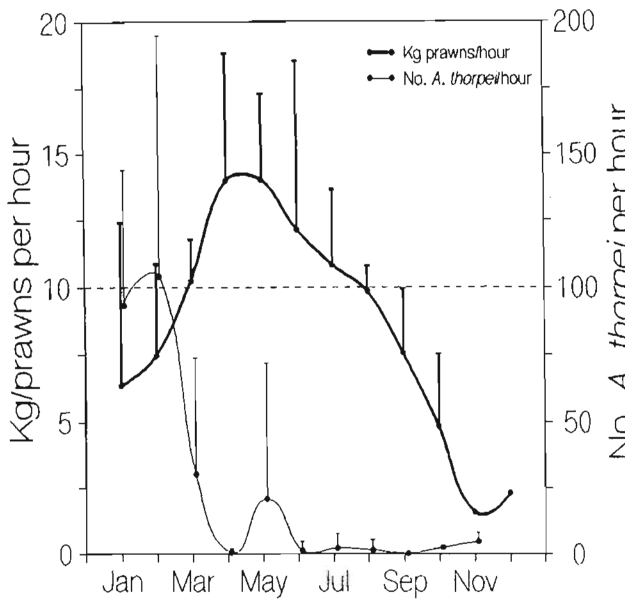


Figure 2.5: **Plot of average hourly Tugela Bank trawl catch rates of penaeid prawns (kg) and *A. thorpei* (numbers), from 1989 to 1992. Dashed line represents the prawn trawling profitability break-even point.**

CHAPTER 3

Aspects of the biology of three common fish species occurring in Tugela Bank prawn trawl catches

3.1 Introduction

The investigation of Tugela Bank prawn trawler by-catch necessitated the examination of large quantities of fish, and provided an opportunity to collect information on the biology of trawlable species. In common with many of the world's penaeid prawn fisheries, the Tugela Bank catches have a high proportion of fish belonging to the sciaenid family (Chapters 1 and 2). These fish are characterised by a highly developed lateral line system and sound producing apparatus, hence their colloquial name of "croakers" or "drums". These features are probably adaptive to a life in turbid waters off river mouths, where these fish commonly occur (Trewavas, 1977). Many of the species form shoals (van der Elst, 1988) and this, together with their demersal habits, probably accounts for their high incidence in bottom trawl catches.

The three species chosen were the bellfish, *Johnius amblycephalus*; the mini-kob, *Johnius dussumieri*, and the snapper kob, *Otolithes ruber*. They were selected owing to their high abundance in Tugela Bank trawl catches and also since little had been published on their biology, either locally or elsewhere. They are widely distributed in the Indo-Pacific (Smith and Heemstra, 1986) and are important components of fisheries in several countries (Fischer and Bianchi, 1984). It is possible, given the ever-increasing demands being made on traditional existing fisheries, that these three species will assume greater local significance as potentially exploitable stocks within the foreseeable future. Biological information is necessary for the wise management of any fish stock and is presented here in anticipation of this eventuality.

3.2 Methods

Owing to the size of the catches, it was not possible to collect data from the whole trawl. Analysis of by-catch composition necessitated the collection of a random half-crate sample once the target penaeid species had been removed (Chapters 1 and 2). From each half crate, a subsample of each of the three sciaenid species above was analysed according to the following procedure:

1 Population composition - The total lengths of a maximum of 50 (undamaged) fish per species were recorded in each sample. An effort was made to measure fish from the full range of depths trawled during a sampling trip. At least 20 fish of each species from each sample were sexed so as to calculate a sex ratio. Individual weights were mostly collected during the first year of sampling in order to establish a length-weight relationship of the form: **weight in grams = a(total length in mm)^b.** The fitted curve is based on a linearised least squares regression (Pauly, 1984).

2 Reproduction

2.1 Gonadal development - At least 20 fish of each species from each sample were assessed using a macroscopic staging index based on Garratt (1985) and Buxton (1987):

Stage 1. Immature

The gonads are initially transparent and thread-like, and sex is not distinguishable. Later in this stage the gonads are thicker and about half the body cavity in length. The ovaries are pale orange/yellow, with no eggs visible. The testes are off-white in colour, with no sperm in the duct.

Stage 2. Active

The gonads are about three-quarters of body cavity in length. The ovaries are slightly swollen, oval in cross-section and darker yellow, with eggs just visible. Testes are firm, white and triangular in cross-section; milt is visible in the spermatic duct.

Stage 3. Ripening

The ovaries are between three-quarters and the full length of the body cavity and are swollen, yellow and packed with opaque eggs. Blood vessels are well developed. Testes may be between half to three-quarters of the body cavity length. They appear swollen, flaccid and white, and milt is extruded when pressure is exerted on them.

Stage 4. Ripe/partly-spawned

Ripe ovaries contain a large number of clear eggs, which, in spawning fish, flow freely from the vent. Ripe testes have milt flowing at the slightest pressure and tend to rupture easily. Partly spawned testes may show pink haemorrhage.

Stage 5. Spent

Spent ovaries are much reduced in volume, are reddish and contain some opaque eggs. Spent testes are mottled, brownish and much reduced in size.

Stage 6. Resting

Gonads in this stage are similar in appearance to those in stage 1, but are longer, extending almost the full length of the body cavity. No resting gonads were observed in this study.

Histological techniques were used to verify the accuracy of the gonadal macroscopic assessment. Since the three species chosen are closely related, and since the outward appearance of the gonads was very similar for all three, it was decided to base the description of the ultrastructural gonadal development on *O. ruber* alone. Five gonads per developmental stage were collected from each sex while on board the trawler, and preserved in 10 percent formalin for three to six months. Thereafter, a cross-section from the middle of the gonad was removed, dehydrated in an alcohol/xylene series, sectioned at 4-5 microns and stained with Erlich's haematoxylin and eosin. The description of the progressive development of the ovaries is derived from Yamamoto (1956), and that of the testes from Hecht (1976).

2.2 Spawning season - Two techniques were used to determine seasonality of spawning, namely a gonado-somatic index and by determining the proportion of reproductively active fish in the sample.

2.2.1 Gonado-somatic index - This involves calculating the mean proportion of gonad weight to body weight on a monthly basis (Buxton, 1987; Mann, 1992):

$$Gonad\ index\ (GI) = \frac{Gonad\ mass\ (g)\ x\ 100}{Body\ mass\ (g)} \tag{1}$$

Lumping of data by month was necessary as consecutive monthly samples could not be collected owing to logistical difficulties in getting on board trawlers. Only mature female fish (i.e. stage 2 of gonadal development and above) were used, in order to avoid the masking effect of fish in lower stages of development (Garratt, 1985) and also because the testes did not always increase greatly in size during development. All weights were obtained from fish which had been frozen and then thawed once, as on-board collection of this information was not possible.

2.2.2 Relative proportion of reproductively active fish - Based on the gonad stages 1-5 above, numbers of fish in each stage of development were expressed as a percentage of the total sample. Stages 4 (spawning) and 5 (spent) were combined to indicate the period of greatest activity. Data were lumped on a monthly basis as above.

2.3 Size at 50 percent maturity - Fish were assessed as being mature from stage 3 onwards. Only female fish were used, as difficulty was experienced in positively staging male fish which had been frozen and numbers of mature males were low. Once the spawning season had been established for each species, the proportion of fish in stages 3-4 of development, collected during months of spawning, was expressed as a percentage of the total for each size class. Size at 50 percent maturity was estimated from fitted logistic curves of the form:

$$Y=\frac{1}{1+\exp(-(X_{mid}-X_{0.5})/\delta)} \qquad (2)$$

where Y is the proportion of mature fish in length class X, X_{mid} is the midpoint of the class interval, $X_{0.5}$ is the length at 50 percent maturity and δ is the width of the maturity ogive (Butterworth *et al*, 1989). Precision of the estimates is presented as 95 percent confidence intervals based on asymptotic standard errors.

3 Feeding - At least 20 fish per species per sample were examined. Stomachs were opened and the contents identified to species level if possible. Assessment was based on the frequency of occurrence method (Ricker, 1971), i.e. the number of stomachs in which a food category appears is expressed as a percentage of the total number of stomachs examined. More detailed analyses of stomach contents, such as volumetric analysis, were not applied owing to the small sizes of the fish and also because of the possibility that discarded species from the by-catch probably constitute a considerable proportion of the diets of all three species. It is possible that these food organisms, which are not normally available as food to fish in the area, become available once discarded by the trawlers. This implies that the dietary composition of fish scavenging on discards would differ from that of fish which foraged "naturally". Some evidence for this has been found in Australia, where prawn trawler discards form part of the diet of fish in the area (Hill and Wassenberg, 1990; Wassenberg and Hill, 1990).

During the first year of data collection, it became apparent that numbers of mature fish were low, presumably owing to the bias of the trawl gear towards small fish. Therefore, the random samples were supplemented by the selection of larger fish from the trawl catches in order to describe aspects of their biology more completely. The data from these fish were used in the calculation of the length-weight equations, gonado-somatic indices and size at 50% maturity for all three species, as well as supplementing stomach content data from randomly sampled fish. Limited additional biological data for these species were also obtained from seine netters operating in Durban, for the month of December (1991), which served to confirm spawning actitivity.

3.3 Results and Discussion

Most publications on the biology of trawlable marine fish species in South Africa have concentrated on species of commercial importance (e.g. Baird, 1974; Zoutendyk, 1974; Hecht, 1976; Payne, 1986). Publications on the biology of sciaenids are limited to the geelbek, *Atractoscion aequidens*, (Griffiths, 1988) and aspects of the life histories of the kobs, *Argyrosomus hololepidotus* (Wallace, 1975; Beckley, 1990) and *A. thorpei* (van der Elst *et al*, 1990). Investigation of the composition of by-catch of prawn trawlers on the Tugela Bank therefore provided an opportunity to collect data on aspects of the biology of three little studied sciaenid species, *Otolithes ruber*, *Johnius dussumieri* and *Johnius amblycephalus*. These are the commonest fish caught by Tugela Bank trawlers, and are widely distributed along the coastal regions of the Indian Ocean, occurring from South-east Africa, through the Arabian Gulf and India, and across to Australia (Druzhinin, 1974; Trewavas, 1977).

1 Population composition

Mean sizes and ranges for random and selected samples of each species are presented in Table 3.1. The three species are all relatively small, typical of prawn by-catch species (Saila, 1983). The codend mesh in these fisheries is generally between 30 and 50 mm (stretched) in order to retain the target species (penaeids), and as a result by-catch organisms tend to be small. The length frequency distributions of randomly sampled *O. ruber* and *J. amblycephalus* are unimodal and positively skewed (Figure 3.1), the latter feature possibly indicating that the full population is not being sampled. The length distribution of *J. dussumieri* is more normally distributed, with a secondary mode possibly indicating the occurrence of two cohorts, although an age and growth study is needed to confirm this.

Table 3.1: Lengths (mm) of three sciaenid species from Tugela Bank prawn trawlers.

	O. ruber	***J. dussumieri***	***J. amblycephalus***
Mean	163	121	121
Range	39-456	38-220	52-248

O. ruber

J. dussumieri

J. amblycephalus

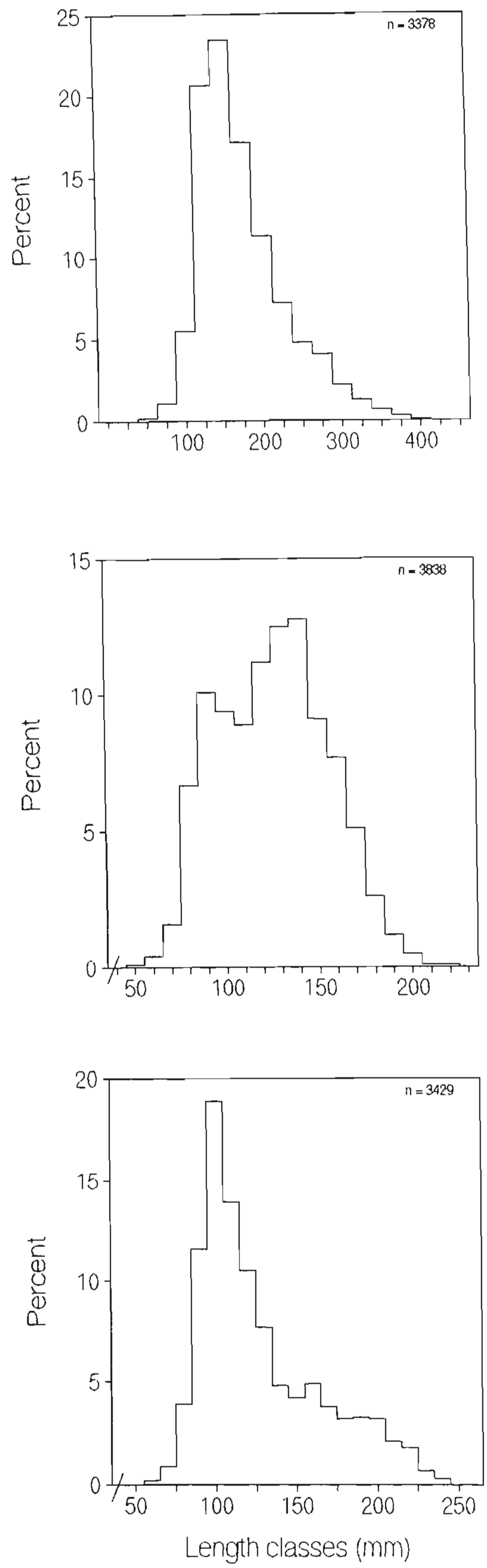


Figure 3.1: **Overall length frequencies of three sciaenids from randomly sampled Tugela Bank prawn trawl catches, from May 1989 to June 1992.**

It is likely that the Tugela Bank functions as a nursery area for these and other demersal species (Chapter 1 and this chapter), which accounts for the predominance of smaller length classes in the catch. *J. dussumieri* is known to utilise estuaries as nursery areas (Wallace *et al*,1983; van der Elst, 1988), so numbers of juveniles of this species in the marine environment are reduced relative to the other two species. This could explain the more centralised mode in the length frequency distribution of *J. dussumieri*.

Although *O. ruber* is reported to attain a size of 800 mm (Smith and Heemstra, 1986), the maximum length recorded in this study was considerably less (Table 3.1). Other investigators also found the size of trawl-caught *O. ruber* to be small. Navaluna (1982) reported an average length of 110 mm for this species in the Phillipines, while in the Gulf of Aden the average length was 210 mm (Druzhinin and Filatova, 1977). Large specimens of about 500 mm sometimes occur in local ski-boat catches (pers. obs.), but not often. *J. dussumieri* and *J. amblycephalus* are reported to attain lengths of 270 and 230 mm respectively (Day *et al*, 1981; Smith and Heemstra, 1986), which are close to the maximum sizes reported in this study (Table 3.1). The mean size of these species caught on the Tugela Bank is, however, considerably smaller. Mean sizes and ranges in this study were similar to those obtained for the same species caught in prawn trawlers on the Sofala Bank of Mozambique (Brinca *et al*, 1984).

Length frequency distributions over three depth ranges are presented for all three species in Figure 3.2. The categories are shallow (20-24 m), medium (28-33 m) and deep (33-45 m). The overall range of depths is not great, but some trends are apparent. There is a general increase in size with depth in all three species. *O. ruber* shows the strongest size-related depth preference with larger individuals occurring in deep water, and fish from medium depths intermediate in size between fish from the other two depth categories. Smaller fish clearly occur mostly in shallower waters. The carnivorous habits of this species (Navaluna, 1982; Figure 3.10, this chapter) may result in fish of a similar size shoaling together in order to reduce intraspecific predation, a phenomenon which has also been suggested for other sciaenids, namely *Argyrosomus thorpei* on the Natal coast (van der Elst *et al*, 1990), and *Macrodon ancylodon* in British Guiana (Lowe-McConnell, 1966).

O. ruber

J. dussumieri

J. amblycephalus

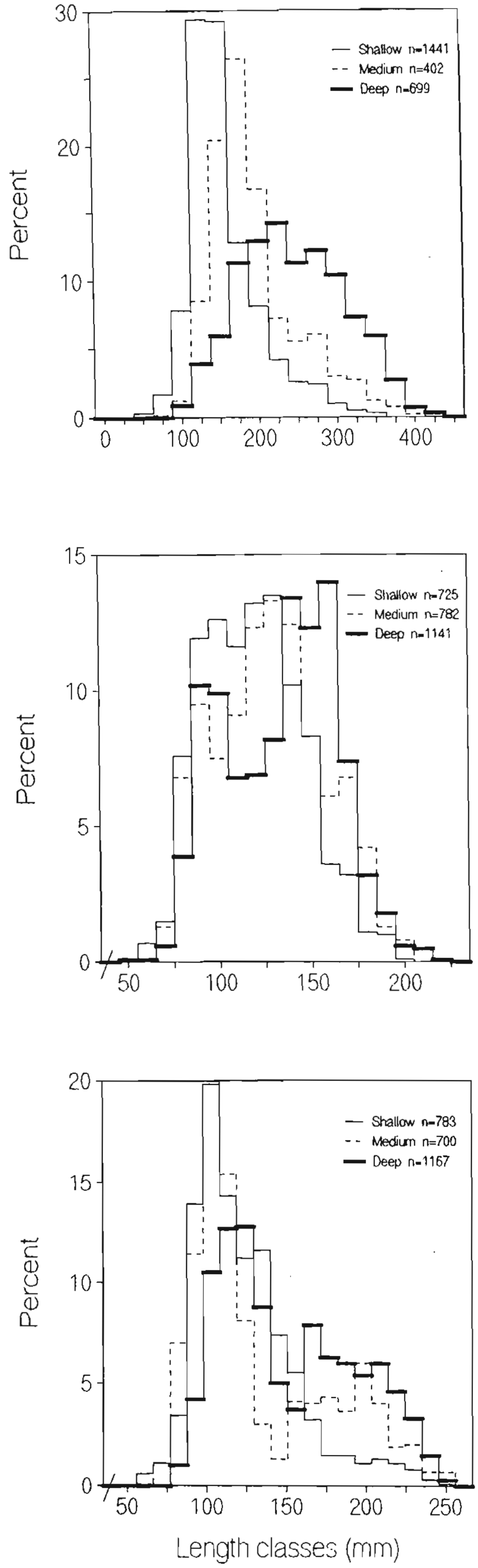


Figure 3.2: **Length frequencies (by depth) of three sciaenids from randomly sampled Tugela Bank prawn trawl catches, from May 1989 to June 1992.**

The frequency distribution of fish from deeper water approaches normality (Figure 3.2), and has a higher mode, so the skewed frequency distribution of the overall sample (Figure 3.1) is probably not entirely due to gear selectivity but is also a result of the preference of smaller individuals for shallower water, from which most samples were obtained. Small *J. amblycephalus* dominate all three depth categories, with larger fish occurring in greater numbers in medium and deep water. The skewed overall frequency distribution of this species is therefore probably a reflection of the real situation i.e. small *J. amblycephalus* are in the majority over the range of depths trawled. It is possible that larger individuals occur in deeper water beyond the prawn grounds, but this needs to be confirmed. Large *J. dussumieri* tend to be caught in deeper water, but overall there is no clear size-depth correlation.

Overall sex ratios of randomly sampled fish (Table 3.2) show that females outnumber males in all three species. The chi-squared values are not very high, so the deviation from the expected 1:1 ratio is not significant. Randomly sampled females are slightly larger than males in *O. ruber* and *J. dussumieri* and outnumber males in the larger size classes (Figure 3.3). However, if the larger selected (i.e. non-random) fish are included in the distribution of sex ratios by size class (Table 3.3), it is apparent that sex ratios of *O. ruber* and *J. dussumieri* differ markedly from 1:1 in the larger size classes: most larger fish are female in these two species. Deviations from a 1:1 sex ratio may be used to infer sex reversal in exploited populations (Wenner, 1972), but neither macrosopic staging nor histological techniques produced evidence of sex reversal (Section 2.1). An alternative explanation for the departure from a 1 : 1 sex ratio and size disparity between sexes may be a differential growth rate for males and females (Garratt, 1984), but this would need to be confirmed by an age and growth study. Other studies have also reported larger sizes for trawled females of *O. ruber* (Devadoss, 1969), and *J. dussumieri* (Day *et al*, 1981).

Table 3.2: Overall sex ratios and mean lengths of three sciaenid species from random samples of Tugela Bank prawn trawl catches (May 1989 to June 1992).

	O. ruber	***J. dussumieri***	***J. amblycephalus***
Ratio ♀:♂	1:1.28	1:1.15	1:1.13
Chi-square	15.05	5.60	4.02
Mean length ♀ (mm)	214	139	140
Mean length ♂ (mm)	202	127	138

O. ruber

J. dussumieri

J. amblycephalus

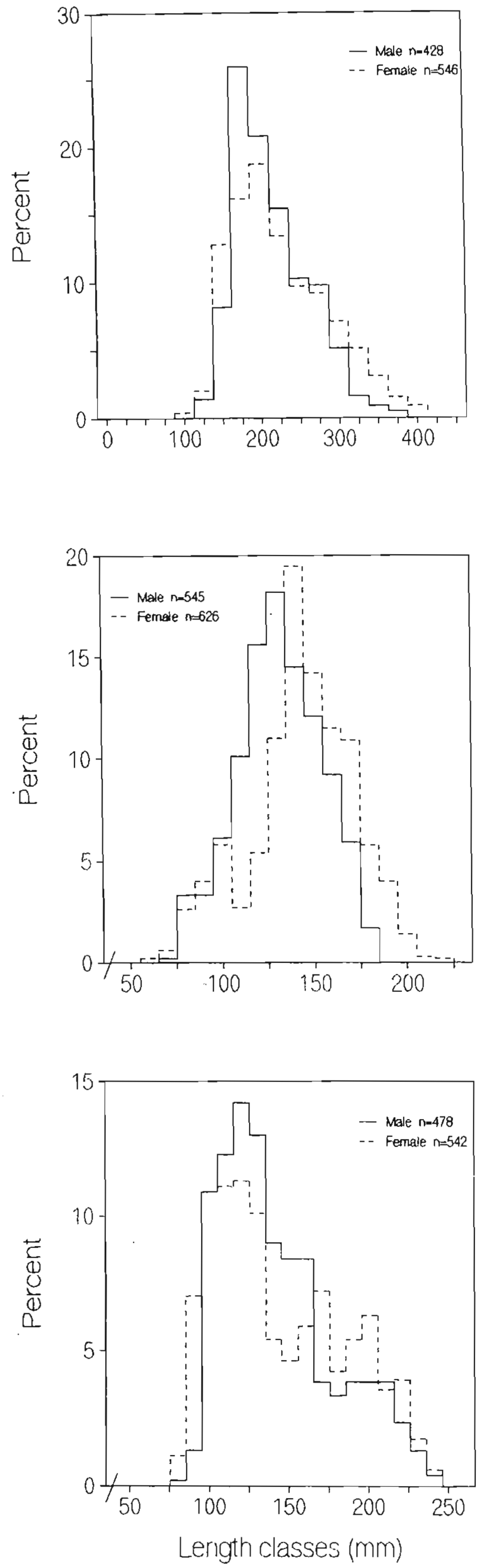


Figure 3.3: Length frequencies (by sex) of three sciaenids from randomly sampled Tugela Bank prawn trawl catches, from May 1989 to June 1992.

Table 3.3: **Sex ratios (♀:♂) by size class of three sciaenid species from random and selected samples of Tugela Bank prawn trawl catches.**

Species	Size classes (upper limit mm)	n(♀)	n(♂)	Sex ratio	Chi-square
O. ruber	100	2	-		
	125	11	6	1 : 1.83	.69
	150	71	36	1.97	.94
	175	92	116	0.79	.04
	200	106	92	1.15	.02
	225	81	69	1.17	.03
	250	65	52	1.25	.06
	275	76	60	1.27	.07
	300	100	46	2.17	1.37
	325	118	25	4.72	13.84
	350	117	27	4.33	11.09
	375	75	5	15.0	196.0
	400	33	-		
	425	18	-		
	450	4	-		
	475	3	-		
J. dussumieri	60	1	-		
	75	11	12	1 : .92	.01
	90	34	25	1.36	.13
	105	47	53	.89	.01
	120	44	121	.36	.41
	135	131	148	.89	.01
	150	168	118	1.42	.18
	165	132	92	1.44	.19
	180	98	35	2.8	3.24
	195	70	-		
	210	20	-		
	225	2	-		
J. amblycephalus	90	26	25	1 : 1.04	.002
	105	89	80	1.11	.01
	120	91	99	.92	.01
	135	72	91	.79	.04
	150	37	56	.66	.12
	165	64	63	1.02	.0004
	180	56	36	1.56	.31
	195	64	44	1.46	.21
	210	64	47	1.36	.13
	225	66	36	1.8	.64
	240	33	11	3	4
	255	3	1	3	4

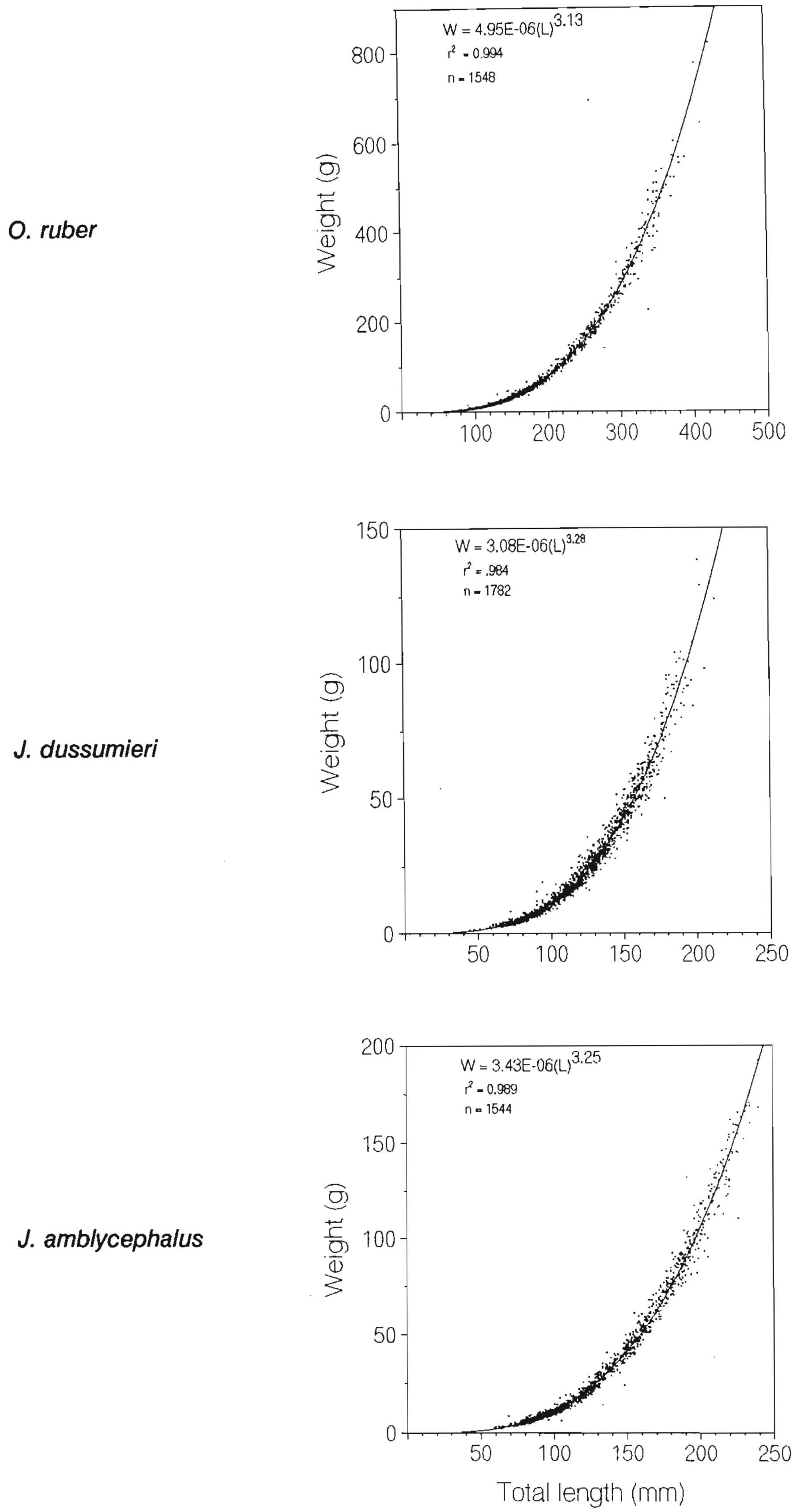


Figure 3.4: Length-weight plots of three sciaenids from Tugela Bank prawn trawl catches, from May 1989 to June 1992.

Length-weight plots and equations for the three species are presented in Figure 3.4. The high r^2 values indicate that the data are well correlated in all three species. The a and b parameters for *J. amblycephalus* and *J. dussumieri* are virtually identical, the body form of these species being very similar. *O. ruber* has a higher length:body depth ratio relative to the former two species, hence the lower b parameter. A b value of greater than three indicates allometric growth, i.e. there is an increase in girth of the fish with no further increase in length. Values of a and b parameters for *O. ruber* and *J. dussumieri* trawled on the Tugela Bank are similar to those obtained by Druzhinin and Filatova in the Arabian Gulf (1977); Navaluna in the Phillipines (1982) and Brinca *et al* in Mozambique (1984). No previous length-weight data are available for *J. amblycephalus*.

2 Reproduction

2.1 Gonadal development - Histological examination verified the classification of gonads based on visual assessment.

Histological development of the ovary

Stage 1 - Immature (Figure 3.5a)

This stage is characterised by the numerous pre-vitellogenic (i.e. pre-yolk formation) oocytes, which are asymmetrical in shape. They occur in ovigerous folds of the tunica albuginea (the ovary wall). These oocytes have large, central nuclei which contain several peripheral basophilic nucleoli of varying sizes. The cytoplasm, which is also darkly stained, has a large volume relative to the nucleus.

Stage 2 - Active (Figure 3.5b)

Some of the oocytes have increased in size and are more regularly shaped. They are scattered throughout the ovary, and are just visible with the naked eye. Numbers of nucleoli have increased, and these are smaller and more obviously on the periphery of the nucleus. A thin pink-staining membrane, the zona radiata develops around the oocyte, which marks the commencement of yolk development. The volume of cytoplasm is reduced as a result of the increased size of the nuclei, and is not as basophilic. Some oocytes have cytoplasmic yolk vesicles developing on their periphery.

Stage 3 - Ripening (Figure 3.5c)

This stage has oocytes in several stages of development. The most developed are the 3° oocytes, which are large and circular in cross-section. They have many yolk granules in their cytoplasm, an irregularly shaped nucleus with no nucleoli and a thick zona radiata. These oocytes occupy the majority of the ovary and are easily visible with the naked eye. By the end of this stage the oocytes are packed with yolk granules (mature yolk stage), and the nuclear membrane has begun to degenerate. Most of the ovary is filled with these ripe oocytes.

Stage 4 - Ripe/partly-spawned (Figure 3.5d)

At this stage, many oocytes are fully developed, being transparent and at their maximum size. Normally spherical, the oocytes in Figure 3.5d have collapsed as a result of the sectioning process. The yolk granules in the oocytes have coalesced into a uniform yolk mass. Partly-spawned ovaries have gaps between oocytes where eggs have been released. Even at this stage there are oocytes in several stages of development, indicating that the eggs are not all released at once. It is therefore probable that these fish are serial spawners.

Stage 5 - Spent (Figure 3.5e)

This stage is characterised by atresia of oocytes which have not been spawned. There are also oocytes in several stages of development, and the general appearance is that of an ovary at early stage 2 of development. There are, however, gaps between oocytes where eggs have been released and strands of connective tissue may be evident.

Histological development of the testes

Stage 1 - Immature (Figure 3.6a)

Testes initially consist of a matrix of undifferentiated connective tissue, with spaces that form the lumina of the seminiferous tubes (lobules). These lobules lead into the main sperm duct. Spermatogonia, appearing as large grey cells, develop on the periphery of the lumina.

Stage 2 - Active (Figure 3.6b)

The spermatogonia proliferate to produce smaller 1° spermatocytes in bundles or cysts around the periphery of the lumina. These 1° spermatocytes in turn divide to produce 2° spermatocytes which are even smaller. All three divisional stages can be seen in cross-section in the lobules. The more mature lobules tend to occur towards the centre of the testes (in cross section). Division of the 2° spermatocytes into spermatids by meiosis commences in this stage.

Stage 3 - Ripening (Figure 3.6c)

This stage is marked by the enormous quantities of spermatocytes, spermatids and spermatozoa. The latter are concentrated in the lumina of the lobules, and particularly near the spermatic duct. Adhesion of the spermatozoan tails leads to aggregations which dissociate towards the end of the stage, producing free sperm, some of which is released into the duct.

Stage 4 - Ripe/partly-spawned (Figure 3.6d)

Masses of spermatozoa are concentrated in the spermatic duct, and partially empty lobules are apparent, particularly near the spermatic duct. Spermatocytes and spermatids still occur, but are concentrated in lobules on the periphery of the testes.

Stage 5 - Spent (Figure 3.6e)

The numbers of spermatozoa in the lobules and spermatic duct are much reduced. Sperm remaining within the lobules appears to be degenerating. Spermatogonial cells have been reported to begin reappearing in the lobule walls at this stage (Hecht, 1976), but were not observed in these sections.

Figure 3.5 a-e: **Oocyte development in *O. ruber***

Figure 3.5a: **Stage 1 - Immature. 160 X.**

Asymmetrically shaped pre-vitellogenic oocytes - PO

Centrally located nucleus - N

Figure 3.5b: **Stage 2 - Active. 160 X.**

Yolk vesicle oocyte - YO

Yolk vesicles in yolk vesicle oocyte - YV

Zona radiata surrounding yolk vesicle oocyte - ZR

Figure 3.5c: **Stage 3 - Ripening. 160 X**

Tertiary oocytes - TO

Yolk granules - YG

Figure 3.5d: **Stage 4 - Ripe/partly-spawned. 160 X.**

Ripe egg - RE

Vacated space (egg already released) - VS

Figure 3.5e: **Stage 5 - Spent. 160 X.**

Atretic oocyte - AO

Connective tissue - CT

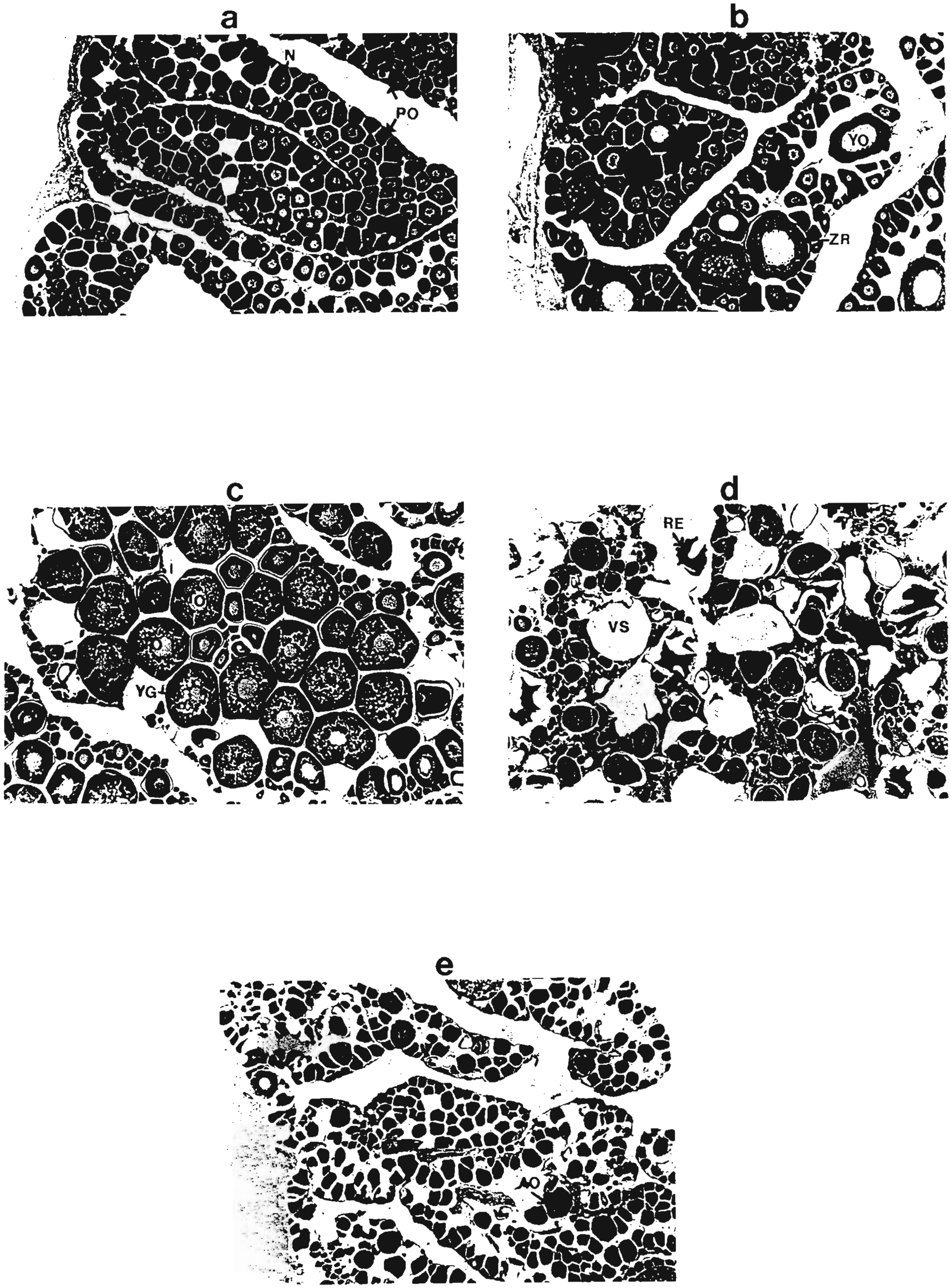

a
N
PO
b
YO
ZR
c
YG
d
RE
VS
e
AO

Figure 3.6 a-e: **Spermatocyte development in *O. ruber***

Figure 3.6a: **Stage 1 - Immature. 320 X.**

Connective tissue - CT

Lobule lumen - LL

Spermatogonia - S

Spermatic duct - SD

Figure 3.6b: **Stage 2 - Active. 320 X.**

Lobule lumen - LL

1° spermatocytes - PS

2° spermatocytes - SS

Figure 3.6c: **Stage 3 - Ripening. 160 X.**

Spermatozoa - SZ

Spermatic duct - SD

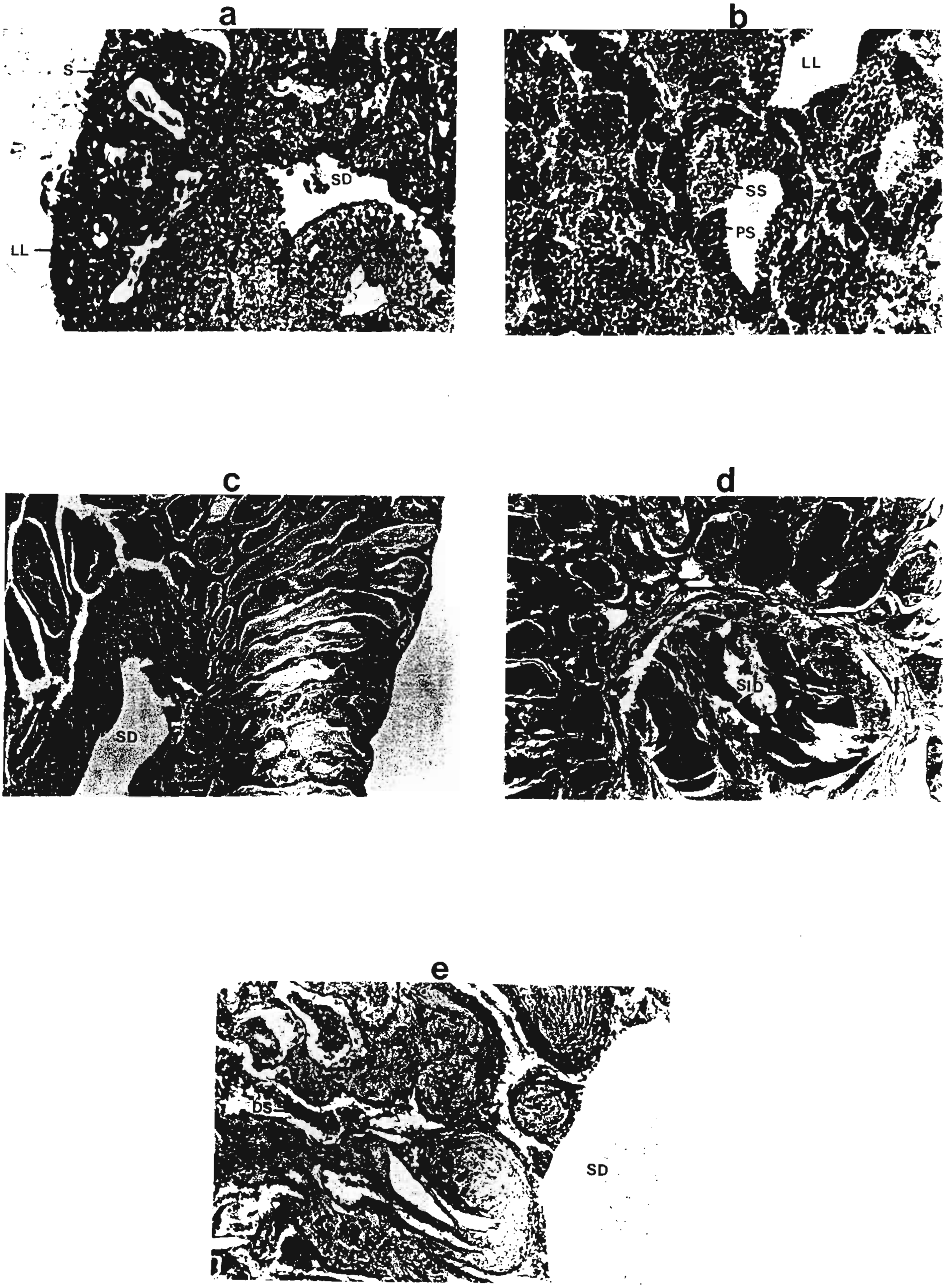
Figure 3.6d: **Stage 4 - Ripe/partly-spawned. 160 X.**

Sperm in duct - SID

Figure 6e: **Stage 5 - Spent. 220 X.**

Degenerating sperm - DS

Spermatic duct - SD

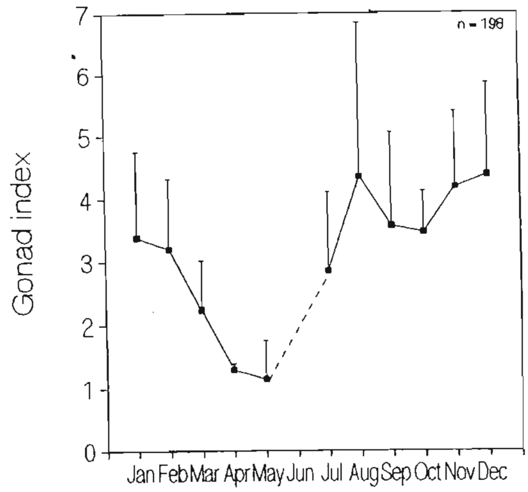

a
S
LL
SD
b
LL
SS
PS
c
SD
d
SID
e
DS
SD

2.2 Spawning season

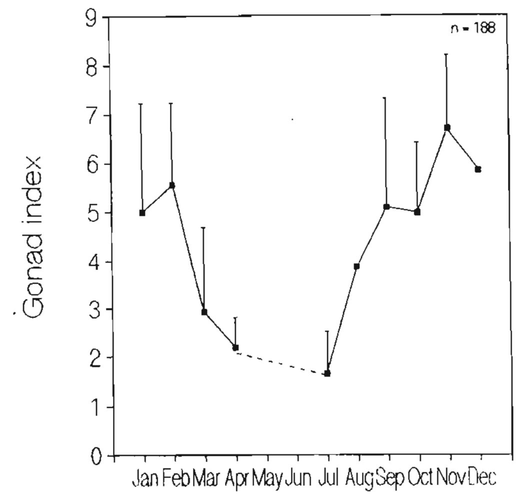
Average monthly gonado-somatic indices are presented in Figure 3.7. Female fish with gonads at stage $\geq$ 2 of development, which were used to calculate the indices for each species, did not always occur every month. As a result there are gaps in the monthly data and sample sizes are small. Trawling seldom takes place from September to November and not at all in December (Chapter 2), although a small sample, obtained from the beach seine netters in Durban in December 1991, was used to supplement trawl data. Increases in the monthly averages indicate an increase in gonadal activity from August to December for *O. ruber*, from September to February for *J. dussumieri* and from November to February, as well as May for *J.amblycephalus*. The peak in May is possibly misleading, as it is based on data from only four fish.

To further identify periodicities of spawning, monthly proportions of fish in various stages of gonadal development are presented in Figure 3.8. Two features are apparent for all three species, namely the preponderance of immature fish (stage 1), and the extremely low numbers of spawning or spent fish (stages 4 and 5 combined). Asterisks have been used for *O. ruber* and *J. amblycephalus* to denote the occurrence of spawning or spent fish, occurring either in selected specimens from trawls, or from Durban beach seine nets in December 1991. *O. ruber* individuals in stage 4 of activity occur in January, August and October, and there is an increase in the proportion of stage 3 (ripe) fish between September and February. In *J. dussumieri*, fish in stage 4 of activity occur in October and November, indicating spawning activity in these months. Again there is an increase in the proportion of ripe fish from September to February, with a concomitant reduction in the proportion of juveniles (stage 1). *J. amblycephalus* individuals at stage 4 of activity are observed in July, September, November and December, with an increase in the proportion of stage 3 fish between November and March. Again there is a matching reduction of the proportion of juveniles in these months. Based on a combination of the data on gonad indices and proportions of juvenile, mature and spawning fish in the catch, spawning seasons are presented in Table 3.4.

O. ruber



J. dussumieri



J. amblycephalus

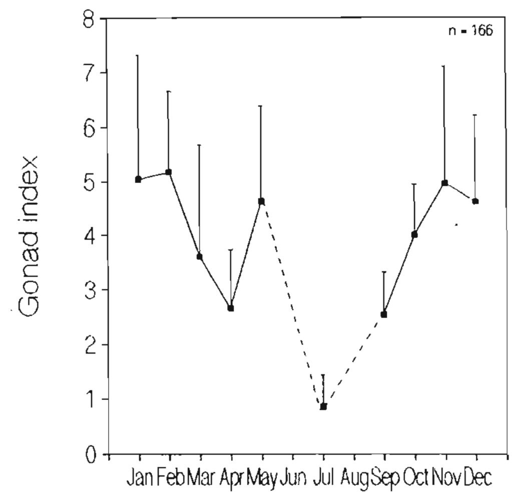


Figure 3.7: **Average monthly female gonad indices (plus 1 std. deviation) of three sciaenids from Tugela Bank prawn trawl catches and Durban seine netters, from May 1989 to June 1992.**

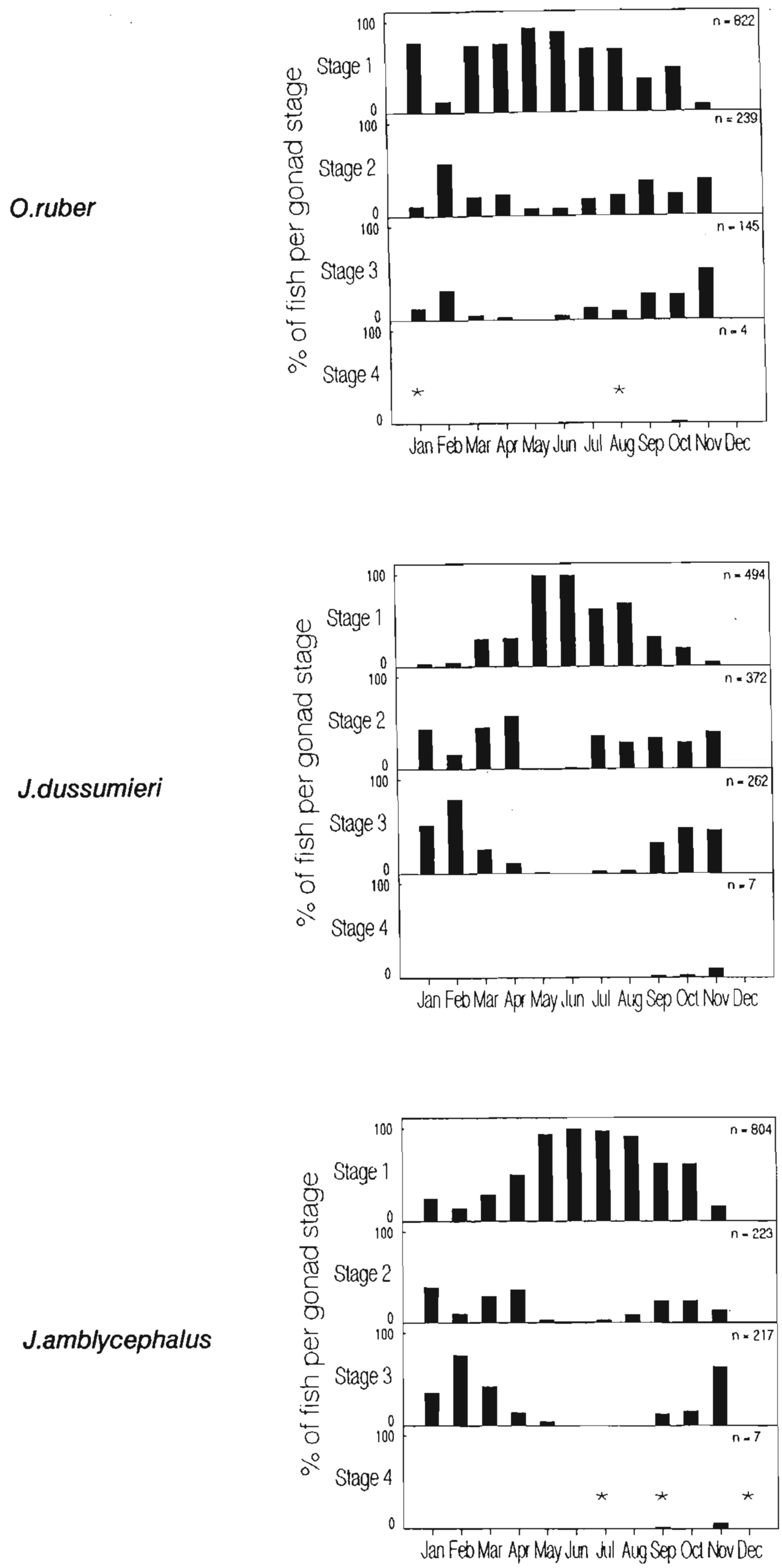


Figure 3.8: **Relative monthly proportions of fish (males and females) per reproductive stage in three sciaenid species from Tugela Bank prawn trawl catches, from May 1989 to June 1992. An asterisk * denotes observations of spawning or spent individuals in selected fish, or from Durban seine net catches (see text).**

Table 3.4: Spawning seasons of three sciaenid species from Tugela Bank prawn trawl catches.

SPECIES	SPAWNING SEASON
O.ruber	August - January
J.dussumieri	September - January
J.amblycephalus	September - March

A combination of small sample sizes and a predominance of immature individuals, in part due to the selectivity of the sampling gear and the sampling area, has confounded the precise identification of spawning season in the three selected species. The data presented indicate extended spawning during late winter, spring and early summer for all three species, as is common with many of the shelf fish of southern Africa (1991). Druzhinin (1974), reported that the sciaenid family have protracted spawning periods in tropical waters, and some species are reported to spawn throughout the year (Lowe-McConnell, 1966; Smale, 1985). Studies on *O. ruber* have reported spawning in January and February on the Natal coast (Wallace and van der Elst, 1975), in April and May in the Gulf of Aiden (Druzhinin and Filatova, 1977), from July to October in India (Devadoss, 1969; Baragi and James, 1983) and in June in Mozambique (Brinca *et al*, 1984).

The winter sea surface temperatures recorded during the latter study are similar to those obtained during summer on the Tugela Bank (pers. obs.), and may be optimal for spawning in this species. This probably also accounts for May spawning in the Gulf of Aden. Spawning of *J. dussumieri* has been reported from September to February in Natal (Wallace and van der Elst, 1975) and in June in Mozambique (Brinca *et al*, 1984). No data on spawning in *J. amblycephalus* are available. Based on the size frequency and gonadal maturity data presented, the inshore areas of the Tugela Bank appear to function as a nursery area for these species, particularly for *O. ruber* and *J. amblycephalus*. More than half of the sampled fish of these two species were immature (Stage 1), whereas most *J. dussumieri* were reproductively active (Stage 2+). As stated above, the latter species is reported to utilise estuaries as nursery areas, which may account for the higher proportion of reproductively active fish offshore.

2.3 Size at 50 percent maturity

Plots of the regressions used to derive lengths at 50 percent maturity for females of the three species are presented in Figure 3.9. The values and estimates of their precision are presented in Table 3.5.

Table 3.5: Estimates of size at 50 percent maturity for females of three sciaenid species from Tugela bank prawn trawl catches, derived from the fitting of logistic curves to maturity data.

Species	Size at 50% maturity (mm)	95% confidence interval	r^2
O.ruber	237	$236 \leq \mu \leq 239$	.998
J.dussumieri	125	$120 \leq \mu \leq 131$	.940
J.amblycephalus	168	$162 \leq \mu \leq 174$	.965

The logistic curves provide a good fit to the data for all three species as indicated by the high r^2 values. Of the three species, only *O. ruber* shows a successive increase in the overall proportion of mature female fish with increasing length (Figure 3.9). For the two *Johnius* species, inconsistencies in proportions of mature females with increasing length may be caused by inadequate sampling or variable individual growth rates. The protracted spawning seasons of these species may also contribute to the variability of the proportions of mature fish at any one time. Reported estimates of length at fifty percent maturity for *O. ruber* include 196 millimetres in India (Devadoss, 1969), and 250 mm in Natal (van der Elst, 1988). Both studies were based on data from males and females combined. A length at 50 percent maturity of 150 mm was obtained by Day *et al* (1981) for *J. dussumieri*.

If the sizes at 50 percent maturity obtained in this study (Table 3.5) are compared to the overall length frequencies (Figure 3.1), it is apparent that female *O. ruber* and *J. amblycephalus* are caught by the prawn trawlers before they are mature. Long-term monitoring of these population parameters is required to fully assess the effects of the trawlers on these species, but given the relatively low levels of fishing effort and the existence of harvest refugia (Chapter 2), the impact is considered to be tolerable.

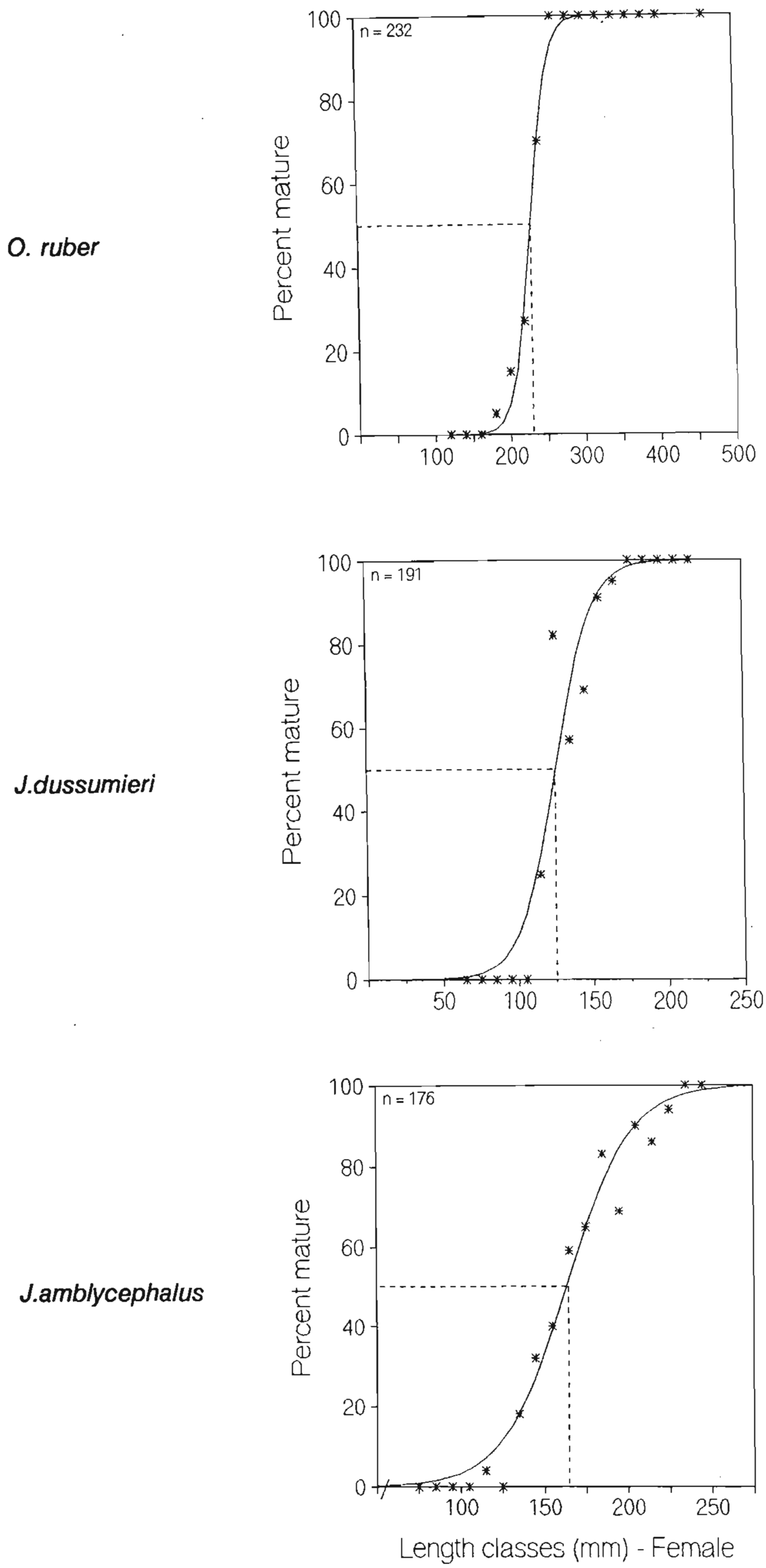


Figure 3.9: Lengths at 50 percent maturity of females of three sciaenid species, collected during their respective spawning seasons from Tugela Bank prawn trawl catches, from May 1989 to June 1992.

3 Feeding

A total of 1711 *O. ruber* stomachs were examined, 1215 stomachs of *J. dussumieri* and 1216 stomachs of *J. amblycephalus*. Figure 3.10 presents the proportions, by frequency of occurrence, of the various stomach content categories. In all three species, between 60 to 70 percent of stomachs had no contents, either being empty or barotraumatised. Crustaceans, in particular the Natantia, dominated in stomachs with contents in all three species. Numbers of stomachs which contained identifiable contents are presented in Table 3.6. The majority of stomachs in all three species contained only one prey item. Forty-one taxa were positively identified, the biggest group comprising teleosts (17 species), followed by brachyurans (10 species) and Natantia (7 species). Most of the prey species in these three groups occur commonly in the by-catch, and it was not possible to determine whether they had been actively sought or scavenged from the discarded component of the trawl catch.

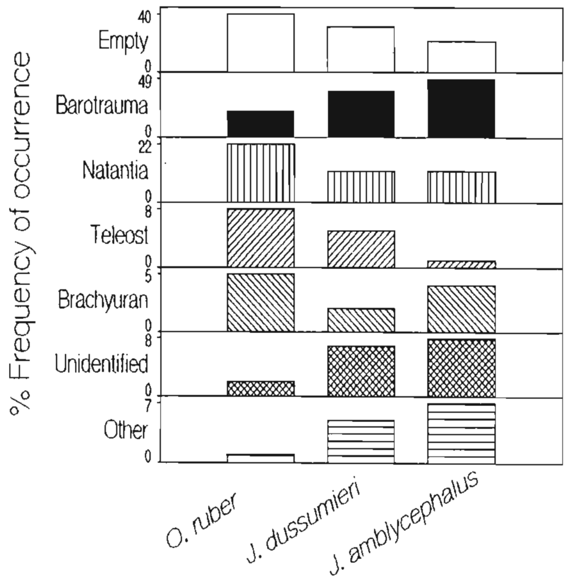


Figure 3.10: Stomach content proportions (by frequency of occurrence) of three sciaenid species from Tugela Bank prawn trawl catches, from May 1989 to June 1992.

The most common food item in all three species was *Parapenaeopsis acclivirostris*, a small penaeid prawn. This species is not caught in quantity and is therefore not kept by trawlers. Its small size makes it ideal prey for the fish on the Tugela Bank. A high proportion of the two *Johnius* species' diet comprised burrowing or epibenthic organisms e.g. mantis shrimps (*Squilla* spp), non-portunid crabs, hermit crabs (*Diogenes* spp), sand prawns (*Callianassa* spp), pistol shrimps (*Alpheus* spp) and polychaetes. *O. ruber* stomachs contained higher proportions of mid-water organisms such as teleosts and cephalopods.

able 3.6: Numbers of stomachs (with contents) of three sciaenids from Tugela Bank prawn trawl catches, from May 1989 to June 1992.

Class	Subclass	Superorder	Suborder	Section	Species	*O. ruber*	*J. dussumieri*	*J. amblycephalus*
Crustacea	Ostracoda				*Pyrocypris*.sp		12	
	Copepoda				*Eucalanus monachus*?		2	
	Malacostraca	Hoplocarida			*Squilla latreillei*			1
					Squilla sp.		1	3
					Unidentified Hoplocarida	3	9	9
		Peracarida			*Gastrosaccus* sp.	5		1
		Eucarida	Reptantia	Brachyura	*Conchoecetes artificiosus*		3	1
					Dorippe lanata		1	
					Monomia gladiator		1	
					Ovalipes punctatus			1
					Philyra globosa		1	3
					Philyra sp.			5
					Portunus hastatoides		3	3
					P. sanguinolinta	1		2
					Portunus sp.			1
					Xanthidae		2	
					Unidentified Brachyura	88	17	33
				Anomura	*Diogenes costatus*		1	
					Diogenes sp.		4	3
					Eupagurinae?			1
					Unidentified Anomura	3	20	26
				Macrura	*Callianassa* sp.		6	11
			Natantia	Penaeidea	*Parapenaeopsis acclivirostris*	176	46	33
					Penaeus indicus	16		
					Penaeus sp.		10	
					Metapenaeus monoceros	5		
				Caridea	*Alpheus bisincissus*		27	20
					Hippolysmata tugelae	13	1	3
					Palaemonidae		1	
					Unidentified Natantia	181	91	115

Table 3.6: (cont.)

Phylum	Class	Species	*O. ruber*	*J. dussumieri*	*J. amblycephalus*
Chordata	Osteichthyes	*Atrobucca nibe*	2		
		Bregmaceros macclellandii	3	4	
		Dussumieria acuta ?	5	8	
		Gonorhynchus gonorhynchus	2		
		Johnius dussumieri	3		
		J.amblycephalus	1		
		Johnius sp.		1	
		Muraenesox bagio	1		1
		Otolithes ruber	1		
		Parachaeturichthys polynema	1		
		Pellona ditchela	1		
		Polydactylus sextarius	1		
		Sardinops ocellatus	1		
		Stolephorus punctifer	14	1	
		Thryssa vitrirostris	1		
		Trichiurus lepturus	4		
		Trypauchen microcephalus			1
		Unidentified Osteichthyes	96	48	14
Mollusca	Pelecypoda	*Macoma gubernaculum*	1		
	Gastropoda	*Polynices didyma*			1
		Ficus ficus		1	
	Cephalopoda	*Loligo duvauceli*	3		
		Loligo sp.	1		1
		Unidentified Cephalopoda	5		
Echinodermata	Asteroidea	Unidentified			1
Annelida	Polychaeta	Unidentified	1	1	24

The prey composition of *O. ruber* indicates that it is a selective predator, having large eyes and a large, terminal mouth with three or more canines. *J. amblycephalus* is a typical bottom feeder, with an inferior mouth, small teeth, well-developed acoustico-lateralis pores and a mental barbel. *J. dussumieri* is similarly developed, but lacks a barbel. Although predominantly a bottom feeder, this species has a higher proportion of teleosts and penaeids in it's stomach contents than *J. amblycephalus*, indicating that it probably also feeds in mid-water, and thus has an intermediate feeding strategy to the other two species. There is therefore evidence of partitioning of food resources between these three sciaenids which allows them to co-exist in a habitat of relatively low diversity. Other feeding studies on this family have produced similar results, i.e. a dietary preference for small fish and prawns obtained by mid-water or benthic feeding (Venkataraman, 1960; Lowe-McConnell, 1966; Suseelan and Somasekharan Nair, 1969; Whitfield and Blaber, 1978).

3.4 Summary and conclusions

The sciaenids *Otolithes ruber*, *Johnius dussumieri* and *Johnius amblycephalus* are the commonest teleost species caught by prawn trawlers on the Tugela Bank. They are shoaling species, and are relatively small in size. They occur at all depths on the prawn grounds, and there is a general increase in their size with depth. Females outnumber males, particularly in the larger size classes. Most of the individuals caught are not reproductively active and the development of the gonads is very similar to that established for other teleosts. The main spawning seasons range from August to March, although there is evidence of spawning in other months. The diet of the three species comprises mostly small epibenthic crustaceans, particularly penaeids and brachyurans, and small fish, all of which are common in the area.

The biological data presented point to the functioning of the Tugela Bank as an inshore area which serves as a nursery for three Natal sciaenids. Data presented in Chapter 2 shows that another sciaenid, *Argyrosomus thorpei* also uses the Tugela Bank as a nursery area. From observations of trawl catches in this area, it is likely that other species also favour this strategy. The Natal coast does not have large bays such as those that occur further north (Maputo Bay) and south (Algoa Bay; False Bay), so the Natal Bight offers the only large-scale protection from the fast-flowing Agulhas current. The turbid waters and abundance of small prey species on the Tugela Bank further make this area suitable as an intermediate habitat for juveniles of several species before they move into open shelf waters. These species include those that utilise estuaries as nurseries such as *Johnius dussumieri* and *Thryssa vitrirostris*, and species that use inshore areas as nurseries such as *Otolithes ruber*, *Johnius amblycephalus*, *Atrobucca nibe* and *Trichiurus lepturus*. The current decreasing trend in linefish catches on the Natal coast is likely to result in the targetting by fishermen of species which have hitherto been less favoured. These could include the three species which were examined in this study and the work presented here will therefore provide useful data should fisheries for these alternative resources develop.

OVERALL SUMMARY AND RECOMMENDATIONS

In this study, the Tugela Bank prawn trawl fishery has been shown to have features in common with penaeid fisheries in several parts of the world. Similarities include the type of gear used (twin otter trawls), conspecific target species (*Penaeus* sp.) and similar by-catch organisms. The by-catch component of many penaeid trawl fisheries is generally characterised by a predominance of a few small-sized, demersal, shoaling fish species, several of which are members of the Sciaenidae. The trawlable Tugela Bank ichthyofauna is dominated by six teleost species (including four sciaenids) which occur throughout the year and over the range of depths trawled (Chapter 1). There is evidence of seasonal and distributional trends in abundance of the major fish species, including the sciaenids *J. dussumieri*, *J. amblycephalus* and *O. ruber*. Another sciaenid, *A. thorpei*, also shows strong seasonality, with juveniles from the previous spawning season recruiting to the Tugela Bank from January to March. The Tugela Bank is seen to function as a nursery area for several trawled fish species, and further evidence for this is presented in Chapter 3.

By-catch quantities caught by the Tugela Bank trawlers are estimated to be in the region of 400 tonnes annually, of which 315 tonnes is discarded. Discard : retained catch ratios were estimated to be 4.25 (± 1.19) : 1 and 15.48 (± 3.86) : 1 for shallow and deep trawls respectively. By-catch quantities and ratios for this fishery are lower than those reported for penaeid trawl fisheries elsewhere. Examination of the composition of Tugela Bank prawn trawl by-catch revealed that linefish species seldom occur. One important linefish species, *A. thorpei*, does occur in trawl catches, particularly during January and February. Trawling effort is generally low in these months, owing to seasonality in prawn abundance, so the total quantities of these age 0+ fish caught by prawn trawlers are not as high as would otherwise be the case. Trawling effort is currently restricted by a limit of five trawlers being permitted to fish on the Tugela Bank at any one time, and because the trawlers can also target deep-water crustaceans on the continental shelf break when inshore fishing is poor. Several areas of the Tugela Bank are inaccessible to trawlers, owing to low profile beachrock outcrops, which are thought to provide harvest refugia for by-catch organisms.

Per-recruit analyses showed that a reduction in trawling effort would result in improved yield-per-recruit and spawning biomass-per-recruit for the squaretail kob fishery. Improved estimates of input parameters (particularly natural and fishing mortalities) to the model are required, but the overall conclusion is that linefish catches of squaretail kob should increase if trawlers catch fewer age 0 fish. Squaretail kob are most abundant on the Tugela Bank during January and February, a period during which prawns are seldom present. Restriction of trawling effort on the Tugela Bank during these months would reduce the trawling component of fishing mortality for *A. thorpei* and may further benefit trawlers by optimising their cost-benefit ratio. Currently, trawlers move to the deep water trawling grounds when catches on the Tugela Bank are poor, although this is dependent on factors such as the individual boat's ability to trawl in the Agulhas current, weather conditions, deep water catches at the time, etc.

Biological data on the three commonest by-catch species revealed that the majority of *Otolithes ruber* and *Johnius amblycephalus* individuals are immature, and are therefore recruited to this fishery before they have spawned. Further evidence of this is the low size at 50 percent maturity for these two species. The other commonest by-catch species is *J. dussumieri*, which utilises estuaries as nursery areas. As a result, the individuals of this species occurring in trawl catches are generally more reproductively active than the other two species. Females are larger and more numerous than males in all three species, possibly as a result of differential growth rates.

There is a general preference by smaller individuals for shallow water, particularly in *O. ruber* and *J. amblycephalus*. Based on available information, the spawning seasons of these species range from August to March. All three species prey on fish and small crustaceans and there is some evidence of resource partitioning of prey species into pelagic, bentho-pelagic and benthic groups. The large numbers of juveniles and the occurrence of suitable prey items lends support to the assertion that the Tugela Bank functions as a nursery area for *O. ruber* and *J. amblycephalus* and to a lesser extent for *J. dussumieri*.

The Tugela Bank is a unique feature of the Natal continental shelf, as it is one of the few inshore areas on this coast where trawling is possible. It is probable that the local trawl fishery for *Penaeus indicus* is sustainable, given the current management strategy which limits trawling effort being applied to the area.

The discarding of catch with low marketability is likely to continue. During the course of this study, there has been an observable increase in quantities of retained by-catch which were previously discarded. Fish such as tongue soles (*Cynoglossus* spp), small-sized kobs (sciaenids) and cutlass fish (*Trichiurus lepturus*) are packed if they are caught in quantity. There is a low acceptance of these by established fish marketers i.e. these products are only taken if the more desirable species, such as reef fish, are not available. There is thus considerable consumer selectivity.

The non-traditional market potential is enormous, but needs to be developed. In Maputo Bay, Mozambique, all the by-catch from the artisanal prawn trawling fleet is retained and marketed on a daily basis. This stems from a need for a cheap source of protein, a need which is rapidly increasing in South Africa. However, the practicalities of fulfilling this need are somewhat different to the Mozambique situation. Firstly, the Natal trawl fishery is oceanic, being based in shelf waters in the open sea, and about 60 nautical miles from the nearest port. The trawlers therefore remain at sea for some time, so catches must be frozen. The possibility of rendezvous with a trawler is hazardous, as the Natal coast is exposed to heavy seas, and furthermore, catches are not always predictable, sometimes comprising small individuals which require extensive sorting. The catch has to remain frozen on return to port, before being sold. The local prawn trawling industry is thus capital-intensive as opposed to the artisanal operations in Maputo Bay, and will expect returns for the extra effort and expense incurred while retaining hitherto discarded catch.

An alternative approach to optimal utilisation of by-catch is that of minimising the quantities caught. This would require considerable investigation, necessitating the design and testing of alternative trawl gear. Work of this nature is currently being done in the Gulf of Mexico, where prawn trawlers are now required by law to use Trawling Efficiency Devices in order to reduce by-catch. There would therefore appear to be merit in investigating this avenue, but funding is unlikely to be forthcoming from the industry or other sources, given the small scale of trawling operations on this coast.

Based on the findings of this study, the following are recommended:

1 - Trawling catch and effort on the Tugela Bank to be monitored more closely in order to assess trends. Recording of logbook data is currently suboptimal. Skippers need to be motivated and encouraged in order to obtain accurate records. There is also a need for a stock assessment of the Tugela Bank penaeid prawns in order to optimise their harvesting.

2 - Results of this study to be communicated to Tugela Bank trawling operations in order to reduce mortality of linefish by a reduction of fishing effort early in the year and particularly when prawn catches are poor.

3 - A further (one year) survey of Tugela Bank by-catch composition to be conducted in six years time, in order to assess longer-term effects of trawling on the ichthyofaunal community in the area.

4 - A comprehensive survey and evaluation of alternative trawling grounds in the Natal Bight to be conducted so as to identify potential trawlable stocks.

REFERENCES

ALLSOPP, W.H.L. 1982 - Use of fish by-catch from shrimp trawling: Future development. In *Fish by-catch ... bonus from the sea*, Ottawa, Ontario; International Development Research Centre: p. 29-36.
ANON. 1984 - Report of the workshop on the scientific bases for the management of penaeid shrimp. In *Penaeid shrimps - their biology and management*, Gulland, A.J. and B.J. Rothschild. (Eds.). Farnham, Surrey; Fishing News Books: p. 9-30.

BAIRD, D. 1974 - *The biology and ecology of the South African mackerel, Scomber japonicus Houttyn, and an analysis of the mackerel fishery in South Africa, 1954-1973. Unpublished Ph D thesis. University of Stellenbosch.* 241 pp.

BARAGI, M. and P.S.B.R. JAMES 1983 - Fishery and bionomics of sciaenids of South Kanara coast. *Matsya* **9-10**: 8-16.

BARRASS, B.J. 1992 - Tangling with trawlers. *Ski-boat.* **8(4)**: 7.

BECKLEY, L.E. 1990 - A description of the early life history stages of the kob, *Argyrosomus hololepidotus* (Pisces: Sciaenidae), from southern Africa. *S. Afr. J. Zool.* **25(4)**: 224-228.

BELLO, R.A. 1987 - Utilisation of shrimp by-catch in Venezuela. *Infofish International* **6**: 23-24.

BEVERTON, R.J.H. and S.J. HOLT 1957 - On the dynamics of exploited fish populations. *Fish. Invest.,Ser. II.* **19**: 1-533.

BIANCHI, G. 1985 - *FAO species identification sheets for fishery purposes. Field guide to the commercial marine and brackish-water species of Tanzania.* Rome; FAO: 199 pp.

BLABER, S.J.M. and T.G. BLABER 1980 - Factors affecting the distribution of juvenile estuarine and inshore fish. *J. Fish Biol.* **17**: 143-162.

BLABER, S.J.M., D.T. BREWER, J.P. SALINI and J. KERR 1990 - Biomasses, catch rates and abundances of demersal fishes, particularly predators of prawns in a tropical bay in the Gulf of Carpentaria, Australia. *Mar. Biol.* **107**: 397-408.

BRANCH, G. and M. BRANCH 1981 - *The living shores of southern Africa.* Cape Town; Struik: 272 pp.

BREWER, D.T., S.J.M. BLABER and J.P. SALINI 1989 - Feeding biology of *Caranx bucculentus* Alleyne and Macleay (teleostei: Carangidae) in Albatros Bay, Gulf of Carpentaria, with special refernce to predation on penaeid prawns. *Aust. J. Mar. Freshwat. Res.* **40**: 657-668.

BRINCA, L., V. MASCARENHAS, B. PALHA DE SOUSA, L. PALHA DE SOUSA, M. SOUSA, R. SAETRE and I. TIMOCHIN 1984 - *A survey on the fish resources at Sofala Bank, Mozambique. May-June 1983.* Bergen; Institute of Marine Research: 90 pp.

BUTTERWORTH, D.S., A.E. PUNT, D.L. BORCHERS, J.B. PUGH and G.S. HUGHES 1989 - A manual of methematical techniques for linefish assessment. *S. Afr. natnl. sci. Prog. Rep.* **160**: 1-89.

BUXTON, C.D. 1987 - *Life history changes of two reef fish species in exploited and unexploited marine environments in South Africa. Unpublished Ph.D. thesis. Rhodes University, Grahamstown. 220 pp.*

CAMPOS, J.A. 1981 - *Shrimp by-catch study on the Pacific coast of Costa Rica. Unpublished M Sc thesis. University of Rhode Island, Newport. 1-97pp.*

CLARK, W.G. 1991 - Groundfish exploitation rates based on life history parameters. *Can. J. Fish. aquat. Sci.* **48**: 734-750.

CLARK, J., W. GRIFFIN and J. RICHARDSON 1991 - Simulated economic impact of TED regulations on selected vessels in the Texas shrimp fishery. *Mar. Fish. Rev.* **53(2)**: 1-8.

CLARKE, K.R.(IN PRESS) 1993 - Non-parametric multivariate analyses of changes in community structure. *Aust. J. Ecol.* 26.

COHEN, D.M. 1973 - Zoogeography of the fishes of the Indian Ocean. In *The biology of the Indian Ocean*, Zeitzschel, B. (Ed.). Berlin; Springer-Verlag: p. 451-463.

CONDREY, R.E. 1991 - Shrimp population models and management strategies: Potentials for increasing yields. In *Frontiers in shrimp research*, Dougherty, W.J. and M.A. Davidson. (Eds.). Amsterdam; Elsevier Science Publishers: p. 33-45.

DAY, J.H., S.J.M. BLABER and J.H. WALLACE 1981 - Estuarine fishes. In *Estuarine ecology*, Day, J.H. (Ed.). Cape Town; Balkema: p. 197-222.

DE FREITAS, A.J. 1984 - The Penaeiodea of southeast Africa. I. The study area and key to the southeast African species. *Invest. Rep. Oceanogr. Res. Inst.* **56**: 1-31.

DEMETRIADES, N.T. 1990 - *Some aspects of the population dynamics of the commercially important Natal penaeid prawns. Unpublished MSc thesis, University of Natal, Durban. 114 pages.*

DENTON, N.R. and R.P. VAN DER ELST 1987 - The squaretail kob - a species profile. 6th National Oceanographic Symposium, Stellenbosch, 6-10 1987. Poster. *Oceanogr. Res. Inst.*

DEVADOSS, P. 1969 - Maturity and spawning in *Otolithus ruber* (Schn.) and *Johnius dussumieri* (C.& V.). *Indian J. Fish.* **16**: 117-128.

DRUZHININ, A.D. 1971 - The distribution of Lutjanidae and Sciaenidae (Pisces) in the Indian Ocean. *Indian J. Fish.* **18(1-2)**: 52-66.

DRUZHININ, A.D. 1974 - On distribution and biology of drums (or croakers) - Sciaenidae family - throughout the world ocean. *Ichthyologia* **6(1)**: 37-47.

DRUZHININ, A.D. and N.A. FILATOVA 1977 - Some data on croakers (Family Sciaenidae) of the Gulf of Aden. *J. Ichthyol.* **19(3)**: 149-151.

FAO, 1991 - FAO Fishery statistics. Catches and landings 1989. *FAO Yearbook* **68**: 1-517.

FAO., 1990 - Review of the state of world fishery resources. *FAO Fish. Circ.* **710**: 1-89.

FENNESSY, S.T. 1990 - An investigation into the discard catch of the Tugela Bank prawn trawlers. *Unpublished Report. Oceanographic Research Institute.* **66**: 34-39.

FIELD, J.G., K.R. CLARKE and R.M. WARWICK 1982 - A practical strategy for analysing multispecies distribution patterns. *Mar. Ecol. Prog. Ser.* **8**: 25-36.

FLEMMING, B. and R. HAY 1988 - Sediment distribution and dynamics on the Natal continental shelf. In *Coastal ocean studies off Natal, South Africa*, Schumann, E.H. (Ed.). Berlin; Springer-Verlag: p. 47-80.

GARRATT, P.A. 1985 - The offshore linefishery of Natal. II. Reproductive biology of the sparids *Chrysoblephus puniceus* and *Cheimerius nufar*. *Invest. Rep. Oceanogr. Res. Inst.* **63**: 1-21.

GARRATT, P.A. and R.P. VAN DER ELST 1990 - Status of the fishery in Natal and Transkei. In *Marine recreational fishing: Resource usage, management and research. South African National Scientific Programmes Report no. 167*, Pretoria; Foundation For Research Development: p. 27-30.

GMFMC (GULF OF MEXICO FISHERY MANAGEMENT COUNCIL), 1989 - Reef fishery management plan: Amendment no.1. *GMFMC* 1-353.

GRANTHAM, G.J. 1980 - The prospects for by-catch utilisation in the Gulf area. FI:DP/RAB/71/278/14. Regional Fishery Survey and Development Project. Rome; FAO: 43 pp.

GRIFFITHS, M.H. 1988 - *Aspects of the biology and population dynamics of the geelbek, Atractoscion aequidens (Cuvier) (Pisces: Sciaenidae) off the South African coast. Unpublished MSc. thesis. Rhodes University, Grahamstown. 149 pp.*

GRIFFITHS, M.H. 1993 - Two South African *Argyrosomus hololepidotus* species: implications for management. In Status, stocks and statistics - Proceedings of the second South African Linefish symposium. *Special publication. Oceanographic Research Institute* **2: 19-22.**

GUASTELLA, L.A. and R.P. VAN DER ELST 1992 - 1991 NPB shore patrol analysis. *Data Report. Oceanographic Research Institute.* **92.1**: 1-17.

GULLAND, J.A. 1970 - The fish resources of the oceans. *FAO Fish. Tech. Pap.* **97**: 1-425.

GUTHERZ, E.J. and G.J. PELLEGRIN 1988 - Estimate of the catch of red snapper, *Lutjanus campechanus*, by shrimp trawlers in the U.S. Gulf of Mexico. *Mar. Fish. Rev.* **50**: 17-25.

HECHT, T. 1976 - *The general biology of six major trawl fish species of the Eastern Cape coast of South Africa, with notes on the demersal fishery, 1967-1975. Unpublished Ph.D. thesis. University of Port Elizabeth, Port Elizabeth.*

HEYDORN, A.E.F. 1966 - *Reports on the activities of the R.V. "David Davies". Oceanographic Research Institute, Durban. Unpublished series. 32pp.*

HEYDORN, A.E.F. 1967 - *Reports on the activities of the R.V. "David Davies". Oceanogrpahic Research Institute, Durban. Unpublished series. 30pp.*

HEYDORN, A.E.F. 1968 - *Reports on the activities of the R.V. "David Davies". Oceanographic Research Institute, Durban. Unpublished series. 30pp.*

HILL, B.J. and T.J. WASSENBERG 1990 - Fate of discards from prawn trawlers in Torres Strait. *Aust. J. Mar. Freshwat. Res.* **41**: 53-64.

HINMAN, K. 1991 - Can we control bycatch? *Salt Water Sportsman.* **52(7)**: 52-53.

HUNTER, I. 1988 - Climate and weather off Natal. pp 81-100. In *Coastal ocean studies off Natal, South Africa*, Schumann, E.H. (Ed.). New York; Springer-Verlag: p. 81-100.

HUTCHINGS, P. 1990 - Review of the effects of trawling on macrobenthic epifaunal communities. *Aust. J. Mar. Freshwat. Res.* **41**: 111-120.

ISAKSEN, B., J.W. VALDEMARSEN, R.B. LARSEN and L. KARLSEN 1992 - Reduction of fish by-catch in shrimp trawl using a rigid seperator grid in the aft belly. *Fish. Res.* **13**: 335-352.

KENNELLY, S.J., R.E. KEARNEY, G.W. LIGGINS and M.K. BROADHURST (IN PRESS) 1993 - *The effect of shrimp trawling by-catch on other commercial and recreational fisheries - an Australian perspective.* Orlando, Florida. 25 pp.

LAEVASTU, T. and F. FAVORITE 1988 - *Fishing and stock fluctuations.* Farnham; Fishing News Books Ltd.: 239 pp.

LOWE-MCCONNELL, R.H. 1966 - The sciaenid fishes of British Guiana. *Bull. mar. Sci* **16(1)**: 20-57.

LUTJEHARMS, J.R.E., M.L. GRUNDLINGH and R.A. CARTER 1989 - Topographicaly induced upwelling in the Natal Bight. *S. Afr. J. Sci* **85**: 310-316.

MAHARAJ, V. and C. RECKSIEK 1991 - The by-catch from the artisanal shrimp trawl fishery, Gulf of Paria, Trinidad. *Mar. Fish. Rev.* **53(2)**: 9-15.

MANN, B.Q. 1992 - *Aspects of the biology of two inshore sparid fishes (Diplodus sargus capensis and Diplodus cervinus hottentotus off the South-East coast of South Africa. Unpublished M Sc thesis. Rhodes University, Grahamstown.* 125 pp.

MATHEWS, C.P. and M. SAMUEL 1989a - Multi-species dynamic pool assessment of shrimp by-catch in Kuwait. *Kuwait. Bull. Mar. Sci.* **10**: 147-168.

MATHEWS, C.P. and M. SAMUEL 1989b - The relation between by-catch, shrimp catches and shrimp landings in Kuwait. *Kuwait. Bull. Mar. Sci.* **10**: 135-145.

MCCORMICK, S., J.A.G. COOPER and T.R. MASON 1992 - Fluvial sediment yield to the Natal coast: a review. *S. Afr. J. Aqua. Sc.* **18 (1/2)**: 74-88.

MERCER, D. 1991 - Declining fish stocks. Who is to blame? *Ski scene.* **14(3)**: 7-8.

MURRAY, J.D., J.J. BAHEN and R.A. RULIFSON 1992 - Management considerations for by-catch in the North Carolina and Southeast shrimp fishery. *Fisheries* **17(1)**: 21-26.

NAVALUNA, N.A. 1982 - Morphometrics, biology and population dynamics of the croaker fish, *Otolithes ruber*. In *Small-scale fisheries of San Miguel Bay, Philippines: biology and stock assessment*, Pauly, D. and A.N. Mines. (Eds.). Manila, Philippines. *ICLARM Technical Reports* **7**: 38-55.

NEPGEN, C.S. 1982 - Diet of predatory and reef fish in False Bay and possible effects of pelagic purse-seining on their food supply. *Fish. Bull. S. Afr.* **16**: 75-93.

NETER, J., W. WASSERMAN and G.A. WHITMORE 1988 - Nonparametric procedures. In *Applied statistics*, 3rd Ed. Boston; Allyn and Bacon, Inc.: p. 511-514.

NICHOLS, S. 1990 - The Bycatch issue. In *The Mississippi shrimp industry: A management perspective. Proceedings of a Mississippi Sea Grant Advisory Service Workshop, 12 April 1989*, Biloxi, Mississippi; p. 40-45.

PAULY, D. 1980 - On the interrelationships between natural mortality, growth parameters, and mean environmental temperature in 175 fish stocks. *J. Cons. int. Explor. Mer.* **39(2)**: 175-192.

PAULY, D. 1984 - *Fish population dynamics in tropical waters: a manual for use with programmable calculators.* Manila; International Center for Living Aquatic Resources Management: 325 pp.

PAULY, D. 1987 - Theory and practice of overfishing - a Southeast Asian perspective. In *Symposium on the exploitation and management of marine fishery resources in Southeast Asia*, Darwin; p. 146-183.

PAULY, D. and R. NEAL 1985 - Shrimp vs. fish in Southeast Asian fisheries: the biological, technological and social problems. In *Recursos Pesqueros Potenciales de Mexico: La Pesca Acompanante del Camaron. Progr. Univ. de Alimentos, Inst. Cienc. del Mar y Limnol., Inst. Nal. de Pesca. UNAM, Mexico D.F.*, p. 487-510.

PAULY, D. and M.L. PALOMARES 1987 - Shrimp consumption by fish in Kuwait waters: a methodology, preliminary results and their implications for management and research. *Kuwait. Bull. Mar. Sci.* **9**: 101-125.

PAYNE, A.I.L. 1986 - *Biology, stock integrity and trends in the commercial fishery for demersal fish on the south-east coast of South Africa. PhD thesis, University of Port Elizabeth*. 368 pp.

PELGROM, H. and M. SULEMANE 1982 - Mozambique. In *Fish by-catch ... bonus from the sea. Regional reports*, Ottawa, Ontario; International Development Research Centre: p. 139-140.

PENNEY, A.J. 1991 - The interaction and impact of net and line-fisheries in False Bay, South Africa. *Trans. Roy. Soc. S. Afr.* **47(4,5)**: 663-681.

PERRA, P. 1992 - By-catch reduction devices as a conservation measure. *Fisheries* **17(1)**: 28-29.

PILFOLD, S.J. and A. PAMPALLIS 1993 - An introduction to the Natal commercial linefishery. In Status, stocks and statistics - Proceedings of the second South African Linefish symposium. *Special publication. Oceanographic Research Institute.* **2**: 118-121.

POINER, I. 1990 - Fisheries and environmental interactions. In *CSIRO Division of Fisheries Research Report 1985-1987*: p. 75-77.

POINER, I.R., R.C. BUCKWORTH and A.N.M. HARRIS 1990 - Incidental capture and mortality of sea turtles in Australia's northern prawn fishery. *Aust. J. Mar. Freshwat. Res.* **41**: 97-110.

RICKER, W.E. 1971 - *Methods for assessment of fish production in fresh waters*. 2nd Ed. Oxford; Blackwell Scientific Publications: 348 pp.

RICKER, W.E. 1975 - Compilation and interpretation of biological statistics of fish populations. *Bull. Fish. Res. Board. Canada.* **191**: 1-382.

SAILA, S.B. 1983 - Importance and assesment of discards in commercial fisheries. *FAO Fish. Circ.* **765**: 1-62.

SAMUEL, M. 1981 - The by-catch and the ratio of mixed fish to mixed shrimp catch in Kuwait waters, 1979 to 1980. In *Kuwait Institute of Science Annual Research Report 1981*, p. 125-128.

SCHUMANN, E.H. 1982 - Inshore circulation of the Agulhas current off Natal. *J. mar. Res.* **40**: 43-55.

SHERIDAN, P.F., J.A. BROWDER and J.E. POWERS 1984 - Ecological interactions beteen penaeid shrimp and bottom fish assemblages. In *Penaeid shrimps - their biology and management*, Gulland, J.A. and P.J. Rothschild. (Eds.). Farnham, Surrey; Fishing News Books: p. 235-254.

SISSENWINE, M.P. and J.G. SHEPERD 1987 - An alternative perspective on recruitment overfishing and biological reference points. *Can. J. Fish. aquat. Sci.* **44**: 913-918.

SLAVIN, J.W. 1982 - Utilisation of the shrimp by-catch. In *Fish by-catch ... bonus from the sea*, Ottawa, Ontario; International Development Research Centre: p. 21-28.

SMALE, M.J. 1985 - Aspects of the biology of *Argyrosomus hololepidotus* and *Atractoscion aequidens* (Osteichthyes: Sciaenidae) in waters off the south-eastern Cape, South Africa. *S. Afr. J. mar. Sci.* **3**: 63-75.

SMITH, M.M. 1980 - Marine fishes of Maputaland. In *Studies on the ecology of Maputaland*, Bruton, M.N. and K.H. Cooper. (Eds.). Grahamstown; Rhodes University: p. 164-187.

SMITH, M.M. and P.C. HEEMSTRA (Eds.) 1986 - *Smith's sea fishes*. Johannesburg; Macmillan: 1046 pp.

SOMERS, I.F. 1990 - Manipulation of fishing effort in Australia's penaeid prawn fisheries. *Aust. J. Mar. Freshwat. Res.* **41(1)**: 1-12.

SUSEELAN, C. and K.V. SOMASEKHARAN NAIR 1969 - Food and feeding habits of the demersal fishes off Bombay. *Indian J. Fish.* **16**: 56-76.

TIMMONS, T.J., T. HOFFNAGLE, R.S. HALE and J.B. SOLDO 1989 - Incidence of sport fishes in the commercial fish catch from Kentucky Lake, Kentucky and Tennessee. *N. Am. J. Fish. Manage.* **9**: 209-212.

TREWAVAS, E. 1977 - The sciaenid fishes (croakers or drums) of the Indo-west-Pacific). *Trans. Zool. Soc. Lond.* **33(4)**: 259-541.

VAN BEEK, F.A., P.I. VAN LEEUWEN and A.D. RIJNSDORP 1989 - *On the survival of plaice and sole discards in the otter trawl and beam trawl fisheries in the North Sea.* ICES, C.M.1989/G:46. ICES, Copenhagen. 15 pp.

VAN DER ELST, R.P. 1988a - Shelf ichthyofauna of Natal. In *Coastal ocean studies off Natal, South Africa. Lecture notes on coastal and estuarine studies: 26*, Schumann, E.H. (Ed.). New York; Springer-Verlag: p. 209-225.

VAN DER ELST, R.P. 1988b - *A guide to the common sea fishes of southern Africa*. 2nd Ed. Cape Town; Struik: 392 pp.

VAN DER ELST, R.P. and F. ADKIN 1991 - Marine linefish priority species and research objectives in southern Africa. *Special publication. Oceanographic Research Institute.* **1:** 1-132.

VAN DER ELST, R.P., A. GOVENDER, S.T. FENNESSY and N. DENTON 1990 - Biology and stock assessment of the squaretail kob, *Argyrosomus thorpei. Progress reports to SANCOR*. 7 pp.

VAUGHAN, D.S., R.J. SEAGRAVES and K. WEST 1991 - An assessment of the status of weakfish stocks, 1982-1988. In *Atlantic States Marine Fisheries Commission, Special Report 21*, Washington,DC.; p. 1-75.

VENDEVILLE, P. 1990 - Tropical shrimp fisheries: Types of fishing gear used and their selectivity. *FAO Fish. Tech. Pap.* 1-75.

VENKATARAMAN, G. 1960 - Studies of the food and feeding relationships of the inshore fishes off Calicut on the Malabar coast. *Indian J. Fish.* **7(2)**: 275-306.

VON BONDE, C. 1928 - *Fisheries and Marine Biological Survey. Report no.5 for the years 1925-1927. Government Printer, Pretoria. 85pp.*

WALLACE, J.H. 1975 - The estuarine fishes of the east coast of South Africa. I Species composition and length frequency distribution in the estuarine and marine environments. II Seasonal abundance and migrations. *Invest. Rep. Oceanogr. Res. Inst.* **40**: 1-72.

WALLACE, J.H., H.M. KOK, L.E. BECKLEY, B. BENNETT, S.J.M. BLABER and A.K. WHITFIELD 1983 - *South African estuaries and their importance to fishes.* Port Elizabeth; Port Elizabeth Museum: 11pp.

WALLACE, J.H. and R.P. VAN DER ELST 1975 - The estuarine fishes of the East Coast of South Africa. IV Occurrence of juveniles in estuaries. V Biology, estuarine dependence and status. *Invest. Rep. Oceanogr. Res. Inst.* **42**: 1-63.

WARWICK, R.M. and K.R. CLARKE 1991 - A comparison of some methods for analysing changes in benthic community structure. *J. Mar. Biol. Assoc. U. K.* **71**: 225-244.

WASSENBERG, T.J. and B.J. HILL 1987 - Feeding by the sand crab *Portunus pelagicus* on material discarded from prawn trawlers in Moreton Bay, Austalia. *Mar. Biol.* **95**: 387-393.

WASSENBERG, T.J. and B.J. HILL 1989 - The effect of trawling and subsequent handling on the survival rates of the by-catch of prawn trawlers in Moreton Bay, Australia. *Fish. Res.* **7**: 99-110.

WASSENBERG, T.J. and B.J. HILL 1990 - Partitioning of material discarded from prawn trawlers in Moreton Bay. *Aust. J. Mar. Freshwat. Res.* **41**: 27-36.

WENNER, A. 1972 - Sex ratio as a function of size in marine crustacea. *Am. Nat.* **106**: 321-350.

WENNER, C.A. and G.R. SEDBERRY 1989 - Species composition, distribution and relative abundance of fishes in the coastal habitat off the southeastern United States. *NOAA Tech. Rep.* **79**: 1-49.

WHITFIELD, A.K. and S.J.M. BLABER 1978 - Food and feeding ecology of piscivorous fishes at Lake St Lucia, Zululand. *J. Fish Biol.* **13**: 675-691.

WILLIAMS, G.C. 1986 - The Torres Strait prawn fishery. In *Torres Strait Fisheries Seminar, Port Moresby, 11-14 February 1985*, Haines, A.K., G.C. Williams and D. Coates. (Eds.). Canberra; Australian Government Publishing Service: p. 233-238.

YAMAMOTO, K. 1956 - Studies on the formation of fish eggs, 1. Annual cycle in the development of ovarian eggs in the flounder, *Liopsetta obscura*. *J. Fac. Sci. Hokkaido Univ.* **12(3)**: 363-373.

YOUNG, P.C. and K.J. SAINSBURY 1985 - CSIRO's North West Shelf program indicates changes in fish populations. *Aust. Fish.* **44**: 16-20.

ZOUTENDYK, P. 1974 - The biology of the Agulhas sole, *Austroglossus pectoralis*, Part 2. Age and growth. *Trans. Roy. Soc. S. Afr.* **41**: 33-41.

APPENDIX 1

List of associated fauna recorded from Tugela Bank prawn catches.

TELEOSTEI

Acanthocepola indica	Bandfish
Aesopia cornuta	Unicorn sole
Alectis ciliaris	Threadfin mirrorfish
Alectis indicus	Indian mirrorfish
Ambassis productus	Longspine glassy
Antennarius striatus	Striped angler
Antigonia rubescens	Boarfish
Apistus carinatus	Bearded waspfish
Apogon kallopterus	Spinyheaded cardinal
Apogon kiensis	Rifle cardinal
Apogonichthys ocellatus	Ocellated cardinal
Archamia fucata	Redbarred cardinal
Archamia mozambiquensis	Mozambique cardinal
Argyrosomus thorpeii	Squaretail kob
Ariodes dussumieri	Tropical seacatfish
Ariomma indica	Indian driftfish
Ariosoma scheelei	Tropical conger
Atrobucca nibe	Blackmouth croaker
Bregmaceros maclellandi	Codlet
Callionymus marleyi	Sand dragonet
Carangoides hedlandensis	Bumpnose kingfish
Carangoides malabaricus	Malabar kingfish
Carangoides uii	Onion trevally
Cheimerius nufar	Santer
Chelidonichthys kumu	Blue-fin gurnard
Chelonodon pleurospilus	Blaasop beauty
Choridactylus natalensis	Three stick stingfish
Chrysoblephus puniceus	Slinger
Cociella sp	Flathead
Cubiceps baxteri	Black fathead
Cyclicthys orbicularis	Birdbeak burrfish
Cynoglossus attenuatus	Four-lined tonguefish
Cynoglossus lida	Roughscale tonguefish
Dactyloptena orientalis	Helmet gurnard
Drepane longimanus	Concertina fish
Dussumieria acuta?	
Dysomma anguillare	Arrowtooth eel
Echeneis naucrates	Remora
Epinephelus andersoni	Catface rockcod
Fistularia commersonni	Smooth flutemouth
Galeichthys feliceps	White seacatfish
Gazza minuta	Toothed soapy
Gerres filamentosus	Threadfin pursemouth
Gonorhynchus gonorhynchus	Beaked sandfish
Halieutea fitzsimonsi	Spiny seabat
Johnius dussumieri	Mini-kob
Lactoria diaphana	Spiny boxfish
Lagocephalus guentheri	Blackback puffer
Lagocephalus inermis	Smooth puffer
Leiognathus equula	Slimey
Lithognathus mormyrus	Sand steenbras
Lobotes surinamensis	Tripletail

cont.

Lophiomus setigerus	Monkfish
Lutjanus russellii	Russell's snapper
Megalaspis cordyla	Torpedo fish
Mene maculata	Pony fish
Minous coccineus	One stick stingfish
Monocentris japonicus	Pineapple fish
Muraenesox bagio	Pike conger
Otolithes ruber	Snapper salmon
Parachaeturichthys polynema	Tail-eyed goby
Paralichthodes algoensis	Measles flounder
Paraplagusia bilineata	Fringelip tonguefish
Parastromateus niger	Black pomfret
Parupeneus cinnabarinus	Redspot goatfish
Pellona ditchela	Indian pellona
Polysteganus coeruleopunctatus	Blueskin
Polydactylus sextarius	Bastard mullet
Pomadasys commersonnii	Spotted grunter
Pomadasys kaakan	Javelin grunter
Pomadasys maculatum	Saddle grunter
Pomadasys olivaceum	Olive grunter
Pomatomus saltatrix	Shad
Priacanthus cruentatus	Glass bigeye
Pseudorhombus arsius	Largetooth flounder
Pseudorhombus elevatus	Ringed flounder
Pseudorhombus natalensis	Smalltooth flounder
Pterois russelli	Plaintail firefish
Rhabdosargus sarba	Natal stumpnose
Rhabdosargus holubi	Cape stumpnose
Sardinella albella	White sardinelle
Sardinella gibbosa	Goldstripe sardinelle
Sardinops ocellatus	Pilchard
Saurida undosquamis	Largescale lizardfish
Scomber japonicus	Mackerel
Secutor insidiator	Slender soapy
Secutor ruconius	Pugnose soapy
Serranus cabrilla	Comber
Solea bleekeri	Blackhand sole
Sphyraena flavicauda	Yellowtail barracuda
Sphyraena acutipinnis	Sharp-fin barracuda
Stephanolepis auratus	Porky
Stolephorus punctifer	Buccaneer anchovy
Strethojulis strigiventer	Three-ribbon wrasse
Terapon jarbua	Thornfish
Terapon theraps	Straight-lined thornfish
Thryssa setirostris	Longjaw glassnose
Thryssa vitrirostris	Bony
Thyrsoidea macrura	Slender giant moray
Torquigener balteatus	Slender puffer
Trachinocephalus myops	Painted lizardfish
Trachurus delagoa	African maasbanker
Trichiurus lepturus	Ribbon fish
Trypauchen microcephalus	Comb goby
Umbrina canariensis	Baardman
Upeneus vittatus	Yellow-banded goatfish
Uroconger lepturus	Longtailed conger
Uranoscopus archionema	Stargazer
Valamugil cunnesius	Longarm mullet

cont.

ELASMOBRANCHII

Aetobatus narinari	Spotted eagleray
Carcharhinus amboinensis	Java shark
Carcharhinus brevipinna	Spinner shark
Carcharhinus limbatus	Blacktip shark
Carcharhinus obscurus	Dusky shark
Carcharhinus plumbeus	Sandbar shark
Dasyatis marmorata capensis	Blue stingray
Dasyatis thetidis	Thorntail stingray
Gymnura natalensis	Butterfly ray
Halaelurus lineatus	Banded catshark
Mustelus mosis	Hardnosed smooth-hound shark
Myliobatis aquila	Bull ray
Pteromylaeus bovinus	Duckbill ray
Raja miraletus	Twineye skate
Rhina ancyclostoma	Bowmouth guitarfish
Rhinobatos annulatus	Lesser guitarfish
Rhinobatos leucospilus	Greyspot guitarfish
Rhizoprionodon acutus	Milk shark
Rhynchobatus djiddensis	Giant guitarfish
Sphyrna lewini	Scalloped hammerhead
Squatina africana	Angel shark
Stegostoma fasciatum	Zebra shark
Torpedo sinuspersici	Marbled electric ray

REPTILIA: CHELONIA

Dermochelys coriacea	Leatherback turtle
Caretta caretta	Loggerhead turtle

CRUSTACEA: REPTANTIA

Arcania septumspinosum
Calappa lophos
Charybdis cruciata
Charybdis variegata
Conchoecetes artificiosus
Doclea muricata
Dorippe lanata
Gonioneptunus africanus
Ixoides sp.
Macropodia formosa
Matuta sp.
Monomia gladiator
Ovalipes punctatus
Philyra globosa
Philyra globulosa
Platylambrus quemvis
Portunus sanguinolinta
Portunus hastatoides
Scylla serrata
Diogenes costatus

CRUSTACEA: NATANTIA

Aegeon cataphractus
Alpheus bisincissus
Hippolysmata tugelae
Metapenaeus monoceros
Metapenaeopsis mogiensis
Panulirus homarus
Panulirus ornatus
Parapenaeopsis acclivirostris

Penaeus indicus
Penaeus japonicus
Penaeus monodon
Penaeus semisulcatus
Solenocera choprai
Thenus orientalis
Trachypenaeus curvirostris

cont.

STOMATOPODA

Squilla latreillei
Lysiosquilla maculata

CEPHALOPODA

Loligo duvauceli
Sepiella cyanea
Sepia officinialis vermiculata

GASTROPODA

Amalda contura
Amalda optima
Architectonica perspectiva
Bufonaria crumena
Bullia similis
Chicoreus litos
Cymatium pileare
Eudolium pyriforme
Ficus ficus
Murex brevispinna
Phalium bisulcatum
Polynices didyma
Nassarius bicallosus
Nassaria gracilis
Rapana bulbosa
Thais capensis
Tonna tessellata
Tonna allium
Tonna galea tenebrosa
Xenophora solaris

PELYCOPODA

Anadata natalensis
Chlamys furtoni
Glycymeris queckettí
Macoma gubernaculum
Mactra aequisulcata
Modiolus siranensis
Pecten sp.
Solen sloani
Vepricardium burnupi