AN ASSESSMENT OF CHANGES IN THE ICHTHYOFAUNAL BYCATCH OF THE TUGELA BANK PRAWN TRAWLERS IN KWAZULU NATAL

By

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PREFACE

The work in this thesis was carried out at the Oceanographic Research Institute in Durban, under the supervision of Dr S.T. Fennessy (Senior Scientist) and Professor R. van der Elst (Director) from February 2003 to February 2005.

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.

ACKNOWLEGDEMENTS

This study was funded by Marine and Coastal Management as well as the South African Association for Marine Biological Research and I am very grateful to them for making this possible.

I would also like to personally thank the following people:

Dr Sean Fennessy who has played a very vital role in the completion of this study, as he was the one reading countless drafts trying to get the final product perfect. Thank you for the weekends you put in reading and correcting my work, my writing skills are the better because of your input. I would like to thank Risha Persad, my partner in sorting all the samples from the prawn trawlers, it was a smelly job, but someone had to do it. To Nico and the other observers from Capricorn Fisheries Monitoring who went onboard the trawlers for weeks on end to bring back the samples for me. Many thanks to Nat for helping me with the shark and ray species identification. The University of KwaZulu-Natal for awarding me with a Graduate Assistant Bursary to study at the university.

I would also like to thank the South African Institute of Aquatic Biodiversity (SAIAB) and IZIKO Natural History Museum (Cape Town) for the identification of some of the specimens.

ABSTRACT

Bycatch refers to the portion of the catch that is captured incidentally to the target species and is one of many growing problems facing the world's marine fisheries in recent years. Prawn trawling is one of the world's most lucrative marine fisheries, contributing about 3% to the total annual production of the world's marine fisheries. It is also one the most wasteful because it is associated with large quantities of bycatch. This is because of the high diversity and abundance of other organisms in areas where prawn trawling occurs, and the non-selective nature of the otter trawl used to land prawns. The South African shallow water prawn trawl fishery is typical of penaeid fisheries, and operates on the Tugela Bank off northern KwaZulu-Natal. The bycatch of penaeid prawn trawlers operating on the Tugela Bank was analysed between March 2003-July 2004 as a follow up to an initial study between May 1989-June 1992. The aim of this study was to determine if there has been any change in bycatch species composition over the 13-years and to determine the impacts of trawling on the environment.

Catch composition data were recorded from 168 trawls processed onboard trawlers and on-shore. A total of 122 species was identified with teleosts contributing more than 60% to relative abundance by number. Comparison between the 1989-1992 and 2003-2004 data sets showed that although the species compositions were similar, there was an increase in the relative abundance of pelagic species. It is not clear if the change is due to trawling impacts or due to fluctuations in recruitment of these taxa.

The annual discarded bycatch was estimated at 88 tonnes in 2003 and the prawn catch was estimated at 11 tonnes, both substantially lower than in 1989-1992. There was no difference in discard rate between trawls from shallow and medium depths. However, there were significant differences in discard rates between large and medium gears, and warm (December-April) and cool (May-November) seasons. Kolmogorov-Smirnov tests revealed that there were significant differences between the 1990s and 2000s length frequency distributions of three sciaenid species (*Otolithes ruber*, *Johnius dorsalis* and *J. fuscolineatus*), which all showed an increase in fish size for the 2003-2004 data. This assessment, however, is confounded by a gear effect as mesh size differs between the two sample periods.

Based on the results of the study, management recommendations were made to improve the management of the Tugela Bank prawn trawl fishery by reducing bycatch. It was recommended that the observer programme continue for further investigation into the changes in species dynamics. Further research on BRDs (Bycatch Reducing Devices) and gear types that reduce bycatch is also recommended.

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1. INTRODUCTION

Commercial prawn trawling occurs in the majority of the world's oceans, and provides a total catch of up to 3 million tonnes per year which accounts for about 3.2% of the total production from the world's marine fisheries (FAO, 2002). Many marine fisheries, including prawn trawling are faced with the problem of bycatch. Bycatch refers to the portion of the catch that is caught incidental to the target species (Saila, 1983), and it has played a significant role in the decline of many of the world's fish stocks because high catches of juveniles of many bycatch species. Bycatch makes up approximately 10% of the total annual global landings (Japp, 1997). Discarded bycatch makes up 90% of what is caught in prawn trawls world wide, with only 10% of the catch being retained (Smith, 2000). The high percentage of discarded bycatch in prawn trawls is a result of the poor selectivity of the otter trawl, which is the gear most commonly used to catch prawns (Vendeville, 1990). The issue of bycatch in commercial fisheries has presented serious problems and has proved to be one of the most important issues facing the fishing industry to date (Kennelly *et al.*, 1998).

A major concern of bycatch is the catching of species that are targeted in other fisheries (Vaughan *et al.*, 1991; Kennelly *et al.*, 1993), the consequence of which is the reduction of the recruitment, biomass and yield of these stocks. This is largely because of the high mortality of their juveniles and subadults which are caught as bycatch (Andrew and Pepperell, 1992; Broadhurst, 2000). This threatens the maintenance of biodiversity and long term sustainability of marine ecosystems, and contributes to ecosystem degradation (FAO, 1995).

Penaeid (prawns with a juvenile estuarine stage in their development) fisheries are one of the world's most lucrative because of the high value of the catch, but they are also one of the most wasteful because of the large quantities of bycatch associated with them (Andrew and Pepperell, 1992). In most of these fisheries, the species that are of commercial value are retained, and the so-called 'trash' component of the bycatch is discarded because of it's poor marketability (Andrew and Pepperell, 1992; Fennessy, 1994a).

Most of the world's penaeid prawn fisheries are situated on the continental shelf in tropical or sub-tropical regions where there is a high abundance and diversity of other organisms (van der Elst, 1988; Fennessy, 1994b). The South African prawn trawl fishery occurs in sub-tropical KwaZulu-Natal and consists of shallow and deep water fisheries (Fennessy and Groeneveld, 1997). The shallow water fishery, which operates at depths of 20-50 m, is situated on the Tugela Bank trawling grounds off the KwaZulu-Natal north coast and the deep water fishery operates at 100-600 m. There are limited possibilities for penaeid prawn trawling in South Africa because of the narrow width of the continental shelf along most of the South African coastline, and the Tugela Bank grounds are one of the few suitable areas because the shelf is at it's widest here (Figure 1; Fennessy *et al.*,1994; Fennessy, 1995). The Tugela Bank coincides with an area of mud deposition from discharges of many rivers in the area, which makes it ideal for penaeid prawns (McCormick *et al.*, 1992). The Tugela Bank supports a seasonal fishery which catches white prawn, *Fenneropenaeus indicus*, but also catches a large amount of teleosts, elasmobranchs, gastropods, cephalopods and other crustaceans as bycatch (Fennessy, 1994b; Fennessy *et al.*,1994; Fennessy and Groeneveld, 1997).

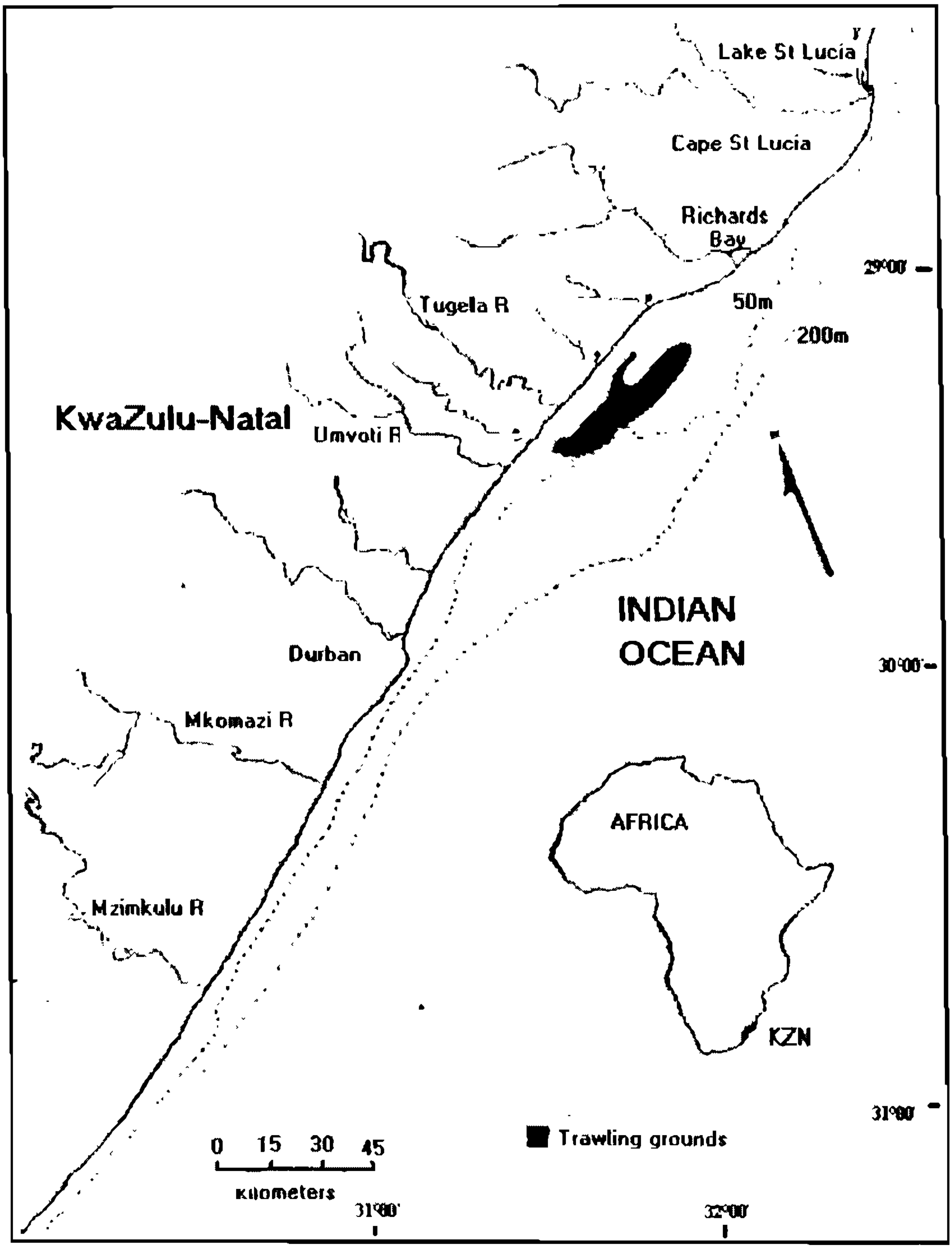
Although the scale of this fishery is small compared to other larger commercial fisheries in South Africa, the bycatch and discard proportions are high in comparison with other South African fisheries (Japp, 1997). There are other important fisheries operating in the Tugela area, such as the skiboat linefishery and the shore linefishery which are either commercial or recreational in nature (Mann *et al.* 1997). Participants in these sectors believe that the trawl fishery is responsible for the decline in species targeted by the other fisheries operating in the area (Fennessy, 1993, Mann *et al.*, 1997). The aim of this study is to investigate the species composition and to quantity of the bycatch from prawn trawlers operating on the Tugela Bank. An initial survey from 1989 to 1992 provided a baseline description of the bycatch (Fennessy *et al.*, 1994; Fennessy, 1993), and the intention of the current study was to repeat the survey after a 13-year period, to attempt to assess the impact that trawlers may have had on the region. This study also aims to provide management recommendations to reduce bycatch.

2. STUDY AREA: DESCRIPTION OF THE TUGELA BANK

The trawl grounds are situated two to four nautical miles offshore from the Matikulu River mouth (29°06'36''S, 31°36'48''E) on the KZN north coast, about 100 km from Durban (Figure 1). The grounds cover an area of approximately 500 km^2, with trawl depths ranging from 20 to 50 m (Fennessy, 1995). The continental shelf is at it's widest here, with the shelf break occurring 50 km offshore due to the gentle Natal Bight found between Durban and St Lucia (Lutjeharms *et al.*, 1989). The hydrodynamics of this area are dominated by wave action, rather than the Agulhas Current, which is forced further offshore by the Bight (Flemming and Hay, 1988). The south flowing Agulhas Current is a dominating dynamic feature that affects the flow along the entire KZN coastal region and it flows in a south-southeasterly direction (Schumann, 1982). There is also a strong counter-current inshore of the Agulhas Current, which flows in a north-easterly direction (Lutjeharms and Connell, 1989). This counter-current is thought to be driven by a vortex shedding from the Natal Bight, known as the Natal Pulse. These pulses originate at the Bight and grow laterally, moving downstream with average diameters of 170 km, whereas the Agulhas Current seldom exceeds 15 km in width (Lutjeharms and Connell, 1989).

The KwaZulu-Natal shelf water temperatures are generally well mixed because of the high-energy coastline (Schumann, 1982). Monthly mean sea surface temperatures measured close to the Tugela Bank ranged from 20 to 24.4°C (Fennessy, 1993). The water temperature measured at 10 m depth on the Bank was 17.75°C which was of 3°C lower than ambient shelf waters, and 8°C lower than the Agulhas Current surface waters (Lutjeharms *et al.*, 1989). The occurrence of cooler waters on the Bank is assumed to be a result of upwelling activity (Lutjeharms *et al.*, 1989), and re-circulation in the area (Schumann, 1982). In summer temperatures in the centre of the Bight are 18°C with surface temperature exceeding 22°C (Lutjeharms *et al.*, 1989). North-easterly and southerly winds predominate and they can attain speeds of up to 35 and 60 knots respectively (Hunter, 1988); these contribute to the high energies of the KwaZulu-Natal coast.

Figure 1: Location of the Tugela Bank prawn trawling grounds (After Fennessy, 1993). R=River.



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Trawling in this fishery started around 1921, during the Fisheries and Marine Biological Survey on the S.S. Pickle, which was commissioned by the Fisheries Survey Committee of the Department of Mines and Industries (Fennessy, 1993). Trawling then occurred sporadically until 1976 when two vessels began more regular trawling (Fennessy, 1993). However, recording of catch and effort data only started in 1985 using a standard logbook system instituted by the Department of Sea Fisheries (Fennessy and Groeneveld, 1997). Regular statistics were only collected from 1988, when at the time, the fishery was comprised of 12 companies and 21 vessels (Fennessy and Groeneveld, 1997). By 1995, the number of trawlers in operation had dropped to only 7 vessels owned by 4 companies (Fennessy and Groeneveld, 1997), while only 3 trawlers were operating in 2004.

Trawling on the Tugela Bank is seasonal, occurring mainly between March and September (Fennessy, 1993; Fennessy *et al.*, 1994), and is closed from November to February, to reduce bycatch of squaretail kob, *Argyrosomus thorpei* (DEAT, 2002). The target species for this fishery is the white prawn, *F. indicus*, but there are catches of brown prawns, *Metapenaeus monoceros*, and tiger prawns, *Penaeus monodon* (Fennessy, 1993; Fennessy *et al.*, 1994). Although Total Allowable Effort (TAE) is controlled by a permit system, there have been no stock assessments done for any of the targeted species for this fishery, but it is believed to be fully exploited (DEAT, 2002).

The vessels used are steel boats with lengths ranging from 24 to 40 m, and generating between 500 and 1000 hp (Fennessy and Groeneveld, 1997). The gear used is the otter trawl, ranging from single nets to boom-operated twin or triple nets, with footrope lengths of 25 to about 70 m (Fennessy and Groeneveld, 1997). The stretched mesh size is 55 mm in both the wings and the codend (Fennessy and Groeneveld, 1997). Trawling occurs on a 24 h basis with trawl speeds of two to three knots and drag duration averaging 4-5 hours. Trawlers carry crews of between 12 and 20, (Fennessy and Groeneveld, 1997) and the duration of trawl trips can be up to one month.

At the end of each trawl the catch is sorted by the crew and the prawn component is graded by size, packed in cartons and blast frozen as soon as possible (Fennessy, 1993). A large portion of the retained catch is prawns but the largest portion of the catch is bycatch, which, if commercially viable, is packed for marketing. This includes crabs, *Portunus sanguinolentus*, cephalopods, *Uroteuthis duvauceli*, *Sepiella cyanea* and several marketable fish species (Fennessy, 1993). The rest of the bycatch, which has a low market value is discarded.

4. MATERIALS AND METHODS

4.1 Sampling procedure

An initial survey of the bycatch species composition of the prawn trawlers operating on the Tugela Bank was done between May 1989-June 1992 (Fennessy, 1993) and the current study between March 2003 and July 2004 was a follow up to this initial survey.

An observer from Marine and Coastal Management (MCM), a directorate of the South African Department of Environmental Affairs and Tourism, was placed onboard the trawlers to collect discarded bycatch samples. There were a maximum of 120 observer days per year allocated for both shallow and deep water trawling. The trawler trips were of 3-4 weeks duration and trawlers sometimes switched from shallow to deep water trawling during a trip depending on the amount of target species available, so there was no control over the regularity of sampling. Four drags were sampled each day, three of which were processed onboard the trawler by the observer and one sample was frozen for on-shore processing. After the crew had removed the target species and the retained bycatch, the observer removed larger elasmobranchs from the bycatch and collected a +-20 kg sample of the discarded catch. A species identification catalogue was provided to assist with onboard species identification, and the species that were not included in the catalogue were labelled with a name and trawl details for later identification. Both the observer and the skipper recorded depth, position, time of day and duration of each sampled trawl in drag books. The quantities of retained prawn, retained bycatch and discarded bycatch were also recorded by the observer.

The frozen samples of discarded bycatch were taken to the Oceanographic Research Institute (ORI), in Durban for processing and analysis on-shore. Sorting of the samples included a breakdown of the sample by weight and number of all taxa, and recording the total lengths (TL) of at least fifty individuals of the three most commonly recorded teleost species. A third of the crustacean component was sub-sampled when it was too large to count and weigh each individual. Afterwards necessary corrections were made to estimate actual weight and number of crustaceans in that particular sample. Smith and Heemstra (1986) was used for teleosts species identification and Barnard (1950) for most of the crustaceans. Unidentified specimens were sent to the South African Institute of Aquatic Biodiversity (SAIAB) in Grahamstown and IZIKO Natural History Museum in Cape Town for positive identification. The data were captured onto Microsoft Excel spreadsheets, from which tables of the catch composition were produced illustrating the occurrence and relative contributions by weight and number of the teleosts, invertebrates and elasmobranchs to the total bycatch.

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Much of the data is descriptive, and is presented in the form of comparative tables. A more rigorous approach, such as multivariate analysis, was considered and rejected, since there was little control over sampling, which was ad hoc (see results).

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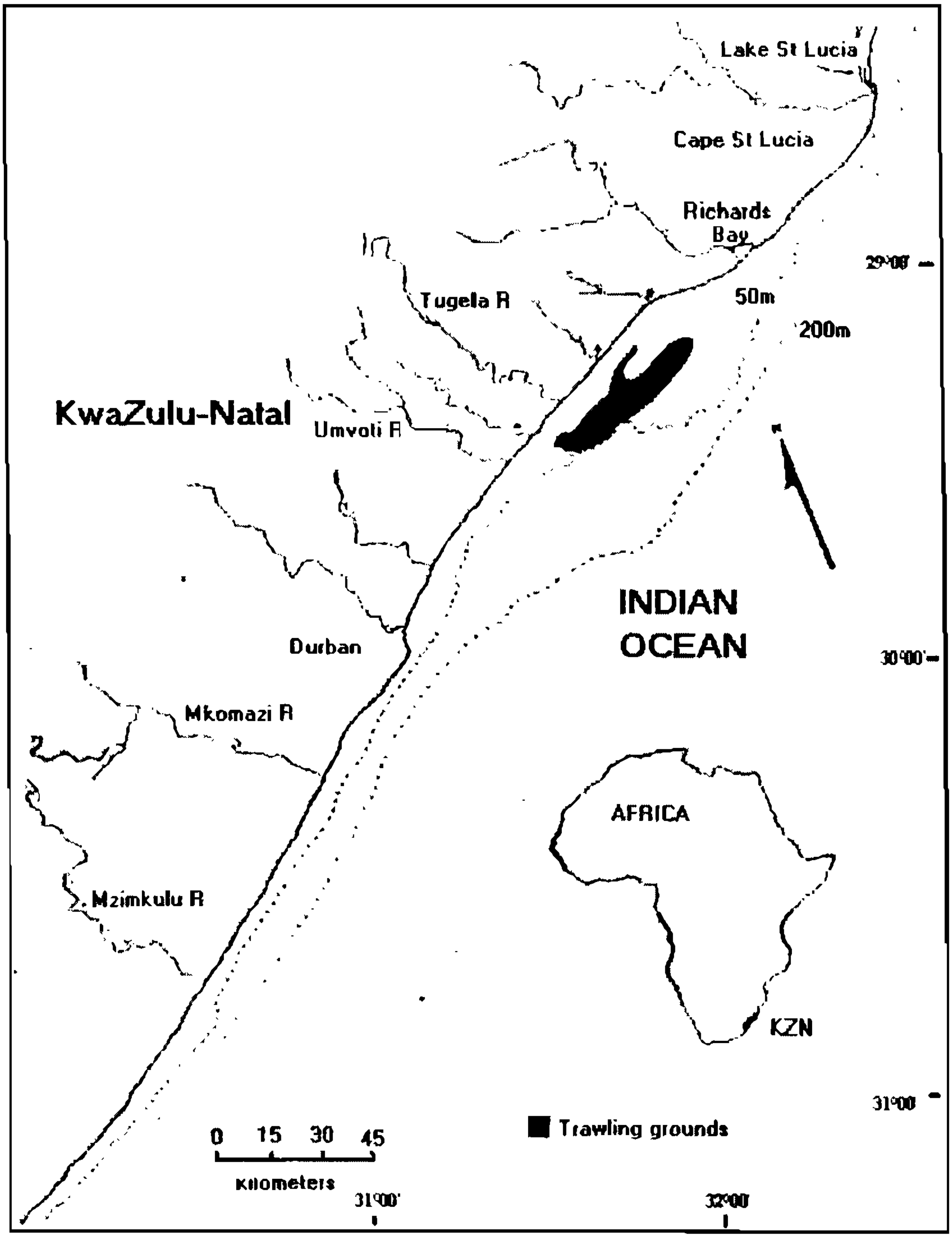

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The total lengths of the three most commonly recorded and consistently discarded bycatch species (*O. ruber*, *J. fuscolineatus* and *J. dorsalis*) were measured using a measuring board. A maximum of 50 randomly selected individuals of each species were measured per sample. The data were captured onto Excel worksheets and length frequency distribution histograms were produced. The Kolmogorov-Smirnov two sample test was applied to the data sets from 1989-1992 and 2003-2004 to test for any differences.

5. RESULTS

5.1 General

A total of 47 on-shore and 121 onboard discarded bycatch samples were collected between April 2003 and July 2004. The trawling trips were approximately one month in duration. The observer was instructed to collect and sort three onboard samples per day, but this did not always happen because of bad weather. There were also difficulties experienced in obtaining monthly samples due to low catch rates of the white prawn, *F. indicus*, which resulted in reduced fishing effort (Table 1.1).

Table 1.1: The number of discarded on-shore and onboard bycatch samples collected from Tugela Bank prawn trawlers during 2003-2004.

Month	Year	On-shore samples	Onboard samples
April	2003	7	20
May	2003	13	24
March	2004	10	21
April	2004	2	6
June	2004	2	3
July	2004	13	47
TOTAL		47	121

For analysis purposes, two seasons were defined based on sea surface temperatures: a 'warm' season (December-April) and a 'cool' season (May-November). Trawling occurred at depths ranging between 16 and 50 m and trawls were categorised as 'shallow' (16-24 m), 'medium' (26-30 m) and 'deep' (33-45 m). These depth and season categories (Table 1.2) were selected based on those described in Fennessy *et al.* (1994), to facilitate comparison with the 1989-1992 data. For convenience, the 1989-1992 data will be referred to as the 1990s data set and the 2003-2004 as the 2000s data set.

Table 1.2: The number of discarded on-shore and onboard bycatch samples collected from Tugela Bank prawn trawlers at different depths, seasons and time of day (April 2003-July 2004). On-shore = 47, onboard = 121.

Season	On-shore	Onboard	Depth	On-shore	Onboard	Time of day	On-shore	Onboard
Cool	28	74	Shallow	40	100	Day	41	105
Warm	19	47	Medium	7	16	Night	6	16
			Deep		5			

5.2 Overall catch composition of discarded bycatch

A total discarded on-shore bycatch sample weight of 842 kg, comprising 23 401 vertebrate and invertebrate individuals, was obtained during the survey. There were 14 560 teleost individuals and 8 812 invertebrates, making up 62% and 38% by number respectively of all samples. The onboard samples comprised a total of 43 567 individuals, 29 163 (67%) of which were teleosts and 12 276 (28%) were invertebrates.

Only 24 elasmobranch (sharks and rays) individuals were found in the on-shore samples whereas the onboard samples comprised 2 104 elasmobranchs (Table 2.1). This is because the observer was instructed to exclude the larger elasmobranchs from collected samples. The top five elasmobranch species in the onboard samples were (scalloped hammerhead shark) *Sphyrna lewini*, (duckbill ray) *Pteromylaeus bovinus*, (spotted eagleray) *Aetobatus narinari*, (stingray) *Himantura gerrardi* and (butterfly ray) *Gymnura natalensis* (Table 2.1). The identity of the onboard elasmobranchs could not be verified and should be treated with caution.

Table 2.1: Overall relative abundance of discarded bycatch elasmobranch species from Tugela Bank commercial prawn trawls (April 2003-July 2004). On-shore samples = 47, onboard samples = 121.

Scientific name Species	On-shore Total number	Onboard Total number	Onboard Percent by number	Onboard Percent of trawls
Sphyrna lewini	2	534	25.4	63.2
Pteromylaeus bovinus	0	463	22.0	51.6
Aetobatus narinari	0	361	17.1	18.3
Himantura gerrardi	5	197	9.4	44.7
Gymnura natalensis	0	134	6.4	55.9
Rhinobatos annulatus	10	126	6.0	37.1
Rhinoptera javanica	0	94	4.5	4.6
Dasyatis chrysonata	1	39	1.9	26.7
Rhinobatos leucospilus	0	28	1.3	5.6
Squatina africana	1	28	1.3	13.4
Scylliogaleus quecketti	0	25	1.2	5.1
Torpedo sinuspersici	4	21	1.0	3.2
Himantura uarnak	0	11	0.5	19.7
Rhynchobatus djiddensis	0	10	0.5	10.6
Mustelus mosis	0	9	0.4	1.3
Dasyatis thetidis	0	7	0.3	21.2
Rhinobatos holcorhynchus	0	5	0.2	3.1
Himantura draco	0	4	0.2	1.1
Carcharhinus obscurus	0	3	0.1	2.2
Rhizoprionodon acutus	0	3	0.1	2.2
Taeniura melanospilos	0	2	0.1	1.2
Holohalaelurus punctatus	1	0	0	0

The top five most commonly recorded invertebrate species made up 74% and 87% of all invertebrate on-shore and onboard samples by number respectively, with portunid crabs dominating the invertebrate catch. In the on-shore samples these were (crabs) *Portunus hastatoides*, *P. sanguinolentus*, *Matuta* sp., (mantis shrimp) *Squilla armata* and (cuttlefish) *Sepiella cyanea*. The top five invertebrate species in the onboard samples were *Matuta* sp., *P. sanguinolentus*, *S. armata*, *P. hastatoides* and (cuttlefish) *Sepia vermiculata* (Table 2.2). There is, however a likelihood of misidentification of the onboard invertebrate species because, unlike for the teleosts, the observer did not have an extensive identification catalogue for this group. For example, the considerable numbers of *S. vermiculata* recorded in the onboard samples compared to on-shore samples could be because of misidentification by the observer, as this species can be easily confused with *S. cyanea* (Table 2.2). There was also a high number of unidentified decapod crustaceans (crabs) recorded in the onboard samples because of difficulty in species identification.

Table 2.2: Overall relative abundance of discarded bycatch invertebrate species from Tugela Bank commercial prawn trawls (April 2003-July 2004). On-shore samples = 47, onboard samples = 121.

Scientific Name Species	On-shore Total number	Onboard Total number	On-shore Percent by number	Onboard Percent by number	Onshore/ Onboard Percent difference	On-shore Percent of trawls	Onboard Percent of trawls
Portunus hastatoides	1720	928	19.5	7.5	12	85.1	16.5
Portunus sanguinolentus	1437	3596	16.3	29.2	12.9	93.6	93.4
Matuta sp.	1420	3748	16.1	30.5	14.4	76.6	80.2
Squilla armata	1367	1719	15.5	14	1.5	78.7	62.8
Sepiella cyanea	537	0	6.1	0	6.1	95.7	0
Fenneropenaeus indicus	507	0	5.8	0	5.8	68.1	0
Mactra aequisulcata	456	0	5.2	0	5.2	63.8	0
Parapenaeopsis acclivirostris	376	230	4.3	1.9	2.4	66	14.9
Charybdis merguensis	188	3	2.1	0	2.1	40.4	2.5
Anadata natalensis	137	0	1.6	0	1.6	42.6	0
Ficus ficus	112	0	1.3	0	1.3	46.8	0
Chlamys furtoni	101	0	1.2	0	1.2	44.7	0
Conchoeceies artificiosus	100	187	1.1	1.5	0.4	48.9	30.6
Uroteuthis duvauceli	76	0	0.9	0	0.9	53.2	0
Philyra globulosa	48	178	0.5	1.4	0.9	42.6	17.4
Bufonaria crumena	35	0	0.4	0	0.4	36.2	0
Gonioneptunus africanus	31	7	0.4	0.1	0.3	25.5	2.5
Platylambrus quemvis	23	12	0.3	0.1	0.2	25.5	5.8
Polynices didyma	22	0	0.2	0	0.2	19.1	0
Trachypenaeus curvirostris	20	0	0.2	0	0.2	8.5	0
Eudolium pyriforme	13	0	0.1	0	0.1	19.1	0
Ixoides cornutus	12	0	0.1	0	0.1	17	0
Charybdis cruciata	12	0	0.1	0	0.1	21.3	0
Unidentified bivalves	12	0	0.1	0	0.1	4.3	0
Unidentified sea hare	12	0	0.1	0	0.1	12.8	0
Panulirus homarus	11	37	0.1	0.3	0.2	16.5	16.5
Unidentified asteroids	10	19	0.1	0.2	0	19.1	5.8
Dorippe lanata	7	0	0.1	0	0.1	12.8	0
Doclea muricata	5	0	0.1	0	0.1	4.3	0
Charybdis natator	4	0	0.1	0	0.1	8.5	0
Sepia vermiculata	1	757	0	6.2	6.1	2.1	38.0
Unidentified jellyfish	0	211	0	1.7	1.7	0	17.4
Loligo duvauceli	0	60	0	0.5	0.5	0	18.2
Unidentified cephalopod	0	41	0	0.3	0.3	0	5.8
Unidentified decapod crustaceans	0	543	0	4.4	4.4	0	11.6

The top five teleost species made up 64% and 66% by number of the total teleost catch of the on-shore and onboard discarded bycatch samples respectively. The most commonly recorded fish species, *Otolithes ruber, Johnius dorsalis, J. fuscolineatus, Secutor ruconius* and *Trichiurus lepturus*, occurred in similar proportions in both sample sets (Table 2.3).

Table 2.3: Overall relative abundance of discarded bycatch teleost species from Tugela Bank commercial prawn trawls (April 2003-July 2004). Only species that contributed greater than or equal to 0.1% by number in the on-shore or onboard samples were included. A comprehensive list is provided in Appendix 1. On-shore n= 47, onboard n=121.

Scientific Name	On-shore	Onboard	On-shore	Onboard	On-shore/ Onboard	On-shore	Onboard
Species	Total number	Total number	Percent by number	Percent by number	Percent difference	Percent of trawls	Percent of trawls
Otolithes ruber	2904	6926	20	23.7	3.8	95.7	94.3
Johnius dorsalis	2337	5617	16.1	19.3	3.2	100	87.8
Johnius fuscolineatus	1875	1960	12.9	6.7	6.2	100	57 7
Secutor ruconius	1303	2482	9.0	8.5	0.4	63.8	48
Trichiurus lepturus	887	2396	6.1	8.2	2.1	83.0	82.1
Atrobucca nibe	512	688	3.5	2.4	1.2	61.7	4 1
Thryssa vitrirostris	479	955	3.3	3.3	0	83.0	75.6
Pomatomus saltatrix	412	916	2.8	3.1	0.3	78.7	69.9
Pellona ditchela	411	740	2.8	2.5	0.3	55.3	18.7
Leiognathus equula	360	248	2.5	0.9	1.6	40.4	13 8
Upeneus vittatus	342	654	2.4	2.2	0.1	48.9	41.5
Alepes djedaba	295	357	2.0	1.2	0.8	44.7	17.1
Polydactylus malagasyensis	292	299	2.0	1.0	1.0	68.1	30.1
Cynoglossus attenuatus	227	900	1.6	3.1	1.5	85.1	75.6
Carangoides malabaricus	180	289	1.2	1.0	0.2	42.6	8.9
Cociella heemstrai	180	363	1.2	1.2	0	70.2	71 5
Saurida undosquamis	178	448	1.2	1.5	0.3	57.0	59.3
Parachaeturichthys polynema	151	0	1 0	0	1.0	27.7	0
Pomadasys olivaceum	139	371	1.0	1.3	0.3	38 3	28.5
Argyrosomus thorpei	117	80	0.8	0.3	0 5	40 4	28.1
Stolephorus punctifer	113	29	0.8	0.1	0.7	21.3	9 8
Sardinops sagax	112	925	0.8	3.2	2.4	10.6	18.7
Cynoglossus lida	98	48	0 7	0.2	0.5	40.4	10 6
Gazza minuta	91	328	0.6	1.1	0.5	38.3	25.2
Lagocephalus guentheri	59	76	0.4	0.3	0.1	46.8	19 5
Sphyraena acutipinnis	58	54	0.4	0.2	0.2	21 3	13.0
Drepane longimanus	50	126	0.3	0.4	0.1	42.6	38 2
Parastromateus niger	33	68	0.2	0.3	0	19.1	14.0
Paralichthodes algoensis	28	79	0.2	0.3	0.1	38.3	20.3
Cyclichthys orbicularis	26	33	0.2	0.1	0.1	27.7	9.8
Lagocephalus inermis	14	47	0.1	0.2	0.1	21.3	17.1
Ariomma indica	13	37	0.1	0.1	0	17	4.1
Epinephelus andersoni	12	43	0.1	0.1	0.1	17	14.6
Solea bleekeri	9	64	0.1	0.2	0.2	4 3	9.8
Champsodon capensis	0	171	0	0.6	0.6	0	23.6
Unidentified fish 1	0	95	0	0.3	0.3	0	2.4
Pomadasys kaakan	2	49	<0.1	0.4	0.4	2.1	8.0
Pomadasys commersonnii	0	46	0	0.2	0 2	0	3.0
Unidentified fish 2	0	35	0	0.1	0 1	0	3.3
Uroconger lepturus	0	17	0	0.1	0 1	0	8.9

However, the relatively higher contribution of *J. dorsalis* in the onboard samples as compared to the on-shore samples is possibly because of confusion with *J. fuscolineatus* and probably also explains the discrepancy between on-shore and onboard numbers of *J. fuscolineatus*. In general, though there were only minor discrepancies between onboard and on-shore samples in terms of relative abundance. In terms of percent abundance, however, there were some substantial discrepancies between the two data sets. For example, although the relative contributions of *A. nibe* and *Carangoides malabaricus* were similar in both sets of data, the percent of trawls occurrence in the onboard samples was much lower than in the on-shore samples (Table 2.3). These discrepancies could be due to onboard identification problems, or due to onboard sampling coinciding with the trawling of large, irregularly occurring shoals of these species.

5.2.1 Comparison of data from 1989-1992 and 2003-2004

Comparisons were made between the 1989-1992 (1990s) data and the 2003-2004 (2000s) on-shore data, to identify any changes in the discarded bycatch species composition of the Tugela prawn trawlers. Only the fish data were used for comparison because the 1989-1992 invertebrate data were not available. To reduce confounding effects as much as possible, only samples collected during the same months and depth ranges were included in the analysis. A total of 58 samples from 1989-1992 were selected for comparison (Table 2.4). Season and depth categories were based on those in Fennessy *et al.* (1994).

Table 2.4: The number of discarded on-shore samples collected from Tugela Bank prawn trawlers at different depths, seasons and time of day (1989-1992, n=58).

Season	Number of samples	Depth	Number of samples	Time of day	
Cool	42	Shallow	22	Day	45
Warm	16	Medium	31	Night	13
		Deep	5		

Overall species composition in both surveys was similar but contributions by individual species were different (Table 2.5). The top five most commonly recorded species in the 1990s survey were *J. dorsalis*, *J. fuscolineatus*, *O. ruber*, *T. lepturus* and *A. nibe*, whereas in 2000s, *O. ruber*, *J. dorsalis*, *J. fuscolineatus*, *S. ruconius* and *T. lepturus* were the most common (Table 2.5).

Of the 15 most commonly recorded fish species in the 1990s, 11 showed a decline in relative abundance of 5-91%, nine of which are demersals, and four species showed an increase of 20-189%. Of the 11 species which declined, nine are demersal, one is pelagic and one (*Trichiurus lepturus*) is bentho-pelagic. Of the four species which increased in relative abundance, two are demersal and two are pelagic. The most marked increase was shown by three pelagic species *S. ruconius*, *P. saltatrix* and *L. equula*, which increased in relative abundance by more than 2000%. As a group, members of the family Sciaenidae (kobs) showed an overall decline in their contribution to relative abundance by number from 63.6% in the 1990s to 53.3% in the 2000s. Three sciaenid species (*J. dorsalis*, *J. fuscolineatus* and *A.*

tibe) showed a decline in percent relative abundance of 26-59%, while *O. ruber* and *A. thorpei* increased in relative abundance by 32% and 189% respectively.

Examinations of changes in percent frequency of occurrence show that there are considerable differences between the two data sets for some species. Ten of the 15 most commonly recorded species in the 1990s showed a decline of 3-68% in percent occurrence in the 2000s, and eight of these are demersal species. Only one pelagic species, *T. vitrirostris*, showed a decline in frequency of occurrence. Five species (*Parastromateus niger, Epinephelus andersoni, L. equula, P. saltatrix* and *Pseudorhombus natalensis*) showed an increase of more than 200% in frequency of occurrence and three of these are pelagic species.

There were 24 species in the 1990s samples which did not occur in the 2000s, some of which were quite commonly recorded in the earlier samples, e.g. *B. maclellandi* and *U. lepturus* (Table 2.5). Similarly, there were 25 species in the 2000s samples which did not occur in the 1990s, some of which were also commonly recorded in the current samples, e.g. *A. djedaba* and *Stolephorus punctifer* (Table 2.5). However, 10 of these species were recorded in other samples from the 1990s, i.e. from months and/depths that were not included in the comparison (see Appendix).

Table 2.5:

Comparison of overall relative abundance of teleost species between 1989-1992 (n=58) and 2003-2004 (on-shore samples = 47) surveys. Only species that contributed greater than or equal to 0.1% by number were included. + or – signs indicate an increase or decrease in percent differences in relative abundance and frequency of occurrence. The percent differences in relative abundance and frequency of occurrence values have been rounded off for better presentation.

Scientific name	1989-1992 Number	1989-1992 Percent number	1989-1992 Percent of trawls	2003-2004 Number	2003-2004 Percent number	2003-2004 Percent of trawls	Percent Change in abundance	Percent Change in frequency of occurrence	Pelagic (P) Demersal (D)
Johnius dorsalis	5237	22.0	96.6	2337	16.1	100	-27	+4	D
Johnius fuscolineatus	4167	17.5	98.3	1875	12.9	100	-26	+2	D
Otolithes ruber	3617	15.2	98.3	2904	20.0	95.7	+32	-3	D
Trichiurus lepturus	2456	10.3	98 3	887	6.1	83.0	-41	-16	P/D
Atrobucca nibe	2041	8 6	93.1	512	3.5	61.7	-59	-34	D
Thryssa vitrirostris	1752	7.3	98.3	479	3 3	83 0	-55	-16	P
Lagocephalus guentheri	840	3.5	84.5	59	0.4	46.8	-89	-45	D
Drepane longimanus	797	3.3	82.8	50	0 3	42.6	-91	-49	D
Cynoglossus attenuatus	495	2.1	94.8	227	1.6	85 1	-23	-10	D
Cynoglossus lida	271	1.1	58.6	98	0.7	40.4	-38	-31	D
Carangoides malabaricus	239	1 0	39.7	180	1.2	42.6	+20	+7	P
Pellona ditchela	231	1.0	37.9	411	2.8	55.3	+189	+46	P
Gazza minuta	150	0.6	46.6	91	0.6	38.3	-5	-18	D
Pomadasys olivaceum	145	0.6	36.2	139	1.0	38.3	+65	+6	D
Lagocephalus inermis	135	0.6	67.2	14	0.1	21.3	-82	-68	D
Saurida undosquamis	117	0.5	51.7	178	1.2	57 4	+145	+11	D
Upeneus vittatus	115	0.5	37.9	342	2.4	48.9	+398	+29	D
Polydactylus malagasyensis	111	0.5	69.0	292	2.0	68.1	+330	-1	D
Ariomma indica	103	0.4	36.2	13	0.1	17.0	-77	-53	P
Secutor ruconius	95	0.4	36.2	1303	9.0	63.8	+2160	+76	P
Cociella heemstrai	72	0.3	46.6	180	1 2	70.2	+298	+51	D
Solea bleekeri	71	0.3	50.0	9	0.1	4.3	-66	-91	D
Argyrosomus thorpei	66	0.3	20 7	117	0 8	40.4	+189	+95	D
Thryssa setirostris	66	0.3	31 0	32	0.2	29.8	-20	-4	P
Bregmaceros maclellandi	57	0.2	15.5	0	0	0	-100	-100	P
Uroconger lepturus	51	0.2	17.2	0	0	0	-100	-100	D
Sardinops sagax	38	0.2	10.3	112	0.8	10.6	+285	+3	P
Sardinella albella	31	0.1	12.1	0	0	0	-100	-100	P
Antennarius striatus	26	0.1	25.9	0	0	0	-100	-100	D
Epinephelus andersoni	25	0.1	3.4	12	0.1	17.0	-5	+400	D
Mene maculata	24	0.1	5.2	0	0	0	-100	-100	P
Parachaeturichthys polynema	17	<0.1	15.5	151	1.0	27.7	+940	+79	D
Acsopia cornuta	16	<0.1	15.5	0	0	0	-100	-100	D
Pseudorhombus natalensis	13	<0.1	6.9	43	0.3	21.3	+200	+209	D
Cyclichthys orbicularis	11	<0.1	10.3	26	0.2	27.7	+100	+169	D
Dysomma anguillare	9	<0.1	12.1	11	0.1	19.1	-20	+58	D
Leiognathus equula	8	<0.1	8.6	360	2 5	40.4	+2370	+370	P
Pomadasys maculatum	8	<0.1	6.9	13	0 1	8.5	-10	+23	D
Callionymus marleyi	6	<0.1	6.9	20	0.1	8 5	+40	+23	D
Parastromateus niger	2	<0 1	3 4	33	0.2	19.1	+100	+462	P
Alepes djedaba	0	0	0	295	2 0	44 7	~	~	P
Archamia mozambiquensis	0	0	0	39	0 3	23.4	~	~	D
Pagellus bellottii natalensis	0	0	0	31	0.2	2 1	~	~	D
Paralichthodes algoensis	0	0	0	28	0 2	38 3	~	~	D
Pseudorhombus natalensis	0	0	0	43	0.3	21.3	~	~	D
Sillago sihama	0	0	0	11	0.1	17.0	~	~	D
Sphyraena acutipinnis	0	0	0	58	0.4	21.3	~	~	P
Sphyraena flavicauda	0	0	0	12	0.1	12.8	~	~	P
Stolephorus punctifer	0	0	0	113	0.8	21.3	~	~	P

5.3 Differences in discard rates

The effects of gear size (Table 3.1), season, depth and day or night on discard rates (kg discard.trawl hour^{-1}) were tested using t-tests. These differences were tested for all the trawls for which the observer had recorded discard rates in the 2000s study period.

Table 3.1: Gear types used in prawn trawlers on the Tugela Bank during the 2000s study and their respective size coding.

Gear type	Size coding	Footrope length(m)
Florida Flyer (FF)	Medium	2x24
Tri-net (2)	Medium	2x24
4-seam	Medium	47
Chico 500	Large	70
Tri-net (3)	Large	3x24

When testing for the effect of a factor on discard rate, the potentially confounding effect of other factors was minimised. For example, to test for the discard rate differences between day and night trawls, only trawls done during the cool season, in shallow depths and using large gear were considered. The combination of factors was selected to maximise the number of trawls being tested (Table 3.2).

Table 3.2: Number of Tugela Bank trawls for which discard rates were estimated, with associated variables.

Day/ Night	Number of trawls	Season	Number of trawls	Depth	Number of trawls	Gear size	Number of trawls
Day	105	Cool	74	Shallow	100	Medium	55
Night	16	Warm	47	Medium	16	Large	66
				Deep	5		
Total	**121**						

There was no difference in discard rate between trawls from shallow and medium depths. The test did not include trawls from deep depths because there were only five trawls in deep waters. However, the t-tests done on the gear size and season factors revealed significant differences in

5.4 Length frequencies

The mean lengths for *O. ruber, J. dorsalis* and *J. fuscolineatus* in this study were higher than those found in the 1989-1992 study by Fennessy (1993), suggesting that the fish caught are larger now than 10 years ago (Table 5.1). The Kolmogorov-Smirnov tests revealed that there were significant differences between the 1990s and 2000s length frequency distributions of all

three species (Table 5.2). However, the interpretation of these results is complicated by the fact that the mesh size has increased substantially since the 1990s study, from 38 mm to 55 mm (stretched mesh).

Table 4.1: A comparison of the total lengths of three trawled sciaenid species in trawler discards from 1989-1992 (1990s) and 2003-2004 (2000s).

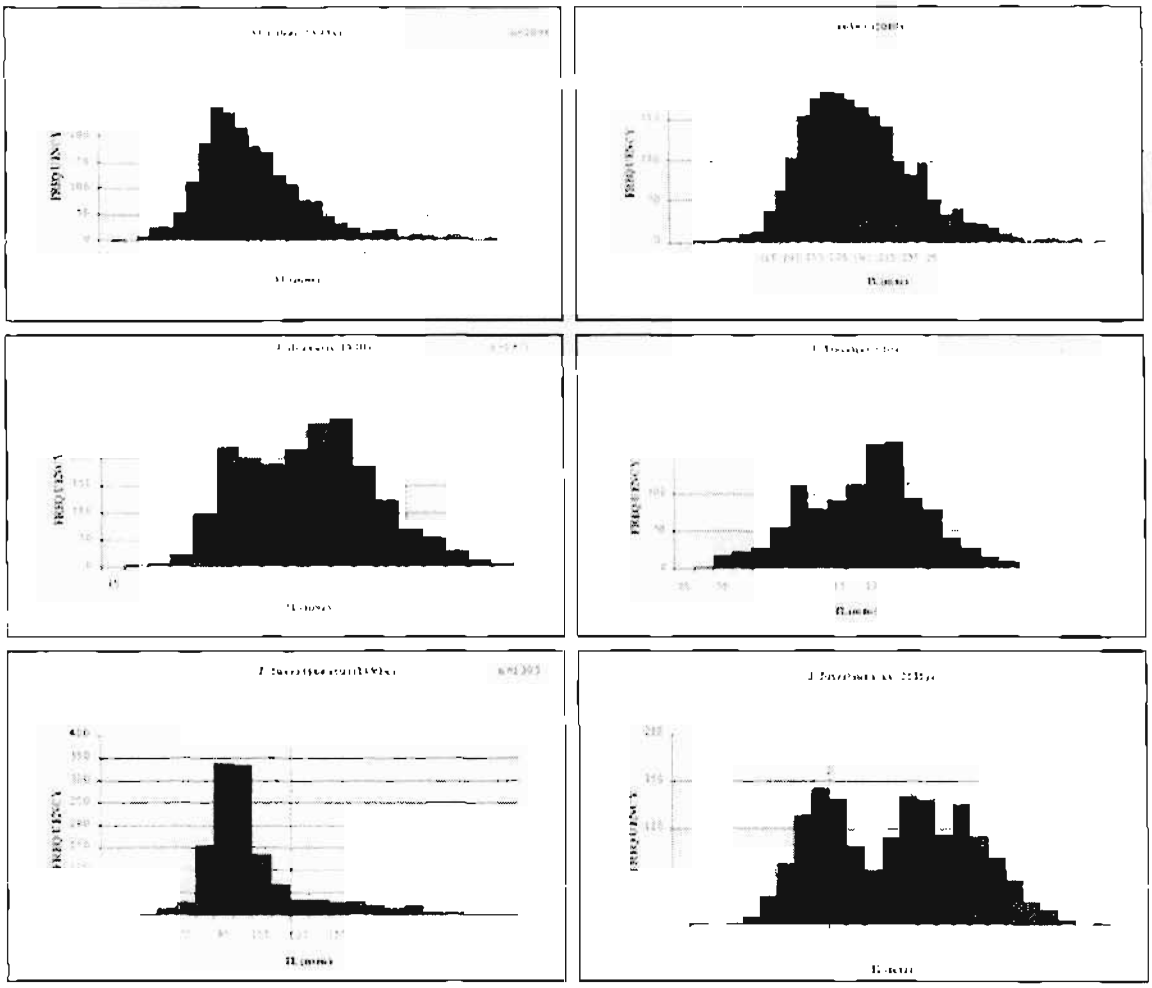
	O. ruber		*J. fuscolineatus*		*J. dorsalis*	
	1990s	**2000s**	**1990s**	**2000s**	**1990s**	**2000s**
N	2096	2067	1303	1459	1978	1123
MEAN	151	187.8	107	154.3	116	126
RANGE (TL mm)	39-456	50-390	52-248	45-275	38-220	45-205

Table 4.2: Results of the Kolmogorov-Smirnov test to illustrate differences between the 1990s and 2000s length frequency distributions of three sciaenid species from 1989-1992 (1990s) and 2003-2004 (2000s).

	O. ruber	*J. dorsalis*	*J. fuscolineatus*
Critical value	0.042	0.051	0.052
Test Value (D)	0.348	0.158	0.531

The length frequency distribution for *O. ruber* was positively skewed in the 1990s, while in the 2000s, it is approaching a normal distribution because there is a higher proportion of larger fish (Figure 3). The length frequency distribution for *J. fuscolineatus* in the 1990s was unimodal, while in the 2000s, it has two modes (Figure 3). This suggests that most of the size classes of these two species are now vulnerable to trawling, whereas before, mainly smaller size classes were trawled. However, the length frequencies of *J. dorsalis* from both year data sets are normally distributed and similar in appearance (Figure 3).

Figure 2: A comparison of length frequency distributions of three sciaenid species in trawler discards from 1989-1992 (1990s) and 2003-2004 (2000s) showing size at 50% maturity.



6. DISCUSSION

6.1 General

Bycatch is defined as "the part of the gross catch which is captured incidentally to the species toward which there is directed effort" (Saila, 1983). This bycatch can either be retained or discarded depending on its marketability/use. The discarded catch is the part of the bycatch that is thrown back into the sea. In recent years, most of the world's marine fisheries have been faced with the problem of bycatch (Broadhurst, 2000), as it is believed to play a significant role in the decline of many of the world's fish stocks. This is because discarded bycatch makes up approximately 10.6% of the total annual global landings (Japp, 1997). Many of the species caught as bycatch are targeted by other fisheries and this additional catch reduces the recruitment, biomass and yield of stocks that form these fisheries (Vaughan *et al.*, 1991; Kennelly *et al.*, 1993; Lowry *et al.*, 2001). As a large proportion of the bycatch consists of juveniles and subadults (Andrew and Pepperell, 1992; Broadhurst, 2000), this mortality represents a threat to biodiversity and long-term sustainability of marine fisheries.

Commercial prawn trawling occurs in the majority of the world's oceans and accounts for a significant portion of the total production of the world's marine fisheries (Broadhurst, 2000). Most of the world's prawn trawl fisheries are situated in shelf waters of tropical or sub-tropical waters, where there is high abundance and diversity of other organisms (van der Elst, 1988, Fennessy,1993). This factor, coupled with the highly indiscriminate nature of the otter trawl used for prawn trawling, accounts for the high percentage of bycatch in prawn trawl fisheries (Fennessy, 1994a).

The only crustacean trawl fishery in South Africa operates on the east coast of KwaZulu-Natal (KZN), and although it is small in scale, it is of considerable local commercial importance. The shallow water prawn trawl fishery is located on the Tugela Bank, and it is associated with a high diversity of bycatch. A previous study found this fishery to have the highest bycatch and discard rates of all the South African fisheries (Japp, 1997). There is also evidence that the fishery has been partly responsible for the decline of at least one species targeted by other fisheries (Fennessy, 1994b). An initial survey from 1989-1992 of the Tugela fishery bycatch composition focused on identifying species that were caught by trawlers and other fisheries sectors. A comparison of the bycatch data from 1989-1992 with the current information permitted a preliminary assessment of the wider potential impacts of trawling on fish in the area.

6.2 Overall catch composition and effort

Prawn trawling for the white prawn, *F. indicus* occurs on the Tugela Bank, but there are also significant catches of teleosts, elasmobranchs and invertebrate species, as shown in the earlier study by Fennessy (1993). The analysis of bycatch species composition in the current study supports this, showing high ichthyofaunal catch (122 species). Other studies have also recorded high and diverse levels of bycatch in commercial prawn trawl fisheries e.g. Australia (Harris and Poiner, 1991); Indonesia (Evans and Wahju, 1996); America (Nance and Scott-Denton, 1997) and Scotland (Stratoudaski *et al.*, 2001).

There were 22 elasmobranch species in the discarded bycatch, which contributed about 5% to the total discarded bycatch by number. Numerically four of the top five elasmobranchs are rays, which are demersal species and therefore highly susceptible to capture in prawn trawls (Stobutzki, 2002). Three of the top five species in the onboard samples occurred in more than 50% of the trawls. The impact of the prawn trawl fishery on the sustainability of elasmobranch species has yet to be addressed. An Australian study found that more than 50% of elasmobranchs caught in prawn trawls were immature and 66% died in the trawl net (Stobutzki *et al.*, 2002). Fennessy (1994a) also found high mortalities of some elasmobranchs in prawn trawls in South Africa.

In this study the invertebrates contributed 38% and 28% to the on-shore and onboard samples respectively, with portunid crabs dominating the catch. These are benthic and therefore vulnerable to capture in prawn trawls. Three of the top five most abundant invertebrate species in the on-shore samples occurred in more than 85% of trawls, and two species in the onboard samples occurred in more than 80% of trawls. Two of the five most commonly caught invertebrate species, the spotted crab (*P. sanguinolentus*) and swimming crab (*Matuta sp.*) were also abundant in a study of prawn trawl bycatch done by Walter (1997) in the East Frisian islands.

The Tugela prawn trawl bycatch consisted mostly of teleosts, contributing 64% and 66% to the total discarded bycatch by number in both the on-shore and onboard samples respectively. The fish bycatch community comprised of a mix of demersal and pelagic species with the demersal species dominating the catch. Most of the fish are shoaling species which also accounts for their vulnerability to the trawl gear (Fennessy, 1994a). Four of the top five fish species are demersal and *T. lepturus* is a semi-demersal species. The demersal nature of prawn trawling and slow trawling speeds probably accounted for the relatively lower abundance of pelagic species. A few species dominated by number and weight, a trend reported from many other prawn trawl bycatch studies, including in the Gulf of Carpentaria, Australia (Blaber *et al.*, 1990) ; the Great Barrier Reef, Australia (Watson *et al.*, 1990) and the Gulf of Paria, Trinidad (Maharaj and Recksiek, 1991). It has also been observed in other bycatch studies that the largest component of bycatch is fish (Hill and Wassenberg, 2000), and that nearly all prawn trawler discards are dead (Hill and Wassenberg, 1990).

Although there is a possibility of some species misidentification in the onboard samples, most of the fish species were recorded in both the on-shore and onboard samples. Furthermore, the relative contribution of individual fish species to the total discarded bycatch was similar for both data sets, with no species exceeding a percent difference of 4%. This is an indication that the sampling procedure is being followed consistently, and onboard observers are correctly identifying the catch.

Sciaenids are largely distributed in the Tugela Bank trawl catches (three of the top five most commonly recorded species in both the on-shore and onboard samples) further supports the reports of common occurrence of this family on coastlines close to river mouths. Species of this family are widely distributed in shelf waters of the tropical and sub-tropical Indian, Pacific and Atlantic oceans (Lowe-McConnell, 1962; Longhurst and Pauly, 1987; Sasaki, 1996) and are important components of fisheries in many countries (Fennessy, 1994). These species are usually regarded as 'indicator' species of penaeid fishing grounds (Pauly and Neal, 1985). Investigation into the biology of the three most commonly recorded species, *O. ruber, J. fuscolineatus* and *J. dorsalis*, showed that the two latter species use the Tugela Bank as a nursery area, accounting for their abundance in bycatches in the area (Fennessy, 2000). The suitability of the Tugela Bank as a nursery area (Fennessy, 2000) is enhanced by the high turbidity of the area. The turbidity is due to the many rivers that flow into the sea, which in turn contributes to mud deposition on the east coast of South Africa (Flemming and Hay, 1988). In addition, the Tugela Bank is situated in the Natal Bight, which provides protection form the rough seas which characterise the east coast; these qualities make the Tugela Bank suitable as a nursery area for sciaenids (Fennessy, 2000).

6.3 Potential effects of trawling

Bottom trawling is a source of chronic and widespread disturbance on the seabed of shallow seas (Schratzberger *et al.*, 2002). Studies in the North Sea have shown that trawling has profound effects on the ecosystem because trawlers remove large portions of the biomass of target and bycatch species, and because trawl gears have direct impacts on the substratum and associated biota (Jennings *et al.*, 1999). The disturbance to the substratum is because trawls are in direct contact with the seabed, and because gear-induced water movements lead to resuspension of surface sediments (Jennings *et al.*, 1999). This physical disturbance of the sediment can lead to loss of biological organisation and can reduce species richness (Hall, 1995).

This study examined the temporal impacts of bottom trawling on the fish community on the Tugela Bank after a 13 year interval, by comparing the initial (1989-1992) survey of the bycatch composition by Fennessy (1994b) with the current composition (2003-2004). The species presence from both surveys was similar although the relative contributions by individual species differed. Several sciaenids featured prominently in the discarded bycatch, with three species present in the top five most common fish species in the 2003-2004 survey, and four species in the top five in the 1989-1992 study. The species that showed the most change in relative abundance was *S. ruconius*, which featured in the top five most commonly recorded species in 2003-2004, replacing *A. nibe* in the 1989-1992 study. The high overall relative abundance of *S. ruconius* was partly due to high contributions from a few samples (three samples contributed over 50% of the total numbers of this species). *S. ruconius* is a slow-swimming fish which sometimes swims in dense, slow-moving shoals over the seabed (van der Elst, 1981), which accounts for the high relative abundance in some samples.

Of the 15 most commonly recorded species in the 1990s, 11 showed a decline and four showed an increase in relative abundance. Seven of the eight most commonly recorded species in the 1990s showed a decline in relative abundance of 26-91%, which suggests that trawling may have had a negative effect on the abundance of these species over time. Three of the five sciaenid species featuring in the 1990s and 2000s data sets showed a decline in relative abundance with *A. nibe* declining the most (59%). In contrast, *O. ruber* and *A. thorpei* increased in abundance by 32% and 189% respectively.

Also of significance are the observed changes in frequency of occurrence (Table 2.5). Of the species which were commonly recorded in 1990s, those which showed the greatest decline in frequency of occurrence were demersal species. *A. nibe*, for example, was a ubiquitous species in the 1989-1992 samples, but only occurs in 62% of trawls in the 2003-2004 data. *L. guentheri* and *D. longimanus* both occurred in more than 80% of trawls in the 1990s, but currently only feature in about 45% of trawls.

Considering the species which exhibit the greatest changes over the 13-year period, it is apparent that most of the species that showed large increases in relative abundance or frequency of occurrence are pelagic, and the species that showed large decreases are demersal. This is perhaps to be expected because demersal species occur close to the seabed, which makes them more likely than pelagic species to be vulnerable to the effects of bottom trawling over time. The growth rate of the species also has an effect on their vulnerability to harvesting, i.e. if the species is slow growing (growth rate $k<0.3\ yr^{-1}$), there is a higher probability of decreased abundance over time as a result of trawling. This is because stocks of short-lived, early maturing species are less affected by trawling, whereas long-lived, late-maturing species are more vulnerable (Alverson *et al.*, 1994; Stobutzki *et al.*, 2001). Fecundity can also affect the species' vulnerability to trawling because if low numbers of larvae are produced, fast stock recovery would be difficult. Seasonality also affects vulnerability, since species which occur more commonly in the main trawling season (April-July) are more vulnerable than species which are more common out of the main trawling season. In order to relate the observed changes in abundance/occurrence to a species' vulnerability to trawling, a simple index of change was derived, by taking the product of the absolute change in relative abundance and the frequency of occurrence (Table 5). For the species which showed the most change in abundance and/or frequency of occurrence, Table 5 illustrates how the biology of these species contributes to their vulnerability to trawling and attempts to explain the increased relative abundance of pelagic species over time.

Table 5: Species that showed the most change in relative abundance and/or frequency of occurrence over the 13-year period, with characteristics which determine their resilience to trawling. The index of change is a product of absolute change in relative abundance and frequency of occurrence.

Scientific name	Change in relative abundance	Change in frequency of occurrence	Index of change	Pelagic (P) Demersal (D)	Shoaling	Slow Growing ($K<0.3\ yr^{-1}$)	Migration	Fecundity	Resilience to Trawling[1]
Sectator ruconius[1]	9	28	237	P	YES	NO	YES	HIGH	HIGH
Atrobucca nibe[2]	-5	-31	-159	D	YES	YES	YES[a]	LOW	LOW
Pomatomus saltatrix[3]	3	56	152	P	NO	YES	YES	HIGH	HIGH
Drepane longimanus[4]	-3	-40	-122	D	NO	YES	YES	LOW	LOW
Lagocephalus guentheri[1]	-3	-38	-118	D	NO?	NO	NO?	HIGH	HIGH?
Alepes djedaba[5]	2	45	89	P	YES	NO	NO	HIGH	HIGH
Leiognathus equula[5]	2	32	75	P	YES	NO	NO	HIGH	HIGH
Trichiurus lepturus[5, 6]	-4	-15	-64	P/D	YES	YES?	YES?	LOW	LOW
Thryssa vitrirostris[5]	-4	-15	-62	P	YES?	NO	NO	HIGH	HIGH
Pellona ditchela[1]	2	17	32	P	YES	NO	NO	HIGH	HIGH

a. Juveniles occur on the Tugela Bank, sub-adults and adults move to deeper waters.

[1] Froese and Pauly (2005)
[2] Fennessy (2000)
[3] Govender (1996)
[4] Hoda and Khan (1994)
[5] van der Elst (1981)
[6] Kwok and Ni (1999)

The biological characteristics of these species i.e. whether they are pelagic or demersal, shoaling, slow-growing, migratory or highly fecund, were established from the literature or assigned a rating based on the most likely scenario. Theoretically, population dynamics suggests that slow growing species, which grow to large sizes and mature late in their life cycle, should decrease faster due to fishing pressure compared with fast growing, early maturing species (Southwood, 1976; Hoenig and Gruber, 1990). The species that showed a positive index of change i.e. they showed an increase in their relative abundance and/or frequency of occurrence, have high resilience to trawling. In contrast, species which had a negative index of change have low resilience to trawling, with the exception of *L. guentheri* and *T. vitrirostris*. However there is some uncertainty about the resilience of *L. guentheri* as Fishbase (2005) assigns the species a theoretical high growth rate of 0.46 yr^{-1} based on small maximum size (26cm) whilst Smith and Heemstra (1986) reports a maximum length of at least 41cm, which implies a slower growth rate. This species then, may in fact be less resilient than indicated in the table. The decline in *T. vitrirostris* is surprising given it's high resilience, but this species is highly estuarine dependent (Whitfield, 1999) and is particularly abundant in the St Lucia Estuary (Wallace, 1975). This estuary mouth has been closed for 3 years, so it is possible that recruitment of this species to the Tugela Bank has been affected, which in turn would reduce abundance in trawl catches.

Table 5 re-emphasises the resilience of pelagic species to trawling and the vulnerability of demersal species. Notwithstanding the apparent decline of several species of demersal fish on the Tugela Bank as a result of trawling, it is not necessarily true to say that the increase in some pelagic species is due to trawling. Pelagic species frequently demonstrate large shifts in abundance due to recruitment failures or success. This possibility cannot be ruled out for pelagic species such as *S. ruconius*, *P. saltatrix* and *L. equula* on the Tugela Bank.

Few other studies have examined the potential impacts of trawling over a long period. An Australian study also found that there was a decline in demersal species as a result of trawling because of their high susceptibility to capture by trawls (Stobutzki *et al.*, 2001). The species that are less susceptible to capture by trawls were generally pelagic with a broad depth distribution and wider range in the trawl grounds (Stobutzki *et al.*, 2001). These species also have a greater recovery capacity from the impacts of trawling. Harris and Poiner, (1991) compared the changes in abundance of fish species over a 20-year period of prawn trawling in the Southern Gulf of Carpentaria, Australia, and discovered that the total fish abundance had decreased. This study showed that although there was an overall decrease in total fish abundance, the abundance of most fish taxa had not changed. A total of 18 taxa had decreased, 12 had increased in relative abundance and 52 showed no significant change. The taxa that decreased were mostly benthic/demersal species, while those that increased were bentho-pelagic species, as in the current study. Tiews (1983) analysed the German shrimp fishery for 27 years between 1954-1981 to assess the stock sizes of 25 indigenous fish and crustacean species. This study showed a decline in the species abundance of seven species, while three species increased in abundance. Another study by Philippart (1996) showed a reduction of demersal fish and benthic invertebrate species to very low levels of abundance over 35 years, as a result of bycatch in the bottom trawl fishery of the southeastern North Sea.

6.4 Estimated bycatch quantities

Gear size and season had a significant effect on the bycatch discard rate and although gear size was coded as large, medium and small trawl sizes, it is a much more complex factor than the length of the footrope. The number of nets, number of seams, number of floats, trawl door size, trawl speed, etc. all influence the effective net opening, and therefore the potential catch rates. For example, although the chico 500 and tri-net are both coded as large nets, the chico 500 has a larger vertical opening than the tri-net. In the absence of controlled experimental conditions, it has not been possible to determine inter-gear calibration co-efficients, so a simple proxy (gear size) was used. Comparison of catch rates between gear sizes, seasons and depths should therefore be treated with caution, and the estimation of total discard quantities is therefore also only an approximation. Consequently, differences in discard rates between the various depths and seasons will not be discussed further.

Some species that are caught as bycatch on prawn trawlers are marketable and therefore retained. This component of the bycatch is referred to as retained bycatch, and includes fish like *A. thorpei*, *O. ruber*, *S. sagax*, *P. saltatrix* and *P. kakaan*. The estimated total discarded bycatch for 2003 was about 89 tonnes, which is much lower in comparison to the bycatch quantities estimated in the 1989-1992 study, which was 357 tonnes per year. However, the fleet effort for 1989-1992 was between 6 601 and 12 457 hours per year, whereas in 2003 the fleet effort was 1 032 hours. The reduced effort is partially because of the closed season between November-February, but also because only three trawlers were operating during the course of the current study. There was about 19 tonnes of retained catch in 2003 with the target species *F. indicus* contributing 10 tonnes to the retained catch, i.e. the prawn/discarded bycatch ratio is 1:9, which is similar to that estimated in the 1989-1992 survey, which was between 1:6 and 1:9. Other studies that have shown similar prawn/discarded bycatch ratios are by Young and Romero (1979) in the Gulf of California (1:15); Perez Mellado *et al.* (1982) in the Gulf of California (1:9.8); Pender *et al.* (1993) in Northern Australia (1:8-1:21); Kennelly *et al.* (1998) in New South Wales (1:10.4); Brewer *et al.* (1998) in the Gulf of Carpentaria (1:15.7-1:19.4); Cascorbi (2004) in the Gulf of Mexico (1:5.3) and the United States South Atlantic Regions (1:4.5).

6.5 Length Frequencies

O. ruber, J. fuscolineatus, J. dorsalis and *A. nibe* caught in the bycatch during this study were relatively small, which is typical of prawn trawl bycatch (Saila, 1983). The codend mesh in the prawn trawl fisheries is generally between 35 and 55 mm in order to retain prawns, resulting in bycatch of various size classes (Fennessy, 1994b). The predominance of smaller length classes in the catch is because the Tugela Bank functions as a nursery area for these and other demersal species. The sizes of these sciaenid species at 50% maturity for both sexes are 237 mm (*O. ruber*), 125 mm (*J. fuscolineatus*) and 168 mm (*J. dorsalis*) respectively (Fennessy, 1994b; Fennessy, 1999). Most of the individuals of *O. ruber* and *J. dorsalis* caught in the 1990s and 2000s, were immature (Figure 2). The majority of *J. fuscolineatus* caught in the bycatch from the 1990s were immature, whilst most of the individuals caught in the 2000s are larger than the size at 50% maturity. Although the mean sizes of all three species has increased in the past 13 years, this is probably a result of a gear change, since mesh size increased from 35mm in the 1990s to 55mm in the 2000s. However *J. dorsalis* and *J. fuscolineatus* showed an increase in minimum size and a decrease in the maximum size caught. This suggests that there are fewer large fish of these species, which could be a sign of overexploitation.

7. MANAGEMENT OF THE FISHERY AND RECOMMENDATIONS

Globally bycatch in prawn trawl fisheries is problematic and effective management of these fisheries is necessary to ensure the sustainability of both the target and bycatch species. The high abundance and diversity of other organisms in areas where penaeid trawling occurs requires a multispecies management approach to reduce bycatch without reducing the prawn catch. Although this is a difficult task, there are various management measures that have attempted to reduce bycatch both in South Africa and internationally. The South African Marine Living Resources Act (1998) includes bycatch issues in its objectives in that there is a "need to protect the ecosystem as a whole, including species that are not targeted for exploitation." The United Nations' Law of the Sea Convention (1994), to which South Africa is a signatory, recognised the need for the conservation, protection and co-ordinated management of the marine and coastal environment and its resources. Since bycatch is a growing issue, it is recommended that it be included in more detail in both South African and international legislation. This may include a requirement for fishing companies to make every effort to reduce bycatch, eg. the use of Bycatch Reducing Devices (BRDs). These devices improve selectivity, thus reducing bycatch quantity (Broadhurst, 2000) and many of the world's prawn trawl fisheries are required to use BRDs (Tillman, 1993). BRDs protect the target species of the prawn trawl fisheries and its juveniles, and also the target species of other fisheries (Broadhurst and Kennelly, 1995). Imposing maximum limits on the fishery specific targets:bycatch ratios could also be included in the legislation. The implementation of legislated management measures is a difficult task and it is a challenge to enforce these laws.

From the results of this study, there is evidence that there are species that have shown an increase and others a decline in relative abundance over the 13 years since the initial survey. Stobutzki *et al.* (2001) noted that bycatch threatens the sustainability and recovery capacity of certain species groups, which results in shifts in species dominance. This study shows that there has been an increase in the relative abundance of pelagic species. This shift in species abundance in turn potentially threatens the populations of certain species, and threatens the sustainability of the ecosystem as a whole. Trawling effort is currently restricted to a maximum of five trawlers operating at any one time on the Tugela Bank and there is a closed season between November and February. However there are some precautions that could be taken in order to reduce the amount of bycatch caught on prawn trawlers. For example, the compulsory installation of BRDs on trawlers should be researched, tested and implemented as soon as possible, as this will go a long way in reducing the bycatch volumes. In some countries (Australia) BRDs are used in conjunction with other management measures such as seasonal, spatial and daytime closures, limited entry and gear restrictions designed to control fishing effort (Brewer *et al.*, 1998). Countries like the United States of America (USA) have gone as far as to ban imports of penaeids from countries that do not use or enforce the use of BRDs on their commercial prawn trawl fisheries (Brewer *et al.*, 1998). The compulsory use of BRDs has proved highly successful in Norway (Isaksen, 2000), Australia (Kennelly, 2000), Mexico (Garcia-Caudillo *et al.*, 2000). Studies on the effectiveness of BRDs on prawn trawlers in the USA have also proved that BRDs not only significantly lower fish biomass caught on prawn trawlers, but also catch more prawns (Rogers *et al.*, 1997).

RECOMMENDATIONS

- It is recommended that more discarded bycatch samples be taken in deep waters (>30m) and during the night, so that ongoing comparisons can be made with historic data (Fennessy, 1993).
- Although it was not demonstrated conclusively in this study, gear type appears to have an impact on the discard bycatch rate, therefore it is advisable to do more research on gear types in order to determine which gear catches prawns optimally and reducesbycatch quantities.
- Studies should be undertaken on the effectiveness of BRDs and BRD use should ultimately be made compulsory for all prawn trawlers operating on the Tugela Bank.
- In addition, to reduce bycatch, a closed season from the 1st September until the 31st October should be implemented, as at this time prawn catches are low.
- The observer programme should continue in order to assess if the changes in species composition. Ongoing education of the observers on species identification is required for improved data quality.
- There should be more comprehensive assessment studies on the most commonly caught bycatch species, to determine their stock status and to assess their ability to withstand fishing pressure.

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APPENDIX

List of associated fauna recorded from Tugela Bank prawn catches in 2003-2004 including a teleost list from the 1989-1992 survey.

TELEOSTEI (1989-1992)

Acanthocepola indica	BANDFISH
Aesopia cornuta	UNICORN SOLE
Alectis ciliaris	THREADFIN MIRROFISH
Alectis indicus	INDIAN MIRROFISH
Antennarius striatus	STRIPED ANGLER
Apogon kallopterus	SPINYHEAD CARDINAL
Apogon nigripinnis	BULLSEYE CARDINAL
Argyrosomus thorpei	SQUARETAIL KOB
Ariomma indica	INDIAN DRIFTFISH
Ariosoma scheelei	TROPICAL CONGER
Atrobucca nibe	BLACKMOUTH CROAKER
Bregmaceros atlanticus	CODLET
Callionymus marleyi	SAND DRAGONET
Carangoides hedlandensis	BUMPNOSE KINGFISH
Carangoides malabaricus	MALABAR KINGFISH
Chelonodon pleurospilus	BLAASOP BEAUTY
Choridactylus natalensis	THREE STICK STINGFISH
Cociella heemstrai	SPOTFIN FLATHEAD
Cubiceps baxteri	BLACK FATHEAD
Cyclichthys orbicularis	BIRDBEAK BURRFISH
Cynoglossus attenuatus	FOUR-LINED TONGUEFISH
Cynoglossus lida	ROUGHSCALE TONGUEFISH
Dactyloptena orientalis	HELMET GURNARD
Drepane longimanus	CONCERTINA FISH
Dysomma anguillare	ARROWTOOTH EEL
Epinephelus andersoni	CATFACE ROCKCOD
Galeichthys sp.	CATFISH
Gazza minuta	TOOTHED SOAPY
Gerres filamentosus	THREADFIN PURSEMOUTH
Halieutea spicata	SPINY SEABAT
Hilsa kelee	RAZORBELLY
Johnius dorsalis	SMALL KOB
Johnius fuscolineatus	BELLFISH
Lagocephalus guentheri	BLACKBACK PUFFER
Lagocephalus inermis	SMOOTH PUFFER
Leiognathus equula	SLIMEY
Lutjanus russellii	RUSSEL'S SNAPPER
Megalaspis cordyla	TORPEDO FISH
Mene maculata	PONY FISH
Minous coccineus	ONE STICK STINGFISH

Muraenesox bagio	PIKE CONGER
Otolithes ruber	SNAPPER KOB
Parachaeturichthys polynema	TAIL-EYED GOBY
Paraplagusia bilineata	FRINGELIP TONGUEFISH
Parastromateus niger	BLACK POMFRET
Pellona ditchela	INDIAN PELLONA
Polydactylus sextarius	BUSTARD MULLET
Pomadasys kaakan	JAVELIN GRUNTER
Pomadasys maculatum	SADDLE GRUNTER
Pomadasys olivaceum	OLIVE GRUNTER
Pomatomus saltatrix	SHAD
Pseudorhombus arsius	LARGETOOTH FLOUNDER
Pseudorhombus natalensis	SMALLTOOTH FLOUNDER
Sardinella albella	GOLDSTRIPE SARDINELLE
Sardinops sagax	PILCHARD
Saurida undosquamis	LARGESCALE LIZARDFISH
Scomber japonicus	MACKEREL
Scomberomorus plurilineatus	NATAL SNOEK
Secutor ruconius	PUGNOSE SOAPY
Serranus cabrilla	COMBER
Solea bleekeri	BLACKHAND SOLE
Stephanolepis auratus	PORKY
Terapon jarbua	THORNFISH
Terapon theraps	STRAIGHT-LINED THORNFISH
Thryssa setirostris	LONGJAW GLASSNOSE
Thryssa vitrirostris	BONY
Torquigener balteatus	SLENDER PUFFER
Trachurus delagoa	AFRICAN MAASBANKER
Trichiurus lepturus	RIBBON FISH
Trypauchen microcephalus	COMB GOBY
Upeneus vittatus	YELLOW-BANDED GOATFISH
Uranoscopus archionema	STARGAZER
Uroconger lepturus	LONGTAIL CONGER

TELEOSTEI (2003-2004)

Alepes djedaba	SHRIMP SCAD
Antennarius hispidus	SHAGGY ANGLER
Apogon quadrifasciatus	TWOSTRIPE CARDINAL
Archamia mozambiquensis	MOZAMBIQUE CARDINAL
Argyrosomus thorpei	SQUARETAIL KOB
Ariomma indica	INDIAN DRIFTFISH
Atrobucca nibe	BLACKMOUTH CROAKER
Bregmaceros atlanticus	CODLET
Callionymus marleyi	SAND DRAGONET
Carangoides dinema	SHADOW KINGFISH
Carangoides ferdau	FERDY KINGFISH
Carangoides malabaricus	MALABAR KINGFISH
Cheimerius nufar	SANTER
Cociella heemstrai	SPOTFIN FLATHEAD
Cyclichthys orbicularis	BIRDBEAK BURRFISH
Cynoglossus attenuatus	FOUR-LINED TONGUEFISH
Cynoglossus lida	ROUGHSCALE
Drepane longimanus	CONCERINA FISH
Dysomma anguillare	ARROWTOOTH EEL
Epinephelus andersoni	CATFACE ROCKCOD
Epinephelus rivulatus	HALFMOON ROCKCOD
Galeichthys sp.	CATFISH
Gazza minuta	TOOTHED SOAPY
Johnius dorsalis	SMALL KOB
Johnius fuscolineatus	BELLFISH
Lagocephalus guentheri	BLACKBACK PUFFER
Lagocephalus inermis	SMOOTH PUFFER
Lagocephalus sceleratus	SILVER STRIPED PUFFER
Leiognathus equula	SLIMEY
Macroramphosus scolopax	SLENDER SNIPEFISH
Megalaspis cordyla	TORPEDO SCAD
Monocentris japonicus	PINEAPPLE FISH
Otolithes ruber	SNAPPER KOB
Pagellus bellottii natalensis	SAND SOLDIER
Parachaeturichthys polynema	TAIL-EYED GOBY
Paralichthodes algoensis	MEASLES FLOUNDER
Parapriacanthus ransonneti	SLENDER SWEEPER
Parastromateus niger	BLACK POMFRET
Pelates quadrilineatus	TRUMPETER
Pellona ditchela	INDIAN PELLONA
Polydactylus sextarius	BUSTARD MULLET
Pomadasys kaakan	JAVELIN GRUNTER
Pomadasys maculatum	SADDLE GRUNTER
Pomadasys olivaceum	OLIVE GRUNTER
Pomatomus saltatrix	SHAD
Psettodes erumei	ADALAH

Pseudorhombus natalensis	SMALLTOOTH FLOUNDER
Pterois russelli	PLAINTAIL FIREFISH
Rastrelliger kanagurta	SUGAR MACKEREL
Rhabdosargus holubi	CAPE STUMPNOSE
Sardinops sagax	PILCHARD
Saurida undosquamis	LARGESCALE LIZARDFISH
Secutor ruconius	PUGNOSE SOAPY
Sillago sihama	SILVER SILLAGO
Solea bleekeri	BLACKHAND SOLE
Sphyraena acutipinnis	SHARP-FIN BARRACUDA
Sphyraena flavicauda	YELLOW-FIN BARRACUDA
Stephanolepis auratus	PORKY
Stolephorus punctifer	BUCCANEER ANCHOVY
Terapon jarbua	THORNFISH
Thryssa setirostris	LONGJAW GLASSNOSE
Thryssa vitrirostris	BONY
Trachinocephalus myops	PAINTED LIZARDFISH
Trichiurus lepturus	RIBBON FISH
Upeneus vittatus	YELLOW-BANDED GOATFISH

ELASMOBRANCHII (2003-2004)

Aetobatus narinari	SPOTTED EAGLERAY
Carcharhinus obscurus	DUSKY SHARK
Dasyatis chrysonata	STINGRAY
Dasyatis thetidis	THORNTAIL STINGRAY
Gymnura natalensis	BUTTERFLY RAY
Himantura draco	DRAGON STINGRAY
Himantura gerrardi	SHARPNOSE STINGRAY
Himantura uarnak	MARBLED STINGRAY
Holohalaelurus punctatus	SPOTTED CATSHARK
Mustelus mosis	HARDNOSED SMOOTH-HOUND SHARK
Pteromylaeus bovinus	DUCKBILL RAY
Rhinobatos annulatus	LESSER GUITARFISH
Rhinobatos holcorhynchus	SLENDER GUITARFISH
Rhinobatos leucospilus	GREYSPOT GUITARFISH
Rhinoptera javanica	FLAPNOSE RAY
Rhizoprionodon acutus	MILK SHARK
Rhynchobatus djiddensis	GIANT GUITARFISH
Scylliogaleus quecketti	FLAPNOSE HOUNDSHARK
Sphyrna lewini	SCALLOPED HAMMERHEAD
Squatina africana	ANGEL SHARK
Taeniura melanospilos	ROUND RIBBONTAILRAY
Torpedo sinuspersici	MARBLED ELECTRIC RAY

CRUSTACIA: REPTANTIA (2003-2004)

Charybdis cruciata
Charybdis merguensis
Charybdis natator
Conchoecetes artificiosus
Doclea muricata
Dorippe lanata
Gonioneptunus africanus
Ixoides cornutus
Matt sp.
Platylambrus quemvis
Portunus hastatoides
Portunus sanguinolentus

CRUSTACEA: NATANTIA

Fenneropenaeus indicus
Panulirus homarus
Parapenaeopsis acclivirostris
Trachypenaeus curvirostris

STOMATOPODA

Lysiosquilla maculata
Squilla armata

CEPHALOPODA

Sepia vermiculata
Sepiella cyanea
Sepiella cyanea
Uroteuthis duvauceli
Uroteuthis duvauceli

GASTROPODA
Bufonaria crumena
Bufonaria crumena
Ficus ficus
Polynices didyma
Tonna allium

PELYCOPODA
Anadata natalensis
Eudolium pyriforme
Mactra aequisulcata
Unknown heart shaped clam