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Bycatch and discarding in the South African demersal trawl fishery

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Abstract

Observers aboard commercial trawlers collected data on the total catch composition of 614 and 479 hauls made by vessels operating off the south and west coasts of South Africa, respectively. On the south coast, four fishing areas were identified on the basis of target species and fishing depth. On the west coast, hauls were separated into those targeting hake *Merluccius* spp. in four depth ranges (0–300, 301–400, 401–500, and >500 m) and those targeting monkfish *Lophius vomerinus*. For each area, the catch composition was calculated and the species assemblages were investigated using cluster analysis and multi-dimensional scaling. Finally, for each coast, the weight of fish discarded annually was estimated. On the south coast, although hake dominated, between 21% and 47% of the catch was not hake, depending on the fishing area. In comparison, hake dominated west coast catches, the proportion of hake increasing with depth. For each fishery investigated, approximately 90% of the catch was processed and landed. However, estimates of annual discards indicate that the south and west coast fisheries may annually discard 9000 or 10,000 t and 17,000 or 25,000 t, of undersized and unutilizable fish and offal, respectively, depending on the estimation method used. When developing strategies to limit or enhance utilization of bycatch, cognisance should be taken of the differences in catch composition between the south and west coasts and of the importance of bycatch revenue to south coast fishing companies.

Keywords: Agulhas sole; Bycatch; Cape hake; Discarding; Monkfish; South Africa; Trawl

1. Introduction

Demersal trawl fisheries are unselective, capturing non-target species (bycatch), which may be retained if they have a commercial value or discarded if they do not (Saila, 1983). Poor data on bycatch and discarding rates can lead to biased estimates of fishing effort and mortality and can give rise to inaccurate estimates of stock status. Over the past three decades, it has been recognised that in order to manage marine fisheries effectively, we must assess and manage bycatch (Saila, 1983; Alverson et al., 1994) and we must understand its impact on the ecosystem (Pauly et al., 2002).

The South African demersal fishery can be broadly separated into the south coast fishery, based at Mossel Bay and Port Elizabeth, and the west coast fishery based at Cape Town and Saldanha Bay (Fig. 1). The fishery primarily targets two species of Cape hake (shallow-water *Merluccius capensis* and deep-water *Merluccius paradoxus*) (Payne, 1989) and (on the south coast) Agulhas sole *Austroglossus pectoralis* (Payne and Badenhorst, 1989). The annual hake total allowable catch (TAC) is some 150,000 t (Stuttaford, 2000), about two-thirds being allocated to the west coast fishery and the balance to the south coast fishery. However, west coast vessels operating on the south coast land a large proportion of the south coast TAC.

The two fisheries are distinct, primarily because of differences in species abundance and diversity. On the south coast, the Agulhas Bank is the focus of several fisheries (Badenhorst and Smale, 1991; Smale and Badenhorst, 1991), including the trawl fisheries (Japp et al., 1994). Trawl catches are diverse, and several bycatch species contribute to the landings. In the hake-directed fishery, bycatch species include jacopever *Helicolenus dactylopterus*, horse mackerel *Trachurus trachurus capensis*, Agulhas sole and silver kob *Argyrosomus inodorus* (Japp et al., 1994; Payne and Badenhorst, 1989). Similar species are caught as bycatch in the sole-directed fishery, in which hake is a bycatch. Small (14–30 m long) stern or side trawlers (which deploy the net from the side of the vessel) fish inshore and offshore trawling is with larger (35–42 m) stern trawlers. During the period of this study, the south coast demersal trawl fleet was com-

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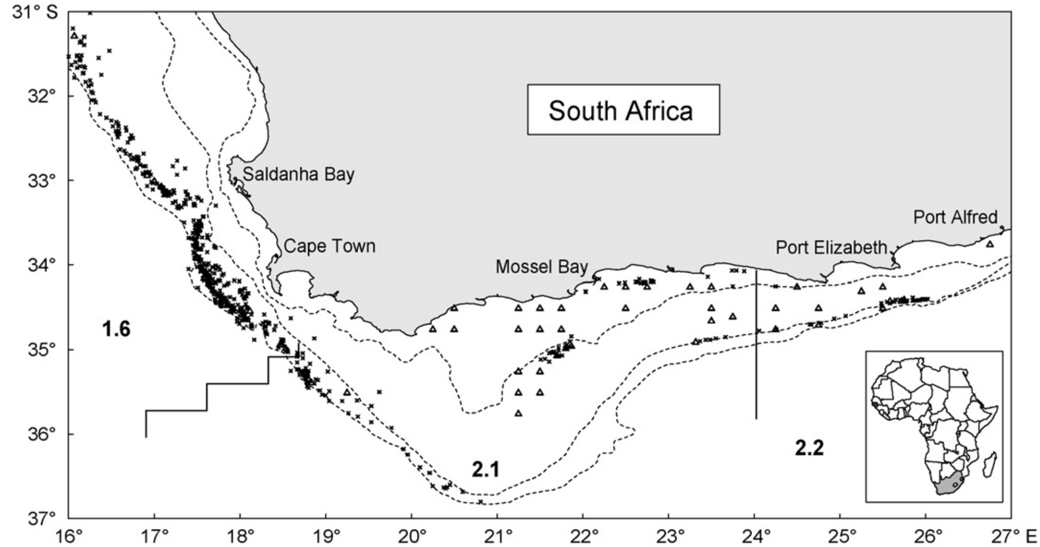

Fig. 1. Map of South Africa showing the locations of trawls monitored by observers between June 1995 and September 2000, and places mentioned in the text. Crosses indicate position of one trawl and open triangles the position of two or more trawls. Solid lines indicate the boundaries of the ICSEAF divisions (numbered in bold). Isobaths are 100, 200, and 500 m.

posed of 29 inshore and 3 offshore wet fish trawlers (Stuttaford, 2000).

On the west coast, bycatch species include horse mackerel, kingklip *Genypterus capensis* and monkfish *Lophius vomerinus* (Payne and Badenhorst, 1989). Large (25–60 m) stern trawlers, that can fish in waters up to ~600 m deep form the majority of the fleet. The fishery has historically been hake-directed, the other species being landed incidentally. Recently, there has been targeting of high-value species such as monkfish (Stuttaford, 2000). Although the same mesh size is used for monkfish as for hake-directed fishing (110 mm stretched mesh, as specified in the South African Government Gazette No. 19205, 2 September 1998), a lower headline height is used to increase the proportion of monkfish in the catch. Although some bycatch is retained and utilized by the trawl fishery (Stuttaford, 2000), a portion is discarded, usually dead (pers. obs.). During the study, the west coast demersal trawl fleet was composed of 1 inshore and 40 offshore wet fish trawlers (Stuttaford, 2000). A graphic illustration of the trawl catch and definition of the terms used in the text is given in Fig. 2. For this study, the term discards refers to bony fish, elasmobranchs and cephalopods.

Historically, catch reporting in the trawl fishery has focused on the landed rather than the total catch. Therefore, little information exists on the true composition of demersal catches (as opposed to landings), and on the levels and patterns of discarding by the fleet. This paucity of information and lack of management measures is of concern when applying an ecosystem approach to management, particularly if there is a move towards increased targeting of previously bycatch species.

Japp (1997) made the only comprehensive estimates of bycatch and discards available for the demersal trawl fishery. Bycatch ratios were calculated from research survey data and applied to commercial landings data to estimate the annual bycatch of non-target species. However, Japp (1997) noted several differences between commercial and survey data that could bias the estimates: commercial trawl gear is more selective than survey gear; surveys may be conducted over substrata unsuitable for commercial trawling; and survey trawls are of a shorter duration than commercial trawls. Also, surveys sample during three or four periods during the year, and species assemblages may be affected seasonally (Roel, 1987).

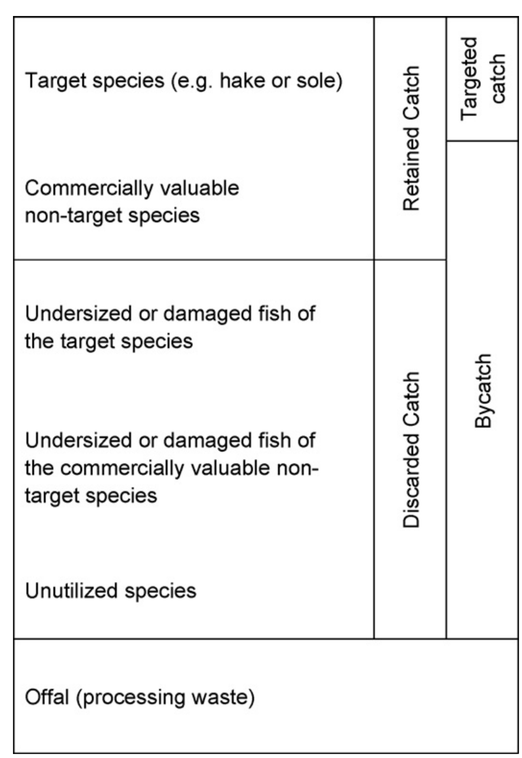

Fig. 2. Graphic illustration of the components of the catch as defined in the text (Note that if nominal retained values are given then the offal component is already included in the total catch.).

This paper presents the first quantitative data on catch composition, bycatch levels and discard estimates of demersal trawlers operating on the south and west coasts of South Africa. The paper also aims to show how understanding the community structure, species abundance and relationships between species can help assess the impact that management measures may have on the ecosystem around a fishery. It is one of two papers that assess and discuss options for bycatch management in South African demersal trawl fisheries.

2. Methods

2.1. Data collection

Data were collected by observers aboard commercial trawlers operating from Mossel Bay or Port Elizabeth (the south coast) between January 1996 and September 2000, and from trawlers operating from Cape Town or Saldanha Bay (the west coast) between June 1995 and September 2000 (Fig. 1). For the south coast, an observer went to sea on one sole-directed and one hake-directed Mossel Bay vessel per month whenever possible. Observers were deployed on Port Elizabeth vessels on an *ad hoc* basis. On the west coast, a pair of observers completed two trips per month, one with each of the two major trawling companies operating in South African waters (Sea Harvest and Irvin & Johnson). In addition, two trips were completed in 2000 on a vessel targeting monkfish. The observers had no influence on trawling location, and the accommodation of an observer aboard was at the discretion of the company involved.

For each trawl, the discarded catch (or a random subsample), was sorted to species, and the weight and length distribution of each species recorded. If the catch was subsampled, one of two methods was employed to estimate the proportion measured. On small vessels the net is emptied onto the deck for sorting. The proportion of the catch subsampled was determined by recording the number of buckets of discards sampled and estimating the total number of buckets of the catch. Although this is not the most accurate estimation method, other methods could not be used because of the limited space and sampling time.

On larger vessels, the net is emptied into a holding pond below deck and a conveyor belt takes the catch to a sorting table. On the sorting table, fish for processing are removed and the remainder conveyed overboard or to a fishmeal plant. It is therefore impossible to visually estimate the volume of the catch or the proportion subsampled. Thus, the proportion of the catch subsampled was estimated by recording the time spent removing discards from the belt, and the total time of belt operation. To reduce bias, the subsampled discards were removed from the discard belt at the beginning, middle, and end of the sorting process. Because of time constraints, the weight or number of invertebrates other than cephalopods, was not recorded.

Also because of time constraints, the retained catch was not measured, and information on this component of the catch was obtained from factory managers. Species such as hake, monkfish, and kingklip are headed and gutted on board and the offal (heads and viscera) discarded. Thus, the information obtained from the factory manager represented the processed weight only. The nominal (whole) retained weight of these species was estimated by multiplying the processed retained weight by Marine and Coastal Management's (MCM) conversion factors (hake, headed and gutted [H&G] = 1.46, hake, gutted = 1.1; monkfish H&G, 3.44; kingklip H&G = 1.52). The total catch was calculated as the sum of the estimated nominal retained weight for each species plus the estimated discard weight. Occasionally, some offal, such as the ovaries (to be sold as roe) or heads (to be sold as bait), is retained because of its higher value and the retained weight is recorded. The total offal weight was estimated as the nominal retained weight minus the processed retained weight. The weight of offal discarded was calculated by subtracting the retained offal weight from the estimated total offal weight. Additional data such as trawl position, duration, and time of day were obtained from the vessel's log.

Between 1995 and 2000, 614 trawls were observed on the south coast (595 from Mossel Bay, 19 from Port Elizabeth) and 479 trawls were observed on the west coast (430 from hake-directed and 49 from monkfish-directed vessels). During the same period, the fleet completed 203,020 and 157,603 trawls on the south and west coasts, respectively. This sample represents 0.30% of the total number of trawls fished (Marine and Coastal Management, unpublished data). The location of all trawls monitored is presented in Fig. 1, and a breakdown of trawls by fishing area and year is given in Table 1.

2.2. Data analysis

For each coast, the data were separated into pre-determined areas and the community structure of each area was investigated. This approach was used rather than a more classical approach, in which the data define the communities, because the purpose of the analysis was to investigate differences between discreet fisheries that already exist. Thus, the results will be applicable to the real fishery situation. This approach was also used as commercial catch data are readily available to researchers stratified by depth, ground and fleet and the results could be used in later extrapolations to the total catch and by other researchers.

On the south coast, four areas were defined: inshore hake-directed, offshore hake-directed (west), offshore hake-directed (east), and sole-directed. Inshore hake-directed fishing is undertaken by side trawlers that are limited to an engine size of 750 bhp, effectively confining them to fishing in water <120 m deep. They generally target hake east from 22°E to Port Elizabeth or Port Alfred. The offshore hake-directed (west) area is a well-defined fishing area off Mossel Bay whose greater depth and westerly position results in a different catch composition from that of inshore hake-directed fishing. Offshore hake-directed (east) refers to an area off Port Elizabeth where fishing takes place in water 200–300 m deep by stern trawlers legally precluded from fishing shallower than 120 m. Sole-directed trawling is with side trawlers generally fishing between 20°E and 22°E. For the west coast, trawls were assigned to one of five defined areas: monkfish-directed or, for hake-directed trawls, one of four depth ranges (0–300, 301–400, 401–500 and >500 m).

Table 1
Number of demersal trawls monitored by observer (by year and fishing area) off the south and west coasts of South Africa between June 1995 and September 2000

Fishery	1995	1996	1997	1998	1999	2000	Total
South coast							
Offshore hake-directed (west)		11	67	26	5	30	139
Offshore hake-directed (east)		4	34	0	1	2	41
Inshore hake-directed		12	26	53	7	42	140
Inshore sole-directed		133	106	34	12	9	294
Total		160	233	113	25	83	614
West coast							
Hake-directed trawls							
0–300 m	1		26	25			52
301–400 m		17	80	38	7		142
401–500 m	17	52	82	39	11		201
>500 m	16	2	8	9			35
Monkfish-directed trawls					15	34	49
Total	34	71	196	111	33	34	479

The fishing areas are defined in the text.

Analysis was carried out using the PRIMER 5 package (v. 5.1.2; Plymouth Marine Laboratory). For south and west coasts separately, each trawl was assigned to a fishing area, and the unstandardized biomass data were root–root transformed. Analysis of similarity (the ANOSIM routine in PRIMER), a non-parametric analysis of variance based on Bray–Curtis similarity, was used to compare the catch compositions between each pair of fishing areas. The data are re-ordered to give a global *R*-statistic that tests the null hypothesis that there is no significant difference between areas. Pairwise comparisons (ANOSIM) between fisheries were used to determine areas that were significantly different (Pierce et al., 1998). SIMPER in PRIMER was used to identify the indicator species within each fishing area and to calculate the level of similarity within, and the level of dissimilarity between, fishing areas.

Smale et al. (1993) investigated south coast community structure using survey data and identified three principal clusters, including an inshore cluster, which corresponds to the area covered by inshore hake and sole-directed fishing in the current study. To determine whether survey data could be split into similar areas, the original data, covering the same time period as this study were obtained. Trawls were separated into those that took place in the commercial hake and sole-directed trawling areas and significant differences between the two areas were investigated using the ANOSIM function.

The catch composition and the fate of the catch were investigated by calculating the total percentage contribution of each species to the catch (by weight) in each area. The percentage of the catch (by weight) subsequently retained or discarded was then determined. Finally, the percentage contribution (by weight and number) of each species to the discarded catch was calculated. Unfortunately, there is no information on the percentage contribution of each species to the total catch by number because the retained catch is recorded by weight only.

Finally, the weight and number of fish discarded annually was estimated by extrapolating the observer data to the total annual catch of the fleet in 1997, the year of most observer effort and, for the west coast, the midpoint of the observer programme. All observer data were pooled and stratified according to the statistical regions defined by ICSEAF (the International Commission for the Southeast Atlantic Fisheries) in order to make them comparable with historical commercial catch records. Two ICSEAF divisions (Divisions 2.1 and 2.2) encompass South Africa's south coast (Fig. 1) and one (Division 1.6) encompasses the west coast. MCM capture commercial catch and effort data by ICSEAF division and fishery (inshore and offshore), so discard estimates were calculated for inshore Division 2.1, offshore Division 2.1, inshore Division 2.2, offshore Division 2.2, inshore Division 1.6, and offshore Division 1.6, and summed to give final discard estimates for the south and west coasts.

Two methods were employed to estimate total discards, effort- and landings-based approaches. If we assume that the distribution of the observed trawls is similar to the distribution of the fleet in a fishing year, then the catch composition of the observed trawls should reflect the catch composition of the fleet for that year. Given that we know the fishing effort expended during observed trawls and the total effort expended by the fleet in a given year, we can estimate the total annual catch (including discards) by the fleet by effort-based extrapolation:

$$\text{annual discard} = \frac{\text{observed catch}}{\text{observed fishing effort}} \times \text{annual fishing effort}. \quad (1)$$

Alternatively, we can assume that the proportions of target and non-target species within the observed catches reflect the proportions of target and non-target species in annual catches made by the fleet. This relationship can therefore be used to extrapolate from the observed catches to the annual catch. This is a landings-based extrapolation:

$$\text{annual discard} = \frac{\text{observed discard}}{\text{observed total catch}} \times \text{annual landing}. \quad (2)$$

If no landings were recorded for a particular species, then the ratio between the observed discarded weight of that species, and the observed nominal hake catch was applied to the 1997 commercial hake landings:

$$\text{annual discard} = \frac{\text{observed discard}}{\text{observed nominal hake catch}} \times \text{annual hake landing}. \quad (3)$$

The underlying assumptions for the two methods were markedly different, and as such were expected to provide different discard estimates. The effort-based approach assumes that the effort deployed catching bycatch is equal to that of hake. However, many species may shoal or have a patchy distribution, so unless the sample distribution is representative of the stock distribution for a given bycatch species, effort directed towards catching such species will be different from that deployed on catching hake. The landings-based approach is more species-specific in that it uses the bycatch ratio of a given species to estimate the annual discard of that species. This method assumes that the observed discard ratio is representative of the true discard ratio, and it makes no assumptions about either the species distribution or the distribution of sampling effort. It is believed that the underlying assumptions in the landings-based approach are more reasonable, and that this approach may give better estimates than the effort-based approach. Nevertheless, in order to undertake a comparative analysis, both methods were investigated.

3. Results

The results of the ANOSIM analysis indicated some heterogeneity on both coasts. On the south coast, all pairwise comparisons except two groups revealed significant differences ($p < 0.1$; Table 2). Inshore hake-directed trawls were not significantly different from the offshore hake-directed (west) or the offshore hake-directed (east) trawls ($p > 0.1$). Analysis of inshore survey trawls revealed a significant difference ($p < 0.1$) between research trawls made east and west of 22°E. On the west coast, pairwise comparisons indicated a significant difference ($p < 0.1$) between the <300 m depth group and all other groups, and between the >500 m depth group and all other groups (Table 2). None of the other west coast pairwise comparisons were significant ($p > 0.1$).

Interannual variation in trawl composition was not investigated, as during the study period there were large differences in the proportion of trawls observed in each fishery within and between years. However, we recognise that this may bias the interpretation of these results.

The results of the SIMPER analysis are presented in Appendix A. On the south coast, the sole-directed and offshore hake-directed (east) fishing areas showed the highest level (73.12%) of dissimilarity and inshore hake-directed and offshore hake-directed (west) trawls were the least dissimilar (45.87%). On the west coast, the 0–300 m and monkfish-directed trawls were the most dissimilar (63.58%), and the 401–500 m and >500 m groups were the least dissimilar (41.01%). Those species contributing the most to the dissimilarity between 0 and 300 m trawls and other trawls were hake, snoek (*Thyrsites atun*), and horse mackerel, while those separating the >500 m trawls from all others were hake, monkfish, and jacopever.

A breakdown of the catch, describing the most important species within each area, is given in Table 3 and a checklist of all species observed is given in Walmsley (2004). Teleosts dominated south coast catches (offshore hake-directed (east) = 98.1%, offshore hake-directed (west) = 92.4%, inshore hake-directed = 92.6% and sole-directed = 88.7%), in particular hake, horse mackerel and panga (*Pterogymnus laniarius*). Cephalopods were of minor importance to the catch, and only in the sole fishery did chondrichthyans contribute more than 10% to the total catch. The greatest species diversity was on the Agulhas Bank, with 56 and 63 species recorded in the inshore hake and sole-directed catches, respectively.

In the west coast hake-directed trawls, the dominance of teleosts, and Cape hake in particular, was clearly evident, as was the relative unimportance of the other bycatch species. In the 0–300 m depth range, species other than hake accounted for 34.6% of the total catch, whereas in trawls >500 m depth, this value was reduced to 9.6%. Important bycatch species in the shallower trawls were horse mackerel, snoek, and ribbonfish (*Lepidopus caudatus*). In deeper trawls, monkfish and jacopever

Table 2
Results of ANOSIM analysis indicating the significant differences in catch composition between four areas or fisheries of the south coast (top panel), and between five fishing depth ranges or fisheries on the west coast (bottom panel)

Fishery and ground	Sole-directed	Offshore hake-directed (west)	Inshore hake-directed	Offshore hake-directed (east)
Sole-directed		**	**	**
Offshore hake-directed (west)			–	**
Inshore hake-directed				–
Offshore hake-directed (west)				

Fishery and hake-directed depth	0–300 m	301–400 m	401–500 m	>500 m	Monkfish-directed
0–300 m		**	**	**	**
301–400 m			–	**	–
401–500 m				**	–
>500 m					**
Monkfish-directed					

–, no significant difference ($p > 0.1$).
** Significant difference ($p < 0.1$).

Table 3
Species composition of demersal trawls observed between January 1996 and September 2000 off the south coast of South Africa and between June 1995 and September 2000 off the west coast of South Africa

Taxon	Offshore hake-directed (west) ($n = 139$)		Offshore hake-directed (east) ($n = 41$)		Inshore hake-directed ($n = 140$)		Sole-directed ($n = 294$)	
	Weight (kg)	% of catch	Weight (kg)	% of catch	Weight (kg)	% of catch	Weight (kg)	% of catch
South coast total catch	215,007.9		87,314.4		235,013.3		138,439.1	
Teleostei	198,643.9	92.39	85,621.7	98.06	217,494.3	92.55	122,842.7	88.73
Merluccius spp.	120,873.6	56.22	60,934.5	69.79	124,822.5	53.11	84,922.1	61.34
Chelidonichthys queketti	1,078.5	0.50	802.6	0.92	3,805.1	1.62	404.6	0.29
Lepidopus caudatus	44.2	0.02	520.9	0.60	48.3	0.02	0.0	0.00
Helicolenus dactylopterus	376.9	0.18	2,887.6	3.31	1,162.0	0.49	13.2	0.01
Genypterus capensis	1,055.0	0.49	441.6	0.51	1,749.6	0.74	897.7	0.65
Lophius vomerinus	2,484.5	1.16	1,663.8	1.91	2,253.2	0.98	292.8	0.21
Trachurus t. capensis	52,205.0	24.28	13,065.5	14.96	38,973.0	16.58	3,055.3	2.21
Chelidonichthys capensis	2,792.3	1.30	926.5	1.06	2,437.5	1.04	2,123.0	1.53
Austroglossus pectoralis	1,021.2	0.47	0.5	0.00	906.0	0.39	24,031.7	17.36
Argyrosomus inodorus	0.0	0.00	123.0	0.14	157.4	0.07	2,666.2	1.93
Pterogymnus laniarius	13,396.7	6.23	1,677.5	1.92	32,702.9	13.92	833.4	0.60
Other teleosts	3,315.9	1.54	2,577.5	2.95	8,476.9	3.61	3,602.8	2.60
Chondrichthyes	12,901.9	6.00	1,221.9	1.40	10,643.0	4.62	14,061.9	10.15
Squalus megalops	3,041.8	1.41	295.3	0.34	1,298.3	0.56	366.7	0.26
Raja straeleni	6,587.2	3.06	243.7	0.28	5,032.6	2.18	7,603.3	5.49
Raja wallacei	99.0	0.05	257.7	0.30	103.5	0.04	177.1	0.13
Raja pullopunctata	188.8	0.09	4.2	0.00	28.5	0.01	92.1	0.07
Other chondrichthyans	2,985.1	1.39	421.0	0.48	4,180.2	1.81	5,822.7	4.20
Cephalopoda	3,462.0	1.61	470.8	0.54	6,876.0	2.93	1,534.5	1.11
Loligo reynaudii	3,462.0	1.61	470.8	0.54	6,823.0	2.90	1,529.5	1.10
Other cephalopods	0.0	0.00	0.0	0.00	53.0	0.02	5.0	0.00
Number of species identified	38		38		56		63	

	Hake-directed, 0–300 m ($n = 52$)		Hake-directed, 301–400 m ($n = 142$)		Hake-directed, 401–500 m ($n = 201$)		Hake-directed, >500 m ($n = 35$)		Monkfish-directed ($n = 49$)	
	Weight (kg)	% of catch	Weight (kg)	% of catch	Weight (kg)	% of catch	Weight (kg)	% of catch	Weight (kg)	% of catch
West coast total catch	188,497		690,819		1,060,740		132,491		137,278	
Teleostei	182,647	97.00	685,169	99.18	1,051,777	99.15	129,227	97.54	134,712	98.13
Merluccius spp.	123,074	65.36	593,809	85.96	979,965	92.39	119,835	90.45	84,475	61.54
Lophius vomerinus	7,502	3.98	20,779	3.01	25,570	2.41	1,951	1.47	45,030	32.80
Thyrsites atun	21,497	11.42	15,243	2.21	618	0.06	–	–	–	–
Trachurus t. capensis	12,107	6.43	16,112	2.33	1,154	0.11	–	–	136	0.10
Helicolenus dactylopterus	1,778	0.94	9,141	1.32	11,067	1.04	1,378	1.04	1,969	1.43
Lepidopus caudatus	9,209	4.89	7,956	1.15	1,804	0.17	307	0.23	–	–
Caelorinchus symorhynchus	1,938	1.03	4,800	0.69	6,061	0.57	1,078	0.81	1,024	0.75
Zeus capensis	1,680	0.89	6,483	0.94	4,982	0.47	611	0.46	115	0.08
Genypterus capensis	343	0.18	4,674	0.68	6,173	0.58	568	0.43	1,448	1.05
Malacocephalus laevis	268	0.14	3,383	0.49	4,835	0.46	899	0.68	379	0.28
Scomber japonicus	1,732	0.92	767	0.11	376	0.04	–	–	1	0.00
Other teleosts	1,518	0.81	2,020	0.29	9,172	0.86	2,601	1.96	136	0.10
Chondrichthyes	5,158	2.74	2,926	0.42	4,529	0.43	3,007	2.27	330	0.24
Holohalaelurus regani	471	0.25	492	0.07	273	0.03	54	0.04	–	–
Scyliorhinus capensis	167	0.09	471	0.07	809	0.08	62	0.05	69	0.05
Squalus megalops	254	0.13	181	0.03	594	0.06	166	0.13	192	0.14
Squalus acanthias	1	0.00	0	0.00	332	0.03	30	0.02	21	0.01
Other chondrichthyans	4,264	2.26	1,781	0.26	2,522	0.24	2,695	2.03	49	0.04
Cephalopoda	693	0.26	2,724	0.39	4,435	0.42	256	0.19	2,235	1.63
Red squid (*Todaropsis eblanae* and *Todarodes angolensis*)	432	0.23	2,222	0.32	3,891	0.37	250	0.19	1,255	0.91
Other cephalopods	261	0.14	503	0.07	544	0.05	6	0.00	980	0.71
Number of species identified	41		42		62		56		19	

Table 4
The retained and discarded portions and percentages of the total weight and number of fish discarded by demersal trawlers operating off the south coast (top panel) and the west coast (bottom panel)

	Offshore hake-directed (west) ($n = 139$)				Offshore hake-directed (east) ($n = 41$)				Inshore hake-directed ($n = 140$)				Sole-directed ($n = 294$)			
	Weight (kg)	% of total catch	% of discards by weight	% of discards by number	Weight (kg)	% of total catch	% of discards by weight	% of discards by number	Weight (kg)	% of total catch	% of discards by weight	% of discards by number	Weight (kg)	% of total catch	% of discards by weight	% of discards by number
South coast total catch	215,007.9				87,314.4				235,013.3				138,439.1			
South coast retained catch	206,168.6	95.89			81,515.0	93.36			222,265.3	94.58			111,830.5	80.78		
Merluccius spp.	118,922.2	55.31			59,989.5	68.71			120,460.6	51.26			67,860.1	49.02		
Trachurus t. capensis	51,857.0	24.12			12,965.0	14.85			38,613.0	16.43			2,807.0	2.03		
Pterogymnus laniarius	13,381.0	6.22			1,668.0	1.91			32,650.0	13.89			670	0.48		
Austroglossus pectoralis	1,016.0	0.47			–	–			906	0.39			23,515.0	16.99		
Raja straeleni	5,871.0	2.73			178	0.08			4,658.0	2.17			6,851.0	3.19		
Other retained catch	15,121.4	7.03			6,714.5	7.81			24,977.7	10.44			10,127.4	9.08		
South coast discarded catch	8,839.2	4.11	100.00	100.00	5,799.4	6.64	100.00	100.00	12,748.0	5.42	100.00	100.00	26,608.6	19.22	100.00	100.00
Teleostei	4,477.3	2.08	50.65	70.3	5,037.7	5.77	86.87	93.46	10,344.0	4.4	81.14	91.06	21,276.2	15.37	79.96	91.98
Merluccius spp.	1,951.4	0.91	22.08	35.82	945	1.08	16.29	22.6	4,361.9	1.86	34.22	38.08	17,062.0	12.32	64.12	69.69
Chelidonichthys queketti	1,078.5	0.5	12.2	15.33	802.6	0.92	13.84	20.48	3,805.1	1.62	29.85	33.83	404.6	0.29	1.52	1.88
Lepidopus caudatus	14.2	0.01	0.16	0.07	498.9	0.57	–	2.81	3.3	0	0.03	0.01	–	–	–	–
Helicolenus dactylopterus	85.9	0.04	0.97	0.84	710.6	0.81	12.25	17.38	138	0.06	1.08	0.9	13.2	0.01	0.05	0.05
Genypterus capensis	9.2	0	0.1	0.17	72.3	0.08	1.25	0.35	3.1	0	0.02	0.02	20.6	0.01	0.08	0.09
Lophius vomerinus	0.8	0	0.01	0.01	380.7	0.44	6.56	0.89	–	–	–	–	0.4	0	0	0
Trachurus t. capensis	348	0.16	3.94	4.61	100.5	0.12	1.73	1.39	360	0.15	2.82	3.82	248.3	0.18	0.93	2.23
Chelidonichthys capensis	104.3	0.05	1.18	1.4	315.5	0.36	5.44	3.61	354.5	0.15	2.78	2.16	1,034.0	0.75	3.89	3.13
Austroglossus pectoralis	5.2	0	0.06	0.21	0.5	0	0.01	0.01	–	–	–	–	516.7	0.37	1.94	6.54
Argyrosomus inodorus	–	–	–	–	–	–	–	–	0.4	0	0	0	399.2	0.29	1.5	2.67
Pterogymnus laniarius	15.7	0.01	0.18	0.28	9.5	0.01	0.16	0.14	52.9	0.02	0.41	0.43	163.4	0.12	0.61	0.83
Other teleosts	863.9	0.4	9.77	11.56	1,201.5	1.38	29.35	23.8	1,264.9	0.54	9.93	11.82	1,413.8	1.02	5.32	4.87
Chondrichthyes	4,361.9	2.03	49.35	29.7	742.9	0.85	12.81	6.08	2,399.0	1.02	18.82	8.93	5,328.9	3.85	20.03	8.01
Squalus megalops	3,037.8	1.41	34.37	22.28	295.3	0.34	5.09	2.18	1,255.3	0.53	9.85	5.49	366.7	0.26	1.38	0.8
Raja straeleni	716.2	0.33	8.1	4.86	65.7	0.08	1.13	0.25	374.6	0.16	2.94	1.56	752.2	0.54	2.83	1.51
Raja wallacei	99	0.05	1.12	0.7	257.7	0.3	4.44	2.03	103.5	0.04	0.81	0.4	177.1	0.13	0.67	0.32
Raja pullopunctata	188.8	0.09	2.14	0.59	4.2	0	0.07	0.03	28.5	0.01	0.22	0.06	92.1	0.07	0.35	0.06
Other chondrichthyans	320.1	0.15	3.62	0.75	120	0.14	2.08	1.59	637.2	0.27	5	1.42	3,940.7	2.85	14.8	5.32
Cephalopoda	–	–	0	0	18.8	0.02	0.32	0.46	5	0	0.04	0.01	3.5	0	0.01	0.01

Table 4 (*Continued*)

	0–300 m ($n = 52$)				301–400 m ($n = 142$)				401–500 m ($n = 201$)				>500 m ($n = 35$)				Monk-directed ($n = 49$)			
	Weight (kg)	% of total catch	% of discards by weight	% of discards by number	Weight (kg)	% of total catch	% of discards by weight	% of discards by number	Weight (kg)	% of total catch	% of discards by weight	% of discards by number	Weight (kg)	% of total catch	% of discards by weight	% of discards by number	Weight (kg)	% of total catch	% of discards by weight	% of discards by number
West coast total catch	188,497				690,819				1,060,740				132,491				137,278			
West coast retained catch	161,284	85.6			615,799	89.1			970,878	91.5			120,599	91.0			131,637	95.9		
Merluccius spp.	111,050	58.9			545,123	78.9			921,131	86.8			118,315	89.3			81,218	59.2		
Genypterus capensis	337	0.2			4,668	0.7			6,042	0.6			558	0.4			1,429	1.0		
Lophius vomerinus	7,286	3.9			20,224	2.9			22,965	2.2			974	0.7			45,030	32.8		
Helicolenus dactylopterus	959	0.5			5,189	0.8			7,232	0.7			186	0.1			1,680	1.2		
Thyrsites atun	21,494	11.4			15,216	2.2			493	0.1			–	–			–	–		
Other retained catch	20,158	10.7			25,380	4.0			13,014	1.2			567	0.4			2,280	1.7		
West coast discarded catch	27,213	14.4	100.0	100.0	75,019	10.9	100.0	100.0	89,862	8.5	100.0	100.0	11,892	9.0	100.0	100.0	5,641	4.1	100.0	100.0
Teleostei	21,614	11.5	79.4	93.9	70,004	10.1	93.3	95.0	81,399	7.7	90.6	92.0	8,629	6.5	72.6	90.6	5,175	3.8	91.8	97.6
Merluccius spp.	12,024	6.4	44.2	59.4	48,686	7.1	64.9	70.3	58,834	5.6	65.5	71.8	1,521	1.2	12.8	30.9	3,257	2.4	57.7	66.6
Lophius vomerinus	216	0.1	0.8	0.5	556	0.1	0.7	0.2	2,605	0.3	2.9	0.3	977	0.7	8.2	0.7	–	–	–	–
Thyrsites atun	3	0.0	0.0	0.0	27	0.0	0.0	0.0	125	0.0	0.1	0.0	–	–	–	–	–	–	–	–
Trachurus t. capensis	584	0.3	2.2	1.7	451	0.1	0.6	0.3	244	0.0	0.3	0.2	–	–	0.0	0.0	56	0.0	1.0	0.3
Helicolenus dactylopterus	819	0.4	3.0	4.6	3,952	0.6	5.3	4.6	3,835	0.4	4.3	3.3	1,192	0.9	10.0	4.7	289	0.2	5.1	2.3
Lepidopus caudatus	3,620	1.9	13.3	6.3	5,283	0.8	7.0	2.7	1,529	0.1	1.7	0.4	307	0.2	2.6	0.4	–	0.0	–	–
Caelorinchus symorhynchus	1,938	1.0	7.1	16.4	4,800	0.7	6.4	13.3	6,061	0.6	6.7	12.7	1,078	0.8	9.1	15.5	1,024	0.8	18.1	26.1
Zeus capensis	387	0.2	1.4	0.8	1,847	0.3	2.5	0.9	1,097	0.1	1.2	0.4	44	0.0	0.4	0.1	15	0.0	0.3	0.1
Genypterus capensis	6	0.0	0.0	0.0	7	0.0	0.0	0.0	131	0.0	0.2	0.0	10	0.0	0.1	0.0	19	0.0	0.3	0.1
Malacocephalus laevis	268	0.1	1.0	0.9	3,383	0.5	4.5	2.0	4,835	0.5	5.4	2.1	899	0.7	7.6	3.5	379	0.3	6.7	1.7
Scomber japonicus	1,522	0.1	5.6	1.8	522	0.1	0.7	0.1	90	0.0	0.1	0.0	–	–	–	–	1	–	0.0	0.0
Other teleosts	226	0.1	0.8	1.7	490	0.0	0.7	0.6	2,013	0.2	2.2	0.8	2,601	2.0	21.8	34.8	136	0.1	2.4	0.5
Chondrichthyes	5,158	2.7	19.0	3.5	2,926	0.4	3.9	0.5	4,529	0.4	5.0	0.8	3,007	2.3	25.3	5.5	330	0.2	5.9	1.3
Holohalaelurus regani	471	0.3	1.7	0.8	492	0.1	0.7	0.2	809	0.1	0.9	0.3	62	0.1	0.5	0.1	69	0.1	1.2	0.3
Scyliorhinus capensis	167	0.1	0.6	0.2	471	0.1	0.6	0.1	332	0.0	0.4	0.1	30	0.0	0.3	0.1	21	0.0	0.4	0.1
Squalus spp.	819	0.4	3.0	1.1	554	0.0	0.7	0.1	313	0.0	1.0	0.1	189	0.1	3.0	0.2	–	–	3.4	0.9
Other chondrichthyans	3,701	2.0	13.6	1.5	1,409	0.0	1.9	0.2	3,075	0.3	2.8	0.3	2,727	2.1	21.6	5.2	241	0.2	0.9	0.1
Cephalopoda	442	0.2	1.6	2.6	2,089	0.3	2.8	4.5	3,935	0.4	4.4	7.2	256	0.2	2.2	4.0	135	0.1	2.4	1.1

were the most important bycatch. As with the south coast, chondrichthyans and cephalopods were a minor component of the catch in all depth ranges. Despite the dominance of hake in west coast trawls, there was high species diversity.

The composition of monkfish-directed trawls demonstrates the efficacy of the net construction in targeting this species. Monkfish contributed 32.8% by weight of the monkfish-directed catch, compared with 3.0% of the catch of hake-directed trawls at the same depth (301–400 m). Species diversity was low in monkfish-directed trawls, with only 19 species (mostly benthic) being recorded compared with 79 species in west coast hake-directed trawls.

A breakdown of the catch into retained and discarded portions is presented for the south and west coasts in Table 4. For all fishing areas on both coasts, a high proportion of the catch was processed and landed. On the south coast, although hake dominated the retained portion of the catch (offshore hake-directed (east) = 68.7%, offshore hake-directed (west) = 55.3%, inshore hake-directed = 51.3% and sole-directed = 49.0%), several other species were landed. Small hake dominated the discarded portion of the catch, particularly in the sole-directed fishery where 20% of the hake caught were subsequently discarded. On the west coast, hake dominated the retained portion, contributing between 58.9% (<300 m) and 89.3% (>500 m) of the total retained catch. Monkfish, snoek, and ribbonfish contributed significantly to the retained catch (18.2% of the total) in the 0–300 m depth range, but as depth increased, hake increasingly dominated the landed catch. This was accentuated by an increase in unutilizable species such as macrourids. In all areas, the majority of discards by weight and number were hake.

A breakdown of the discards by weight and number is given in Table 4. On the south coast, teleosts such as hake and lesser gurnard (*Chelidonichthys queketti*) dominated the discards by weight and number. In the offshore hake-directed (west) area, chondrichthyans made up 29.7% (by number) of the discards. On the west coast, teleosts dominated the discards, contributing between 72.6% (>500 m) and 93.3% (301–400 m) by weight and between 90.6% (>500 m) and 95.9% (301–400 m) by number of the total discards, depending on the depth band.

The estimated weight of fish discarded annually using the two methods of extrapolation is presented in Table 5. The results indicate that the south coast fishery annually discards some 8000 t of fish and cephalopods (both methods) and 10,000 t or 13,000 t of offal (landings-based and effort-based estimates, respectively). This includes approximately 2000 t of hake (both estimation methods) and 650 t or 1500 t of ribbonfish (landings-based and effort-based estimates, respectively). Further, west coast vessels seemingly discard 17,000 t (effort-based) or 25,000 t (landings-based) of fish and 30,000 t (landings-based) or 46,000 t (effort-based) of offal annually. The two methods used yielded essentially similar results, although the landings-based extrapolations generally produced higher estimates of discards. A full list of the weight and number of fish discarded annually by the south and west coast fisheries using the landings-based estimate only can be found in Walmsley (2004).

Table 5
Estimated weight (t) of fish and cephalopods discarded annually by the trawl fleet operating off the south coast (top panel) and the west coast (bottom panel) of South Africa, calculated from observer data collected during 1997 and extrapolated to the annual catch using effort-based and landings-based approaches

	Effort-based	Landings-based
Teleostei	6410.4	5,727.4
Merluccius spp.	1868.5	2,002.7
Chelidonichthys queketti	639.7	814.4
Lepidopus caudatus	1555.8	649.7
Helicolenus dactylopterus	383.9	648.5
Genypterus capensis	30.6	245.5
Lophius vomerinus	183.0	213.9
Trachurus t. capensis	55.4	179.4
Chelidonichthys capensis	226.6	165.4
Austroglossus pectoralis	37.4	18.6
Argyrosomus inodorus	24.2	10.0
Pterogymnus laniarius	3.5	5.6
Other teleosts	1401.8	767.2
Chondrichthyes	2323.8	3,005.6
Squalus megalops	510.9	502.9
Raja straeleni	137.1	207.2
Raja wallacei	325.7	491.1
Raja pullopunctata	147.7	206.5
Other chondrichthyans	1202.4	1,598.0
Cephalopoda	197.3	15.1
Loligo reynaudii	6.6	15.1
Other cephalopods	190.7	0
Offal	9818.4	13,422.8
Merluccius spp.	8783.1	11,933.5
Genypterus capensis	280.1	791.2
Lophius vomerinus	755.2	698.0

	Effort-based		Landings-based	
	Weight (t)	Number	Weight (t)	Number
Teleostei	16,702	85,829,871	24,751	71,237,110
Merluccius spp.	11,920	64,322,456	6,915	37,313,931
Lophius vomerinus	145	193,874	254	338,576
Thyrsites atun	27	10,141	24	9,137
Trachurus t. capensis	152	445,814	159	466,855
Helicolenus dactylopterus	678	3,185,825	426	2,002,211
Lepidopus caudatus	553	775,649	14,198	19,929,663
Caelorinchus symorhynchus	1,458	13,019,208	846	7,552,539
Zeus capensis	271	508,313	335	1,151,196
Genypterus capensis	3	1,034	4	1,182
Malacocephalus laevis	999	1,947,340	579	1,129,666
Scomber japonicus	117	73,620	754	474,757
Other teleosts	380	1,346,597	258	867,397
Chondrichthyes	1,347	1,086,556	759	551,567
Holohalaelurus regani	177	311,974	103	180,978
Scyliorhinus capensis	48	38,866	28	22,546
Squalus megalops	79	155,602	46	90,266
Squalus acanthias	24	7,530	14	4,368
Other chondrichthyans	1,019	572,584	568	253,408
Cephalopoda	666	5,988,061	4,109	37,518,089
Red squid (*Todaropsis eblanae* and *Todarodes angolensis*)	654	5,977,539	4,106	37,515,091
Other cephalopods	12	10,521	3	2,998
Offal	45,658		29,859	
Merluccius spp.	42,562		24,690	
Genypterus capensis	397		454	
Lophius vomerinus	2,700		4,715	

4. Discussion

Analysis of the community structure of trawl catches indicated that there are significant differences between fishing areas on both coasts. These differences mirror community areas suggested by survey data. Spatially, the three south coast communities identified by Smale et al. (1993), using research survey data, can be loosely correlated with those identified in the current study based on commercial catches. The species assemblages of the offshore hake-directed (west) areas equate to Smale et al.'s (1993) mid-shelf region and the offshore hake-directed (east) to the shelf-edge/upper slope. However, whereas survey data suggested a single inshore community (Smale et al., 1993), the present study suggests that the community structure of the areas east and west of 22°E is significantly different. Similarly, west coast assemblages identified using commercial data reflect the shallow-water and deep-water assemblages identified by Roel (1987) using survey data. These findings suggest that despite the fact that gear is designed to target only part of the community, commercial catches can provide important information on community boundaries.

Information on community structure could be used to tailor management measures to specific areas. For example, given that the community structure of the sole-directed fishing area is significantly different from the other south coast areas, only two management units—a sole-directed fishery unit and a hake-directed fishery unit may be needed. Thus management strategies for the sole fishery (e.g. to reduce the discarding of juvenile hake) may not be required for a hake fishery. Similarly, three management units could be defined on the west coast, a shallow unit (<300 m depth), a shelf unit (301–500 m depth) and a deep unit (>500 m depth). Recent years have seen an increase in targeting large *M. capensis* (which have a high export value) in shallow trawls, which could be cause for concern. Measures to manage such targeting could be introduced for trawls <300 m depth only.

On the west coast the proportion of hake and monkfish in the catch and the number of species present in monkfish-directed trawls was notably different from hake-directed trawls at 301–400 m depth. These differences could either be due to intrinsic differences between the respective community structures in the hake and monkfish trawling grounds, or gear selectivity. The fact that SIMPER analysis found no significant differences between monkfish-directed trawls and hake-directed trawls at 301–400 m would suggest that gear selectivity rather than community structure accounts for the differences in catch composition.

Despite the fact that trawlers target hake and sole, non-target species make a significant contribution to the total catch, particularly on the south coast. However, much of the non-target south coast catch is utilizable, contrasting with the non-target west coast catch, which consists mainly of unutilizable species. Thus, although the proportion of target species in the catch differs between the south and west coasts, a similar proportion of the catch (approximately 90%) is processed and landed. These differences have implications for managing the two fisheries, particularly with regard to the economic revenue derived from bycatch. It is estimated that in the inshore hake-directed fishery, offshore hake-directed (east), and offshore hake-directed (west) areas, bycatch species contribute 36%, 15% and 30% of the landed value of the catch, respectively (Erstadt, unpublished). In comparison, bycatch species contribute only 7% of the landed value of west coast catches (Erstadt, unpublished).

The two methods used to assess the weight and number of fish discarded annually by the trawl fleet generally provided estimates for a given species of the same order of magnitude. However, in some cases notably different estimates were obtained, particularly shoaling species that are either absent from a trawl or contribute a notable proportion to the total catch. For example, the effort-based estimate for ribbonfish on the south coast suggested that 1500 t might be discarded annually. In contrast, the landings-based estimate suggested that just 650 t were discarded. Similarly, on the west coast, the effort-based estimate for ribbonfish yielded an annual discard rate of 553 t, whereas the landings-based estimate was 14,198 t. The fact that the shoaling species and targeted bycatch species produce the largest differences in the discard estimates illustrates the problems associated with the use of these models to predict discards of target and non-target species.

The discard estimates obtained during this study are generally lower than those of Japp (1997). For example, Japp (1997) estimated that 8500 t of hake were discarded annually on the south coast, compared with the 2000 t estimated in the current study. For the west coast, Japp (1997) estimated that 17,000 t of hake were discarded annually, compared with 6000 t of hake in the current study. There are many possible reasons for these differences, such as the issues raised by Japp (1997) that were highlighted in the introduction. A further reason may be changes in fish abundance, fishing strategy or discarding practices between the time when Japp's (1997) data were collected and the collection of these data (1996–2000).

Despite the different estimates obtained from the two extrapolation methods and the differences between this study and that of Japp (1997), the data indicate high levels of bycatch and discarding occur. Although the current study suggests that only 10% of the catch is discarded this represents a substantial amount of fish, which may have negative effects on target or non-target stocks. No matter how well bycatch is utilized, good management practice requires that it be sustainable and a measure of the impacts that fishing activities have on the resource is required (Kennelly, 1997). One area that gives cause for concern is the sole-directed fishery, where a high proportion of hake, most of them juveniles, are discarded. This juvenile fishing mortality may represent a direct loss that can negatively impact future yield. These issues require further clarification, and the ecological impact of fishing mortality on bycatch populations needs to be investigated further.

Other species that may be negatively affected by trawling are the juveniles of linefish species such as silver kob. The estimates suggest that the fishery may discard between 10.0 and 24.2 t of this species annually (landings-based and effort-based estimates, respectively). Many of South Africa's linefish resources are overexploited or have already collapsed (Griffiths, 2000), but there is no information available on the impact of trawling on linefish stocks. Several studies are currently underway to address such issues, but in the meantime, it would appear prudent to try to restrict trawl catches of these species.

The use of observers aboard commercial vessels is a useful method of obtaining data on trawl catch composition (Liggins et al., 1996; Allen et al., 2001). This is especially true when extrapolating data from research surveys that are designed to answer specific questions regarding target species, and information on bycatch or the catch composition on commercial grounds is viewed as less important. Consequently, research survey data may yield biased estimates of bycatch. However, observer data can also be biased and these biases must be understood and recognised when interpreting the results (Liggins et al., 1997).

In this study, as in many other similar ones, funding constraints limited the number of observer expeditions that could be undertaken, and it was calculated that in 1997 (the year of highest observer coverage), the programme only managed to collect data from 0.62% of south coast trawls and 0.49% of west coast trawls. A further bias was the limited coverage of Port Elizabeth, where all observations were made on offshore vessels and the majority of fishing took place on the offshore hake-directed (east). Inshore vessels were not covered.

Another bias was that not all the trawling companies in the fishery could be monitored and the assumption was made that all companies use the same fishing practices and strategies. This assumption may have been erroneous, particularly on the west coast where the two companies that were sampled were the two largest operators, maintaining large factories and distribution facilities. Therefore, their fishing strategies are likely to differ from those of smaller companies with limited facilities. It is also possible that some companies may have assigned observers to vessels with skippers associated with particularly low levels of bycatch, or could have ordered skippers to fish in areas where bycatch is traditionally low. However, a variety of vessels (14 and 19) and skippers (14 and 22) were used for the south and west coasts, respectively, and the distribution of observed trawls was similar to the distribution of annual trawling effort. Sorting practices may also have changed while the observers were aboard, especially in the case of small Cape hake. While these issues are extremely difficult to quantify, it is reasonable to suggest that as the study was directed at research rather than compliance, the usual practices were not modified.

Despite the limitations listed above, the work has provided the first comprehensive estimates of the catch composition of South African demersal trawlers and has highlighted issues of concern within the fishery, such as rate of discarding of juvenile hake and the incidental capture of linefish. Although awareness of these issues can be used to advise in the formulation of a bycatch management plan, for several issues there is insufficient information on the scale of the problem. This highlights the need for a programme specifically designed to answer the outstanding questions. A stratified approach is required to ensure that all fishing companies and fishing areas are adequately covered. Further, seasonal trends in catch composition or discarding pattern should be monitored, such that the efficacy of management strategies can be assessed.

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Appendix A

Results of the SIMPER analysis of observed catches made by demersal trawlers operating off (a) the south coast and (b) the west coast of South Africa. Data were collected between January 1996 and September 2000 and between June 1995 and September 2000 for the south and west coasts, respectively. The tables show the between-fishery comparisons, indicator species and related data from the analysis. *s* is the similarity within the group, Av. Ab. is the average abundance contribution of the species to the fishery, and Av. Te. is the average Bray–Curtis contribution of each species to distinguish between groups. Ratio is the percentage contribution of the species to the separation between fisheries. The cumulative percentage (Cum.) is given for comparison between groups. Species showing the top 75% and 90% of total dissimilarity are given for the south and west coasts, respectively. For an explanation of these species groups, see Walmsley (2004).

(a) South coast

(i) Sole-directed vs. inshore hake-directed (average dissimilarity 65.50%)

Species	Av. Ab.		Av. Te.	Ratio	%	Cum. (%)
	Sole	Inshore hake				
Austroglossus pectoralis	81.74	6.47	5.34	1.76	8.15	8.15
Trachurus t. capensis	10.39	278.38	5.21	1.40	7.95	16.10
Pterogymnus laniarius	2.83	233.59	4.48	1.18	6.83	22.93
Merluccius spp.	288.85	891.59	4.16	1.20	6.35	29.29
Loligo reynaudii	5.20	48.74	3.48	1.30	5.32	34.61
Chelidonichthys queketti	1.38	27.18	3.35	1.50	5.12	39.72
Raja straeleni	25.86	35.95	3.03	1.14	4.63	44.36

Appendix A (*Continued*)

(a) South coast

(i) Sole-directed vs. inshore hake-directed (average dissimilarity 65.50%)

Species	Av. Ab.		Av. Te.	Ratio	%	Cum. (%)
	Sole	Inshore hake				
Callorhinchus capensis	4.87	19.94	2.61	1.10	3.99	48.34
Chelidonichthys capensis	7.22	17.41	2.61	1.19	3.98	52.32
Squalus megalops	1.25	9.27	2.44	1.28	3.72	56.04
Argyrosomus inodorus	9.07	1.12	2.10	0.94	3.20	59.24
Genypterus capensis	3.05	12.50	1.77	0.80	2.71	61.95
Galeorhinus galeus	2.31	6.09	1.70	0.95	2.60	64.55
Raja alba	4.98	2.18	1.58	0.82	2.41	66.96
Zeus capensis	0.80	1.77	1.58	1.22	2.41	69.37
Poroderma africanum	2.29	0.33	1.53	0.97	2.33	71.70
Scomber japonicus	1.62	11.06	1.37	0.58	2.09	73.79
Raja miraletus	1.87	0.02	1.30	0.84	1.99	75.71

(ii) Sole-directed vs. offshore hake-directed (west) (average dissimilarity 63.39%)

Species	Av. Ab.		Av. Te.	Ratio	%	Cum. (%)
	Sole	Offshore hake-directed (west)				
Trachurus t. capensis	10.39	375.58	6.07	1.59	9.58	9.58
Austroglossus pectoralis	81.74	7.35	4.26	1.62	6.73	16.30
Merluccius spp.	288.85	869.59	3.75	1.20	5.92	22.22
Pterogymnus laniarius	2.83	96.38	3.62	1.31	5.71	27.93
Raja straeleni	25.86	47.39	3.17	1.27	4.99	32.92
Loligo vulgaris reynaudii	5.20	24.91	2.98	1.36	4.70	37.62
Chelidonichthys capensis	7.22	20.09	2.63	1.31	4.14	41.76
Squalus megalops	1.25	21.88	2.62	1.40	4.13	45.89
Lophius vomerinus	1.00	17.87	2.42	1.13	3.82	49.70
Callorhinchus capensis	4.87	13.20	2.23	1.11	2.52	53.23
Chelidonichthys queketti	1.38	7.76	2.07	1.38	3.27	56.50
Genypterus capensis	3.05	7.59	1.95	1.09	3.08	59.58
Argyrosomus inodorus	9.07	0.00	1.88	0.95	2.96	62.54
Zeus capensis	0.80	3.39	1.85	1.45	2.92	65.46
Galeorhinus galeus	2.31	6.00	1.83	1.10	2.88	68.34
Poroderma africanum	2.29	0.00	1.37	0.96	2.16	70.50
Rhinobatos annulatus	1.47	6.85	1.36	0.79	2.14	72.64
Raja alba	4.98	0.91	1.28	0.75	2.02	74.66
Raja miraletus	1.87	0.00	1.18	0.84	1.86	76.52

(iii) Sole-directed vs. offshore hake-directed (east) (average dissimilarity 73.12%)

Species	Av. Ab.		Av. Te.	Ratio	%	Cum. (%)
	Sole	Offshore hake-directed (east)				
Trachurus t. capensis	10.39	318.67	6.21	1.63	8.49	8.49
Austroglossus pectoralis	81.74	0.01	6.11	2.80	8.36	16.86
Merluccius spp.	288.85	1486.21	5.02	1.34	6.87	23.73
Helicolenus dactylopterus	0.04	70.43	4.58	1.55	6.26	29.99
Lophius vomerinus	1.00	40.85	3.98	1.58	5.44	35.43
Zeus spp.	0.80	32.89	3.54	1.51	4.84	40.27
Raja straeleni	25.86	5.94	2.59	1.11	3.54	43.81
Chelidonichthys capensis	7.22	22.60	2.57	1.08	3.52	47.33
Loligo reynaudii	5.20	11.48	2.23	1.11	3.04	50.38
Argyrosomus inodorus	9.07	3.00	2.09	0.97	2.86	53.24
Scomber japonicus	1.62	12.72	2.00	0.88	2.74	55.97
Squalus megalops	1.25	7.20	1.94	1.01	2.66	58.63
Chelidonichthys queketti	1.38	19.58	1.88	0.72	2.57	61.20
Lepidopus caudatus	0.00	12.70	1.88	0.70	2.57	63.77
Pterogymnus laniarius	2.83	40.92	1.82	0.65	2.49	66.26
Genypterus capensis	3.05	10.77	1.82	0.83	2.48	68.74
Raja wallacei	0.60	6.29	1.79	0.95	2.44	71.19
Cynoglossus zanzibarensis	0.20	13.22	1.59	0.77	2.17	73.35
Galeorhinus galeus	2.31	5.34	1.51	0.86	2.06	75.42

Appendix A (*Continued*)

(iv) Inshore hake-directed vs. offshore hake-directed (west) (average dissimilarity 45.87%)

Species	Av. Ab.		Av. Te.	Ratio	%	Cum. (%)
	Inshore hake	Offshore hake-directed (west)				
Pterogymnus laniarius	233.59	96.38	3.71	1.28	8.10	8.10
Trachurus t. capensis	278.38	375.58	3.64	1.12	7.93	16.03
Raja straeleni	35.95	47.39	2.75	1.19	6.00	22.02
Loligo reynaudii	48.74	24.91	2.54	1.19	5.54	27.56
Lophius vomerinus	16.09	17.87	2.25	1.14	4.91	32.47
Callorhinchus capensis	19.94	13.20	2.18	1.14	4.75	37.23
Chelidonichthys capensis	17.41	20.09	2.17	1.16	4.72	41.95
Chelidonichthys queketti	27.18	7.76	2.05	1.27	4.47	46.42
Merluccius spp.	891.59	869.59	1.92	1.09	4.19	50.62
Genypterus capensis	12.50	7.59	1.87	1.01	4.07	54.68
Squalus megalops	9.27	21.88	1.78	1.23	3.88	58.56
Galeorhinus galeus	6.09	6.00	1.72	1.10	3.76	62.32
Austroglossus pectoralis	6.47	7.35	1.69	0.96	3.69	66.01
Zeus capensis	1.77	3.39	1.29	1.15	2.82	68.82
Scomber japonicus	11.06	2.08	1.27	0.67	2.76	71.59
Helicolenus dactylopterus	8.30	2.71	1.18	0.74	2.57	74.15
Congiopodus torvus	1.02	1.30	1.05	0.86	2.30	76.45

(v) Inshore hake-directed vs. offshore hake-directed (east) (average dissimilarity 55.54%)

Species	Av. Ab.		Av. Te.	Ratio	%	Cum. (%)
	Inshore hake	Offshore hake-directed (east)				
Pterogymnus laniarius	233.59	40.92	4.06	1.16	7.31	7.31
Trachurus t. capensis	278.38	318.67	3.77	1.16	6.79	14.10
Helicolenus dactylopterus	8.30	70.43	3.63	1.38	6.54	20.64
Lophius vomerinus	16.09	40.58	3.29	1.41	5.92	26.56
Merluccius spp.	891.59	1 486.21	3.02	1.10	5.45	32.01
Loligo reynaudii	11.48	48.74	2.90	1.37	5.23	37.23
Chelidonichthys queketti	19.58	27.18	2.83	1.37	5.09	42.32
Zeus spp.	32.89	1.77	2.65	1.40	4.77	47.10
Chelidonichthys capensis	22.60	17.41	2.56	1.17	4.61	51.71
Raja straeleni	5.94	35.95	2.39	1.14	4.31	56.02
Callorhinchus capensis	19.94	2.00	2.32	1.08	4.18	60.20
Squalus megalops	9.27	7.20	2.09	1.37	3.76	63.96
Scomber japonicus	11.06	12.72	2.04	0.96	3.67	67.63
Genypterus capensis	12.50	10.77	1.67	0.74	3.01	70.64
Lepidopus caudatus	0.35	12.70	1.66	0.72	3.00	73.64
Cynoglossus zanzibarensis	8.04	13.22	1.65	0.82	2.96	76.60

(vi) Offshore hake-directed (west) vs. offshore hake-directed (east) (average dissimilarity 51.97%)

Species	Av. Ab.		Av. Te.	Ratio	%	Cum. (%)
	Offshore hake-directed (west)	Offshore hake-directed (east)				
Helicolenus dactylopterus	2.71	70.43	3.45	1.47	6.63	6.63
Pterogymnus laniarius	96.38	40.92	3.37	1.28	6.48	13.11
Raja straeleni	47.39	5.94	3.10	1.52	5.96	19.07
Trachurus t. capensis	375.58	318.67	3.00	1.24	5.77	24.85
Chelidonichthys capensis	20.09	22.60	2.68	1.55	5.16	30.00
Merluccius spp.	896.59	1 486.21	2.55	1.11	4.91	34.91
Lophius vomerinus	17.87	40.58	2.40	1.14	4.61	39.52
Loligo reynaudii	24.91	11.48	2.34	1.32	4.51	44.03
Zeus spp.	3.39	32.89	2.21	1.45	4.25	48.28
Squalus megalops	21.88	7.20	2.20	1.40	4.23	52.52
Callorhinchus capensis	13.20	2.00	2.05	1.12	3.94	56.46
Chelidonichthys queketti	7.76	19.58	2.03	1.18	3.90	60.36
Genypterus capensis	7.59	1077	1.88	1.06	3.61	63.97
Galeorhinus galeus	6.00	5.34	1.72	1.10	3.30	67.27
Scomber japonicus	2.08	12.72	1.68	0.93	3.24	70.50
Lepidopus caudatus	0.32	12.70	1.56	0.77	3.00	73.50
Raja wallacei	0.71	6.29	1.47	1.09	2.82	76.32

Appendix A (*Continued*)

(b) West coast

(i) 0–300 m vs. 301–400 m (average dissimilarity 51.99%)

Species	Av. Ab.		Av. Te.	Ratio	%	Cum. (%)
	0–300 m (*s* = 47.17%)	301–400 m (*s* = 56.51%)				
Merluccius spp.	2366.81	4181.75	31.84	1.50	61.24	61.24
Thyrsites atun	413.39	107.35	5.06	0.58	9.74	70.98
Trachurus t. capensis	232.82	113.47	3.74	0.69	7.20	78.17
Lepidopus caudatus	177.10	56.03	2.60	0.35	5.00	83.18
Lophius vomerinus	144.27	146.33	2.28	0.67	4.39	87.57
Helicolenus dactylopterus	34.20	64.37	0.94	0.59	1.81	89.38
Zeus capensis	32.30	45.65	0.84	0.58	1.62	91.00

(ii) 0–300 m vs. 401–500 m (average dissimilarity = 52.89%)

Species	Av. Ab.		Av. Te.	Ratio	%	Cum. (%)
	0–300 m (*s* = 47.17%)	401–500 m (*s* = 62.52%)				
Merluccius spp.	2366.81	4875.45	35.58	1.63	67.27	67.27
Thyrsites atun	413.39	3.08	4.19	0.50	7.93	75.20
Trachurus t. capensis	232.82	5.74	2.83	0.64	5.35	80.55
Lepidopus caudatus	177.10	8.97	2.07	0.33	3.92	84.46
Lophius vomerinus	144.27	127.21	2.06	0.61	3.89	88.35
Helicolenus dactylopterus	34.20	55.06	0.81	0.55	1.53	89.88
Zeus capensis	32.30	24.78	0.64	0.40	1.20	91.09

(iii) 0–300 m vs. >500 m (average dissimilarity 51.14%)

Species	Av. Ab.		Av. Te.	Ratio	%	Cum. (%)
	0–300 m (*s* = 47.17%)	>500 m (*s* = 59.12%)				
Merluccius spp.	2366.81	3423.86	30.39	1.47	59.43	59.43
Thyrsites atun	413.39	0.00	4.81	0.52	9.41	68.84
Trachurus t. capensis	232.82	0.00	3.29	0.65	6.42	75.27
Lepidopus caudatus	177.10	8.76	2.43	0.34	4.75	80.02
Lophius vomerinus	144.27	55.73	1.92	0.53	3.75	83.77
Helicolenus dactylopterus	34.20	39.37	0.81	0.63	1.59	85.36
Caelorinchus symorhynchus	37.27	30.80	0.79	0.45	1.54	86.90
Zeus capensis	32.30	17.47	0.74	0.48	1.45	88.35
Raja wallacei	44.37	1.55	0.61	0.49	1.20	89.55
Caelorinchus braueri	0.91	38.52	0.54	0.45	1.054	90.60

(iv) 0–300 m vs. monkfish-directed (average dissimilarity 63.58%)

Species	Av. Ab.		Av. Te.	Ratio	%	Cum. (%)
	0–300 m (*s* = 47.17%)	Monkfish (*s* = 58.02%)				
Merluccius spp.	2366.81	1731.87	29.40	1.52	46.24	46.24
Lophius vomerinus	144.27	938.12	15.62	1.67	24.56	70.80
Thyrsites atun	413.39	0.00	5.36	0.54	8.43	79.23
Trachurus t. capensis	232.82	2.84	3.70	0.67	5.82	85.06
Lepidopus caudatus	177.10	0.00	2.68	0.34	4.21	89.27
Helicolenus dactylopterus	34.20	41.02	0.85	0.74	1.34	90.61

(v) 301–400 m vs. 401–500 m (average dissimilarity 41.16%)

Species	Av. Ab.		Av. Te.	Ratio	%	Cum. (%)
	301–400 m (*s* = 56.51%)	401–500 m (*s* = 62.52%)				
Merluccius spp.	4181.75	4875.45	31.94	1.49	77.60	77.60
Lophius vomerinus	146.33	127.21	1.73	0.92	4.20	81.80
Trachurus t. capensis	113.47	5.74	1.11	0.31	2.69	84.50
Thyrsites atun	107.35	3.08	1.08	0.32	2.62	87.12
Helicolenus dactylopterus	64.37	55.06	0.93	0.59	2.26	89.38
Zeus capensis	45.65	24.78	0.67	0.43	1.64	91.02

Appendix A (*Continued*)

(vi) 301–400 m vs. >500 m (average dissimilarity 42.87%)

Species	Av. Ab.		Av. Te.	Ratio	%	Cum. (%)
	301–400 m (s = 56.51%)	>500 m (s = 59.12%)				
Merluccius spp.	4181.75	3423.86	31.50	1.45	73.46	73.46
Lophius vomerinus	146.33	55.73	1.75	0.93	4.07	77.53
Thyrsites atun	107.35	0.00	1.22	0.32	2.84	80.37
Trachurus t. capensis	113.47	0.00	1.21	0.30	2.82	83.19
Helicolenus dactylopterus	64.37	39.37	0.99	0.62	2.32	85.51
Zeus capensis	45.65	17.47	0.76	0.49	1.77	87.28
Lepidopus caudatus	56.03	8.76	0.74	0.18	1.72	88.99
Genypterus capensis	32.92	16.22	0.63	0.42	1.47	90.46

(vii) 301–400 m vs. monkfish-directed (average dissimilarity 60.04%)

Species	Av. Ab.		Av. Te.	Ratio	%	Cum. (%)
	301–400 m (s = 56.51%)	Monkfish (s = 58.02%)				
Merluccius spp.	4181.75	1731.87	38.99	1.65	64.94	64.94
Lophius vomerinus	146.33	938.12	12.78	1.41	21.28	86.22
Trachurus trachurus capensis	113.47	2.84	1.37	0.31	2.28	88.50
Thyrsites atun	107.35	0.00	1.35	0.33	2.26	90.76

(viii) 401–500 m vs. >500 m (average dissimilarity 41.02%)

Species	Av. Ab.		Av. Te.	Ratio	%	Cum. (%)
	401–500 m (s = 56.51%)	>500 m (s = 59.12%)				
Merluccius spp.	3423.86	4875.45	33.19	1.51	80.91	80.91
Lophius vomerinus	55.73	127.21	1.50	0.79	3.66	84.57
Helicolenus dactylopterus	39.37	55.06	0.86	0.59	2.10	86.66
Caelorinchus symorhynchus	3080	30.15	0.55	0.50	1.33	88.00
Genypterus capensis	16.22	30.71	0.54	0.58	1.30	89.30
Zeus capensis	17.47	24.78	0.50	0.30	1.23	90.53

(ix) 401–500 m vs. monkfish-directed (average dissimilarity 60.27%)

Species	Av. Ab.		Av. Te.	Ratio	%	Cum. (%)
	401–500 m (s = 56.51%)	Monkfish (s = 58.02%)				
Merluccius spp.	4875.45	1731.87	43.43	1.76	72.06	72.06
Lophius vomerinus	127.21	938.12	12.15	1.44	20.15	92.22

(x) >500 m vs. monkfish-directed (average dissimilarity 60.49%)

Species	Av. Ab.		Av. Te.	Ratio	%	Cum. (%)
	>500 m (s = 59.12%)	Monkfish (s = 58.02%)				
Merluccius spp.	3423.86	1731.87	37.75	1.61	62.41	62.41
Lophius vomerinus	55.73	938.12	15.86	1.59	26.21	88.62
Helicolenus dactylopterus	39.37	41.02	0.95	0.81	1.57	90.19

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