THE ASSESSMENT AND MANAGEMENT OF BYCATCH AND DISCARDS IN THE SOUTH AFRICAN DEMERSAL TRAWL FISHERY.

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Abstract

Over the past few decades it has become recognised that an ecosystem approach is required to manage world fisheries. Management strategies must ensure that non-target (bycatch) as well as target catches are sustainable. To achieve this, detailed commercial catch and biological information is required.

The composition of catches made by trawlers operating off the south and west coasts of South Africa was investigated. Distinct fishing areas were identified on each coast, based on target species and fishing depth. Catch composition differed markedly among the areas defined. Although hake *Merluccius* sp. dominated South Coast catches, a large proportion of the catch was composed of bycatch. On the West Coast, hake dominated catches and this domination increased with increasing depth. On both coasts approximately 90% of the observed nominal catch was processed and landed. Estimates of annual discards suggested that the fishery discarded 38 thousand tons of fish per annum (16% of the nominal trawl catch). The data also indicated that hake discarding, the capture of linefish and the increased targeting of high value species might be cause for concern. Spatial analysis indicated that a variety of factors such as trawling position, catch size and catch composition affects bycatch dynamics.

The monkfish *Lophius vomerinus* is a common bycatch species that has been increasingly targeted by demersal trawlers. This study showed that *L. vomerinus* is a slow-growing, long-lived species (West Coast males L_∞ =

68.50cm *TL*, t_o = *-1.69yr*, *K* = 0.10yr^{-1}; West Coast females L_∞ = 110.23cm *TL*, t_o = -1.54yr, *K* = 0.05yr^{-1}; South Coast sexes combined L_∞ = 70.12cm *TL*, t_o = -0.80yr, *K* = 0.11yr^{-1}), that matures at approximately 6 years of age. These traits could have serious management implications for the species. Per-recruit analysis suggested that the stock might be overexploited, although further investigation is required to confirm this.

Solutions were suggested for each of the concerns raised, taking cognisance of the differences observed between the South and West Coasts and the economic dependence of South Coast companies on bycatch. The needs of future research were considered.

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To Emma

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Chapter 1 -
Introduction.

The bycatch issue

Archaeological evidence shows that man has actively targeted marine resources for thousands of years (Yellen *et al.* 1995). Presently, a wide range of methods are employed to catch fish and other marine organisms, ranging from simple netting and trapping, which require low technology gear to modern trawling, which utilises state-of-the-art vessels and equipment to locate and catch fish. Despite the diversity of fishing methods in use today almost all are unselective in some way, resulting in the capture of organisms that are not the target of the fishing operation (Saila 1983, Alverson *et al.* 1994). This non-target catch (commonly know as bycatch) may be retained if it has a commercial value or discarded if it does not (Saila 1983).

Many concerns exist regarding the effect that fishing, bycatch and discarding have on marine systems (ICES 1995, Dayton *et al.* 1995, Alverson 1998, Pauly *et al.* 2002). Fishing concerns include population effects, such as the removal of a portion of the population by the fishing activity (Crowder and Murawski 1998); ecosystem effects (Gulland 1987, Botsford *et al.* 1997); habitat effects (*e.g.* de Groot 1984, Jones 1992, McConnaughey *et al.* 2000); food web effects (Dayton *et al.* 1995, Botsford *et al.* 1997) and the issue of bycatch itself (Dayton *et al.* 1995).

Bycatch concerns may be biological or economic. Biological concerns include the generation of skewed effort estimates for quota-regulated and bycatch species in the absence of bycatch information; the over-exploitation of the bycatch species (Alverson *et al.* 1994); impacts on other fisheries (Alverson 1998); and food web effects (Blaber and Wassenberg 1989, Hill and Wassenberg 1990; Laptikhovsky and Fetisov 1999). In addition, biodiversity issues are raised if the impact on non-target species is unsustainable.

The economic implications of bycatch include the foregone income of discards and the reduction of potential revenue if one fishery type impacts on another (Pascoe 1997). In addition, the sorting and discarding of unwanted fish represents a waste of time and energy (Crowder and Murawski 1998). Moreover, market forces will work towards achieving the maximum economic benefit, which may encourage high-grading *i.e.* the discarding of small and damaged marketable fish that are of less value than larger fish (Arnason 1994).

Debate on bycatch issues has been clouded by terminology. The word bycatch has been used to describe the portion of the catch discarded at sea, the retained and sold non-target portion of the catch and more recently has become a general term for "waste" by the world's fisheries (Alverson *et al.* 1994, Hall 1996). For the purposes of this thesis, a modified version of the definition of Saila (1983, p1) will be used:

"That part of the gross catch which is captured incidentally to the species toward which there is directed effort. Some, all or none of the by-catch may become the discard catch."

For this study, undersized target species such as hake are considered part of the bycatch. A graphical illustration of a breakdown of the trawl catch and the definitions used in this thesis can be found in Fig. 1.1.

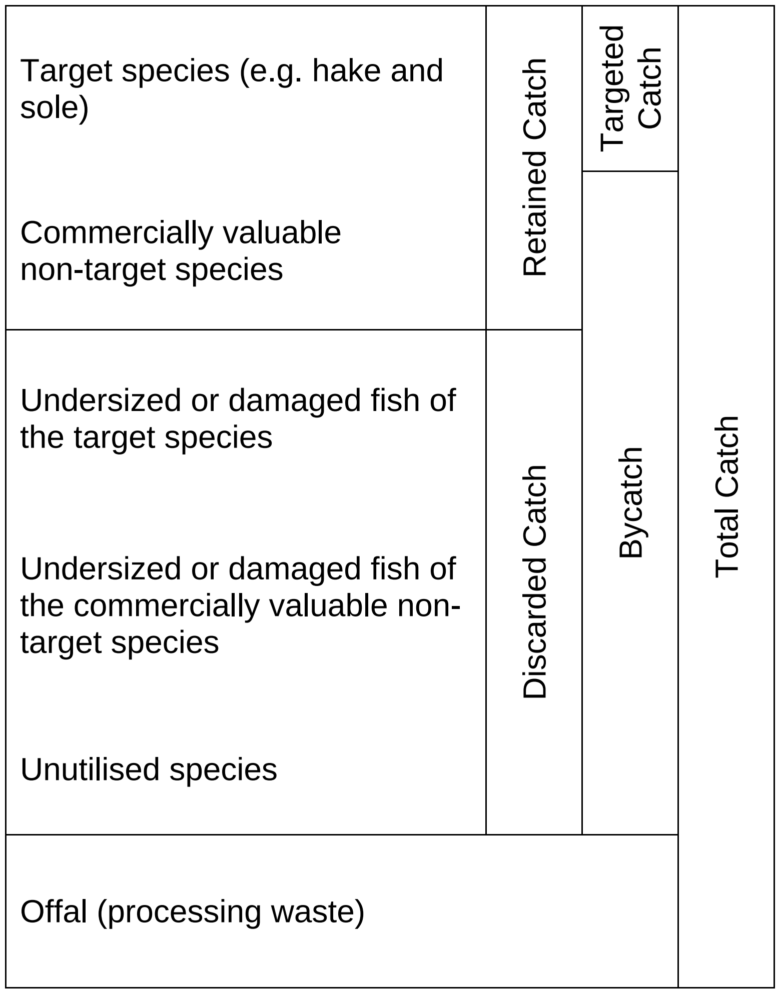


Fig. 1.1: Graphic illustration of the components of the catch as defined in the text.
(Note that if nominal retained values are given, then the offal component is already included in the total catch).

Bycatch assessment and management

The importance of assessing and managing bycatch was highlighted by Saila (1983), who estimated that approximately 6.72 million tons of fish and shellfish were discarded annually by the world's fisheries. However, this estimate was limited by a lack of data and did not include groups such as mammals and birds. More comprehensive estimates were produced by Alverson *et al.* (1994) who, using information from over 800 papers, estimated that 27 million tons (18 - 40 million tons) were discarded annually by the global fishing industry. It is accepted that while this figure was something of an over-estimation, the true figure is still extremely high (Alverson 1998). Given the current declining state of world fisheries (Alverson and Dunlop 1998, Pauly *et al.* 2002) and increased public awareness of conservation issues, the explosion of interest in bycatch issues seen over the last two decades is easy to understand (Alverson and Hughes 1996).

In order to manage bycatch and discards efficiently, not only must the scale of the problem be understood, but also the reasons why bycatch occurs. Simply put, bycatch occurs when a fishing method is not completely selective *i.e.* fish that are not the target of the fishing activity are caught in addition to those that are (NOAA/ NMFS 1998). Possibly one of the most important reasons for high bycatch is that fisheries have historically been managed on a single-species basis. Therefore, to a large extent bycatch has been ignored (Davis 1995). Further, the collection of bycatch data has been impaired by the fact that only information on the retained catch is collected for many fisheries.

Reasons for discarding fall into one of two broad categories - regulatory or economic. Regulatory discards are those that may not be retained for legal reasons (Alverson 1998). Such discards occur where there is a minimum or maximum size limit for a given species or if the catch limit of one species has been reached but fishing continues for other regulated species. Economic discards occur either: when a species has no commercial value, when the demand and commercial value of the species fluctuate or when companies attempt to maximise their profits (Clucas 1996, Alverson 1998). A full understanding of all these factors is required if bycatch is to be managed effectively.

Bycatch in trawl fisheries

Trawling is the least selective of all fishing methods. Whereas prawn trawling has a higher bycatch ratio and results in the highest levels of annual discards (Alverson *et al.* 1994), demersal trawling for finfish is also unselective. Andrew and Pepperell (1992) reviewed the issue of bycatch in prawn trawl fisheries. Additional information on bycatch in specific prawn-trawl fisheries can be found elsewhere (Watts and Pellegrin 1982; Atkinson 1984; Maharaj and Recksiek 1991; Howell and Langan 1992; Kennelly 1995; Liggins and Kennelly 1996).

With regard to bycatch in demersal finfish fisheries worldwide, Hall (1996) and Kennelly (1995) have published reviews on the assessment and management of trawl bycatch. In general, management for many demersal fisheries is at the data-gathering stage, although bycatch management plans have been proposed for several Australian fisheries (AFMA 2002a, b & c). Studies have been conducted to estimate bycatch and discards for demersal trawl fisheries in the United States (*e.g.* Jean 1963, Howell and Langan 1987, Murawski *et al.* 1995), the Mediterranean Sea (*e.g.* Vassilopoulou and Papaconstantinou 1998, Stergiou *et al.* 1998, Borges *et al.* 2001, Machias *et al.* 2001), and the North and Irish Seas (*e.g.* Connolly and Kelly 1996, Stratoudakis *et al.* 1998, 1999, Tamsett and Janacek 1999, Tamsett *et al.* 1999, Rochet *et al.* 2002).

In addition, many methods have been employed to reduce, avoid or utilise the bycatch from demersal trawlers. These include the use of closed areas (Olsen 1995, Witherell and Pautzke 1997); exclusion devices or gear modification (Olsen 1995, De Alteris *et al.* 1997, Stergiou *et al.* 1997, Gauvin and Rose 1998); the setting of bycatch limits (Gauvin *et al.* 1995, Witherell and Pautzke 1997); and prohibiting the discarding of all or some species (Gauvin and Rose 1998). For many fisheries several methods are used in combination. In general however, regulations are introduced on a species-by-species basis, rather than as part of a structured plan. Also, subsequent to the introduction of bycatch management measures, there has often been little or no research directed towards assessing their success or failure. A summary of methods adopted to manage bycatch and examples of their utilisation in world fisheries is given in Table 1.1.

Table 1.1: Summary of management measures that have been applied to demersal trawl fisheries.
1 = minimum mesh size, 2 = time/area closures, 3 = abandonment of trawl grounds when bycatch levels reach pre-determined level, 4 = percentage or mass of bycatch limited annually or per trip limit, 5 = compulsory observer programme or vessel monitoring system (VMS), 6 = all discarding prohibited, 7 = minimum size limit, 8 = compulsory use of sorting/ exclusion device (*e.g.* square mesh panel), 9 = Individual Transferable Quota system, 10 = Hake may not be reduced to fish meal, 11 = Effort limit through number of vessels or number of days at sea, 12 = Catch limit of target species.

Fishery	Management method												Source
	1	2	3	4	5	6	7	8	9	10	11	12	
Canadian Atlantic trawl fisheries	*		*	*	*	*		*					Duthie (1996)
Canadian Pacific trawl fisheries				*	*							*	Newton (1996)
US Gulf of Alaska/ Aleutian Islands	*	*	*	*	*							*	Witherell & Pautzke (1997); Gauvin *et al.* (1995); Gauvin and Rose (1998); NOAA/ NMFS (1998)
US Northeast groundfish fisheries	*	*		*							*		NOAA/ NMFS (1998)
US West Coast groundfish fisheries				*								*	NOAA/ NMFS (1998)
US Northwest silver hake fishery	*			*								*	De Alteris *et al.* (1997); NOAA/ NMFS (1998)
Argentinean trawl fisheries	*	*		*						*		*	Bezzi *et al.* (1995)
Chilean hake fishery	*									*		*	Aguayo-Hernández (1995)
Peruvian hake fishery	*	*					*						Espino *et al.* (1995)
Falkland Islands finfish and skate/ ray fisheries	*	*									*		Nolan and Yau (1996)
Greek trawl fisheries	*	*					*					*	Stergiou *et al.* (1997)
Mediterranean trawl fisheries	*	*										*	Machias *et al.* (2001)

Table 1.1 Continued

	1	2	3	4	5	6	7	8	9	10	11	12	
Norwegian trawl fisheries	*	*	*			*		*			*	*	Olsen (1995)
Portuguese trawl fisheries	*						*				*		Borges *et al.* (2001)
UK, Irish Sea *Nephrops* fishery	*						*	*				*	CEFAS (2002a)
UK, Irish Sea beam/ otter mixed trawl fishery	*	*					*	*				*	CEFAS (2002a)
UK, North Sea otter/ beam trawl fishery	*	*					*	*				*	CEFAS (2002b)
UK, South West *Nephrops* fishery	*						*	*				*	CEFAS (2002c)
UK, South West beam/ otter trawl fishery	*						*					*	CEFAS (2002c)
UK, South West hake, angler & megrim	*											*	CEFAS (2002d)
UK, N Sea/ E Channel plaice and sole	*	*										*	CEFAS (2002e)
Australian Sub-Antarctic trawl fishery	*		*	*							*	*	AFMA (2002a)
Australian Southeast trawl fishery	*	*			*				*		*	*	AFMA (2002b)
Great Australian Bight trawl fishery	*	*			*							*	AFMA (2002c)
New Zealand trawl fisheries (hoki-directed)									*			*	Coleman (1995)
Eastern Central Atlantic fisheries	*	*					*				*		Guerra (1996)
Namibian hake fishery	*	*			*						*	*	Van der Westhuizen (2001)
Northwest African hake fisheries	*	*											Martos and Peralta (1995)

The South African demersal trawl fishery

The demersal trawl sector is an economically important component of the South African fishing industry, contributing approximately 39% by mass and 53% by (landed) value to the entire industry (Stuttaford 2001). Demersal trawl fisheries exist for both finfish and prawns. It is not the intention of this thesis to describe the prawn trawl fishery in detail but briefly, trawling for prawns takes place off the Tugela Bank area on the eastern coast of KwaZulu-Natal (~30°S). In addition to prawns *Penaeus indicus* and *Haliporoides triathrus,* langoustines *Metanephrops mozambicus*, rock lobster *Palinurus delagoae*, and a variety of finfish species are caught incidentally by this fishery. An assessment of the bycatch component was undertaken by Fennessy (1994a & b, 1995) and Fennessy *et al.* (1994), representing the most comprehensive investigation of bycatch in any of South Africa's trawl fisheries. Subsequent to this study, Fennessy investigated the use of bycatch reduction devices in the prawn trawl fishery, but due to funding constraints, the adoption of such measures has not been implemented (Fennessy 2002).

Demersal trawling for finfish in South Africa began towards the end of the nineteenth century on the South Coast, when a steam tug from Port Elizabeth (Fig. 1.2) was used to catch sole *Austroglossus pectoralis* (Japp *et al.* 1994). In 1892 a Norwegian trawler arrived to catch sole in False Bay, but with little success (Lees 1969, Payne and Badenhorst 1989). Finally in 1899 the steam trawler *Undine* started catching sole on the Agulhas Bank and the industry was born (Japp *et al.* 1994). A summary of the most important events in the development of the industry is outlined in Table 1.2.

Sole was the target species of the demersal industry for the first two decades, with trawling taking place in False Bay and the inshore regions of the South Coast. The first attempts at catching hake *Merluccius* sp. were promising, but markets were limited by low demand and the quality was variable (Payne 1989). At this time, most hake-directed fishing took place within sight of Cape Town. The shallow-water hake *M. capensis* probably made up the majority of the catch. The potential of the hake resource began to be recognised after World War I, when demand for protein increased (Payne and Punt 1995) and catches averaged approximately 1000 tons per annum (Lees 1969).

By World War II, 26 trawlers were operating in South African waters. After the war period, vessel size increased allowing fishing to take place further offshore. Catches increased and the full potential of the resource began to be realised. By 1950 hake catches had reached 50 000 tons and in 1955 the catch was 115 000 tons (Payne 1989). During the early 1960's, foreign fleets arrived to fish for hake and catches rapidly increased. A peak was reached in 1972 when almost 300 000 tons of hake were landed in South Africa (Fig. 1.3). In addition to the high catches, it is almost certain that large scale discarding of small hake took place by South African and western European fleets at that time (Payne and Punt 1995).

These high catches were inevitably followed by a crash caused by years of unrestricted fishing (Fig. 1.3). Catches dropped to uneconomic levels and many fleets departed (Payne 1989). In an attempt to stabilise catches, in 1975 the International Commission for the South-East Atlantic Fisheries (ICSEAF) introduced a minimum mesh size of 110 mm stretched mesh for hake-directed fishing. However, since foreign fleets were considered to have less interest in preserving South African stocks than local fleets, in 1977 the South African government declared a 200 mile Economic Exclusion Zone (EEZ), which excluded the majority of the foreign trawl fleets and initiated a plan for the conservation and re-building of the resource. Currently, South African hake stocks are recovering well from the 1970's levels and the fishery is one of the best managed in the world. Approximately 151 000 tons of hake and 860 tons of sole were landed in 1998, with a landed value of R392 million (approximately US$62.7 million) and R8.8 million (approximately US$1.5 million), respectively (Stuttaford 2001).

South African hake is composed of two species, the shallow-water hake and the deep-water hake *M. paradoxus*. A third species of hake, the Benguela hake *M. polli* also occurs off southern Africa, but its distribution is limited to southern Angola and northern Namibia. As its name suggests, the shallow-water hake is the more inshore of the two Cape hake species and is distributed from inshore waters to approximately 380 m depth (Payne 1989). Body size tends to increase with increasing depth. From approximately 150 m, *M. capensis* overlaps with the deep-water hake, whose distribution extends to approximately 800 m depth. The distribution by density of the southern African hake species is illustrated in Fig. 1.4.

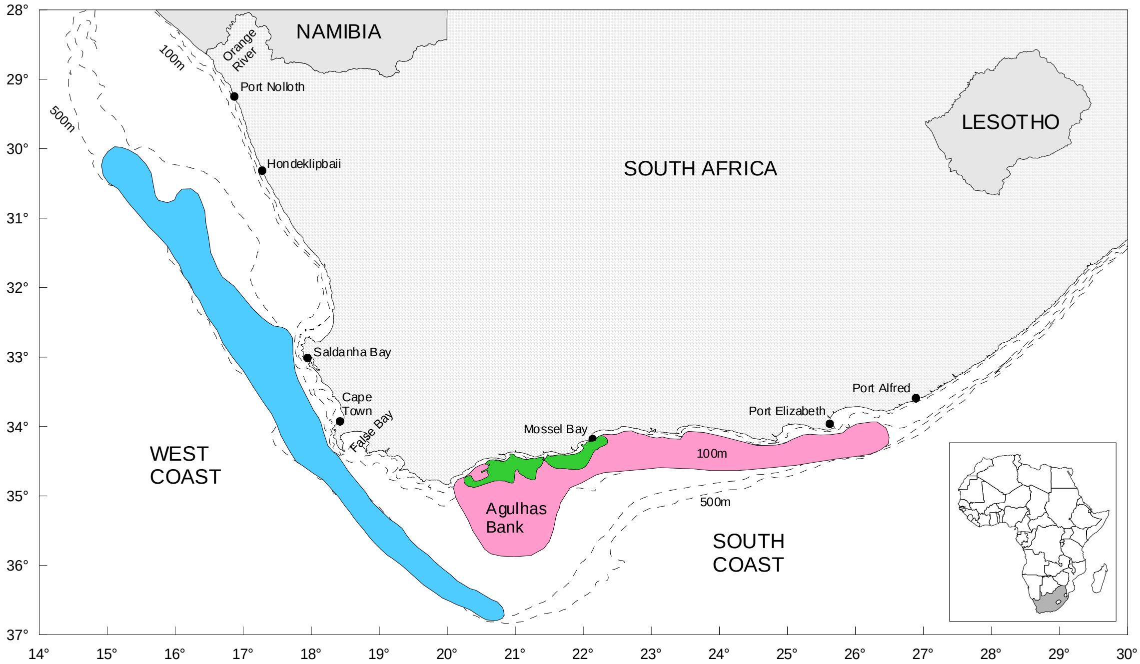


Fig. 1.2: Map of South Africa showing the position of South Africa and places mentioned in the text.
Coloured areas represent the main demersal fishing grounds: the blue area indicates West Coast grounds, the pink area indicates South Coast hake directed fishing and the green area indicates South Coast sole-directed fishing areas.

Table 1.2: Summary of the development of the demersal trawling industry in South Africa.

Year	Event
1878	A steam tug from Port Elizabeth conducts the first demersal trawling in South Africa
1892	Arrival of a Norwegian trawler in False Bay
1899	Steam trawler *Undine* begins sole trawling. Birth of the industry
1914	Outbreak of WWI, 8 trawlers are registered in South Africa
1925	35 trawlers registered
1928	False Bay closed to trawling
1935	Western part of Algoa Bay (Port Elizabeth) closed to trawling. Minimum mesh size of 75 mm stretched mesh imposed for sole trawling operations
1948	40 trawlers registered - over half based in Cape Town
1973	The number of inshore vessels in the fishery is limited
1975	Introduction of a 110 mm mesh size for hake-directed operations by ICSEAF (International Commission for South East Atlantic Fisheries)
1977	Declaration of a 200-mile Economic Exclusion Zone for South Africa. Departure of the majority of foreign fishing vessels
1978	First global sole catch limit set (700 tons), and inshore hake catch limit set (7000 tons) Deep sea trawlers excluded from fishing below 110m depth east of Cape Agulhas
1979	Setting of individual catch limits
1982	Separate catch limits set for hake and sole in the inshore fishery
1983	Annual sole catch limit raised to 950 tons
1994	Sole catch limit reduced to 872 tons
1997	Release of White paper on future of South Africa's fisheries - "A marine fisheries policy for South Africa."
1998	Adoption of a new Marine Living Resources Act (27th May 1998 - Government Gazette No 18930)
2003	Allocation of medium-term right (4 year duration) for the demersal fishery

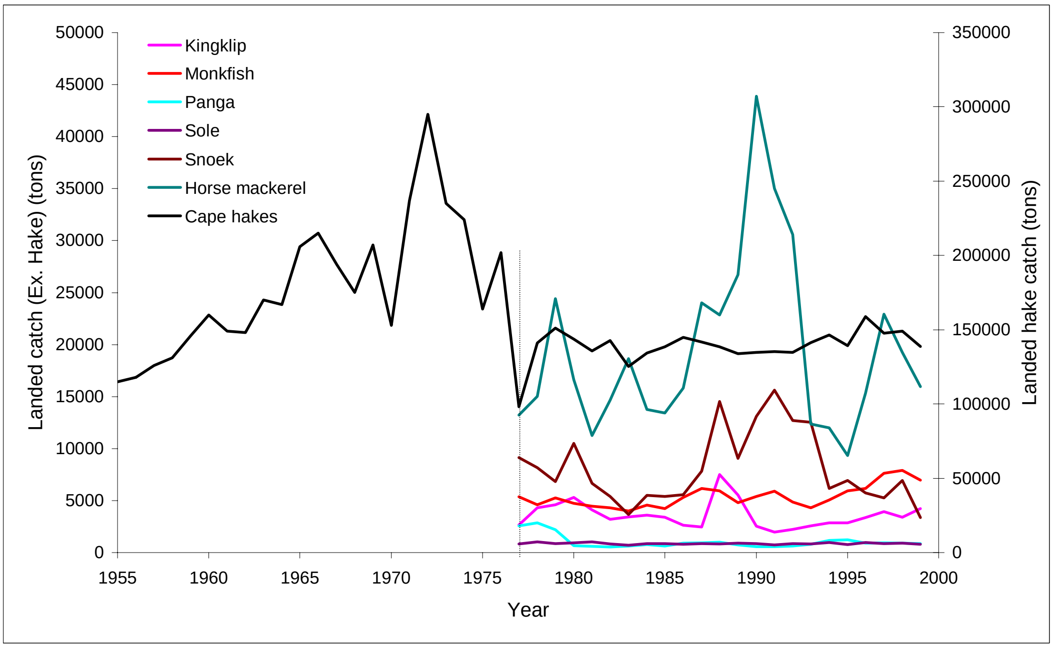


Figure 1.3: Graph showing historical landings of hake (between 1955 and 2000) and six other important main demersal trawl species (between 1977 and 2000) in South Africa (Stuttaford 1989, 1991 & 2001).

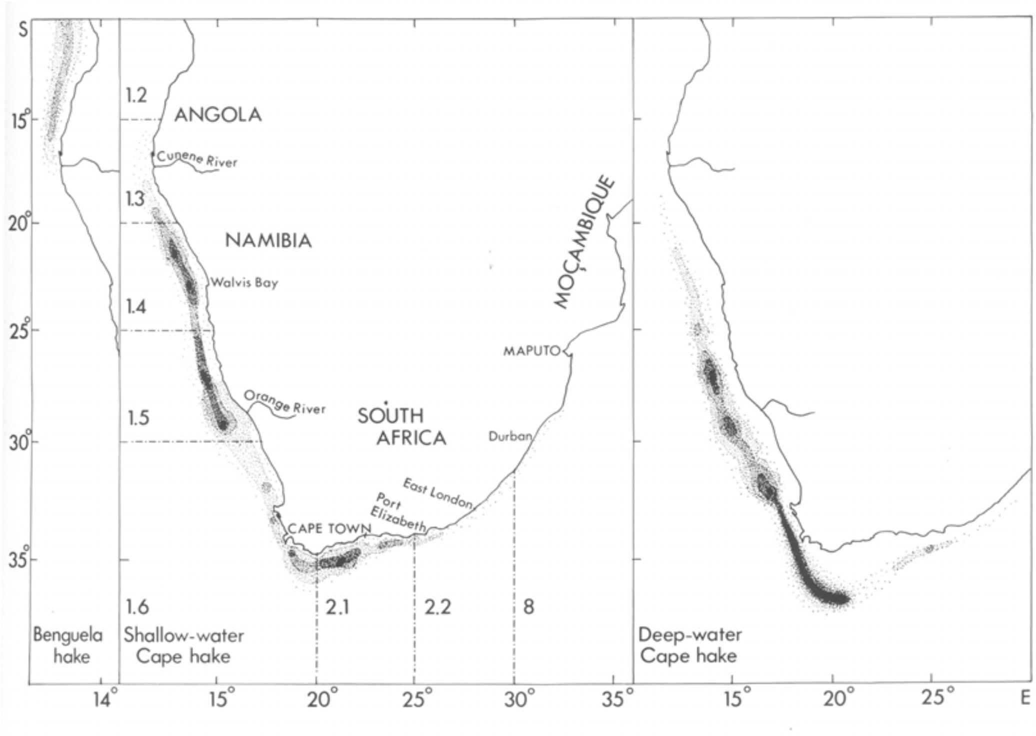


Fig 1.4: Map of southern Africa showing the distribution by density of the Benguela and Cape hake stocks and the ICSEAF statistical divisions. (Reproduced from Payne 1989).

In addition to comprising two distinct species, the South African hake fishery operates over two coasts (the West and South Coasts), whose oceanographic and physical characteristics differ significantly. Since an understanding of these characteristics is essential to understanding the structure of the fishing industry, a description of the two areas is given below.

The Cape south coast

The Agulhas Bank on the Cape south coast is a triangular extension of the continental shelf (Fig. 1.5)(Shannon 1989). The Bank is approximately 800 km long and 250 km offshore at its apex (Hutchings 1994), encompassing approximately 29 000 square nautical miles (Japp *et al.* 1994). The shelf drops steeply at the coast to 50 m then gradually deepens to 200 m before dropping steeply at the shelf break (Hutchings 1994). The Bank is bounded to the west by the Benguela current and to the east by the Agulhas current, the warm western boundary current of the Indian Ocean (Boyd and Shillington 1994). Currents over the Bank are sluggish and rotate slowly. In the westerly area, the surface drift is to the north-west, while in the east currents move clockwise, onshore and to the east (Shannon 1989). A semi-permanent "cold ridge" extends from the shore at Knysna to ±100 m off Stil Bay. In addition, warm water intrusions from the Agulhas Current create strong thermoclines over the Bank during the austral summer, which are eroded during winter storms (Shannon 1989).

The Agulhas Current is a narrow, fast-flowing body of tropical water that becomes established between 25°S (southern Mozambique) and 30°S (Durban) (Shannon 1989), generally flowing in a southwesterly direction following the continental shelf. At approximately 30°S it flows close to shore, but by 34°S it begins to move away from the coast and by the time it reaches 20°E, the current bends south-east to form the Agulhas Return current (Shannon 1970). The average surface speed of the current is 1-2 ms^{-1}, but speeds of 2.6 ms^{-1} have been recorded (Shannon 1989). The oceanography of the Agulhas Bank area is largely dependent on the local coastline and orientation of bottom bathymetry to the prevailing winds. Localised areas have their own oceanographic characteristics, such as wind driven upwelling inshore in the summer (Boyd and Shillington 1994).

Much of the Agulhas Bank is covered with sandy sediments and mud is common in the west (Shannon 1989). Coarser substrates are found at the edges of the bank, testament to faster current flow. The sediments west of 21°E are richest in organic material, whereas those to the east are organically poor and composed of mud and calcium carbonate (Shannon 1989). The distribution of these muddy patches is of significance to sole, which prefer these substrates (Zoutendyk 1973a, Le Clus *et al.* 1994, 1996). In addition, large areas of rocky reef are present (Japp *et al.* 1994) and the wide variety of habitats available supports a diverse fauna (Boyd and Shillington 1994) that is more varied than the west coast (Hutchings 1994). The inshore areas of the Agulhas Bank are highly important nursery areas for juveniles of many species. Offshore, there is a high abundance of species important to the demersal trawl fishery such as hake (Smale *et al.* 1994). Due to the high species diversity on the Agulhas Bank, highly complex community interactions are observed (Smale *et al.* 1993), which may have major implications for fisheries management.

The position of the western boundary of the Agulhas Bank depends on several factors. Oceanographically, the 20°E line is considered an appropriate boundary between the Benguela and Agulhas systems (Japp *et al.* 1994). However, for the assessment of fish stocks, it is more appropriate to include the area from 20°E to the westward boundary of the Agulhas Bank (Fig 1.5)(Japp *et al.* 1994).

The West Coast

The continental shelf in the region of the West Coast is deep and varies greatly in width (Shannon 1985). The shelf is at its narrowest at Hondeklip Bay, Cape Columbine and Cape Point and widest (~180km) at the Orange River mouth (Fig. 1.5)(Shannon 1989). The oceanography of the area is dominated by one of the four major eastern boundary current systems in the world, the Benguela Current system, which affects the region from Cape Agulhas (Fig. 1.5) northwards to 15°S (southern Angola)(Boyd and Nelson 1998). The important physical process on the shelf is wind-driven upwelling (Shannon 1989). Although the prevailing winds favour upwelling along the entire coast, some areas are more favourable than others influenced, for example, by differences in wind strength, coastal orientation or shelf width. This variation causes centres of upwelling to form where the wind is strongest and the shelf narrowest, for example off Hondeklip Bay and off Cape Columbine (Shannon 1989). One such area of upwelling occurs off Lüderitz (approximately 29°S), where it is extremely windy and the water is normally colder than the rest of the coast. The Lüderitz upwelling cell occurs between 25.8°S and 28.5°S and effectively divides the Benguela Current into northern and southern components (Shannon 1989).

The Southern Benguela is found between Cape Agulhas in the south and the Lüderitz upwelling cell in the north, a distance of approximately 780 km and a surface area (to the 200 m depth contour) of approximately 105 000 km^2 (30 613 nautical $miles^2$). Coastal upwelling in the area is driven by southeasterly winds that occur mainly in the summer months (Jury 1985). The current can be variable and off Cape Point may be affected by Agulhas water and wind forcing (Boyd and Nelson 1998). It is an area of intense biological productivity as the upwelled waters contain a high concentration of nutrients, which support high plankton production and high fish abundance. The bulk of South Africa's commercial fisheries catch occurs on the West Coast and is dominated by the purse-seine fishery for sardine *Sardinops sagax* and anchovy *Engraulis capensis*, the demersal trawl fishery for hake and the handline fishery for snoek *Thyrsites atun* (Crawford *et al.* 1987). Historical landings of hake, sole and other common demersal bycatch species for the demersal trawl fishery (West and South coasts combined), can be found in Fig. 1.3 (Stuttaford 1989, 1991 and 2001).

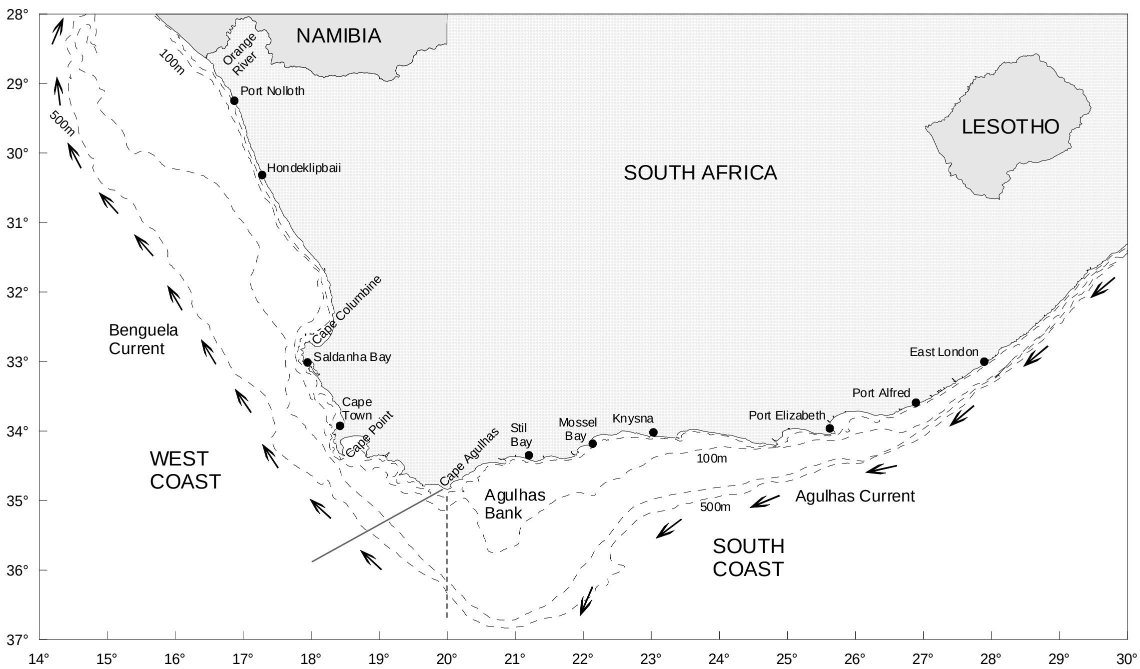


Fig 1.5: Map of South Africa showing the direction of the Agulhas and Benguela Currents systems and places mentioned in the text.
The solid line indicates the western boundary of the Agulhas Bank and the dotted line the oceanic boundary between the Agulhas and Benguela systems. Isobaths are 50 m, 100 m, 200 m and 500 m.

The bycatch and management of the South African trawl fishery

Currently the West and South Coast fisheries are managed separately, based upon integral stock units agreed upon by ICSEAF scientists in the 1970's (Fig. 1.4)(Payne 1989). The South Coast fishery has offshore (hake-directed) and inshore (hake and sole-directed) components, whereas the West Coast fishery is almost exclusively offshore (hake-directed). The main fishing grounds are shown in Fig. 1.2. For hake, a global TAC of approximately 160 000 tons is set annually, based upon an age-structured production model. Up to 10% may be allocated to the linefishery and as a bycatch reserve. Approximately 10 000 tons *p.a.* is allocated to the South Coast inshore trawl fishery. The remainder is allocated to the offshore fishery in a ratio of 2:1 between the West and South Coasts, respectively. The annual sole catch limit has been set at 872 tons for the past several years (Stuttaford 2001).

In addition to the TAC, both fisheries are managed by a variety of controls. Rights are allocated to individual companies and minimum mesh sizes exist for the inshore and offshore fisheries. On the South Coast several bays are closed to trawling, the engine size of inshore vessels is limited and offshore vessels are prohibited from fishing shallower than 110 m depth. Discarding of regulated species is prohibited, but occurs nonetheless. There are currently no management measures for bycatch species.

Large stern trawlers (approximately 35-60 m in length) conduct the majority of fishing on the West Coast. Most vessels, based at the ports of Cape Town and Saldanha Bay, are wet fish vessels (packing their catch on ice) staying at sea for approximately five to seven days. Fishing is primarily directed towards hake, the majority of which is headed and gutted on board. Several bycatch species are also retained, including horse mackerel *Trachurus trachurus capensis*, ribbonfish *Lepidopus caudatus* and monkfish *Lophius vomerinus*. A handful of freezer vessels also operate here, but the trend in recent years has been to convert these to wet fish vessels, or else to use other options, such as to deploy them on the high seas, to move them to subsidiary companies in other countries or to sell them. West Coast vessels may also fish on the South Coast.

The South Coast fishery, with vessels based at Port Elizabeth or Mossel Bay (Fig. 1.2) can be separated into inshore and offshore components. The majority of offshore vessels are large, wetfish stern trawlers (35-42 m in length) targeting hake. These vessels are restricted from fishing below 110 m depth. The inshore fishery has two components - a hake-directed component and a sole-directed component. Both fisheries use small (14-30 m) side trawlers, which are capable of spending up to ten days at sea. Hake-directed vessels generally fish east of 22°E, whereas sole-directed trawling takes place west of 22°E. Inshore operators are allocated rights for both hake and sole to cover hake bycatch when targeting sole. However, this may lead to increased discarding as operators attempt to maximise both allocations.

As with many fisheries world-wide, bycatch issues in the South African demersal trawl fishery received limited attention from the industry or scientists during the development of the industry. During the early days of the industry, sole was the mainstay and market demand for hake and other bycatch species was low. Therefore, it is assumed that only the largest hake were retained (high-grading) and that there would have been a high discard rate of small hake and other bycatch species (Payne and Punt 1995). With increasing demand for fish in the latter part of the twentieth century, the potential for bycatch species was recognised and markets began to open. In addition, since there was little or no size-based price differential for hake, small hake were retained rather than discarded. Recent years have seen the development of a lucrative export market for PQ hake ("Prime Quality" - gutted, head on), which has brought about a large size-based price difference and created an economic incentive to high-grade.

Since the early 1990's, there have been many changes in the structure of the South African fishing industry. During the post-war period, market forces forced many small operators out of the industry, while other companies amalgamated and took over their competitors (Lees 1969). This was largely due to the fact that trawling is extremely capital intensive and success pivots around distribution and marketing efficiency (Sauer *et al.* 2003). The result was an industry dominated by several large companies, so that by 1978 three entities held approximately 97% of the annual hake TAC. A description of the early history of the industry can be found in Lees (1969). At the end of the apartheid era, the need for redistribution of rights in the fishery was recognised. Emphasis was placed on including those previously excluded, using a SMME (Small Micro Medium Enterprise) approach. A process of consultation took place in the early 1990's resulting in the publication of a white paper on the future of South Africa's marine fisheries. All stakeholders were consulted during this process, including established fishing companies and those who had previously been excluded, but wished to gain entrance to the fishery. This paper became law in 1998, when South Africa adopted it as the Marine Living Resources Act (MLRA 1998). The desired changes regarding access to the fishery are clearly reflected in the fact that by 2001, the number of entities holding demersal fishing rights had risen to 57 and many companies are currently owned or jointly owned by those previously disadvantaged (Sauer *et al.* 2003).

Not only does the Marine Living Resources Act include provision for inclusivity in the fishery, but for the first time provision has been made for the sustainable management of all marine resources, including bycatch species. During the course of fishing operations cognisance must be taken of the impact of the operation on non-target species. South Africa's commitment to sustainable utilisation is further reflected in its status as signatory to the FAO Code of Conduct for Responsible Fisheries (FAO 1996). Prior to the promulgation of the MLRA, however, the issue of sustainable utilisation of marine resources had begun to be realised by research institutions and the need for a structured management plan to ensure such sustainable utilisation was recognised.

In order to formulate a good management plan, a variety of data are required. Firstly, information on the composition of the catches and estimates of the current levels of discarding is essential. In addition, the data must cover the entire range of the fishing operations. This is particularly true if the fishery is mixed or has markedly different components such as the West Coast hake-directed fishery and the South Coast sole-directed fishery. Furthermore, data on the life history and stock status of target and non-target species are required to assess the impact that the fishery has on target and bycatch stocks.

Catch and biological information cannot be considered in isolation however. Other aspects that must be taken into account include the structure of the industry, economic effects and enforcement issues. It is imperative that the type of company (small/ large) and their fishing strategies are fully understood in order to assess the likely impact of management measures. Furthermore, it is meaningless to introduce measures that would result in fishing becoming economically un-viable. Likewise, there is little value in adopting regulations that cannot be enforced or that are impractical. In addition, the reasons for non-compliance need to be understood to ensure that additional regulations will be adhered to.

Once all the relevant information is collected, areas of concern must be highlighted and possible solutions identified in order to formulate a plan of action. There are several ways of formulating a management plan, such as a top-down management approach dictated by government or a fully collaborative process. The latter method recognises that all stakeholders carry the responsibility of sustainable utilisation. An economic assessment of the fishing industry in (Sauer *et al.* 2003) reported that a key element to the successful re-building of the industry in the 1970's and 1980's, following the dramatic collapse of stocks in 1977, was that the industry themselves developed a sense of custodianship of the resource (Sauer *et al.* 2003). Further, the report suggested that it is imperative that this sense of responsibility is not eroded by the development of the industry (Sauer *et al.* 2003.). One method of ensuring continued custodianship is to include all users in the management process. Not only will this ensure that all stakeholders will more readily adopt the final management plan, but it will also ensure that impractical ideas can be discarded in the planning stages rather than when they become part of the regulations.

With the entrance of smaller operators with limited allocations into the industry, bycatch management is likely to face new challenges. It is possible that the practice of high-grading hake has increased, and landing data show that there has been an increase in targeting of high value bycatch species such as monkfish and kingklip *Genypterus capensis*. Both strategies take place to ensure the highest economic return from the limited hake allocation. The increased pressure on these resources must be assessed. In addition, the inclusion of new operators means that data capture and processing takes longer and the task of enforcing regulations become substantially more difficult.

The first steps towards a bycatch management plan for South African demersal trawl fisheries began with the initiation of a research programme in 1995. This programme was launched after deliberations between several academic institutions, the Sea Fisheries Research Institute (SFRI, now Marine and Coastal Management - a branch of the government Department of Environmental Affairs and Tourism, which is responsible for marine resource management) and SANCOR (the South African Network for Coastal and Oceanic Research). Entitled "Towards improving national, social and economic benefits through enhanced utilisation and management of the offshore resources of the east, south and west coasts of South Africa" the programme represented the first co-ordinated approach to assessing South African demersal trawl bycatch and discards. The aim was to investigate the status and potential of trawl fisheries by acquiring the information necessary to improve the management of regulated and unregulated stocks.

The basis of the programme involved observers who were sent to sea on commercial trawlers (Fig. 1.5) to collect the required information. Observers have been employed to collect data from commercial vessels in many trawl fisheries world-wide and their use represents one of the most effective means of data collection (Liggins *et al.* 1997). However, when initiating such a programme several factors must be borne in mind, such as the data analysis required at the end, the number of observers that can be deployed and finally, given that the observer coverage may be limited, the best way of deploying the observers. Also, in the absence of regulations requiring the accommodation of observers aboard commercial vessels, the achievement of the desired distribution of observer effort will largely depend on the willingness of individual companies to participate.

The observer programme initiated in 1995 operated until 2000 with several aims. These were to assess the potential of a national observer programme for collecting information on bycatch and discards in the South African demersal trawl fishery; to quantify the bycatch and discards, identify immediate areas of concern and provide possible management solutions; and to provide a basis for a national observer programme. The pilot programme collected information on the size and mass structure of the discard portion, details of the retained catch and trawl details such as position and depth. During that time full details of the trawl catch were obtained for 1093 trawls along with length-frequency information for an additional 131 trawls. These trawls represent many of the vessel types and fisheries in operation around the Cape south and west coasts and the data provided the first comprehensive study on the composition of demersal trawl catches. In addition, biological material was collected for studies on the life history of several bycatch species. These species include: the spiny dogfish *Squalus megalops*, the Cape gurnard *Chelidonichthys capensis*, the yellowspot skate *Raja wallacei*, the slime skate *R. pullopunctata*, the Cape dory *Zeus capensis*, the jacopever *Helicolenus dactylopterus*, the ribbonfish, the snub-nosed grenadier *Caelorinchus symorhynchus*, the purple grenadier *Malacocephalus laevis*, the soupfin shark *Galeorhinus galeus* and the monkfish.

Thesis aims and structure

The aim of this thesis is to provide the basis for a bycatch management plan for the South African demersal trawl fishery. This will be achieved through the analysis of catch data, biological data and other information to answer the following key questions:

1. What is the catch composition of the South African demersal trawl fishery?
2. What levels of utilisation and discarding occur in the fishery?
3. Can spatial or temporal patterns be identified within the bycatch?
4. Can areas of concern be identified within the bycatch?
5. How can these areas of concern be addressed?
6. What are the basic life history parameters for monkfish?
7. What is the current stock status of monkfish?
8. Is it possible to target selected species such as the monkfish for increased utilisation without increasing the bycatch of regulated species such as hake?
9. How can current management of the trawl fishery, be re-formulated to encompass the optimal management of non-target species?

Chapters 2 and 3 describe the composition of catches made by demersal trawlers operating on the south and west coasts of South Africa, respectively, allowing the scale of the bycatch problem to be assessed. Each chapter presents information on the true catch composition (as opposed to the landed/retained catch), the proportion of bycatch in the catch and the extent to which the non-target catch is currently utilised. Estimates of the mass and number of fish discarded annually are also given. The existence of temporal and spatial trends in hake discarding and bycatch utilisation is investigated in Chapter 4 using a simple Geographic Information System (GIS) and GAMs (Generalised Additive Modelling). The life history and stock status of the monkfish is investigated in Chapter 5 as a model for the impact of current fishing strategies on non-target or non-regulated species. Age and growth characteristics, reproductive biology, feeding biology, distribution patterns and a preliminary per-recruit stock assessment are presented. The process followed in the formulation of a management plan for South African bycatch, using data from this thesis and other sources, is described in Chapter 6. A summary of the data used to formulate this plan is given in Fig. 1.6. Areas of immediate concern are identified and short and medium term solutions for bycatch are discussed. The final product, an adaptable management plan designed to provide a precursor to future research management, is presented.

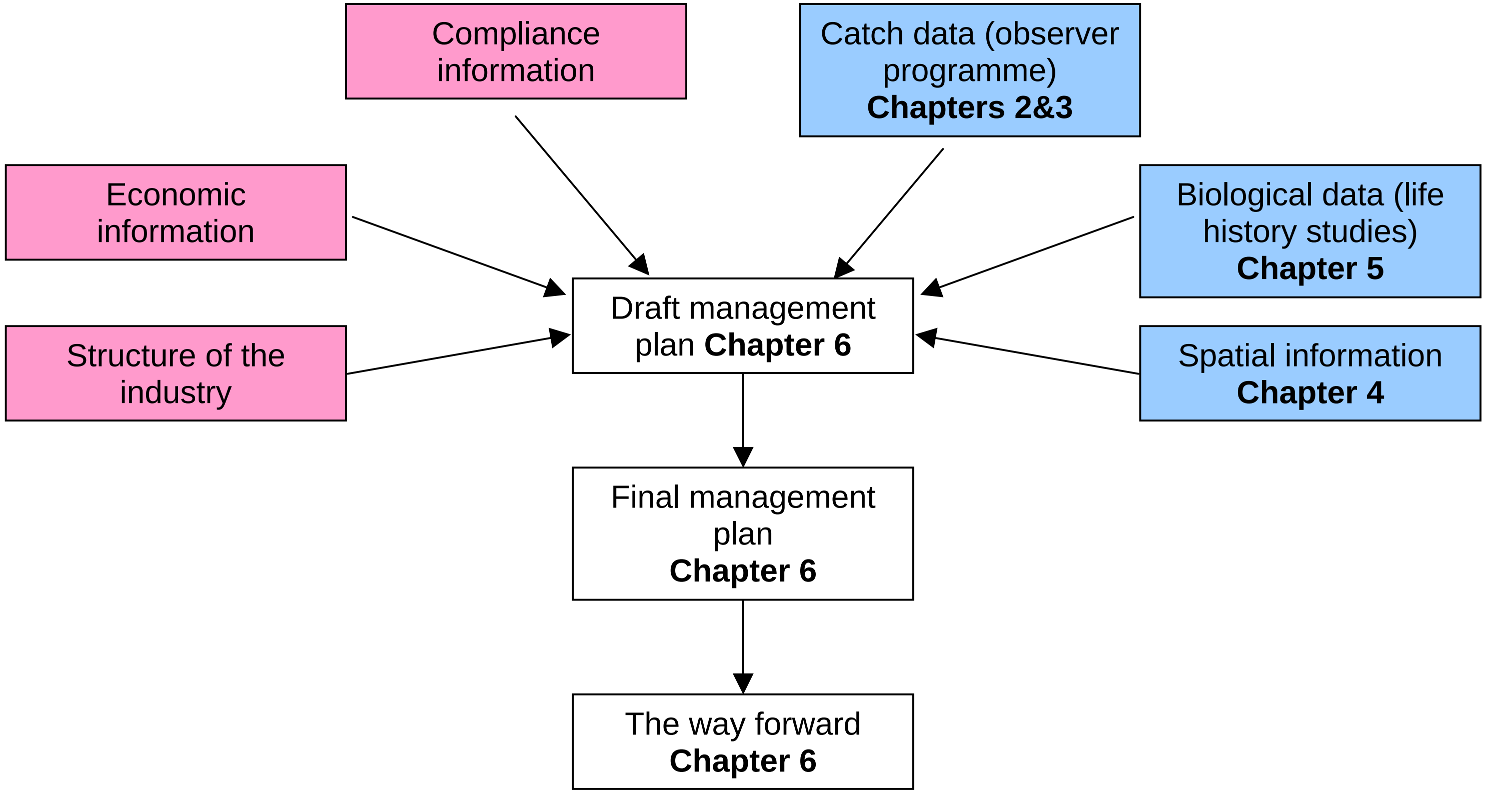


Fig. 1.6: Sources of data utilised in the formulation of a management plan for bycatch and discards in the South African demersal trawl fishery.
Blue blocks indicate original data presented in this thesis, pink blocks indicate data from other sources.

Chapter 2 - Bycatch and discarding in the South African demersal trawl fishery: the Cape south coast.

Introduction

The Agulhas Bank off the South Coast of South Africa supports an abundance of marine life (Smale and Badenhorst 1991), and is the focus of several large-scale fisheries. Two major demersal trawl fisheries exist on the Bank, a hake-directed fishery and a sole-directed fishery, based at the ports of Mossel Bay and Port Elizabeth (Fig. 2.1). The hake-directed fishery can be further separated into three fishing areas - inshore, the Blues Bank and the Chalk Line. Inshore hake-directed fishing is undertaken by small side trawlers (13-25m length) that are limited to an engine size of 750 b.h.p., effectively confining them to fishing in waters less than 120 m deep. These vessels generally target hake between 22°E and Port Alfred (~27°E). The Blues Bank is a well-defined fishing area off Mossel Bay. Although this is an inshore area, the increased depth and more westerly position of the Bank results in a different catch composition compared to that found during inshore hake-directed operations. The Chalk Line (Fig. 2.1) is an offshore area (200-300m depth) off Port Elizabeth, fished by large stern trawlers (35-45m length) that are restricted from fishing shallower than 110m depth.

The sole-directed fishery is undertaken by side trawlers of a similar size to those operating in the inshore hake-directed fishery. However, fishing for sole generally takes place between 20-22°E in waters shallower than the 100m isobath. In addition to South Coast-based trawlers, vessels based at the West Coast ports of Cape Town and Saldanha Bay also fish on the Agulhas Bank.

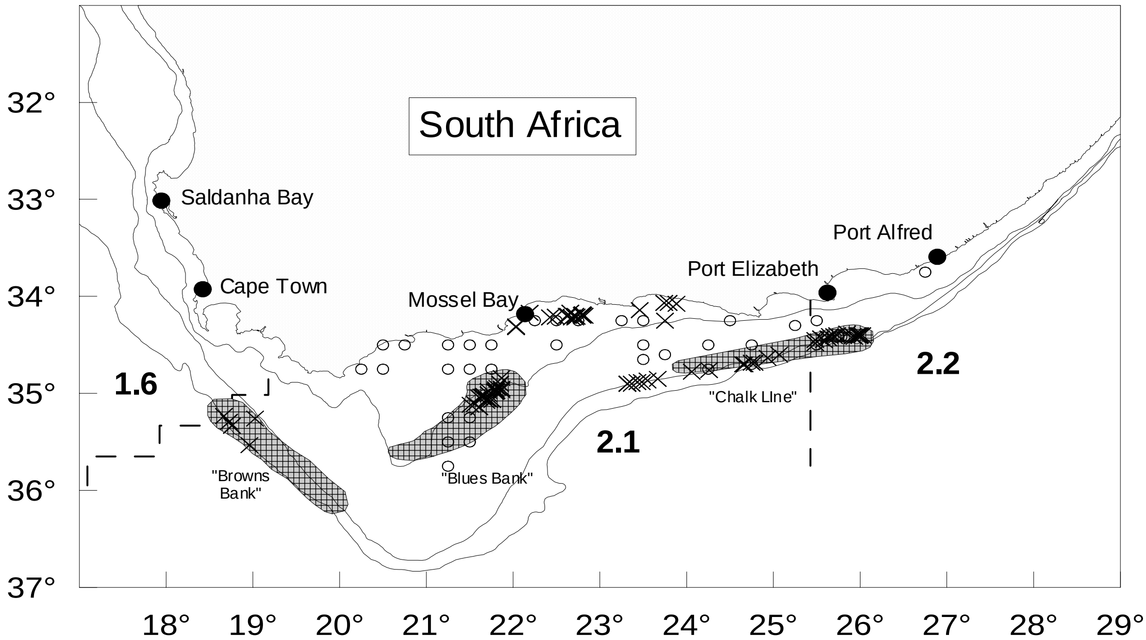


Fig. 2. 1: Map of South Africa showing the 100m, 200m and 500m isobaths and the locations of all observed trawls and places mentioned in the text. X = position of one trawl; O = position of two or more trawls; shaded areas show the popular fishing grounds (Browns Bank, Blues Bank, Chalk Line). Dotted lines indicate the boundaries of the ICSEAF divisions and the numbers in bold are the names of each Division.

Typically, trawl catches from the Agulhas Bank are highly diverse and several non-target species (bycatch) contribute significantly to the landings (Japp *et al.* 1994). In the hake-directed fishery, bycatch species include horse mackerel, jacopever, squid *Loligo vulgaris reynaudii*, sole and various linefish species. Similar bycatch species are caught in the sole-directed fishery, but hake is also a bycatch species. Although horse mackerel is a bycatch species in the hake and sole-directed fisheries, mid-water trawlers may also target it. Despite the fact that some of the bycatch is retained and utilised, a portion is discarded, usually dead. In addition, the trawlers process their catch on board and the offal (heads and guts) is discarded. A graphic illustration of the trawl catch and the terms used in this chapter can be found in Chapter 1.

Historically, the study of Agulhas Bank demersal trawl-caught fish species has focused on the biology and stock status of the two target species - hake (*e.g.* Bohl *et al.* 1971, Botha 1971, 1986, Punt 1994, Osborne *et al.* 1999) and sole (*e.g.* Zoutendyk 1973a, b, 1974, Le Clus *et al.* 1994, 1996). Investigations into the life history and stock status of non-target species are a relatively recent undertaking. These studies have focused primarily on parameters such as age, growth and reproduction of individual species including lesser gurnard *Chelidonichthys queketti* (Booth 1997a), Cape gurnard (McPhail *et al*. 2001), panga *Pterogymnus laniarius* (Booth & Buxton 1997), redspotted tonguefish *Cynoglossus zanzibarensis* (Booth & Walmsley-Hart 2000), horse mackerel (Kerstan and Leslie 1994), Izak catshark *Holohalaelurus regani* (Richardson *et al.* 1999) and spiny dogfish (Watson and Smale 1998, 1999). Other studies have investigated the abundance and distribution of trawl species (Badenhorst and Smale 1991) and their trophic relationships (Meyer and Smale 1991a, b, Smale *et al.* 1994).

Catch reporting in the demersal fishery has historically focused on the landed rather than the total catch and although the logbook provides space for skippers to record the total mass of discards, this is not always reported. Thus, despite the diversity of landings and the abundance of biological studies, little information exists on the composition of commercial catches (as opposed to landings), and on the levels and patterns of discarding by the demersal fleet.

Japp (1996) investigated all South Africa's fisheries using a variety of methods and made the only comprehensive estimates of bycatch and discards available for the demersal hake-directed trawl fishery. For demersal species, bycatch ratios were calculated from research survey data and applied to commercial landing data to estimate the annual bycatch of non-target species. However, as noted by Japp (1996), several key differences exist between commercial and survey data that could bias the estimates obtained. Possible sources of bias include the fact that commercial trawl gear is more selective than survey gear; surveys may be conducted over substrates unsuitable for commercial trawling; and survey trawls are of a shorter duration than commercial trawls. In addition, surveys are restricted to sampling during two annual periods and species assemblages may be affected seasonally (Roel 1987, MacPherson and Gordoa 1992).

Other bycatch investigated is that of prawn trawlers off the KwaZulu-Natal coast (Fennessy 1994a, b, Fennessy *et al.* 1994) and the incidental catch of seals by demersal trawlers (Wickens and Sims 1994).

This chapter presents data on catch composition, levels of bycatch and estimates of annual discards of demersal trawls on the south coast of South Africa. These data were collected by observers aboard commercial trawlers and represent the first comprehensive data set of their kind in South Africa.

Material and methods

Data collection

Data were collected by observers aboard commercial trawlers operating from Mossel Bay and Port Elizabeth on the south coast of South Africa between January 1996 and September 2000. One full-time observer was based in Mossel Bay and, as far as possible, went to sea on one sole-directed and one hake-directed vessel per month (for a period of 3-10 days each and covering 3-22 net hauls). Observers from Port Elizabeth were employed on a more *ad hoc* basis. The observers had no influence on the trawling locations, and the accommodation of an observer was at the discretion of the company involved. In addition, eleven trawls were made by offshore West Coast trawlers on the edge of the Agulhas Bank (200-500m depth) east of 22ºE. The data obtained from these trawls are included in Chapter 3.

For each trawl, the discarded bycatch was sampled. Where possible all discards were collected. However, if this was not logistically possible, a random sub-sample was taken. On south coast trawlers, the catch is emptied from the cod end onto the deck. Fish for processing are removed and the discards are shovelled overboard. Thus, the proportion of the sub-sample was estimated visually. The sample (or sub-sample) was sorted to species and the weight and size-structure of each species was recorded. If a sub-sample was taken, the total discards were calculated by scaling up the sub-sample. The proportion of the discards sampled was 50 - 100% of the total discards. Due to time constaints only fish and cephalopod discards were sampled. The mass of invertbrates such as echinoderms was not recorded.

Information on the mass of retained fish was obtained from the factory managers. Some species such as hake, monkfish and kingklip were headed and gutted on board and the offal was discarded. The nominal (whole) retained mass of these species was calculated by multiplying the processed retained mass 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 nominal retained mass for each species plus the observed discard mass. Occasionally, part of the offal such as the ovaries or heads were retained due to their commercial value. If this was the case, the mass of this retained offal was recorded. The total offal mass was calculated as the nominal retained mass minus the processed retained mass. The mass of discarded offal was calculated by subtracting the retained offal mass from the estimated total offal mass. Additional trawl data such as the trawl position, duration, and the time of day were obtained from the vessel's log.

Data analysis

The data collected represented several vessel types, fishery types and a wide geographical area. It was postulated that these factors would influence trawl catches and discarding patterns. To investigate this, the community structure in each of the four fishing areas described in the introduction, (sole-directed, inshore hake-directed, Blues Bank hake-directed and Chalk Line hake-directed), was investigated using PRIMER 5 (Version 5.1.2, Plymouth Marine Labs, 2000). The results were also used to determine fishing areas for use in the GAM analysis (Chapter 4).

Each trawl was assigned to one of the four fisheries, and the unstandardised biomass data were root-root transformed. A similarity table was constructed using the Bray-Curtis measure of similarity, and the group average clustering method was used to derive the dendrogram (Field *et al.* 1982, Smale *et al.*, 1993). Analysis of similarity (ANOSIM routine in PRIMER) was used to compare the catch compositions between each pair of fishing areas. ANOSIM is a non-parametric analysis of variance based on the Bray-Curtis similarities. The data were re-ordered to give a global R-statistic, which can be used to test the null hypothesis that there is no significant difference among the fishing areas. Pairwise comparisons (ANOSIM) between fisheries were used to determine which areas 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.

Next, the catch composition and fate of the catch was investigated. Initially, the total percentage contribution of each species to the catch (by mass) in each area was calculated. The percentage of the catch (by mass) that was either retained or discarded was then calculated. Finally, the percentage contribution (by mass and number) of each species to the discarded catch was calculated. Unfortunately, the composition by mass and number could be calculated only for the discarded catch because information on the number of fish retained was available for hake only. Finally, the mass and number of fish discarded annually by the South Coast fishery was estimated by extrapolating the observer catch data to the total annual South Coast catch in 1997. Due to the limited nature of the data, it was assumed that the distribution of observed trawls was similar between years.

All data (hake and sole-directed) were pooled and stratified by the statistical regions established by ICSEAF. There are two ICSEAF divisions (2.1 and 2.2) on the Cape south coast (Fig. 1). Historically, MCM captured commercial catch and effort data by ICSEAF division and by fishery (inshore and offshore), so that catch statistics could be reported to ICSEAF in the required statistical areas. This data capture programme is still used. Therefore, discard estimates were calculated for inshore division 2.1, offshore division 2.1, inshore division 2.2 and offshore division 2.2 and summed to give a final discard estimate. Two methods were employed to estimate discards - an effort-based and a landings-based approach.

If one assumes that the distribution of the observed trawls is similar to the distribution of the trawls by whole fleet in a given fishing year, then the catch composition of the observed trawls should reflect the catch composition of the entire fleet for that year. Given that we know the fishing effort expended during observed trawls and the total fishing effort expended by the fleet in a given year, we can obtain a reasonable estimate of the total annual discards of a given species (Sp. A) by the trawl fleet, by extrapolating the observed catch composition upwards. This e*ffort-based extrapolation*, can be expressed as:

$$Annual\ discard\ Sp.\ A = \frac{Observed\ discard\ Sp.\ A}{Observed\ effort} \times Annual\ effort \qquad (1)$$

Alternatively, we can assume that the proportions of target and non-target species within the observed catches reflect the true proportions of target and non-target species in annual catches and that the observed discard ratios reflect the discard ratios of the fleet. In this case, this relationship can be used to extrapolate from the observed catches to the annual catch. This is the *landings-based extrapolation* and can be expressed as:

$$Annual\ discard\ Sp.\ A = \frac{Observed\ discard\ Sp.\ A}{Observed\ total\ catch\ Sp.\ A} \times Annual\ landing\ Sp.\ A \qquad (2)$$

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

$$Annual\ discard\ Sp.\ A = \frac{Observed\ discard\ Sp.\ A}{Observed\ nominal\ hake\ catch} \times Annual\ hake\ landing \qquad (3)$$

The underlying assumptions for the two methods are markedly different, and as such were expected to provide different discard estimates. The effort-based approach assumes that the effort directed towards catching bycatch species is equal to that of hake. However, many species may shoal or have a very patchy distribution and, therefore, effort directed towards catching these species may differ from that for 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 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, therefore, give more defensible estimates than the effort-based approach. Nevertheless, in order to undertake a comparative analysis, both methods were investigated.

Results

A total of 614 trawls were observed - 595 from Mossel Bay vessels, and 19 from Port Elizabeth vessels. The location of all trawls is presented in Fig. 2.1, and a breakdown of trawls by fishing area and year is presented in Table 2.1.

Table 2.1: Number of observed trawls (by year and fishing area) made by demersal trawlers operating off the south coast of South Africa between January 1996 and September 2000. The fishing areas are defined in the text.

Fishery	1996	1997	1998	1999	2000	Total
Blues Bank	11	67	26	5	30	139
Chalk Line	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

Trawls were broadly grouped into the four areas by both CLUSTER analysis and MDS. Due to the large number of data points, the associated dendrogram from the CLUSTER analysis is difficult to interpret and, therefore, only the results from the MDS analysis are presented (Fig. 2.2). The majority of offshore hake-directed trawls are found in the top left region of the MDS plot. The inshore hake-directed and Blue bank trawls are found lower and to the right. The majority of the inshore sole-directed trawls are found in the bottom right region of the plot, highlighting the differences between these trawls and the offshore hake-directed trawls. As a result of the overlap among hake-directed fishing areas, it was decided that for the GAM analysis, only two fishery groups would be used, hake-directed trawls (Blues Bank, Chalk Line and inshore hake-directed fishing combined) and sole-directed trawls.

With the exception of two groups, all the pairwise comparisons (ANOSIM) showed significant differences ($p < 0.1$, the significance level used by the Primer 5 package) between areas. Inshore hake-directed trawls were not significantly different from trawls on either the Blues Bank or the Chalk Line (*p* > 0.1) (Table 2.2).

The results of the SIMPER analysis - which identifies the indicator species and shows the levels of similarity within, and levels of dissimilarity between, fishing areas - are presented in Tables 2.3a - f. Inshore sole-directed and Chalk Line fishing areas showed the highest level of dissimilarity (73.12%), and inshore hake-directed and Blues Bank were the least dissimilar (45.87%).

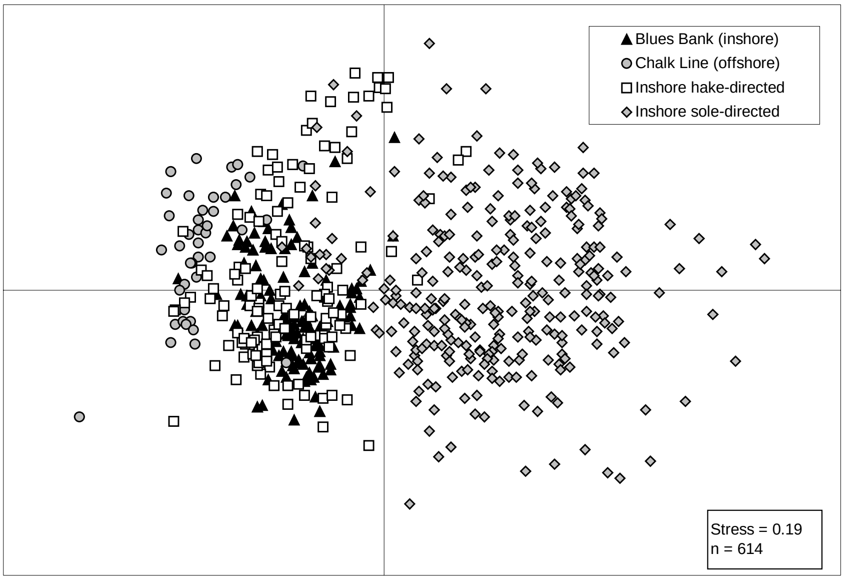


Fig. 2.2: MDS plot of catch composition of observed trawls in the four fishing areas between January 1996 and September 2000 on the south coast of South Africa, showing to which fishery each station was assigned.

Table 2.2: results of ANOSIM analysis indicating the significant differences in catch composition between fishing areas.
- indicates no significant difference ($p > 0.1$), ** indicates significant difference ($p < 0.1$). Sole = sole-directed fishery, Hake = inshore hake-directed fishery, Blues = trawls made on the Blues Bank, Chalk = trawls made on the Chalk Line area.

	Sole	Blues	Hake	Chalk
Sole		**	**	**
Blues			-	**
Hake				-
Chalk				

Table 2.3: Between-fishery comparisons, indicator species and related data from the SIMPER analysis of observed catches made by demersal trawlers operating off the south coast of South Africa between January 1996 and September 2000.
Av. Ab. is the average abundance contribution of the species to the fishery, Av. Te. is the average term, which is the average Bray-Curtis contribution of each species to distinguish between groups. The ratio is the percentage contribution of the species to the separation between fisheries and the cumulative percentage is given for comparison between groups. Only those species that contributed to the top 75% of total dissimilarity are listed.

(a) Sole-directed *v.* hake-directed. Average dissimilarity = 65.50%

Species	Sole	Hake				
	Av. Ab.	Av. Ab.	Av. Te.	Ratio	%	Cum (%)
Austroglossus pectoralis	81.74	6.47	5.34	1.76	8.15	8.15
Trachurus trachurus 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 sp.	288.85	891.59	4.16	1.20	6.35	29.29
Loligo vulgaris 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
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

(b) Sole-directed *v.* Blues Bank. Average dissimilarity = 63.39%

	Sole	Blues Bank				
Species	Av. Ab.	Av. Ab.	Av. Te.	Ratio	%	Cum (%)
Trachurus trachurus 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 sp.	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

(c) Sole-directed *v.* Chalk Line. Average dissimilarity = 73.12%						
	Sole	Chalk Line				
Species	Av. Ab.	Av. Ab.	Av. Te.	Ratio	%	Cum (%)
Trachurus trachurus 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 sp.	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 capensis	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 vulgaris 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

(d) Hake-directed *v.* Blues Bank. Average dissimilarity = 45.87%						
Species	Hake	Blues Bank				
	Av. Ab.	Av. Ab.	Av. Te.	Ratio	%	Cum (%)
Pterogymnus laniarius	233.59	96.38	3.71	1.28	8.10	8.10
Trachurus trachurus 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 vulgaris 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 sp.	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

(e) Hake-directed *v.* Chalk Line. Average dissimilarity = 55.54%						
	Hake	Chalk Line				
Species	Av. Ab.	Av. Ab.	Av. Te.	Ratio	%	Cum (%)
Pterogymnus laniarius	233.59	40.92	4.06	1.16	7.31	7.31
Trachurus trachurus 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 sp.	891.59	1 486.21	3.02	1.10	5.45	32.01
Loligo vulgaris 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 capensis	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

(f) Blues Bank *v.* Chalk Line. Average dissimilarity = 51.97%						
	Blues Bank	Chalk Line				
Species	Av. Ab.	Av. Ab.	Av. Te.	Ratio	%	Cum (%)
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 trachurus 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 sp.	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 vulgaris reynaudii	24.91	11.48	2.34	1.32	4.51	44.03
Zeus capensis	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

A breakdown of the catch within each area, describing the most important species is provided in Table 2.4. A checklist of all species observed in the South Coast demersal trawls is presented in Appendix A. Catches were dominated by teleosts (88-98% of the total catch mass), and in particular hake (53-69% of the total catch mass). Other species such as horse mackerel and panga also contributed substantially to the catch. Only in the inshore sole fishery did chondrichthyans contribute more than 10% to the overall catch. Cephalopods were of little importance to the total catch. The high species diversity recorded on the Agulhas Bank is reflected in the number of species observed in catches, with 56 and 63 species recorded in the inshore hake and sole-directed catches, respectively (Appendix A).

The retained and discarded portion of the catch is presented in Table 2.5. For all fishing areas, a high proportion (90%) of the catch was processed and landed. As would be expected, hake dominated the retained portion of the catch (49-69% of the total catch). Nevertheless, a variety of other species was also landed. Small hake dominated the discarded portion of the catch, particularly in the sole-directed fishery, where 20% of the hake caught was subsequently discarded.

Table 2.4: Species composition of observed demersal trawls between January 1996 and September 2000 off the south coast of South Africa.

	Blues Bank (*n*=139)		Chalk Line (*n*=41)		Hake-directed (*n*=140)		Sole-directed (*n*=294)	
	Mass (kg)	% of Total Catch	Mass (kg)	% of Total Catch	Mass (kg)	% of Total Catch	Mass (kg)	% of Total Catch
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 sp.	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 trachurus 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	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 straelini	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	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 vulgaris reynaudii	3 462.0	1.61	470.8	0.54	6 823.0	2.90	1 529.5	1.10
Other	0.0	0.00	0.0	0.00	53.0	0.02	5.0	0.00
Number of species identified	38		38		56		63	

Table 2.5: The retained and discarded portion of South Coast demersal catches from the four fishing areas identified.

	Blues Bank (*n*=139)		Chalk Line (*n*=41)		Hake-directed (*n*=140)		Sole-directed (*n*=294)	
	Mass (kg)	% of Total Catch	Mass (kg)	% of Total Catch	Mass (kg)	% of Total Catch	Mass (kg)	% of Total Catch
Total catch	**215 007.9**		**87 314.4**		**235 013.3**		**138 439.1**	
Retained catch	**206 168.6**	**95.89**	**81 515.0**	**93.36**	**222 265.3**	**94.58**	**111 830.5**	**80.78**
Merluccius sp.	118 922.2	55.31	59 989.5	68.71	120 460.6	51.26	67 860.1	49.02
Trachurus trachurus 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	0.48
Austroglossus pectoralis	1 016.0	0.47	-	-	906.0	0.39	23 515.0	16.99
Raja straelini	5 871.0	2.73	178.0	0.08	4 658.0	2.17	6 851.0	3.19
Other	15 121.4	7.03	6 714.5	7.81	24 977.7	10.44	10 127.4	9.08
Discarded catch	**8 839.2**	**4.11**	**5 799.4**	**6.64**	**12 748.0**	**5.42**	**26 608.6**	**19.22**
Teleostei	**4 477.3**	**2.08**	**5 037.7**	**5.77**	**10 344.0**	**4.40**	**21 276.2**	**15.37**
Merluccius sp.	1 951.4	0.91	945.0	1.08	4 361.9	1.86	17 062.0	12.32
Chelidonichthys queketti	1 078.5	0.50	802.6	0.92	3 805.1	1.62	404.6	0.29
Lepidopus caudatus	14.2	0.01	498.9	0.57	3.3	0.00	-	-
Helicolenus dactylopterus	85.9	0.04	710.6	0.81	138.0	0.06	13.2	0.01
Genypterus capensis	9.2	0.00	72.3	0.08	3.1	0.00	20.6	0.01
Lophius vomerinus	0.8	0.00	380.7	0.44	-	-	0.4	0.00
Trachurus trachurus capensis	348.0	0.16	100.5	0.12	360.0	0.15	248.3	0.18
Chelidonichthys capensis	104.3	0.05	315.5	0.36	354.5	0.15	1 034.0	0.75
Austroglossus pectoralis	5.2	0.00	0.5	0.00	-	-	516.7	0.37
Argyrosomus inodorus	-	-	-	-	0.4	0.00	399.2	0.29
Pterogymnus laniarius	15.7	0.01	9.5	0.01	52.9	0.02	163.4	0.12
Other	863.9	0.40	1 201.5	1.38	1 264.9	0.54	1 413.8	1.02
Chondrichthyes	**4 361.9**	**2.03**	**742.9**	**0.85**	**2 399.0**	**1.02**	**5 328.9**	**3.85**
Squalus megalops	3 037.8	1.41	295.3	0.34	1 255.3	0.53	366.7	0.26
Raja straelini	716.2	0.33	65.7	0.08	374.6	0.16	752.2	0.54
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	320.1	0.15	120.0	0.14	637.2	0.27	3 940.7	2.85
Cephalopoda	**-**	**-**	**18.8**	**0.02**	**5.0**	**0.00**	**3.5**	**0.00**

The percentage discards by mass and number is shown in Table 2.6. Teleosts dominated the discards, contributing 51-87% by mass. Numerically, teleosts dominated in all areas, except for the Blues Bank where almost 50% of the discarded catch was composed of chondrichthyans. In the Chalk Line and two inshore areas, teleosts contributed over 90% of the discards by number. Hake and lesser gurnard dominated the discards in all areas except the Blues Bank and jacopever was an important component (17%) on the Chalk Line.

The estimated mass of fish discarded annually is presented in Table 2.7. The results suggested that the South Coast fishery discarded approximately 8 000-9 000 tons of fish and 10 000-13 000 tons of offal per annum. Species dominating the discards annually included hake (approximately two thousand tons) and ribbonfish (500 - 1 500 tons).

The majority of the results derived by the two extrapolation methods were of the same order of magnitude. For the reasons previously discussed (see Material and Methods), it is believed that the landings-based estimates were more reliable than the effort-based estimates. Therefore, the annual mass and number of fish discarded by the inshore and offshore regions is provided for the landings-based estimate only (Appendix B). The offshore regions produced 86% by mass and 84% by number of the discards.

Table 2.6: Percentage of taxonomic groups and species comprising the discarded portion of the total catch of fish discarded by observed demersal trawlers operating off the south coast of South Africa.

	Blues Bank (*n*=139)		Chalk Line (*n*=41)		Hake-directed (*n*=140)		Sole-directed (*n*=294)	
	Mass (%)	Number (%)	Mass (%)	Number (%)	Mass (%)	Number (%)	Mass (%)	Number (%)
Teleostei	**50.65**	**70.30**	**86.87**	**93.46**	**81.14**	**91.06**	**79.96**	**91.98**
Merluccius sp.	22.08	35.82	16.29	22.60	34.22	38.08	64.12	69.69
Chelidonichthys queketti	12.20	15.33	13.84	20.48	29.85	33.83	1.52	1.88
Lepidopus caudatus	0.16	0.07	-	2.81	0.03	0.01	-	-
Helicolenus dactylopterus	0.97	0.84	12.25	17.38	1.08	0.90	0.05	0.05
Genypterus capensis	0.10	0.17	1.25	0.35	0.02	0.02	0.08	0.09
Lophius vomerinus	0.01	0.01	6.56	0.89	-	-	0.00	0.00
Trachurus trachurus capensis	3.94	4.61	1.73	1.39	2.82	3.82	0.93	2.23
Chelidonichthys capensis	1.18	1.40	5.44	3.61	2.78	2.16	3.89	3.13
Austroglossus pectoralis	0.06	0.21	0.01	0.01	-	-	1.94	6.54
Argyrosomus inodorus	-	-	-	-	0.00	0.00	1.50	2.67
Pterogymnus laniarius	0.18	0.28	0.16	0.14	0.41	0.43	0.61	0.83
Zeus capensis	5.22	7.23	14.90	17.73	1.94	2.11	0.88	1.26
Other	4.55	4.33	14.45	6.07	7.99	9.71	4.44	3.61
Chondrichthyes	**49.35**	**29.70**	**12.81**	**6.08**	**18.82**	**8.93**	**20.03**	**8.01**
Squalus megalops	34.37	22.28	5.09	2.18	9.85	5.49	1.38	0.80
Raja straelini	8.10	4.86	1.13	0.25	2.94	1.56	2.83	1.51
Raja wallacei	1.12	0.70	4.44	2.03	0.81	0.40	0.67	0.32
Raja pullopunctata	2.14	0.59	0.07	0.03	0.22	0.06	0.35	0.06
Raja alba	1.43	0.07	0.02	0.02	2.39	0.25	5.51	0.36
Callorhinchus capensis	-	-	-	-	0.71	0.34	0.25	0.13
Other	2.19	0.68	2.06	1.57	1.90	0.83	9.04	4.83
Cephalopoda	**0.00**	**0.00**	**0.32**	**0.46**	**0.04**	**0.01**	**0.01**	**0.01**

Table 2.7: Estimated mass (tons) of fish and cephalopods discarded annually by the trawl fleet operating off the south coast of South Africa, calculated using observer data collected during 1997 and extrapolated to the annual catch, using an effort-based and a landings-based approach.

	Effort-based	Landings-based
Teleostei	**6 412**	**5 722**
Merluccius sp.	1 869	2 003
Chelidonichthys queketti	640	814
Lepidopus caudatus	1 556	650
Helicolenus dactylopterus	384	649
Genypterus capensis	31	246
Lophius vomerinus	183	214
Trachurus trachurus capensis	55	179
Chelidonichthys capensis	227	165
Austroglossus pectoralis	37	19
Argyrosomus inodorus	24	10
Pterogymnus laniarius	4	6
Other	1 402	767
Chondrichthyes	**2 324**	**3 007**
Squalus megalops	511	503
Raja straelini	137	208
Raja wallacei	326	491
Raja pullopunctata	148	207
Other	1 202	1 598
Cephalopoda	**198**	**15**
Loligo vulgaris reynaudii	7	15
Other	191	0
Offal	**9 818**	**13 423**
Merluccius sp.	8 783	11 934
Genypterus capensis	280	791
Lophius vomerinus	755	698

Discussion

Smale *et al*. (1993) using data obtained from research trawls investigated the demersal community structure of the Agulhas Bank and determined that three distinct communities exist. These were an inshore community (<100 m depth) dominated by shallow-water hake, panga and a variety of elasmobranch species; a mid-shelf community (90-190 m depth), where horse mackerel became more abundant, and a shelf-edge/upper slope community (>200 m depth) dominated by deep-water hake and showing a decrease in spiny dogfish. In addition, the composition of catches differed between cruises in May and September.

Spatially, the three communities identified by Smale *et al.* (1993), can be loosely correlated with those identified in the current study on the South Coast, using commercial catches, in which the mesh size is larger and more selective than the survey trawl gear. The species assemblages of the Blues Bank compared well with the mid-shelf community identified by Smale *et al.* (1993) and the Chalk Line with the shelf-edge/upper slope community. However, the community structure data for the inshore region provided from survey data (Smale *et al.* 1993) compared poorly with the results from the commercial observer data. This may be because the observer data were further separated into sole and hake-directed areas, while the survey data were not. To determine whether the separation made in the observer data was valid, additional investigations were made using survey data for the years covered by the observer study. These were separated into trawls that took place in the same areas as the commercial hake and sole-directed trawls. Comparisons revealed that research trawls made east and west of 22°E differed significantly (*p*<0.1). This suggests that based upon species assemblages, the inshore area defined by Smale *et al.* (1993) should be split into areas east and west of 22°E. This is not surprising considering that the sole fishery is located west of 22°E, and hake-directed fishing takes place east of this. This factor should be considered when managing the fishery.

Catches by trawlers operating on the Agulhas Bank are extremely diverse with a total of 76 species being recorded during this study. Despite the fact that trawlers specifically target hake and sole, non-target species made a significant contribution to the total catch. The contribution of the target species to the total catch was 60% for the hake-directed fishery, but only 17% in the sole-directed fishery. However, unlike catches made by West Coast trawlers (Chapter 3), much of the non-target South Coast catch was of utilisable species such as panga, and companies made as much use of the bycatch as possible. On the West Coast, approximately 90% of the catch was processed, of which the hake component contributed 59-90% (Chapter 3). On the South Coast, however, although 90% of the catch was processed, hake represented only 50-69% of this figure.

In terms of revenue, hake contributed 39% to 85% of the annual landed value by South Coast vessels, with the remainder coming from the bycatch component (Erstadt 2002). In contrast, on the West Coast, hake contributed almost 93% of the value of the landed catch (Erstadt 2002). These differences must be borne in mind when formulating strategies to manage bycatch.

No matter how well the bycatch is utilised, good management practice requires that the take is sustainable. A measure of the impacts that fishing activities have on the resource is required to determine if those impacts are sustainable. Such impacts should be viewed in relation to the current stock status and life history characteristics of individual bycatch species (Kennelly 1997) taking into account the current catch of that species, even if it is a non-target species.

Two methods were employed to assess the mass and number of fish discarded annually by the trawl fleet on the South Coast and, in general, the estimates for a given species by the two methods were of the same order of magnitude. However, there were several exceptions, where the two estimates were notably different. This was especially true for shoaling species that tend either to be completely absent from a trawl or contribute a high proportion to the total catch. For example, the effort-based estimate for ribbonfish suggested that 1 500 tons were discarded annually. In contrast, the landings-based estimate suggested 650 tons were discarded. The fact that the shoaling species produced the largest differences in the discard estimates illustrates the problems associated with using these models to predict discards in target and non-target species.

The estimates of annual discards obtained during this study are generally lower than those obtained by Japp (1996), who estimated 8 500 tons of hake were discarded annually, compared with 2 000 tons in the current study. In addition to the possible sources of bias recognised by Japp (1996) (which were presented earlier), it is possible that changes in the abundance of fish, in fishing strategies or in discarding practices have occurred between the collection of Japp's (1996) data and the current (1996-2000) data.

The estimates of total discards indicated that several areas of concern exist regarding bycatch practices on the South Coast. The first is the high proportion (20%) of discarded hake by the sole-directed fishery which, given their size, were mostly juvenile. Natural mortality of juvenile fish would be expected to be higher than that of older fish, and it is possible that the fishing mortality inflicted on the juveniles may be partially compensated by a decrease in natural mortality. Hence, it is possible that the overall effect of juvenile fishing mortality may be reduced. Alternatively, if there is no compensation, the juvenile fishing mortality may represent a direct loss that will negatively impact population growth (*i.e.* future yield). These issues require clarification, and the ecological impact of fishing mortality on bycatch populations needs to be investigated.

Other species that may be negatively affected by demersal trawling are the juveniles of linefish-caught species such as kob *Argyrosomus inodorus*. The extrapolation for this species suggested that 10-24 tons of this species may be discarded by the fishery annually. Many of South Africa's linefish resources are currently overexploited or have collapsed (Griffiths 2000), but there is currently no information available on the impact of trawling on the linefishing sector. However, it would seem prudent to restrict trawl catches of these species. Several techniques can be used to reduce the unwanted catch of juvenile linefish and hake. Square mesh panels or exclusion devices have been used to reduce the catch of juvenile teleosts (e.g. Broadhurst and Kennelly 1995a, De Alteris *et al.* 1997, Gauvin and Rose 1998) and further investigations should be undertaken to determine whether these devices could be used in the South African demersal trawl fishery.

It should be noted that the data collected by this observer programme are preliminary and several limitations exist. These include the restricted coverage of the programme in terms of number of trips observed and variety of vessels covered, and the possibility that fishing practices were modified by the presence of an observer. Many of these limitations are relevant to the West and South coasts and are discussed in detail in Chapter 3. On the South Coast specifically, it was estimated that in 1997 (the year with most observer coverage) only 0.62% of trawling effort was observed. This is of concern as these data were extrapolated to give annual discard estimates. The second limitation was the limited coverage of the Port Elizabeth fleet. All the observations made from this port were on offshore vessels and the majority of fishing took place on the Chalk Line. Not only was this coverage limited (19 trawls), but the Port Elizabeth fleet also contains inshore vessels, which were not covered. During the extrapolation process it was assumed that these inshore vessels fish in a similar manner to those from Mossel Bay. but no information exists to verify this assumption.

Although the data were sufficient to highlight areas of concern such as the discarding of juvenile hake, they do not provide enough information on the scale of the problem. In addition, due to the small dataset, the variation in catch composition or discarding levels from year to year could not be investigated. This study highlights the need to distribute future observer coverage over all companies and areas, and for a stratified approach to the extrapolation of observer data. In order for hake discarding to be adequately included in hake stock assessment models, more robust estimates are required. Future work should monitor seasonal trends in catch composition or discarding patterns and the efficacy of management strategies based on discarding. Finally, it is imperative that the objectives of future research are reviewed, as more data become available. Initial goals for data collection should be set and when they are achieved, the results must be assessed and the research modified accordingly.

Despite these limitations, the data highlight the issues that must be considered when managing bycatch. These include biological issues (*e.g.* the impact of trawling on juvenile hake mortality), economic issues (*e.g.* the reliance of operators on bycatch revenue) and fishery-interaction issues (*e.g.* the incidental capture of linefish species by trawlers). In addition, by providing catch and discard information and by highlighting areas of concern, these data, in conjunction with data for the West Coast fishery (Chapter 3), should help guide discussions on the adoption of bycatch management strategies.

Chapter 3 - Bycatch and discarding in the South African demersal trawl fishery: the West Coast.

Introduction

The majority of South Africa's deep-sea trawl fleet is based at Cape Town and Saldanha Bay (Fig. 3.1). It landed between 133 000 and 142 000 tons of hake per annum from 1996 - 1998 (Stuttaford 2001). Large (30 - 45 m length) stern trawlers that pack their catch on ice dominate the fleet. These vessels remain at sea for five to seven days and target hake along the West Coast from approximately 31°S southwards, as far east as 21°E, and along the outer shelf of the Agulhas Bank on the South Coast.

Although West Coast trawlers catch a similar number of species as their South Coast counterparts, the fishery is dominated to a greater extent by hake. In addition to hake, West Coast vessels land several bycatch species including horse mackerel, kingklip and monkfish. Historically, the fishery has been hake-directed, and all other retained species have been landed as incidental bycatch. A fishery for West Coast sole *Austroglossus microlepis* operated for several years, but a population crash in the late 1970's precipitated the closure of the fishery. Recent years have seen increased landings of high value bycatch species such as monkfish (Stuttaford 2000).

Similar to the South Coast, studies have focused on the biology, distribution, trophic relationships and stock status of hake (*e.g.* Botha 1971, 1986, Payne 1987, Pillar and Barange 1993, Punt 1994, Payne and Punt 1995, Osborne *et* *al.* 1999). However, several studies have been undertaken to investigate the biology and distribution of bycatch species (*e.g.* Compagno *et al.* 1991, Freer and Griffiths 1993) or West Coast community structure (*e.g.* Roel 1987) and trophic relationships (Meyer and Smale 1991a, b). In recent years studies into the biology of common bycatch species such as the snub-nosed grenadier, the purple grenadier and the Cape dory have been initiated.

This chapter presents data on catch composition, levels of bycatch and estimates of annual discards for demersal trawlers operating off the west coast of South Africa.

Material and methods

Data collection

Between June 1995 and September 2000, data were collected by observers aboard commercial trawlers operating from Cape Town and Saldanha Bay off the west coast of South Africa (Fig. 3.1). Every month a pair of observers completed two trips, one with each of the two major trawling companies. In 2000, two trips on a vessel targeting monkfish (which uses a trawl with a lower headline height than that used for catching hake) were also completed. The observers had no influence on the trawling locations, and the accommodation of an observer was at the discretion of the fishing company.

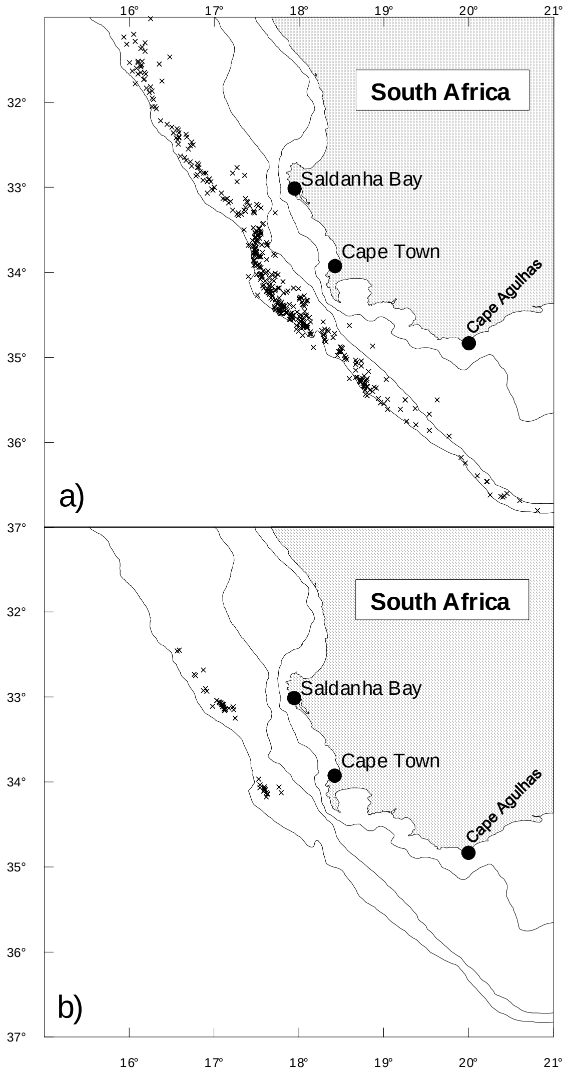


Fig. 3.1: Map showing locations of all a) hake-directed (n = 430) and b) monkfish-directed (n = 49) trawls observed between June 1995 and September 2000. Isobaths are 100 m, 200 m and 500 m.

Each trawl was sampled according to the methods described in Chapter 2. If it was not possible to sample all the discards, a sub-sample was taken. Unlike the small inshore vessels where the catch is processed on deck, the offshore vessels are substantially larger, and the catch is processed in a factory. The net is emptied into a holding pond below deck and a conveyor belt takes the catch from the holding pond to a sorting table in the factory. On the sorting table, fish for processing are removed, while the remainder is dumped on a discard belt and conveyed overboard or to the fishmeal plant. Hence, it is impossible to visually estimate the proportion of the discards sampled. Therefore, the proportion of the catch sub-sampled was estimated by recording the time spent removing discards from the belt, and the total time of belt operation. To reduce bias, the sub-sampled discards were removed from the discard belt at the beginning, middle and end of the sorting process. The proportion of the sub-sample measured was 10 – 100% of the total discards. As on the South Coast, only the fish and cephalopod component of the catch was recorded. The composition of the trawl was re-constructed using the methods outlined in Chapter 2.

Data analysis

Since the data were collected from a wide depth range (180 m - 642 m), it was postulated that the trawl catch composition, and thus discarding patterns, would differ among different depth ranges. In addition, it was hypothesised that differences, attributable to the differences in trawl net configuration, would exist between the hake and monkfish-directed catches. Therefore, the community structures of hake-directed catches from four depth ranges (0-300 m; 301-400 m; 401-500 m and >500 m) and the monkfish-directed catches, were investigated using PRIMER 5 (Version 5.1.2, Plymouth Marine Labs, 2000). The results of these investigations were used to guide the selection of fishing areas in the subsequent GAM analysis (Chapter 4). Each trawl was assigned to one of the five groups, and the unstandardised biomass data were root-root transformed. A similarity table was constructed using the Bray-Curtis measure of similarity, and the group average clustering method was used to derive the dendrogram (Field *et al.* 1982, Smale *et al.*, 1993). Analysis of similarity (the ANOSIM routine in PRIMER) was used to compare the catch compositions between each pair of groups (Chapter 2). The SIMPER routine was used to identify the indicator species, and calculate the level of similarity within and level of dissimilarity between depth ranges.

Next, differences in the catch composition and fate of the catch were investigated for each area. Initially, the total percentage contribution of each species to the catch (by mass) in each area was calculated. The percentage of the catch (by mass) that was either retained or discarded was then calculated. Finally, the percentage contribution (by mass and number) of each species to the discarded catch was calculated. Unfortunately, the composition by mass and number could be calculated only for the discarded catch, because information on the number of fish retained was available for hake only.

Both extrapolation methods described in Chapter 2 were employed to estimate the mass and number of fish discarded annually. Data for 1997, the year with the most data and the mid-point of the observer programme on the West Coast were used for the analysis.

Results

A total of 479 trawls was observed, 430 from hake-directed vessels and 49 from monkfish-directed vessels. A breakdown of trawls by fishing area and year is shown in Table 3.1 and the location of each trawl is shown in Fig. 3.1.

Table 3.1: Number of observed trawls (by year and fishing area) made by demersal trawlers operating off the west coast of South Africa between June 1995 and September 2000.

	1995	1996	1997	1998	1999	2000	Total
Hake-directed trawls							
0-300m	1		26	25			52
301-400m		17	80	38	7		142
401-500m	17	52	82	39	11		201
>500m	16	2	8	9			35
Monkfish-directed trawls					15	34	49
Total	**34**	**71**	**196**	**111**	**33**	**34**	**479**

Both the CLUSTER analysis and MDS broadly grouped trawls into the target species groups and depth ranges described in the methods. Due to the large number of data points, the associated dendrogram from the cluster analysis was difficult to interpret and is not presented. The results of the MDS analysis are presented in Fig. 3.2. In comparison with the South Coast MDS plot, there was less clustering of West Coast trawls. The majority of <300m depth trawls were found on the left side of the plot and the 401-500m depth trawls on the right side. The >500m trawls were clustered in the top right region of the plot.

Pairwise comparisons (ANOSIM) indicated a significant difference ($p<0.1$) between the <300m depth group and all other groups and between the >500m depth group and all other groups. None of the other pairwise comparisons were significant ($p>0.1$) (Table 3.2). Inter-annual variation in the composition of hake-directed trawls was not investigated. This was because during the five-year study period there were large differences in the proportion of trawls within each depth range. In addition, due to the small sample size (49 trawls), the variation in monkfish-directed trawls could not be investigated.

The results of the SIMPER analysis (identifying the indicator species and showing the levels of similarity within and the levels of dissimilarity between fishing areas) are presented in Table 3.3a-j. The 0-300m and monkfish-directed trawls were the most dissimilar (63.58% dissimilarity), and the 401-500m and >500m groups were the least dissimilar (41.01% dissimilarity). Those species contributing the most to the dissimilarity between 0-300m trawls and all other trawls were hake, snoek and horse mackerel, while those separating the >500m trawls from all others were hake, monkfish and jacopever.

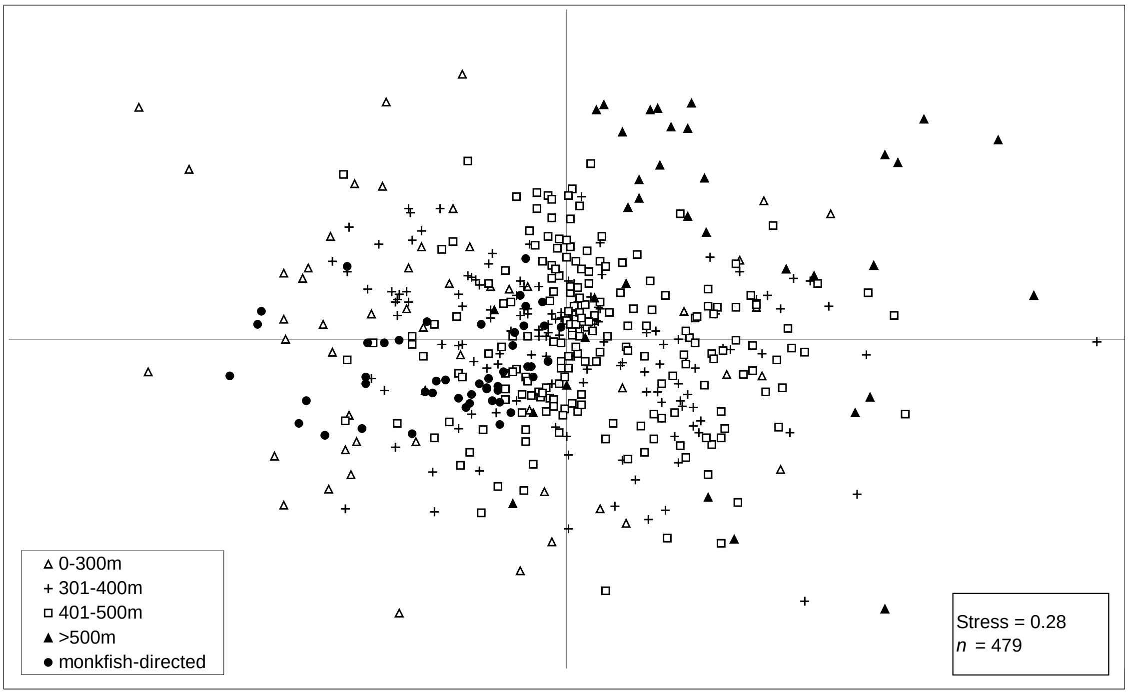


Fig. 3.2: MDS plot of the catch composition of all trawls observed between June 1995 and September 2000 on the west coast of South Africa, showing to which depth range or target species each station was assigned.

Table 3.2: results of ANOSIM analysis indicating the significant differences in catch composition between five fishing areas.
Monkfish-directed trawls were separated from hake-directed trawls and the latter were further separated into four depth ranges (0-300m, 301-400m, 401-500m and >500m). - indicates no significant difference ($p > 0.1$), ** indicates significant difference ($p < 0.1$).

	0-300m	301-400m	401-500m	>500m	monkfish
0-300m		**	**	**	**
301-400m	**		-	**	-
401-500m	**	-		**	-
>500m	**	**	**		**
monkfish	**	-	-	**	

Table 3.3: Between-fishery comparisons, indicator species and related data from the SIMPER analysis of observed catches made by demersal trawlers operating off the west coast of South Africa between June 1995 and September 2000.
s is the similarity within the group, Av. Ab. is the average abundance contribution of the species to the fishery, Av. Te. is the average term, which is the average Bray-Curtis contribution of each species to distinguish between groups. The ratio is the percentage contribution of the species to the separation between fisheries and the cumulative percentage is given for comparison between groups. Only those species that contributed to the 90% of total dissimilarity are listed. [1] For an explanation of these species groups, see Appendix C.

(a) 0-300m *v.* 301-400m. Average dissimilarity = 51.99%

Species	0-300m	301-400m				
	s = 47.17%	s = 56.51%				
	Av. Ab.	Av. Ab.	Av. Te.	Ratio	%	Cum (%)
Merluccius sp.	2 366.81	4 181.75	31.84	1.50	61.24	61.24
Thyrsites atun	413.39	107.35	5.06	0.58	9.74	70.98
Trachurus trachurus 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

(b) 0-300m *v.* 401-500m. Average dissimilarity = 52.89%

Species	0-300m	401-500m				
	s = 47.17%	s = 62.52%				
	Av. Ab.	Av. Ab.	Av. Te.	Ratio	%	Cum (%)
Merluccius sp.	2 366.81	4 875.45	35.58	1.63	67.27	67.27
Thyrsites atun	413.39	3.08	4.19	0.50	7.93	75.20
Trachurus trachurus 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

(c) 0-300m *v.* >500m. Average dissimilarity = 51.14%

Species	401-500m	>500m				
	s = 47.17%	s = 59.12%				
	Av. Ab.	Av. Ab.	Av. Te.	Ratio	%	Cum (%)
Merluccius sp.	2 366.81	3 423.86	30.39	1.47	59.43	59.43
Thyrsites atun	413.39	0.00	4.81	0.52	9.41	68.84
Trachurus trachurus 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

(d) 0-300m *v.* Monkfish-directed. Average dissimilarity = 63.58%

Species	0-400m	Monkfish				
	s = 47.17%	s = 58.02%				
	Av. Ab.	Av. Ab.	Av. Te.	Ratio	%	Cum (%)
Merluccius sp.	2 366.81	1 731.87	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 trachurus 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

(e) 301-400m *v.* 401-500m. Average dissimilarity = 41.16%

Species	301-400m	401-500m				
	s = 56.51%	s = 62.52%				
	Av. Ab.	Av. Ab.	Av. Te.	Ratio	%	Cum (%)
Merluccius sp.	4 181.75	4 875.45	31.94	1.49	77.60	77.60
Lophius vomerinus	146.33	127.21	1.73	0.92	4.20	81.80
Trachurus trachurus 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

(f) 301-400m *v.* >500m. Average dissimilarity = 42.87%

Species	301-400m	>500m				
	s = 56.51%	s = 59.12%				
	Av. Ab.	Av. Ab.	Av. Te.	Ratio	%	Cum (%)
Merluccius sp.	4 181.75	3 423.86	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 trachurus 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

(g) 301m-400m *v.* Monkfish-directed. Average dissimilarity = 60.04%

Species	301-400m	Monkfish				
	s = 56.51%	s = 58.02%				
	Av. Ab.	Av. Ab.	Av. Te.	Ratio	%	Cum (%)
Merluccius sp.	4 181.75	1 731.87	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

(h) 401-500m *v.* >500m. Average dissimilarity = 41.02%

Species	301-400m	>500m				
	s = 56.51%	s = 59.12%				
	Av. Ab.	Av. Ab.	Av. Te.	Ratio	%	Cum (%)
Merluccius sp.	3 423.86	4 875.45	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

(i) 401-500m *v.* Monkfish-directed. Average dissimilarity = 60.27%

Species	401-500m	Monkfish				
	s = 56.51%	s = 58.02%				
	Av. Ab.	Av. Ab.	Av. Te.	Ratio	%	Cum (%)
Merluccius sp.	4 875.45	1 731.87	43.43	1.76	72.06	72.06
Lophius vomerinus	127.21	938.12	12.15	1.44	20.15	92.22

(j) >500m *v.* Monkfish-directed. Average dissimilarity - 60.49%

Species	>500m	Monkfish				
	s = 59.12%	s = 58.02%				
	Av. Ab.	Av. Ab.	Av. Te.	Ratio	%	Cum (%)
Merluccius sp.	3 423.86	1 731.87	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

Catch compositions, including the most important species (in all areas) are presented in Table 3.4. A checklist of all species identified by the observers, and the associated CPUE estimates are presented in Appendix C.

The dominance of teleosts, and hake in particular, in the hake-directed trawls is clearly evident, as is the relative unimportance of the other bycatch species. In the 0-300 m depth range, non-hake species accounted for approximately 35% of the total catch, whereas in the deeper trawls, this value was reduced to approximately 7-9%. Important bycatch species in the shallow region included horse mackerel, snoek and ribbonfish. In the deeper waters, monkfish and jacopever became the most important bycatch species. Despite the dominance of hake in these trawls, many other species were observed.

The catch composition of monkfish-directed trawls clearly demonstrated the efficacy of the trawl net configuration to target this species, which constituted almost 38% by mass of the total catch. However, hake and jacopever comprised 62% and 1.5% of the catch by mass, respectively, indicating that, although the gear could significantly increase the proportion of monkfish in the catch, it could not reduce hake bycatch. The reduction in species diversity in monkfish-directed trawls was clearly evident and only 19 species (mostly benthic) were recorded compared to 75 species in hake-directed trawls. Chondrichthyans and cephalopods formed a minor component of the total catch mass in all depth ranges.

Table 3.4: Composition of hake-directed (from four depth ranges) and monkfish-directed demersal trawls observed between June 1995 and September 2000 off the west coast of South Africa, showing the most species in the trawl catch.

	Hake-directed 0-300m (*n* = 52)		Hake-directed 301-400m (*n* = 142)		Hake-directed 401-500m (*n* = 201)		Hake-directed >500m (*n* = 35)		Monkfish-directed (*n* = 49)	
	Mass (kg)	% of Total Catch	Mass (kg)	% of Total Catch	Mass (kg)	% of Total Catch	Mass (kg)	% of Total Catch	Mass (kg)	% of Total Catch
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 sp.	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 trachurus 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	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	4 264	2.26	1 781	0.26	2 522	0.24	2695	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	432	0.23	2 222	0.32	3 891	0.37	250	0.19	1 255	0.91
Other	261	0.14	503	0.07	544	0.05	6	0.00	980	0.71
Number of species identified	41		42		62		56		19	

The species composition and mass of the retained and discarded portions of the catch are presented in Table 3.5. In all fishing areas, a high proportion of the catch (~90%) was processed and landed. As anticipated, hake dominated the retained portion with 59% (<300 m) to 90% (>300 m) of the total catch being retained hake. However, a variety of other species was landed. In the 0-300 m depth range, monkfish, snoek and ribbonfish contributed significantly to the landed portion (18.2% of the total catch), but as depth increased, the landed catch became dominated by hake. This was accentuated with increasing depth, where an increase in unutilisable species, such as the macrourids, was observed. In all areas, the majority of discards was hake.

A breakdown of the discards (in terms of mass and number) is presented in Table 3.6. In all areas, teleosts dominated the discards, contributing 72 - 93% by mass and 92 - 97% by number of the total discards.

The estimated mass and number of common demersal species discarded annually by the trawl fleet, using the two extrapolation methods, is presented in Table 3.7. The estimated mass and number of all fish species discarded annually, calculated using the landings-based approach, is presented in Appendix D. The results suggested that the West Coast vessels discarded 17 000 - 25 000 tons of fish, and 30 000 - 46 000 tons of offal per annum. The results obtained by the two methods were different - particularly with respect to hake, chub mackerel *Scomber japonicus*, ribbonfish and the snub-nosed grenadier.

Table 3.5: The retained and discarded portion of west coast demersal catches from hake and monkfish-directed fishing areas.

	0-300m (*n* = 52)		301-400m (*n* = 142)		401-500m (*n* = 201)		>500m (*n* = 35)		Monk-directed (*n* = 49)	
	Mass (kg)	% of Total Catch	Mass (kg)	% of Total Catch	Mass (kg)	% of Total Catch	Mass (kg)	% of Total Catch	Mass (kg)	% of Total Catch
Total catch	**188 497**		**690 819**		**1 060 740**		**132 491**		**137 278**	
Retained catch	**161 284**	**85.56**	**615 799**	**89.14**	**970 878**	**91.53**	**120 599**	**91.02**	**131 637**	**95.89**
Merluccius sp.	111 050	58.91	545 123	78.91	921 131	86.84	**118 315**	89.30	81 218	59.16
Genypterus capensis	337	0.18	4 668	0.68	6 042	0.57	558	0.42	1 429	1.04
Lophius vomerinus	7 286	3.87	20 224	2.93	22 965	2.17	974	0.73	45 030	32.80
Helicolenus dactylopterus	959	0.51	5 189	0.75	7 232	0.68	186	0.14	1 680	1.22
Thyrsites atun	21 494	11.40	15 216	2.20	493	0.05	-	-	-	-
Other	20 158	10.69	25 380	4.00	13 014	1.20	567	0.40	2 280	1.7
Discarded catch	**27 213**	**14.44**	**75 019**	**10.86**	**89 862**	**8.47**	**11 892**	**8.98**	**5 641**	**4.11**
Teleostei	**21 614**	**11.47**	**70 004**	**10.13**	**81 399**	**7.67**	**8 629**	**6.51**	**5 175**	**3.77**
Merluccius sp.	12 024	6.38	48 686	7.05	58 834	5.55	1 521	1.15	3 257	2.37
Lophius vomerinus	216	0.11	556	0.08	2 605	0.25	977	0.74	-	-
Thyrsites atun	3	0.00	27	0.00	125	0.01	-	-	-	-
Trachurus trachurus capensis	584	0.31	451	0.07	244	0.02	-	-	56	0.04
Helicolenus dactylopterus	819	0.43	3 952	0.57	3 835	0.36	1 192	0.90	289	0.21
Lepidopus caudatus	3 620	1.92	5 283	0.76	1 529	0.14	307	0.23	-	0.00
Caelorinchus symorhynchus	1 938	1.03	4 800	0.69	6 061	0.57	1 078	0.81	1 024	0.75
Zeus capensis	387	0.21	1 847	0.27	1 097	0.10	44	0.03	15	0.01
Genypterus capensis	6	0.00	7	0.00	131	0.01	10	0.01	19	0.01
Malacocephalus laevis	268	0.14	3 383	0.49	4 835	0.46	899	0.68	379	0.28
Scomber japonicus	1 522	.081	522	0.08	90	0.01	-	-	1	-
Other	226	0.12	490	0.00	2 013	0.20	2 601	2.00	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	809	0.08	62	0.05	69	0.05
Scyliorhinus capensis	167	0.09	471	0.07	332	0.03	30	0.02	21	0.01
Squalus sp.	819	0.43	554	0.00	313	0.03	189	0.14	-	-
Other	3 701	1.96	1 409	0.00	3 075	0.30	2 727	2.10	241	0.20
Cephalopoda	**442**	**0.23**	**2 089**	**0.30**	**3 935**	**0.37**	**256**	**0.19**	**135**	**0.10**

Table 3.6: Percentage contribution of taxonomic groups and species comprising the discarded portion of total catch by demersal trawlers operating off the west coast of South Africa.

	0-300m (*n* = 52)		301-400m (*n* = 142)		401-500m (*n* = 201)		>500m (*n* = 35)		Monkfish-directed (*n* = 49)	
	Mass	Number	Mass	Number	Mass	Number	Mass	Number	Mass	Number
Teleostei	**79.42**	**93.91**	**93.32**	**94.97**	**90.58**	**92.00**	**72.56**	**90.55**	**91.75**	**97.58**
Merluccius sp.	44.18	59.37	64.90	70.32	65.47	71.78	12.79	30.87	57.74	66.58
Lophius vomerinus	0.80	0.47	0.74	0.16	2.90	0.34	8.22	0.70	-	-
Thyrsites atun	0.01	0.00	0.04	0.00	0.14	0.01	-	-	-	-
Trachurus trachurus capensis	2.15	1.65	0.60	0.29	0.27	0.15	0.00	0.00	1.00	0.33
Helicolenus dactylopterus	3.01	4.61	5.27	4.55	4.27	3.33	10.02	4.70	5.12	2.25
Lepidopus caudatus	13.30	6.31	7.04	2.70	1.70	0.41	2.58	0.40	-	-
Caelorinchus symorhynchus	7.12	16.35	6.40	13.30	6.74	12.66	9.07	15.51	18.14	26.05
Zeus capensis	1.42	0.83	2.46	0.94	1.22	0.38	0.37	0.09	0.27	0.07
Genypterus capensis	0.02	0.01	0.01	0.00	0.15	0.03	0.08	0.01	0.33	0.05
Malacocephalus laevis	0.99	0.90	4.51	2.01	5.38	2.10	7.56	3.50	6.71	1.74
Scomber japonicus	5.59	1.76	0.70	0.09	0.10	0.02	-	-	0.02	0.02
Sharp-nose *Caelorinchus* sp.	0.17	0.91	0.20	0.44	0.23	0.18	11.34	29.60	0.32	0.26
Other	0.66	0.74	0.45	0.14	2.00	0.62	10.50	5.17	2.10	0.23
Chondrichthyes	**18.95**	**3.48**	**3.90**	0.51	**5.04**	**0.82**	**25.29**	**5.47**	**5.86**	**1.32**
Holohalaelurus regani	1.73	0.77	0.66	0.20	0.90	0.32	0.52	0.10	1.22	0.32
Scyliorhinus capensis	0.61	0.17	0.63	0.11	0.37	0.07	0.25	0.05	0.36	0.09
Squalus megalops	0.93	0.56	0.24	0.02	0.20	0.04	1.59	0.07	-	-
Squalus acanthias	0.01	0.00	0.00	0.00	0.15	0.01	-	-	-	-
Squalus mitsukurii	2.07	0.53	0.50	0.04	0.66	0.05	1.40	0.08	3.40	0.86
Raja pullopunctata	0.81	0.10	0.63	0.03	0.00	0.00	0.08	0.01	-	-
Other	12.79	1.35	1.25	**0.12**	2.80	0.33	21.50	5.16	0.90	0.05
Cephalopoda	**1.62**	**2.61**	**2.78**	**4.52**	**4.38**	**7.18**	**2.15**	**3.98**	**2.40**	**1.10**

Table 3.7: Estimated mass (tons) of fish and cephalopods discarded annually by the trawl fleet operating off the west coast of South Africa, calculated using data collected during 1997 and extrapolated upwards using an effort-based and a landings-based approach.

	Effort-based	Landings-based
	Mass (tons)	Mass (tons)
Teleostei	**16 702**	**24 751**
Merluccius sp.	11 920	6 915
Lophius vomerinus	145	254
Thyrsites atun	27	24
Trachurus trachurus capensis	152	159
Helicolenus dactylopterus	678	426
Lepidopus caudatus	553	14 198
Caelorinchus symorhynchus	1 458	846
Zeus capensis	271	335
Genypterus capensis	3	4
Malacocephalus laevis	999	579
Scomber japonicus	117	754
Other	380	258
Chondrichthyes	**1 347**	**759**
Holohalaelurus regani	177	103
Scyliorhinus capensis	48	28
Squalus megalops	79	46
Squalus acanthias	24	14
Other	1 019	568
Cephalopoda	**666**	**4 109**
Red squid	654	4 106
Other	12	3
Offal	**45 658**	**29 859**
Merluccius sp.	42 562	24 690
Genypterus capensis	397	454
Lophius vomerinus	2 700	4 715

Discussion

Roel (1987) applied research survey data to investigate the assemblages of demersal communities on the west coast of South Africa. It was established that two assemblages existed, separated by the 385m isobath. Those species that characterised shallow water included the goby *Sufflogobius bibarbatus*, West Coast sole, and the mantid *Pterygosquilla armata capensis*. The deeper water species included macrourids such as *Malacocephalus laevis*, and squalids such as *Centrophorus* sp. Species with wide distribution ranges such as monkfish and deepwater hake were more common below the 385m isobath.

Similar changes in species composition with increasing depth have been observed in communities along other areas of the African coast. Smale *et al.* (1993) identified three distinct assemblages from research catches on the south coast of South Africa, *vis* : an inshore group, a mid-shelf group and a shelf-edge/slope group. Similar groupings have been observed in commercial catches in the same area (Chapter 2). Mas-Riera *et al.* (1990) described four distinct communities off the Namibian coast (separated by latitude and depth), and MacPherson and Gordoa (1992) demonstrated that the boundaries of these areas might be affected by upwelling. Bianchi (1992) investigated the demersal assemblages off the Congo and Gabon. Although 9 distinct communities were identified, the first and second divisions of trawl stations were based upon depth.

This study confirms the presence of at least two distinct fish species assemblages on the West Coast - a shelf assemblage and a shelf-edge assemblage. This distinction was recognised despite the fact that many of the indicator species identified by Roel (1987) were not recorded in this study, possibly as a result of the larger mesh size used by commercial trawlers. However, in contrast to Roel (1987), where the two groups were separated at approximately 385 m, analysis of the commercial data suggested that the assemblages were separated at approximately 300m depth. The current analysis indicated that there is a third distinct assemblage at a depth of 500m. Roel (1987) undertook few trawls deeper than 385m ($n \approx 30$), and thus it is impossible to determine whether this group is a reflection of the selectivity of commercial trawls, or is indeed a distinct group. However, other studies have reported the existence of upper and lower slope communities in deep trawls (Day and Pearcy 1968, Haedrich *et al.* 1975, Snelgrove and Haedrich 1985), and, therefore, it is likely that the >500m depth group identified here represents a lower slope assemblage.

The results of the SIMPER analysis indicated that in addition to hake, a few key species are responsible for the differences observed in the species assemblages. As previously noted, hake, snoek, ribbonfish and horse mackerel were responsible for the majority of the dissimilarity between the shallow water (0-300m) group and all other groups. Hake, monkfish and jacopever contributed the majority of the dissimilarity between the deep (>500m) group and all other groups. For all pairwise comparisons, 90% of dissimilarity was contributed by 9 species or less. In contrast, trawls on the

Agulhas Bank were more diverse, and at least 19 species contributed to 75% of the dissimilarity between fishing areas (Chapter 2).

The catch composition information suggested that monkfish-directed trawls were notably different from hake-directed trawls. This was particularly true with regard to the proportion of hake and monkfish in the catch and the number of species identified in the trawls. These differences could be either due to intrinsic differences between the respective community structures in the hake and monkfish trawling grounds, or to gear selectivity. However, SIMPER analysis revealed that the species assemblage of the monkfish-directed trawls was not significantly different from the hake-directed trawls in the 301-400 m or 401-500 m depth groups (the depth at which monkfish-directed trawling takes place). This would suggest that gear selectivity rather than community composition accounts for these differences.

Catches by West Coast trawlers appear to be as diverse as their South Coast counterparts with 79 species being observed, despite the smaller proportion of non-target species within the catch. As with South Coast catches, a high proportion of the hake and bycatch (approximately 90%) in West Coast trawls was processed and landed. As such, the proportion of fish that was utilised is notably higher than other world demersal trawl fisheries. For example, Machias *et al.* (2001) reported that in the northeastern Mediterranean, the demersal trawl fishery lands approximately 56% of the catch. Borges *et al.* (2001) showed that in 36 fish-directed trawls in the Algarve (southern Portugal) fishery, only an estimated 21% of the catch was retained. It should be noted that these vessels use a smaller mesh size (55-65mm stretched) to that used by West Coast trawlers (110mm stretched), which is likely to result in the capture of smaller fish, and promote higher discarding rates.

In comparison with South Coast vessels, the commercial value of bycatch in West Coast trawls was notably less, due to the higher proportion of bycatch in the South Coast catch. It is estimated that the value of the bycatch in the West Coast trawls was approximately 7% of the total landed value of the catch. This compares to 36%, 15% and 30% of the landed value of hake-directed catches in the inshore hake-directed fishery, the Chalk Line and Blues Bank, respectively (Erstadt 2002).

The methods that were used to estimate annual discards and the underlying assumptions have been discussed in Chapter 2. Concomitant with the South Coast study, the estimates obtained by applying the two extrapolation methods were different. For example, the effort-based estimate for ribbonfish yielded an estimated annual discard rate of 553 tons, whereas the landings-based estimate was 14 198 tons. Similarly, the landings-based estimate for monkfish was also larger than the effort-based result. It should be noted that West Coast trawlers target both these species and, therefore, the increased fishing effort towards these species will not be taken into account by the effort-based approach. In addition, ribbonfish are a shoaling species, which tends to either be absent from trawls or present in large quantities. This may lead to skewing of the effort-based estimate and highlights the problem of using these approaches to estimate annual discards.

As with the estimates of South Coast discards, estimates for the West Coast were generally lower than those produced by Japp (1996), who estimated that on the West Coast, 17 000 tons of hake, 1 600 tons of horse mackerel, 900 tons of monkfish and 940 tons of kingklip were discarded annually. These estimates are much higher than those calculated from this study (6 000 tons of hake, 159 tons of horse mackerel, 254 tons of monkfish and 4 tons of kingklip). As suggested in Chapter 2, it is likely that since the data collected in this study were obtained directly from the commercial trawlers these estimates provide a more accurate reflection of bycatch.

Similarly to the South Coast, the discard data suggested that several areas of concern exist with regard to bycatch in West Coast trawls. The first was the increased targeting of monkfish. Life history characteristics and a preliminary stock assessment (Chapter 5) suggested that this species is vulnerable to overfishing. Further research is required to assess this species and other high value species, (such as kingklip), that are being increasingly targeted. A further issue of concern may be the mass of offal discarded annually. Estimates suggested that almost 30 000 tons of offal were discarded by West Coast trawlers annually. This component of the trawl is unavoidable and although some could be utilised, for example using the heads for rock lobster bait, much is unusable. It is likely that we will have to accept that even if measures are introduced to retain the utilisable portion, the remainder is a necessary part of fishing operations.

The use of observers aboard commercial vessels is a reliable method of collecting data on the composition of trawl catches (Liggins *et al.* 1996, Allen *et al.* 2001). This is especially true when skippers fail to adequately record bycatch. In addition, extrapolating data from research trawls may over- or under- estimate the importance of certain components of the catch. Research surveys are generally designed to answer specific questions regarding target species, and information on bycatch species is often viewed as less important. Further, comparisons between research and commercial data do not take gear selectivity into account and are, therefore, inappropriate. Consequently, the data obtained from research trawling may yield positively biased estimates of bycatch.

However, when using observer data to answer questions on bycatch and discards, limitations in the observer data must be recognised (Liggins *et al.* 1997). In this study, funding constraints severely limited the number of observer expeditions that could be undertaken. By applying the observed effort data and the total fleet effort for 1997 (the year with highest observer effort), it was calculated that the programme only managed to collect data from 0.49% of trawls on the West Coast, (compared with 0.62% of trawls on the South Coast). As a result, annual changes in catch composition could not be investigated. In addition, sampling of monkfish-directed trawls, was extremely limited, and only two expeditions covering 49 trawls were completed. This is insufficient if these results are to be extrapolated to all monkfish-directed operations. This problem is compounded by the fact that during the period of the observer programme, skippers were not required to specify the fact that they were targeting monkfish (a situation that has since been rectified). Therefore, the extent of targeted monkfish operations was difficult to determine. In order to conduct an effective stock assessment on monkfish and to implement a catch limit, information on the extent of incidental bycatch of monkfish from hake-directed operations is required.

Another consideration was that not all the trawling companies in the fishery were observed. Therefore, it had to be assumed that all the companies were using the same fishing practices and strategies. This assumption may have been erroneous, as the two companies that were sampled were the two largest operators, and as such maintained large factories and distribution facilities. Thus, their fishing strategies are likely to differ from those of smaller companies with limited facilities.

Several concerns were noted with regard to the sampling protocols used, the first being the method used to estimate the proportion of the discards sub-sampled. It was particularly difficult to estimate the proportion of discards sampled from the moving discard belt. It is unlikely that either the species or size distribution of fish was uniform along the discard belt. For example, large fish may have been transported from the holding pond first, leaving small fish until the end. Although the observers were instructed to sample discards from the belt at the beginning, middle and end of the sorting time, it is possible that bias occurred. The second area of samplng cncern was the proportion of the discards that was sub-sampled. On the west coast approximately 10 - 100% of the discards were sampled and on the south coast approximately 50 -

100% of the discards were sampled in each trawl. In order to provide better estimates of the discards, this figure should ideally be closer to 100%. Finally, due to time constrants, no data could be collected on the length distribution of the retained catch or the quantity of benthos discarded. Data on the benthos are required to provide more comlete estmates of catch composition.

Due to erroneous perceptions of the observer programme, it is possible that the companies involved may have assigned observers to vessels with skippers known for catching particularly low levels of bycatch, or could have ordered skippers to fish in areas where bycatch is known to be low. However, a variety of vessels (18) and skippers (21) was used, and the distribution of observed trawls was similar to the distribution of annual trawling effort. It is possible that sorting practices changed whilst the observers were aboard - especially in the case of small hake. While this is extremely difficult to quantify, it is reasonable to suggest that as the study was independent of MCM, and was directed at research rather than compliance, the usual practices were not modified.

Finally, observer bias cannot be discounted. In such cases the observers may have consistently over- or underestimated measurements. The importance of assessing observer biases was highlighted by Liggins *et al.* (1997), who found differences between the measurements of retained fish made by the observers while at sea, with measurements of the same fish at the discharge point. Unfortunately, due to the limited nature of this programme, it was impossible to conduct a similar study and it was assumed that such bias was minimal.

This work has provided the first comprehensive estimates of the catch composition of demersal trawlers operating on the West Coast. These data can be used to identify issues that are of concern within the fishery and can be used to guide the formulation of a bycatch management plan. In addition, valuable lessons have been learnt regarding the structure of future observer programmes.

To address the problems outlined above, the following research priorities have been identified. The bycatch issues of small companies need to be assessed as a matter of urgency. In order to do this the number of observers must be significantly greater than that available for this programme. These observers must collect accurate estimates of juvenile hake and monkfish discards. In addition, life history information should be collected for additional bycatch species.

The analyses described in this and the previous Chapter provide a basic description of South African trawl catch composition and the levels of discarding. The following Chapter will investigate the factors that influence these.

Chapter 4 -
The spatial distribution of bycatch and discards.

Introduction

The two previous chapters described the composition of catches made by trawlers operating on the south and west coasts of South Africa. However, these results do not offer any information on spatial or temporal patterns in the catch. Due to physical, environmental and biological factors, it is highly unlikely that the catch composition would be the same between the Benguela and Agulhas ecosystems, or between widely separated areas such as Hondeklip Bay and Cape Point. There are also likely to be seasonal changes. In addition, other factors are likely to affect the degree to which bycatch and discarding of a particular species occurs. These include the size of the catch (a large catch may mean less time to sort the bycatch component), and the time of year (discarding may be affected by the amount of allocation remaining).

Understanding the temporal and spatial factors affecting bycatch and discarding is, therefore, of utmost importance if resources are to be managed effectively and the strategies developed are to be appropriate for a given fishery. This is of particular importance in a large fishery with several distinct components, such as the South African demersal trawl fishery. To increase our understanding of bycatch dynamics, this chapter investigates the factors affecting the spatial and temporal distribution of bycatch, using Generalised Additive Models (GAMs) and a simple Geographic Information System (GIS).

A GIS can be simply described as a series of steps, which begins with observation and data collection and ends with a system upon which decisions can be based, in a spatially referenced manner (Millar 2000). GIS have been used in marine situations (Castillo *et al.* 1996, Stoner *et al.* 2001) to investigate the relationships between fish and their environment. The first application of a GIS to demersal fisheries data in South Africa was by Booth (1997b) who investigated the distribution and abundance of panga on the South Coast. Fairweather (1998) used GIS to develop a Fishery Information System for the management of the fisheries on the northern Cape coast and Millar (2000) used GIS to investigate the influence of environmental variables on the distribution of hake. Fairweather (2001) used GIS to analyse longline and trawl catches for shallow-water hake on the West Coast. In addition, much of the data collected during demersal research surveys and some commercial catch information have been input into a GIS, as part of the joint South African/ French programme "Interactions and Spatial Dynamics of Renewable Resources in Upwelling Ecosystems" (IDYLE).

GAMs are a nonparametric generalisation of multiple linear regressions, which relate a dependent or response variable to covariates using a non-linear function (Swartzman *et al.* 1992) and can be considered as non-parametric generalisations of General Linear Models (GLMs)(Booth 1997b). However, in contrast to GLMs, which require that the relationship between the response and each predictor is specified, GAMs use a smoothing function, which allows for the incorporation of local trends while observing the trends over the entire sample space (Booth 1997b). The additive model consists of the sum of the smooth functions of each covariate in the model. GAMs have been used to investigate the effect of environmental variables on several marine populations, such as groundfish (Swartzman *et al.* 1992), anchovy (Cury *et al.* 1995), pollock (Swartzman *et al.* 1994, 1995) and herring (Maravelias 1997, Maravelias *et al.* 2000). In addition, this technique has been used to identify the spawning patterns of Irish Sea demersal fish (Fox *et al.* 2000); to investigate habitat use and abundance of *Lophius budegassa* in the Mediterranean Sea (Maravelias and Papaconstantinou 2003); to investigate mackerel and horse mackerel egg production (Borchers *et al.* 1997); to determine the factors affecting recruitment (Daskalov 1999, Cardinale and Arrhenius 2000) and to investigate the diet of North Sea cod (Alderstein and Welleman 2000). In South Africa, Millar (2000) used GAMs to investigate the effect of environmental variables on the distribution and abundance of hake and Schoeman and Richardson (2002) used GAMs to investigate factors affecting the recruitment of intertidal clams.

In this study, a GIS will be used to investigate spatial and temporal influences on the density ($kgkm^{-2}hr^{-1}$) of hake discarded from the catch, the density of bycatch in the catch and the density of bycatch subsequently retained. GAMs will be used to investigate trends in hake discarding and bycatch utilisation in the West and South Coast hake fisheries and South Coast sole fishery.

Material and methods

Catch composition data were sorted by fishery sector based on the results of the PRIMER analyses described in Chapters 2 and 3. Because of the high degree of overlap observed in the trawls, the three sectors chosen were West Coast hake-directed trawls (all depth ranges combined), South Coast hake-directed trawls (inshore hake, Blues Bank and Chalk Line data combined) and sole-directed trawls. The monkfish-directed trawls were excluded from the West Coast data set for these analyses due to the different trawl configuration used.

For each trawl, catch data were standardised to account for different trawl configurations, by converting the catch mass to density using the following equation:

$$D = \frac{C}{H \times M \times S} \quad (1)$$

where D is the estimated density per species ($kgkm^{-2}hr^{-1}$), C is the catch (kg), H is the trawl duration (hrs), M is the trawl mouth width (km) and S is the trawling speed ($kmhr^{-1}$). Specific information on the trawl mouth width and trawling speed was obtained from the companies involved.

Next, the standardised trawl catch was summarised into the following components: the total standardised catch; the total, retained and discarded hake catch; the total, retained and discarded bycatch; and in the sole fishery the total, retained and discarded sole catch. In addition, the bycatch component of sole-directed trawls was separated into a hake bycatch and a non-hake bycatch component.

Finally, the percentage of the catch that was hake (P_H); the percentage of the hake catch retained and discarded (P_H^D and P_H^R respectively); the percentage of the catch that was bycatch (P_B); the percentage of the bycatch retained and discarded (P_B^R and P_B^D respectively); the percentage of the catch that was sole (for the sole fishery only) (P_S); and the percentage of the sole catch retained and discarded (for the sole fishery only)(P_S^R and P_S^D respectively); were calculated as:

$$P_H = \frac{H_T}{C_T} \quad (2) \qquad P_H^R = \frac{H_R}{H_T} \quad (3) \qquad P_H^D = \frac{H_D}{H_T} \quad (4)$$

$$P_B = \frac{B_T}{C_T} \quad (5) \qquad P_B^R = \frac{B_R}{B_T} \quad (6) \qquad P_B^D = \frac{B_D}{B_T} \quad (7)$$

$$P_S = \frac{S_T}{C_T} \quad (8) \qquad P_S^R = \frac{S_R}{S_T} \quad (9) \qquad P_S^D = \frac{S_D}{S_T} \quad (10)$$

where: H_T, H_R and H_D is total, retained and discarded hake catch respectively; C_T is total catch; and B_T, B_R and B_D is total, retained and discarded bycatch respectively; and S_T, S_R and S_D is total, retained and discarded sole catch respectively.

The spatial distribution of bycatch and discards

All information was plotted using ArcView 3.2. A base map was constructed containing the South African coast and the 50m, 100m, 200m and 500m isobaths. To show the precise position of trawls and coast, the map was projected using the Transverse Mercator projection, which can be used for mapping on the South African coastline (Millar 2000). Distribution patterns of components of the bycatch and discards were investigated by overlaying data onto the basic coastline/isobath map.

Trawls were grouped by trimester: January - April, May - August and September - December. For each trimester, the density ($kgkm^{-2}hr^{-1}$) of hake discarded; the density of total bycatch in the catch; and the density of bycatch retained was plotted. With the exception of South Coast sole-directed trawls, the starting latitude and longitude were converted to decimal degrees and used to plot the trawl position. In the case of sole-directed trawls, skippers record the 20x20 minute grid block (defined by MCM and used for reporting purposes) in which they fish. Thus the centre of the grid block was used to plot the trawl position.

The spatial distribution of hake discards

Information on the length frequency distribution of discarded hake was extracted from the observer database. The number of hake discards for each trawl were summed into three size classes: <18cm *TL*, 18-25cm *TL* and >25cm *TL*. These size classes were chosen because they represent the size categories used in one of the two commercial hake measuring systems in use in South Africa. The smallest landed size category in the "six small system" is 18 - 25cm *TL*. Therefore, fish below 18cm *TL* are not recorded as being landed and fish larger than 25cm *TL* are placed in the second smallest category or above (Stuttaford 2001). The percentage contribution of each size class to the total number of hake discarded in that trawl was calculated. Data were analysed and plotted on the base map by trimester.

Identifying factors influencing bycatch and discards using GAM

The theory behind GAMs is discussed in Hastie and Tibshirani (1990). A discussion of the application of GAMs in fisheries can be found in Swartzman *et al.* (1992). Briefly, the theory dictates that the dependent variable is transformed by a link function. A known function of the expected value (the link function) is modelled as the sum of smooth functions of the covariates (Swartzman *et al.* 1992). The basic form of a GAM is:

$$g\left(E\left(Y/x\right)\right)=g\left(\mu\right)=\alpha\ +\sum_{i=1} f_i\left(x_i\right) \qquad (11)$$

where g is the link function, α is a constant intercept term and f_i corresponds to the smoothing function, which describes the relationship between the transformed mean response (the link function transfer) and the *i*th predictor (Swartzman *et al.* 1992).

The underlying probability distribution of the data can be any distribution from the exponential family, such as the normal or binomial distributions. In this analysis, data were assumed to come from a Poisson distribution, which is often appropriate for counts data and spatial analysis (Swartzman *et al.* 1992).

The parameter of the Poisson distribution is calculated as follows:

$$\Lambda(x) = \int_{Ax} \lambda(u) du \tag{12}$$

where $\lambda(u)$ is the intensity of the underlying Poisson process and Λx is the area of the observations. The expected value of the Poisson process is $\Lambda(x)$ and the link function is the natural logarithm. Thus the Poisson Generalised Additive Model relates the expected counts to the covariates as:

$$\ln\left[E\left(X|x_1,...,x_n\right)\right] = \ln\left[\Lambda(x)\right] = \sum_{i=1}^{n} S_i\ (x_i) \tag{13}$$

A general algorithm for fitting a GAM consists of scatterplot smoothers, a back-fitting algorithm and a local scoring algorithm (Swartzman *et al.* 1992). The smoothing function is estimated using the scatterplot smooth and replaces the least-squares fit used in linear regression (Swartzman *et al.* 1995). A number of smoothers exist and for this analysis the cubic *B*-spline smoother was used, which seeks a function *f* that minimises the penalised least squares (PLS):

$$PLS = \sum_{i=1}^{n} \left[(y_i - f(x_i))^2 - \lambda \int {''}(t)\, dt \right] \tag{14}$$

The backfitting algorithm fits the smoothing functions one at a time, by taking the residuals and smoothing them against x using the scatterplot smoother. The algorithm iterates until the deviance no longer decreases (Booth 1997b). The measure of fit for the GAM is the deviance, which is twice the natural logarithm of the likelihood ratio between the saturated model and the current model (Swartzman *et al.* 1992). For a Poisson process the deviance is calculated as:

$$\text{Deviance}(x,\mu) = 2\sum_{i=1}^{n} x_i \ln\left[\frac{x_i}{\mu_i}\right] - (x_i - \mu_i) \qquad (15)$$

The dependent variables used in this analysis were the standardised density of hake discards and the standardised density of utilised bycatch. Covariates investigated for the West and South Coast hake fisheries were the latitude, longitude, depth, month, the total standardised catch, the standardised hake catch, the standardised bycatch, the percentage of hake in the catch, the percentage of hake catch retained and the percentage of bycatch in the catch. Catch densities were log-transformed and these values were used for later analysis (Swartzman *et al.* 1992).

For the sole-directed trawls, the total standardised sole catch, the percentage of sole in the catch, the hake bycatch and non-hake bycatch were also used as covariates. For this fishery, the effect of latitude could not be investigated, because as mentioned skippers record only the commercial trawl grid block.

Since the sole fishery is confined to the inshore regions of the South Coast, only three different latitudes were recorded, which was too few to run the analysis.

All statistical analysis was performed using S-Plus software (S-Plus 4.5, MathSoft Inc.). A GAM was fitted for each dependent variable with all covariates included in the model to show the conditional effect - the effect of a given covariate with all other covariates also included (Swartzman *et al.* 1992). Backward, stepwise elimination was used to select the set of significant covariates and a best-fitting model for each dependent variable. This procedure involves running a series of models, where each model differs from its neighbours by a single term. At each step, the programme removes one of the terms and calculates the Akaike's Information Criterion (AIC, Chambers and Hastie 1992). If the AIC calculated is smaller than the previous AIC, the term in question is removed. The process continues, removing non-significant terms until a point is reached where all terms are significant. In the stepwise procedure, the significance of each term as a linear or smoothed term is tested. Therefore, the outcome of the AIC stepwise procedure gives the smallest subset of significant variables, and assesses whether each is linearly or non-linearly (using a smoother) related to the response. In the interests of brevity, only the final model calculated for each dependent variable will be presented.

A pseudo-coefficient of determination (or pseudo R^2) was calculated for each model. Although this is not identical to the classical r^2, this value gives some measure of the ratio of the variance explained by the model to the total variance explained by both the model and any associated error (Swartzman *et al.* 1992). It is calculated as:

$$R^2 = 1 - \frac{\textit{Best model residual deviance}}{\textit{Overall mean or Null model deviance}} \qquad (16)$$

GIS and GAM's were used to investigate the spatial and temporal component of bycatch for several reasons. GIS provides qualitative information on patterns in fish distribution that are easy to interpret visually. Also, as additional data, such as substrate type, become available these can easily be added to the GIS. GAMs, however, provide quantitative information on the influence of covariates on the distribution of fish, adjusting for the effect of other covariates. They can be used to develop models that better represent the underlying data, enhancing our understanding of ecological systems (Guisan *et al.* 2002). Thus, the two techniques together may provide a more complete picture of the factors affecting fish distribution and abundance.

Results

The spatial distribution of bycatch and discards

The West Coast

The distributions of the density of hake discarded, the density of bycatch in the catch and density of bycatch retained / utilised are shown in Figs 4.1 - 4.3, respectively. Spatially, the highest levels of hake discarding were seen off Cape Town in January – April and May – August (Fig. 4.1), and north-west of Saldanha Bay for the period September – December). With regard to the density of hake discarded, the period May – August demonstrated the highest levels. The density of bycatch was highest in the period May - December and the greatest density of bycatch in the catch was found off Cape Town (Fig. 4.2). The pattern of bycatch utilisation mirrored the distribution of the density of bycatch, suggesting that as much of the bycatch is utilised as possible or that a similar proportion of bycatch is processed regardless of the actual mass in the catch (Fig. 4.3).

The South Coast

The distribution patterns of South Coast hake discards, bycatch and bycatch utilisation are shown in Figs 4.4 - 4.6. Unlike the West Coast, catches were more widespread and fewer patterns were seen. In general hake discarding rates were low, when compared with the West Coast (Fig. 4.4), with substantial discarding observed for only a few trawls in each trimester. The high level of bycatch in South Coast trawls (Chapter 2) was clearly seen, with the bycatch ranging between 0 - 3500 $kgkm^{-2}hr^{-1}$, compared with a range of 0 - 270 $kgkm^{-2}hr^{-1}$ of discarded hake (Fig. 4.5). As on the West Coast, much of the bycatch was subsequently utilised (Fig. 4.6). However, no trimester patterns were discerned in the total bycatch present or retained in the catch.

The sole fishery

Patterns in the sole-directed trawls were difficult to determine (Figs 4.7 - 4.9), probably because the limited number of trawl positions available meant that trawls in the same commercial grid block had to be averaged. No patterns were identified in the discarding of hake, although Figs 4.8 and 4.9 suggested that much of the non-hake and non-sole bycatch was subsequently retained.

The spatial distribution of hake discards

The distribution of three size categories of hake discards on the West Coast is given in Fig. 4.10. Discards of all sizes were found over the entire sampling range, but the majority of hake discarded (by number) in the fishery were in the >25cm *TL* group. Although hake of less than 18cm *TL* were encountered in West Coast trawls, numerically they formed a minor component of the discards (Fig. 4.10). The size distribution of South Coast hake discards is seen in Fig. 4.11. As on the West Coast, the <18 cm *TL* group formed a minor component (by number) of the discards. However, the percentage of individuals 18 - 25cm *TL* was much higher, with this group dominating the discard component in some areas.

In the sole fishery, results had to be averaged once again because of the fact that trawls were recorded by grid block rather than geographical position (Fig. 4.12). As can be seen, the discards west of 22° tended to be of the two larger size classes, whereas east of 22°E discards tended to be <18cm *TL*.

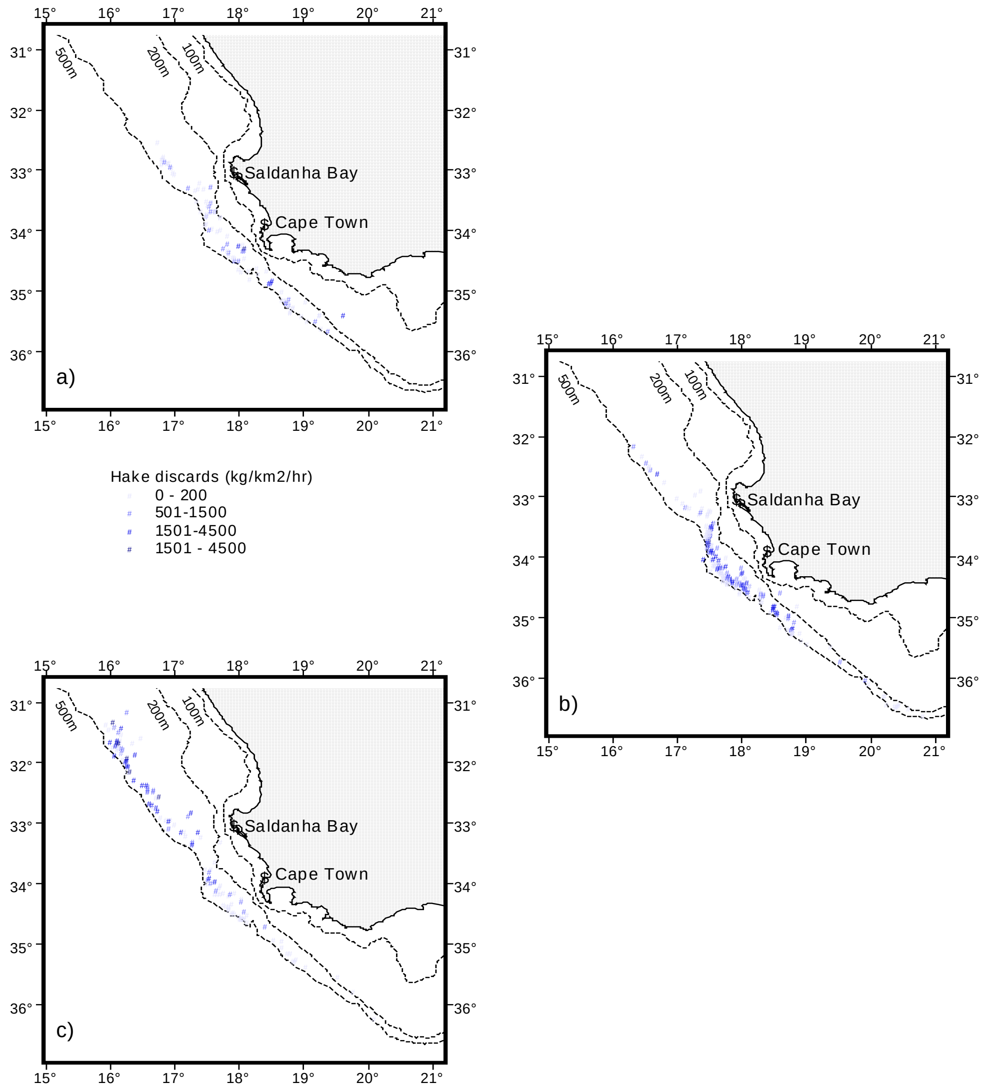


Fig. 4.1: Hake catch ($kgkm^{-2}hr^{-1}$) discarded from West Coast hake-directed trawls in a) January - April, b) May - August and c) September - December for all sampling years combined.

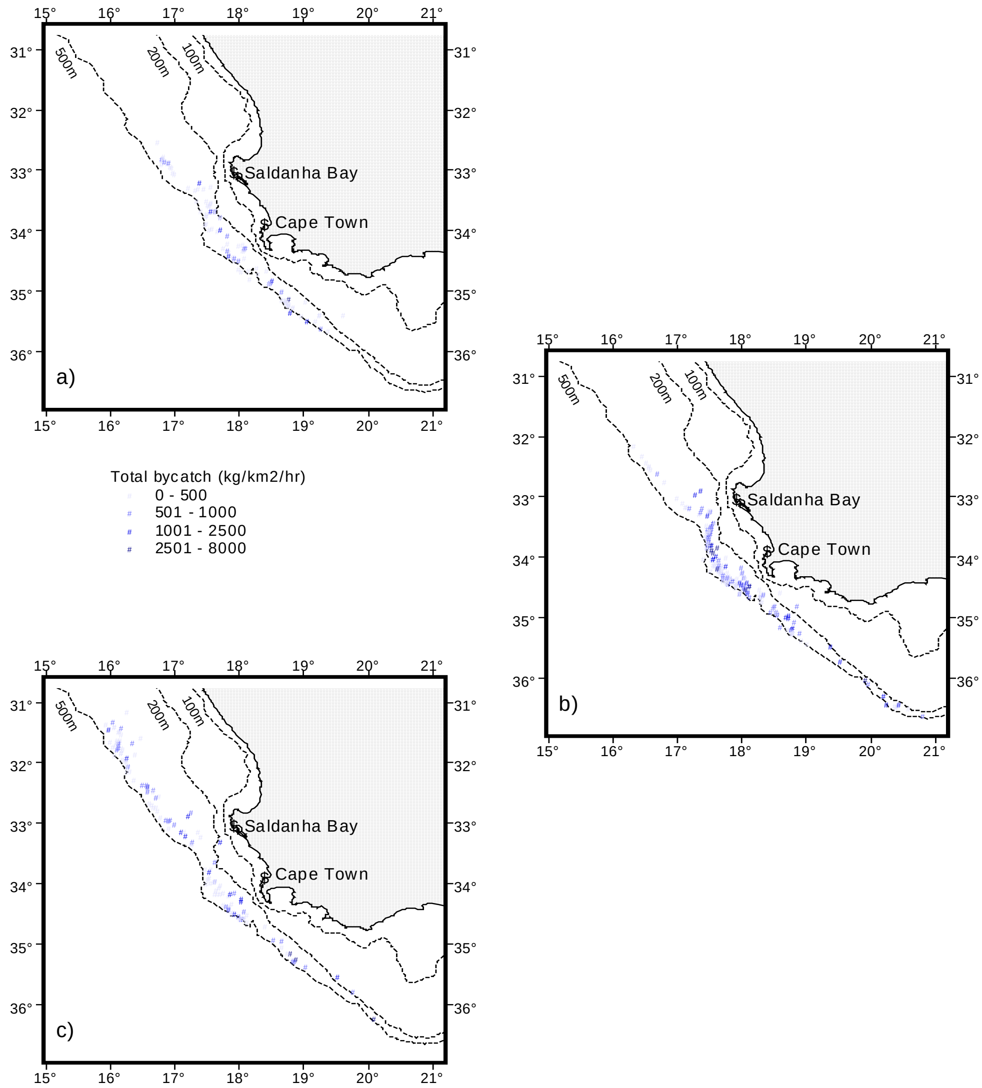


Fig. 4.2: Total bycatch ($kgkm^{-2}hr^{-1}$) in West Coast hake-directed trawls in a) January - April, b) May - August and c) September - December for all sampling years combined.

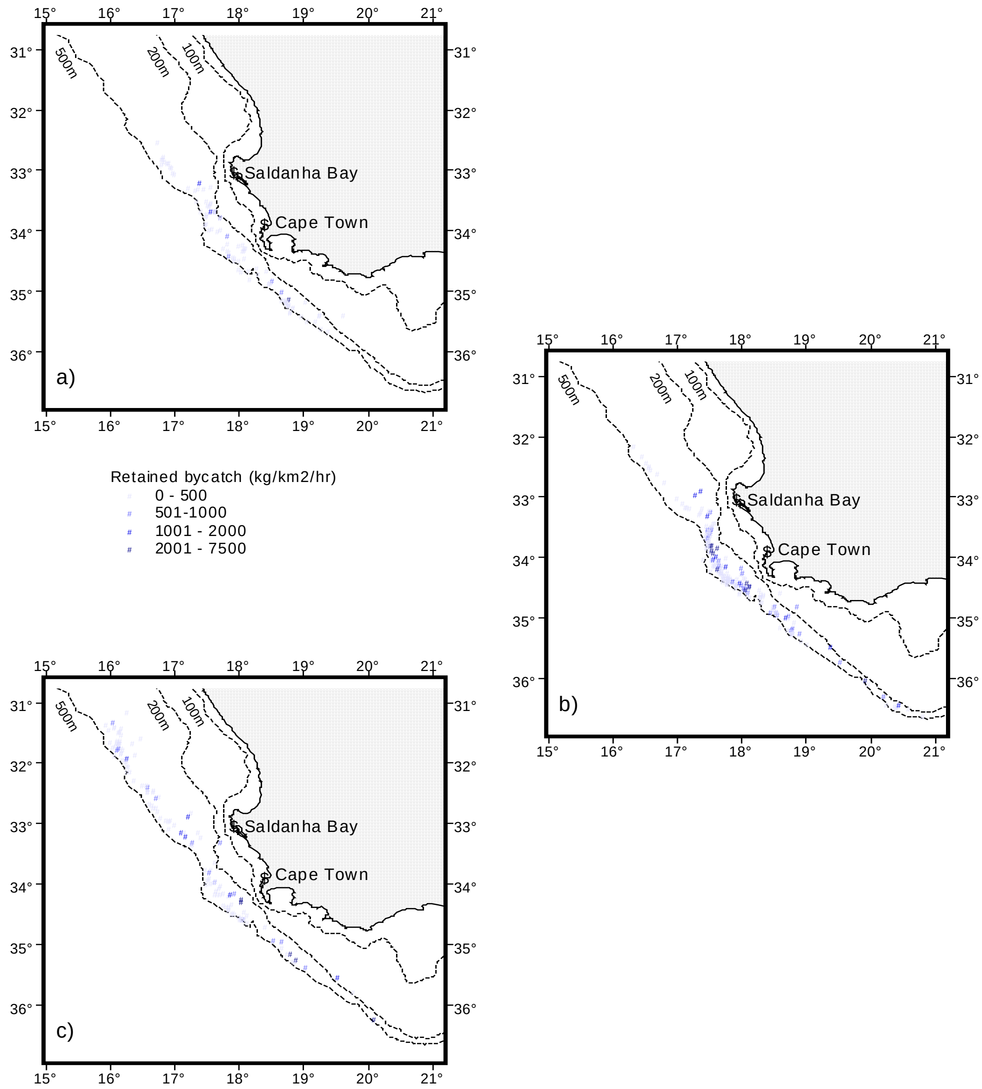


Fig. 4.3: Bycatch retained (kgkm^{-2}hr^{-1}) from West Coast hake-directed trawls in a) January - April, b) May - August and c) September - December for all sampling years combined.

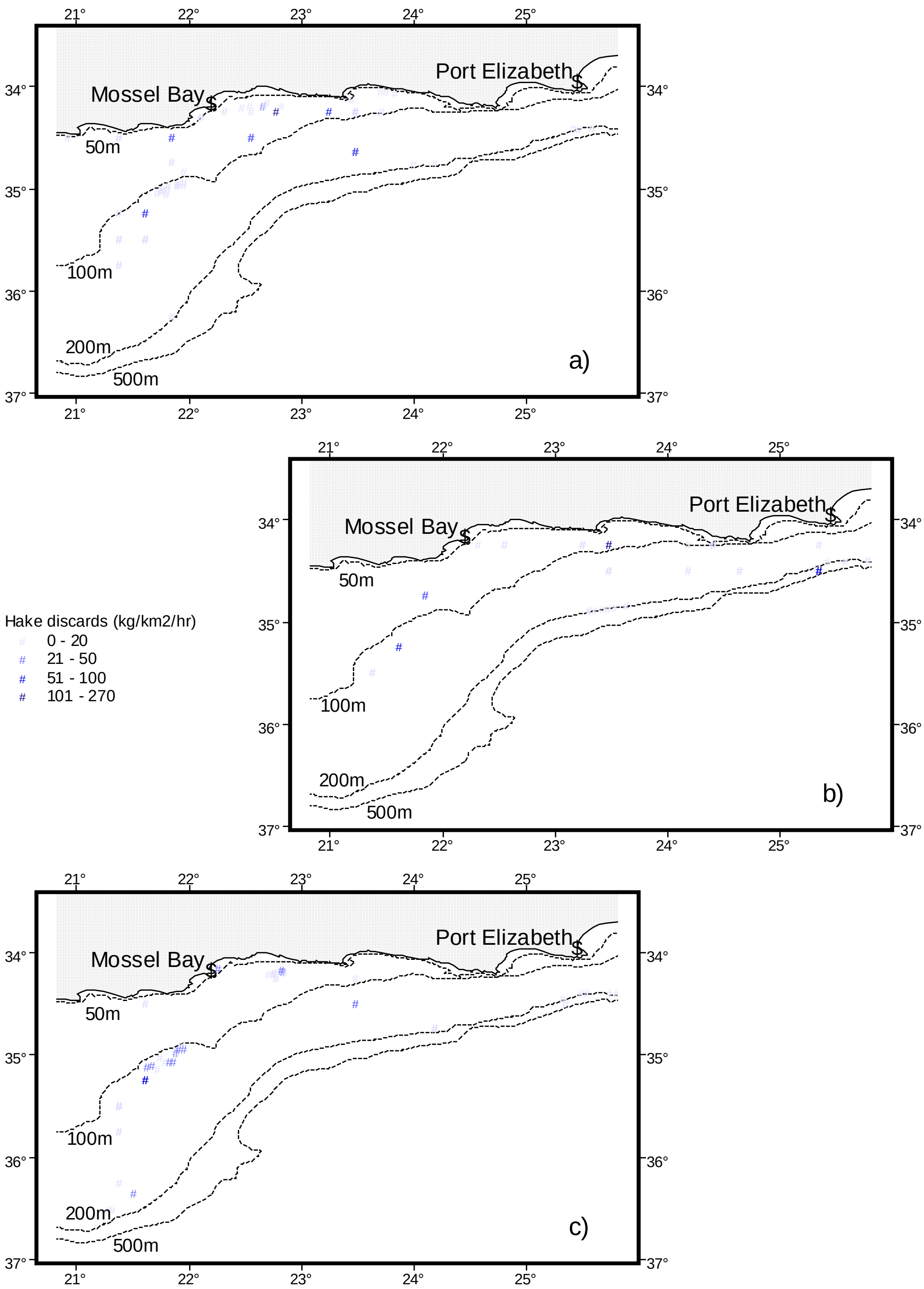


Fig. 4.4: Hake catch (kgkm^{-2}hr^{-1}) discarded from South Coast hake-directed trawls in a) January - April, b) May - August and c) September - December for all sampling years combined.

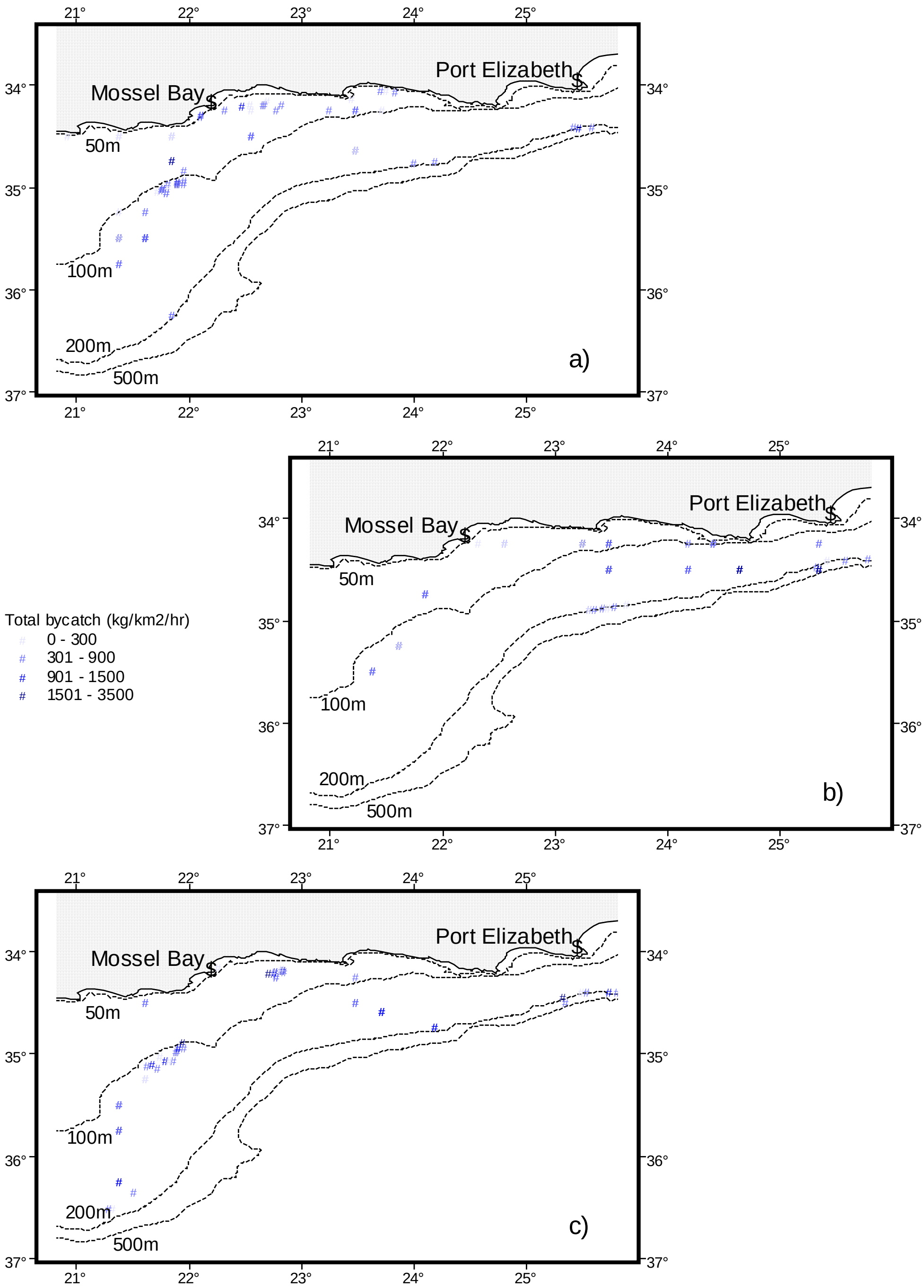


Fig. 4.5: Total bycatch ($kgkm^{-2}hr^{-1}$) in South Coast hake-directed trawls in a) January - April, b) May - August and c) September - December for all sampling years combined.

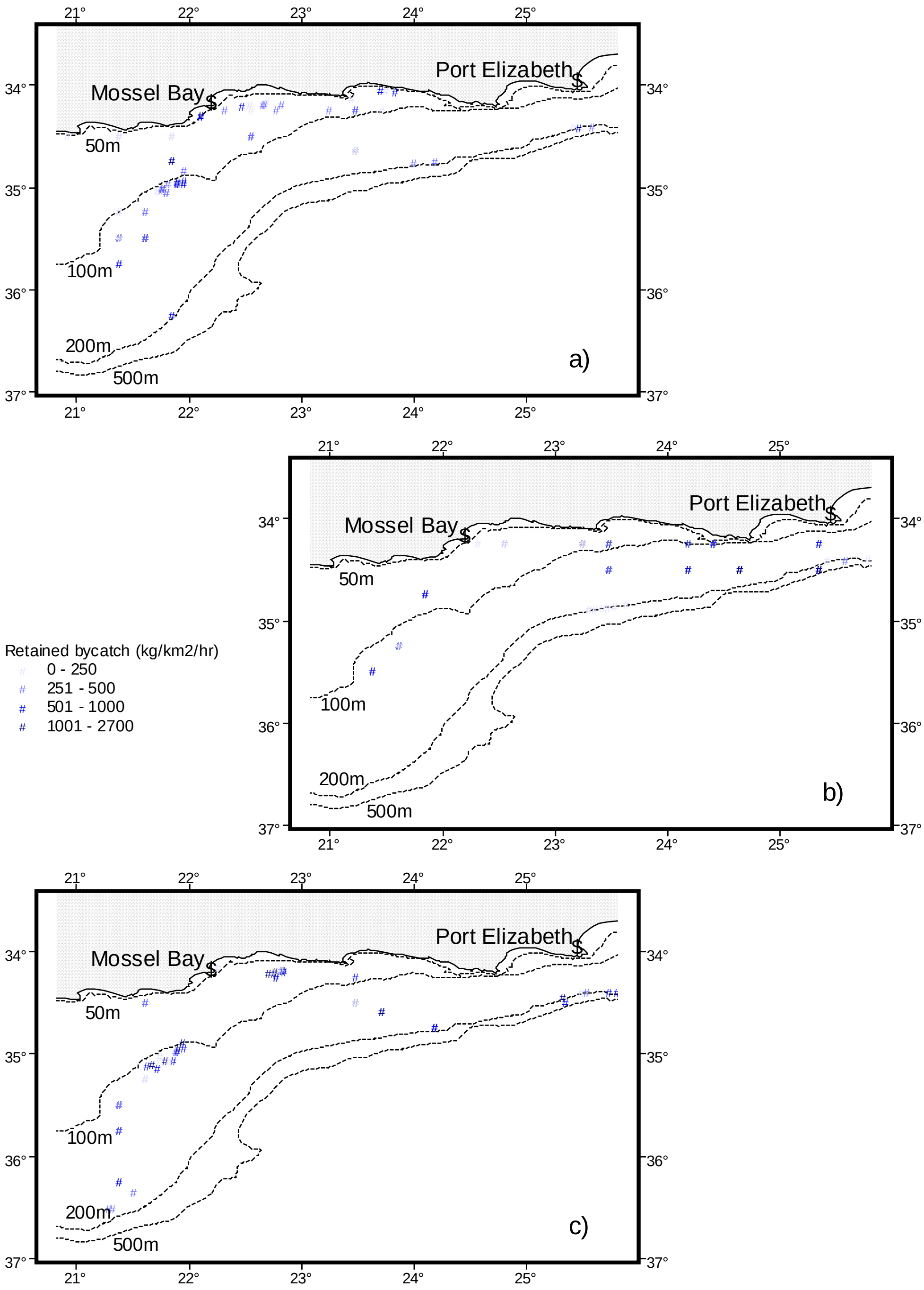


Fig. 4.6: Bycatch retained (kgkm^{-2}hr^{-1}) from South Coast hake-directed trawls in a) January - April, b) May - August and c) September - December for all sampling years combined.

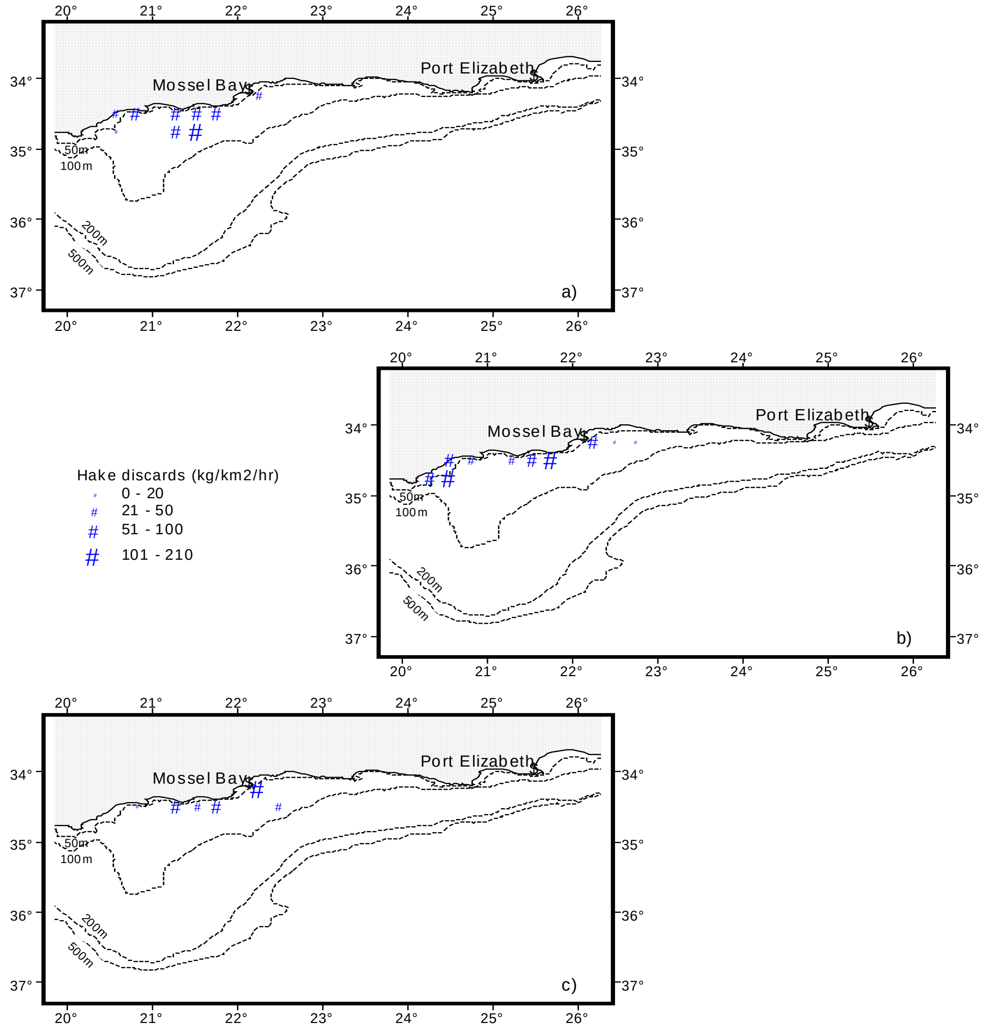


Fig. 4.7: Average hake catch (kgkm^{-2}hr^{-1}) discarded from South Coast sole-directed trawls in a) January - April, b) May - August and c) September - December for all sampling years combined.

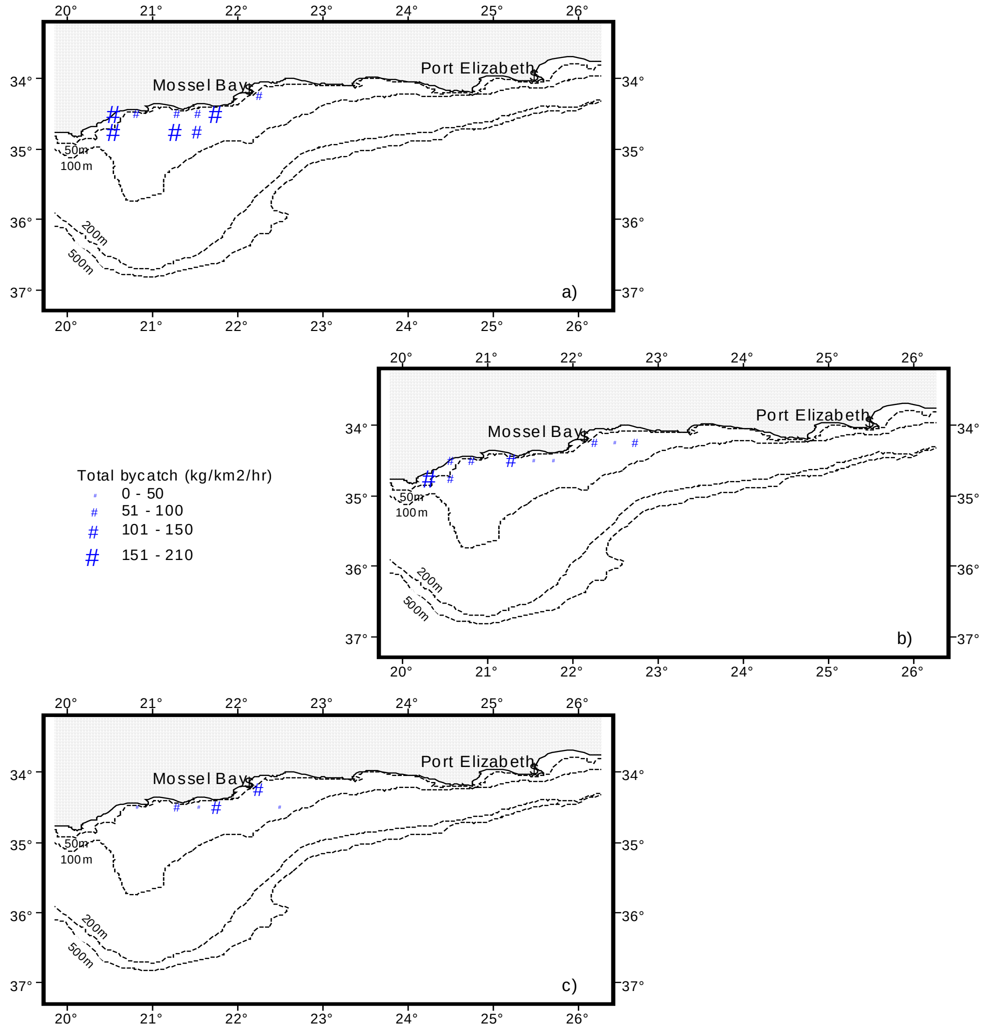


Fig. 4.8: Average non-hake and sole bycatch (kgkm^{-2}hr^{-1}) in South Coast sole-directed trawls in January - April, May - August and September - December for all sampling years combined.

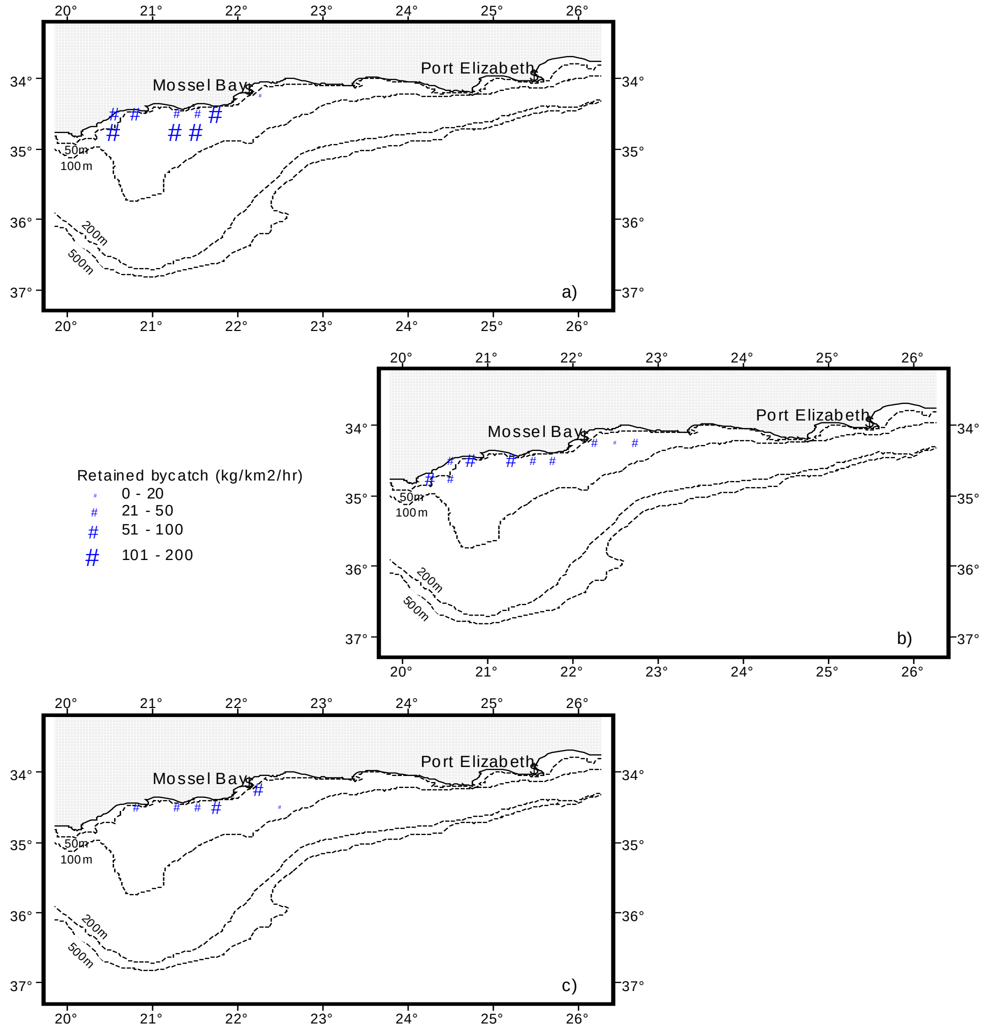


Fig. 4.9: Average non-hake and sole catch (kgkm^{-2}hr^{-1}) retained from South Coast sole-directed trawls in January - April, May - August and September - December for all sampling years combined.

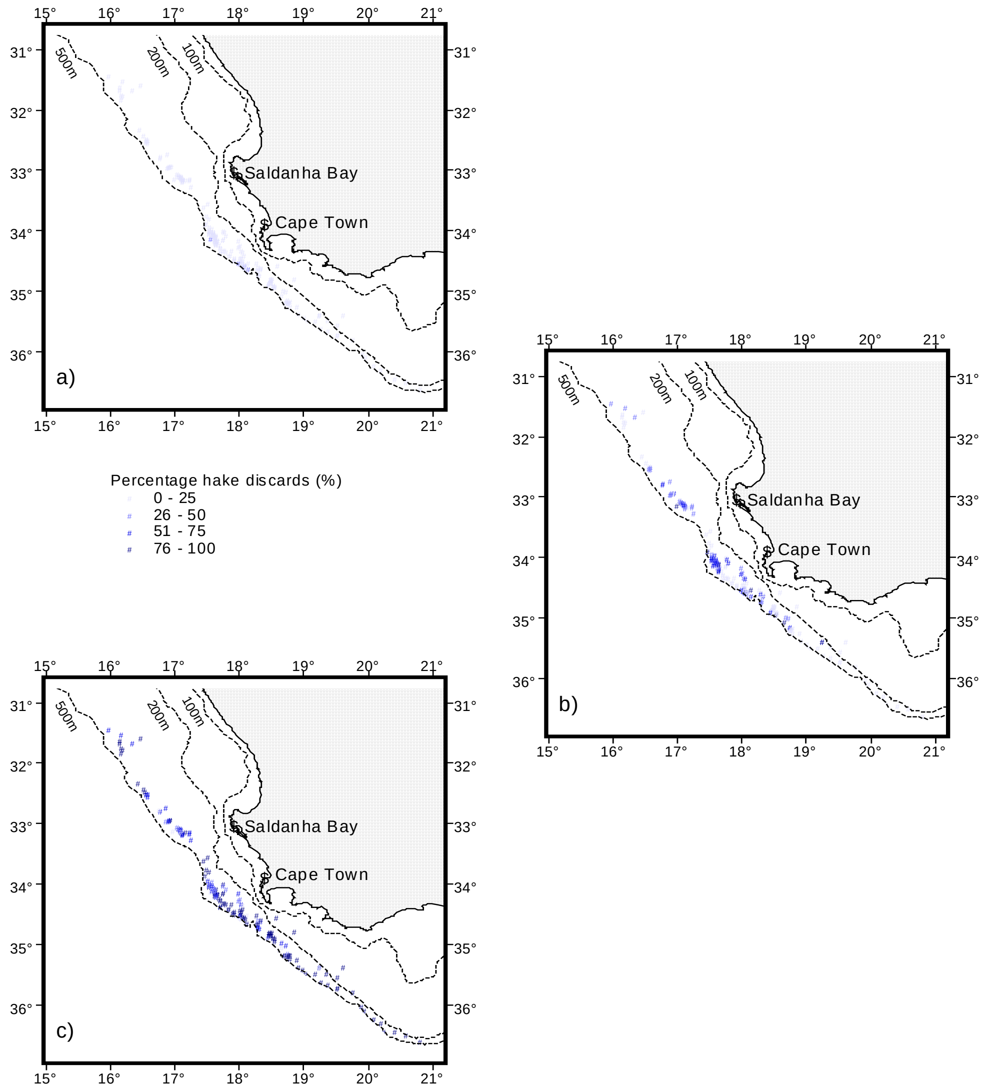


Fig. 4.10: Percentage contribution (%) of a) <18cm *TL*, b) 18 - 25cm *TL*, and c) >25cm *TL* hake discards on the West Coast.

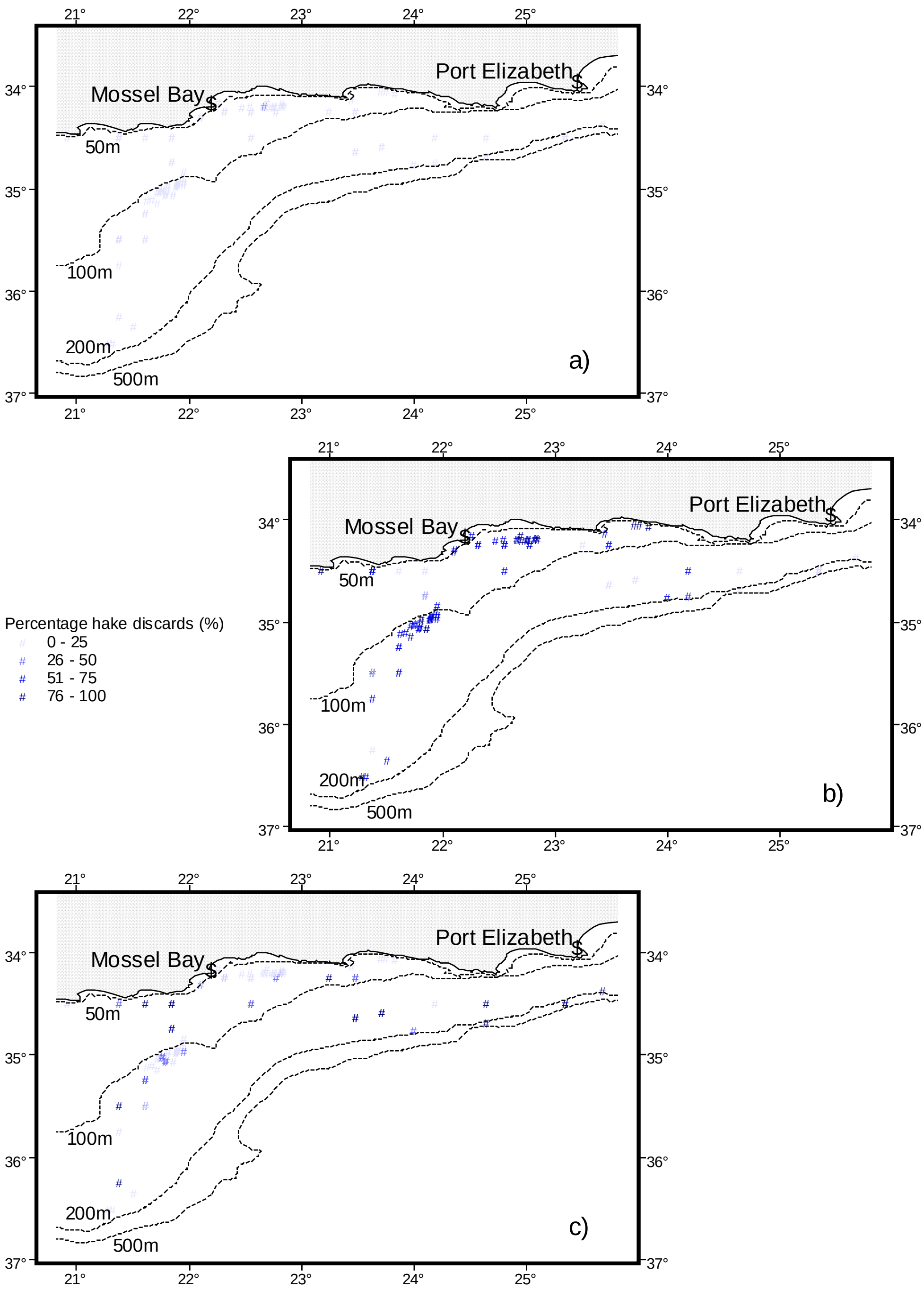


Fig. 4.11: Percentage contribution (%) of a) <18cm *TL*, b) 18 - 25cm *TL*, and c) >25cm *TL* hake discards on the South Coast.

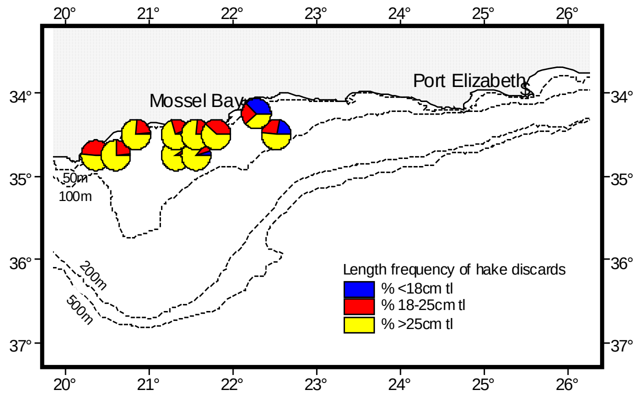


Fig. 4.12: Average percentage contribution (%) of hake discards in the sole-directed fishery.

Identifying factors influencing bycatch and discards using GAM

The West Coast

Figs 4.13 and 4.14 are scatterplot smooths showing the effect that each covariate has on the logarithm of discarded hake (R^2 = 0.40) and the logarithm of retained bycatch (R^2 = 0.91), respectively, for the West Coast fishery. The magnitude of each predictor is given on the x-axis, along with a rug plot showing the distribution of observations made for that predictor. The y-axis reflects the relative importance of the covariate (zero change reflects no explanatory power of that predictor (Maravelias 1997)). The same approximate scale is used on each y-axis for ease of comparison between variables. The dotted lines represent the 95% confidence intervals of each scatterplot smooth. For many covariates, the confidence limits tended to broaden at the extreme values of the x-axis. This is because, as one approaches the extremities, fewer points were used in the smoothing window and there is less confidence in the line. For both dependent variables on the West Coast, the best fit model from the backwards stepwise elimination included all covariates.

The scatterplot smooths indicated that latitude, trawling depth, the size of the total catch and the size of the hake catch were the greatest influences on hake discarding (Fig. 4.13). Although the confidence intervals were reasonably broad, generally the discarding of hake increased as the size of the catch increased, but decreased with increasing total hake catch. Hake discarding increased from approximately 200 m to 300 m before decreasing as trawl depth increased to 600m. The discarding of hake was greater further north than south, but longitude appeared to have a more limited effect. The influence of percentage of hake in the catch, percentage of bycatch retained and month appeared to be minimal. However, these factors were all included in the final model.

In contrast to the density of hake discarding, the density of retained bycatch was influenced by the total bycatch, the total retained hake catch and the percentage of hake in the catch (Fig. 4.14). Bycatch utilisation increased as the total bycatch and the retained hake catch increased and decreased as the percentage of hake in the catch increased. The utilisation of bycatch appeared to decrease with increasing catch size, but the confidence limits at the highest catch sizes might be obscuring the true trend. The effects of longitude, latitude and trawl depth on bycatch utilisation were similar to those observed for hake discarding, but the effect was less pronounced. Once again, the effect of month on the utilisation of bycatch was minor.

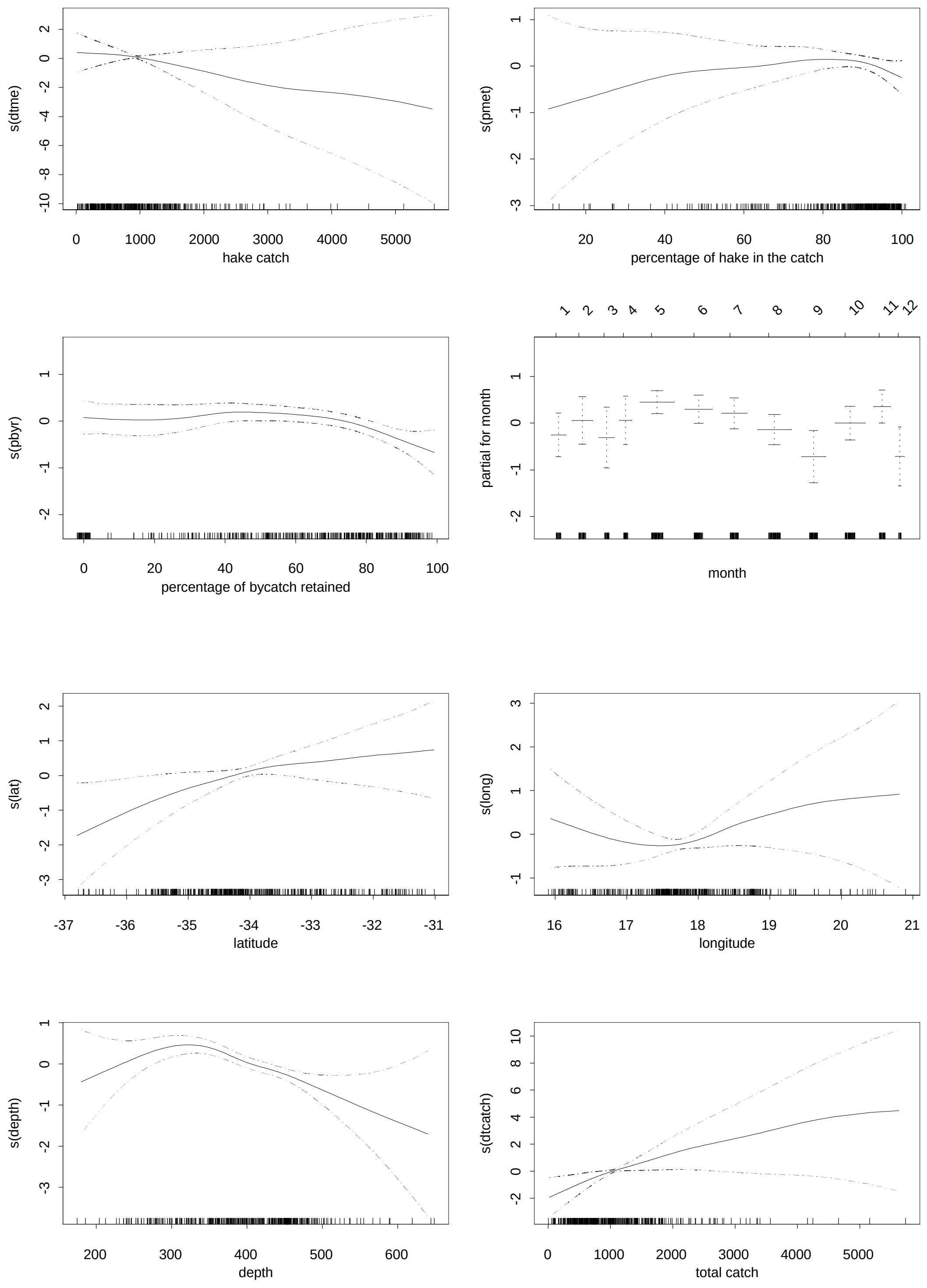


Fig. 4.13: Scatterplot smooths showing the individual effect of various covariates on hake discards in the West Coast hake-directed fishery.
lat = latitude, long = longitude, depth = depth (m), dtcatch = total catch ($kgkm^{-2}hr^{-1}$), dtme = hake catch ($kgkm^{-2}hr^{-1}$), pmet = percentage of hake in the catch (%), pbyr = percentage of bycatch retained (%). The 95% confidence interval is represented by the dotted line and a rugplot is included on the x-axis.

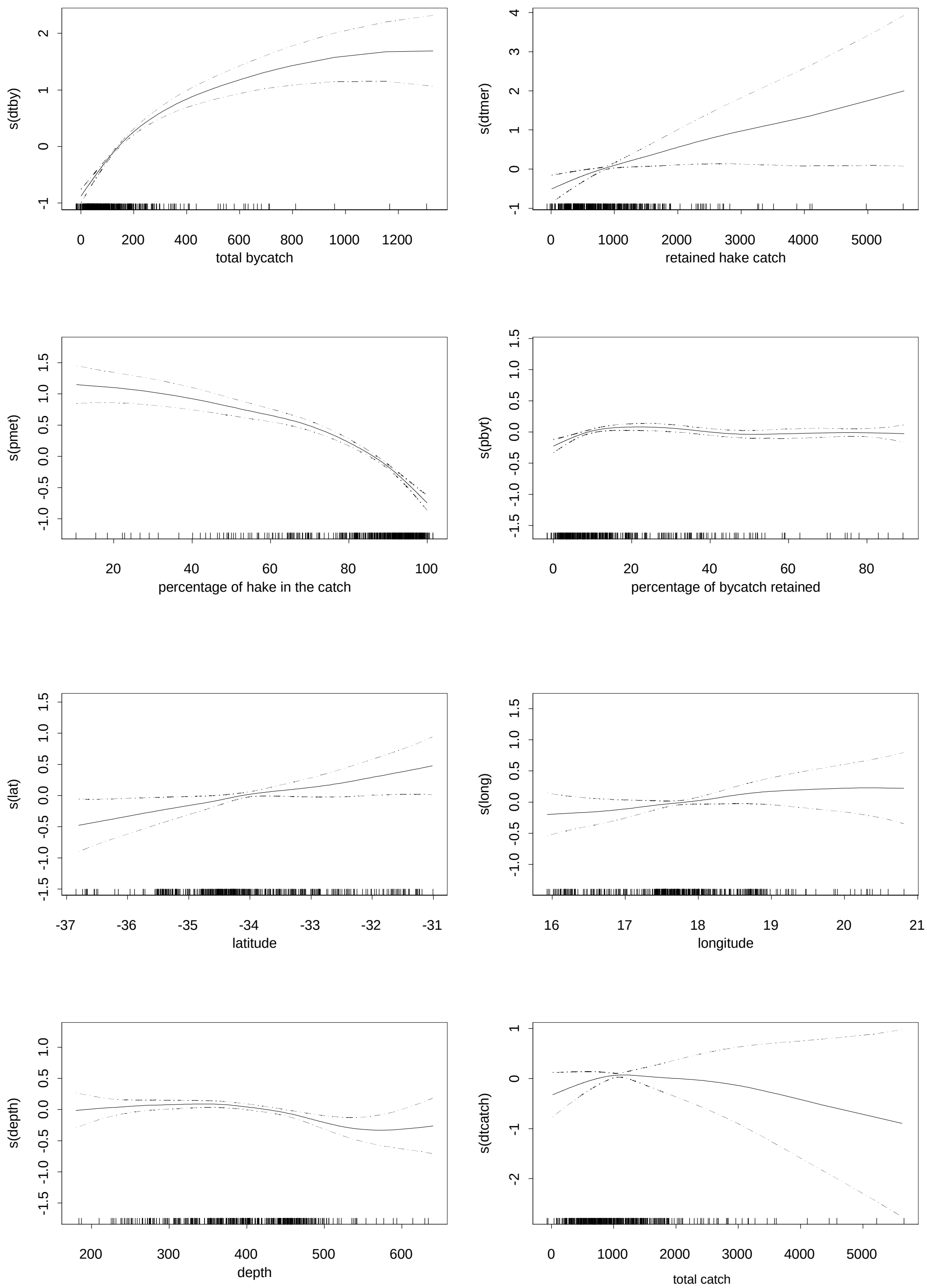
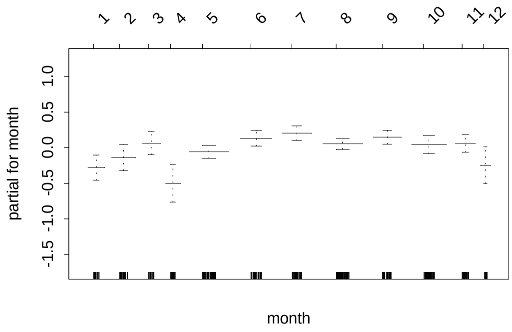


Fig. 4.14: Scatterplot smooths showing the individual effect of various covariates on the retained bycatch in the West Coast hake-directed fishery.
lat = latitude, long = longitude, depth = depth (m), dtcatch = total catch ($kgkm^{-2}hr^{-1}$), dtby = total bycatch ($kg.km^{-2}hr^{-1}$), dtmer = retained hake catch ($kgkm^{-2}hr^{-1}$), pmet = percentage of hake in the catch (%), pbyt = percentage of bycatch in the catch (%). The 95% confidence interval is represented by the dotted line and a rugplot is included on the x-axis.

Fig. 4.14 Continued



The South Coast

Figs 4.15 and 4.16 are scatterplot smoothers of the GAMs showing the effect that each covariate has on the logarithm of hake catch subsequently discarded (R^2 = 0.75) and the logarithm of retained bycatch (R^2 = 0.97), for the South Coast hake directed trawls, respectively.

The catch of hake subsequently discarded was highly influenced by all covariates, in particular depth, the percentage of hake in the catch and the percentage of bycatch retained (Fig. 4.15). Discarding decreased from 50 m down to approximately 130 m, then increased to 210 m before decreasing again, possibly reflecting the fact that the shallower Blues Bank and inshore hake fisheries data were combined with the deeper Chalk Line data. Hake discarding increased with both the percentage of hake in the catch and the percentage of bycatch retained. With regard to latitude, discarding increased from 34°S to 35°S, before decreasing again. Regarding longitude, discarding increased from 21°E to 23°E before decreasing again. Hake discarding appeared to decrease with increasing catch size and increase with increasing hake catch, but due to the broad confidence levels, this interpretation may not be correct. As a result of the backwards, stepwise elimination all covariates were retained in the final model for the percentage of hake discarded.

Trawling depth, the percentage of hake in the catch and percentage of bycatch in the catch appeared to have the greatest influence on the utilisation of the bycatch component (Fig. 4.16). Bycatch utilisation decreased with increasing depth and increasing percentage of hake in the catch, but increased with an increase in the percentage of bycatch in the catch. Latitude, total catch size, total bycatch, retained hake catch and month did not greatly influence bycatch utilisation.

The sole fishery

Figs 4.17 and 4.18 are scatterplot smooths showing the effect that each covariate has on the logarithm of hake discards (R^2 = 0.74) and logarithm of retained bycatch (R^2 = 0.87), respectively, for the South Coast sole-directed trawls. Hake discarding decreased with increasing longitude, total hake catch and total sole catch and increased with increasing percentage of hake in the catch. The stepwise procedure determined that hake discarding decreased linearly with increasing depth. Hake discarding initially increased with increasing catch size up to approximately 45 $kg.km^{-2}hr^{-1}$, before decreasing as catch size increased further.

Only three of the covariates - depth, total catch size and percentage of bycatch in the catch influenced the percentage of (non-hake) bycatch retained by the sole fishery. As with hake discarding, bycatch utilisation decreased linearly with increasing depth. Bycatch utilisation increased with an increase in both the total catch and the percentage of bycatch in the catch.

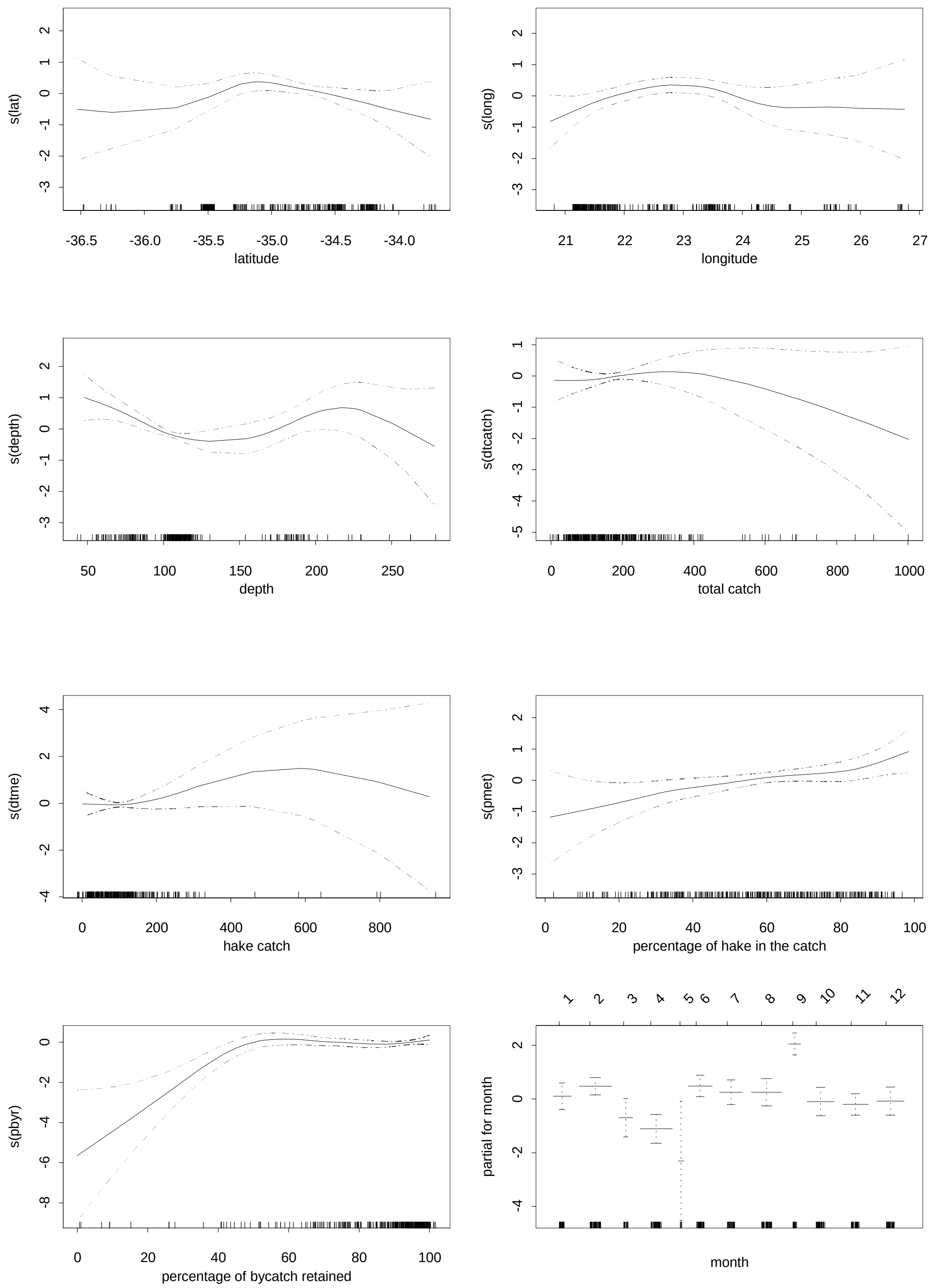


Fig. 4.15: Scatterplot smooths showing the individual effect of various covariates on hake discards in the South Coast hake-directed fishery.
lat = latitude, long = longitude, depth = depth (m), dtcatch = total catch ($kgkm^{-2}hr^{-1}$), dtme = hake catch ($kgkm^{-2}hr^{-1}$), pmet = percentage of hake in the catch (%), pbyr = percentage of bycatch retained (%). The 95% confidence interval is represented by the dotted line and a rugplot is included on the x-axis.

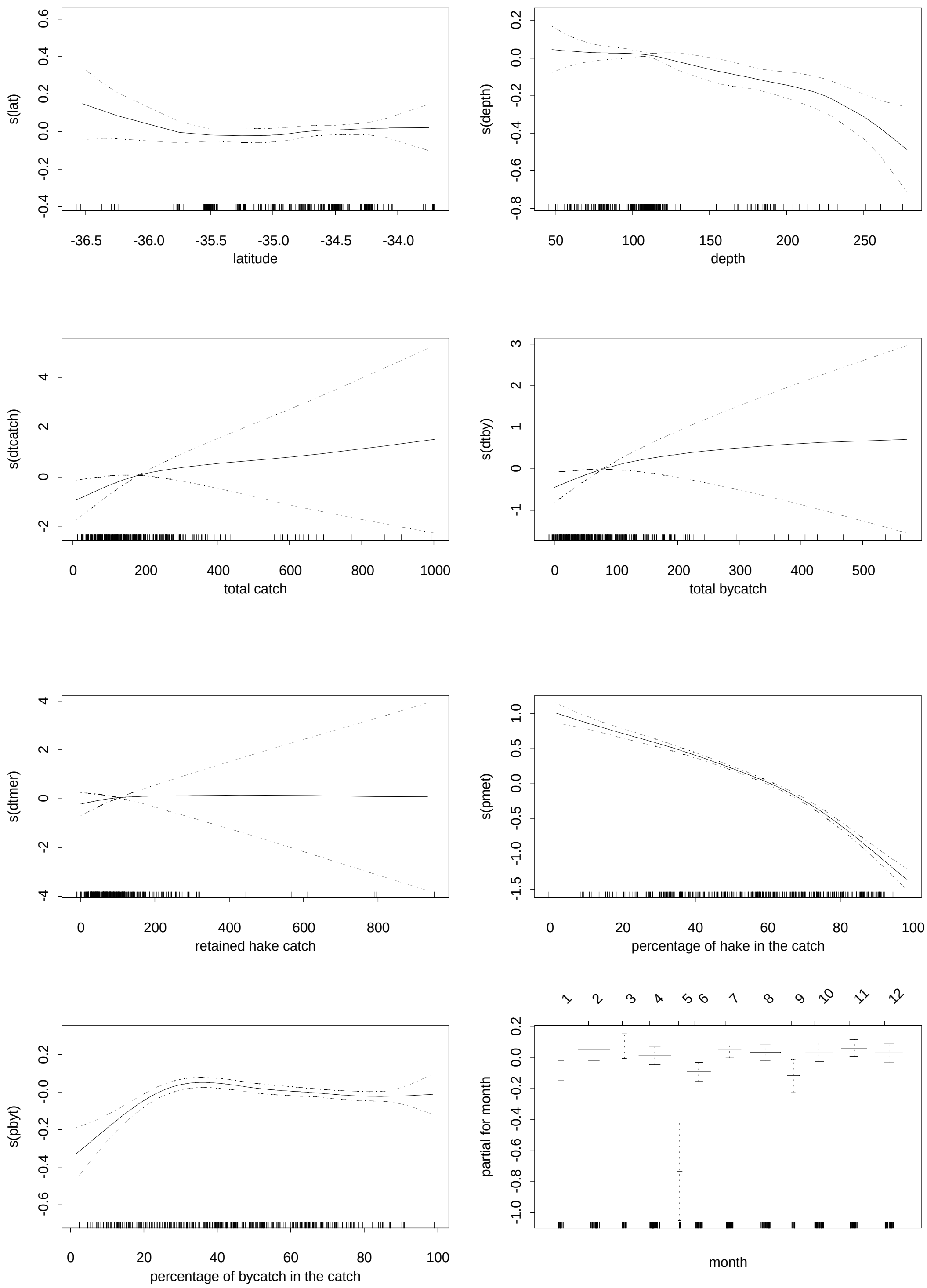


Fig. 4.16: Scatterplot smooths showing the individual effect of various covariates on the retained bycatch in the South Coast hake-directed fishery.

lat = latitude, depth = depth (m), dtcatch = total catch (kg.km^{-2}hr^{-1}), dtby = total bycatch (kgkm^{-2}hr^{-1}), dtmer = retained hake catch (kgkm^{-2}hr^{-1}), pmet = percentage of hake in the catch (%), pbyt = percentage of bycatch in catch (%). The 95% confidence interval is represented by the dotted line and a rugplot is included on the x-axis.

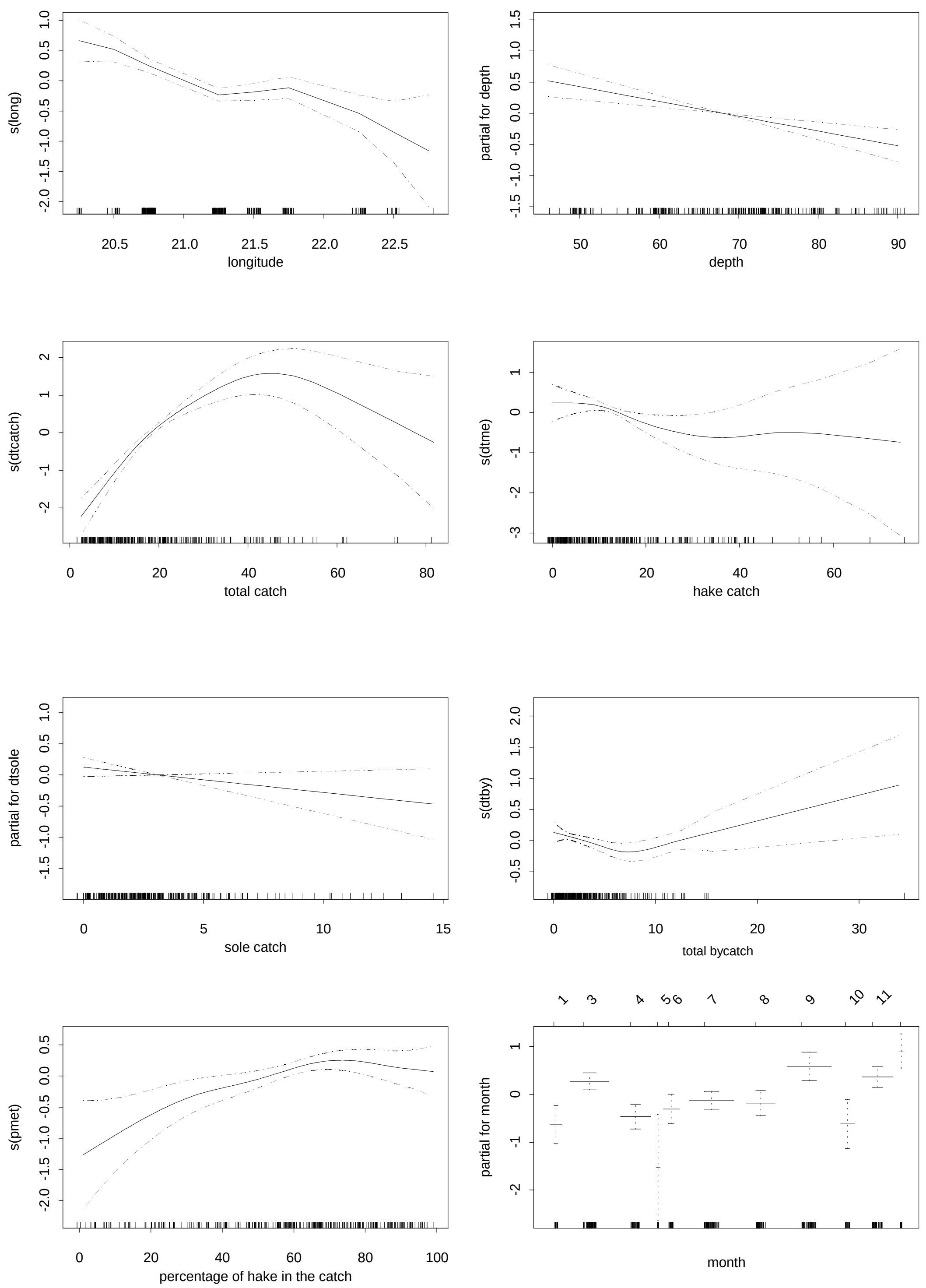


Fig. 4.17: Scatterplot smooths showing the individual effect of various covariates on hake discards in the South Coast sole-directed fishery.
long = longitude, depth = depth (m), dtcatch = total catch ($kgkm^{-2}hr^{-1}$), dtme = hake catch ($kgkm^{-2}hr^{-1}$), dtsole = sole catch ($kgkm^{-2}hr^{-1}$), dtby = total bycatch ($kgkm^{-2}hr^{-1}$), pmet = percentage of hake in the catch (%). The 95% confidence interval is represented by the dotted line and a rugplot is included on the x-axis.

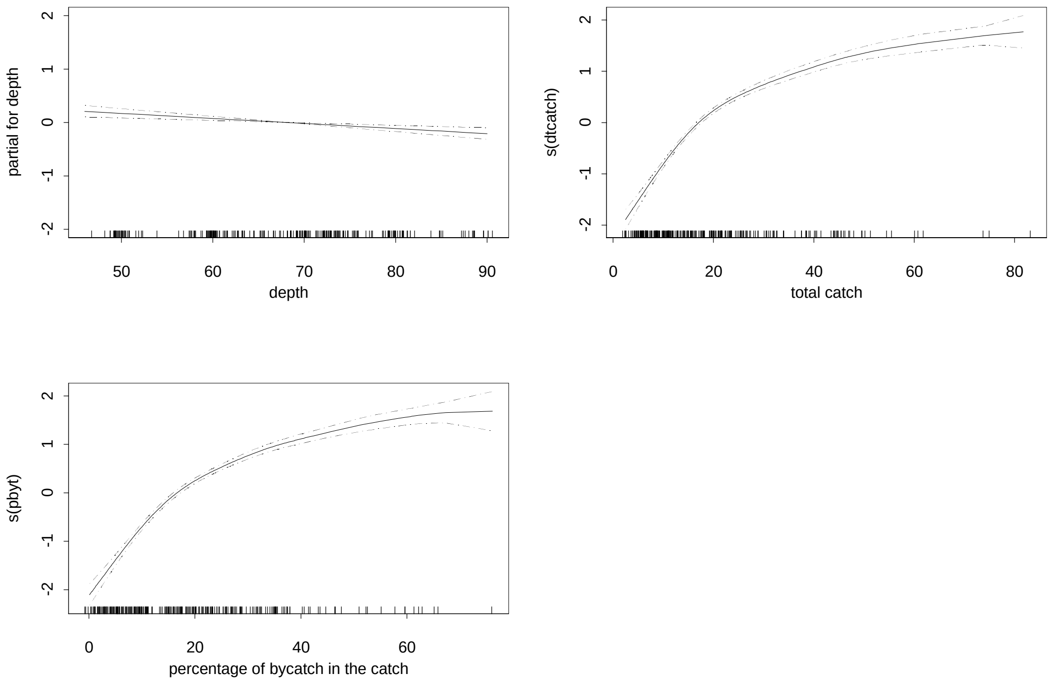


Fig. 4.18: Scatterplot smooths showing the individual effect of various covariates on the retained bycatch in the South Coast sole-directed fishery.
depth = depth (m), dtcatch = total catch ($kgkm^{-2}hr^{-1}$), pbyt = percentage of bycatch in the catch (%). The 95% confidence interval is represented by the dotted line and a rugplot is included on the x-axis.

Discussion

Measuring the levels of bycatch in a given fishery (Chapters 2 and 3) can provide information on the magnitude of the bycatch problem in that fishery. However, information on the factors affecting the spatial and temporal distribution of bycatch is required to manage the problem. The GIS and GAM analyses presented here indicated that hake discarding and bycatch utilisation were affected by a variety of factors such as trawl position, month and catch size. The degree to which these factors affected bycatch varied substantially between the three fisheries investigated, which may have important implications for management. For several of the covariates assessed, contrasting results were obtained from the two analytical methods. For example, although the GIS plots suggested that on the West Coast hake discarding was highest off Cape Town in the middle of the year and off Saldanha Bay at the end of the year, the GAM analysis did not bear this out. Rather, the GAMs suggested that hake discarding was not significantly affected by month and that hake discarding decreased the further south trawls took place. These discrepancies highlight the differences between the two analytical methods. Although the GIS can be used to plot distributions that are visually effective, GAMs provide more information on the effect of covariates. These differences must be borne in mind when interpreting the data.

On the West Coast, a variety of factors affected hake discarding and bycatch utilisation. Hake discarding was highly influenced by depth, latitude, the total catch and the hake catch, whereas bycatch utilisation was influenced by the total bycatch, the mass of hake retained and the percentage of hake in the catch. The observed trend of decreasing hake discarding the further south trawls took place is of interest since the inshore area off Doring Bay (32°S) is a known hake nursery area (Payne *et al.* 1986). One may, therefore, expect increased hake discarding to occur in this area, compared with other more northerly or southerly areas. However, trawling companies routinely avoid fishing in this area to avoid catching the small fish. From the data observed, it would appear that they are successfully achieving this.

The effect of depth on hake discarding, that of increased discarding with increased depth up to approximately 300 m followed by a decrease down to 600 m (Fig. 4.13), may be explained in one of two ways. The first possibility is that the catch composition in the shallower region is highly varied with a large mix of bycatch species such as ribbonfish and snoek. In these mixed catches, hake may be damaged by the spines of the bycatch species and are subsequently discarded. As depth increases, the catches become cleaner with regard to hake and damage (and discarding) will decrease.

The second possibility is that because of the size distribution of hake (increasing size with increasing depth), the catch up to 300 m depth may contain a high proportion of small individuals. Thus, in the shallow regions small individuals will be retained, because of the paucity of large individuals and discarding will be low. As depth, and the proportion of large individuals in the catch increases, so will the discarding of small fish. Finally, a point will be reached where the majority of individuals are of sufficient size to retain and discarding will decrease again.

Whatever the reason for this observation, increased hake discarding at 300 m has serious implications for the management of the fishery. Historically, a few, large-scale operators have dominated the fishery and the fleet has generally comprised vessels capable of fishing up to depths of 600 m. Recent years have seen the inclusion into the fishery of many new companies with limited catch limits and smaller vessels that are incapable of fishing at these depths. In addition, they tend to target large *M. capensis* for export to Europe as PQs (Prime Quality fish) in order to maximise their allocation. These fish are found at intermediate depths where small *M. paradoxus* also occur. This may lead to increased levels of discarding through high-grading - the discarding of a small individual in favour of a larger one that would fetch a higher price. The observation that the highest levels of hake discarding occur at these intermediate depths may be evidence of high-grading taking place. This matter requires further investigation.

The increase in hake discarding with increasing catch size was not unexpected, as a larger catch is likely to require more sorting and processing than a smaller one. With a larger catch the crew can be more selective in the fish that they retain and it is likely that the last fish processed from a big catch will be in a poorer condition than the last fish sorted from a small catch. Thus a higher proportion of the catch is likely to be discarded. This hypothesis was supported by the slight trend of increased discarding with an increase in the percentage of hake in the catch. Again, this result may have implications for bycatch management. The trend in recent years has been for operators to concentrate on quality rather than quantity. This is achieved by reducing trawling time and landing smaller catches, thereby reducing trawl damage to the fish and allowing for quicker processing. However, any move towards landing larger catches could result in an increase in hake discarding.

The decrease in hake discarding with increasing hake catch was surprising in light of the comment above regarding catch size. Why this should be is unclear at present. It may be that bigger catches contain more fish of larger size classes, resulting in reduced discarding. However, without information on the size structure of the retained catch, this hypothesis cannot be tested.

The management of West Coast bycatch needs to take cognisance of the effect of the covariates on bycatch utilisation. Analysis suggested that bycatch utilisation decreased as the catch size and the percentage of hake in the catch increased, possibly reflecting the extra time required to process the hake component. Thus, to ensure that bycatch utilisation is maximised, management strategies should continue to encourage the landing of smaller catches. The observed increase in bycatch utilisation with an increase in total bycatch is likely to be a reflection of the fact that, it is more economically viable to pack many bins of bycatch from a single trawl, than to pack a few bins from each of several trawls. This suggests that companies will utilise bycatch if it is in their economic interests to do so. If the economic incentive to land bycatch could be increased, it could lead to increased bycatch utilisation.

Although few spatial or temporal patterns were observed in the GIS plots of hake discarding and bycatch utilisation in the South Coast hake-directed fishery, several trends were observed in the GAM analysis. Compared with the West Coast, different covariates were more or less influential on the fate of the bycatch component. Longitude, latitude and depth all significantly affected hake discarding and this is probably due to the fact that the data set contained information from three distinct geographic regions, (Blues Bank, Chalk Line and inshore hake-directed), and that the community structure differs among these regions (Chapter 2). Hake discarding appeared to increase with movement offshore (southwards) to approximately 35°S and then decrease. This area would equate to somewhere near the Blues Bank region, where a high percentage of the catch is composed of chondrichthyans (Chapter 2). It is possible that the increased occurrence of these species in the catches increased the incidence of damage to the hake, resulting in increased discarding. However, when looking at the effect of longitude on hake discarding, a peak is seen near 23°E, which is further east than the Blues Bank region. The fact that the trawl position or fishery type had such a pronounced effect on the level of hake discarding must be borne in mind when proposing management measures for the South Coast.

In contrast to the West Coast, hake discarding decreased as catch size increased. This is rather surprising, particularly as hake discarding increased as the percentage of hake in the catch increased, probably due to increased sorting and processing times. Hake discarding also increased as a higher percentage of the bycatch was utilised, which may be a reflection of small hake being discarded in favour of more economically viable large hake and bycatch species such as horse mackerel or panga. If such selective discarding is taking place, investigations into the impact of this practice on small hake should be undertaken.

As noted in the Results section, few of the covariates displayed a pronounced effect on the utilisation of the bycatch component. This may suggest that bycatch utilisation is opportunistic and depends on the time and hold space available. In contrast to hake discarding, bycatch utilisation increased as catch size increased. This was somewhat unexpected, because if more hake is utilised (and less is discarded) as catch size increases, one would expect that there would be less time available to process bycatch and that bycatch utilisation would decrease.

Although the GIS analysis of the sole-fishery provided few clear trends in bycatch patterns, clearer results were obtained from the GAM analysis. Hake discarding decreased with depth and the size of the sole catch and also in an easterly direction. Discarding increased as the mass of bycatch and percentage of hake in the catch increased. Apart from packing on ice, sole require little handling and processing, so an increase in the sole catch may create little additional processing time. In addition, almost all sole are retained due to their high value. Therefore, the total sole catch may not affect the degree to which the hake and non-hake components are retained or discarded. Additional sorting time could be diverted to processing hake and other bycatch, and it is likely that the proportions of the hake and non-hake components in the catch would determine what is retained or discarded in a given trawl. It is probably more worthwhile packing a large hake catch rather than a small one, thus there was decreased discarding with an increase in the hake catch. The increase in hake discarding with an increased percentage of hake in the catch could be a reflection of high-grading. The effect of month on hake discarding was very variable, although there was general trend of increased discarding towards the end of the year. This may have been the result of nearing the catch limit and the fishermen being more selective in the fish that they retained.

Only three covariates were significant in the final model for the percentage of (non-hake) bycatch retained. A linear decrease in bycatch utilisation was seen with increasing depth, which could be explained by the fact that hake tend to move into deeper water with increasing size. It is possible that as operators fish deeper, the hake they catch will be larger and more time will be allocated to processing this component of the bycatch. Thus, less time will be available to process the non-hake bycatch component. In shallower waters, where the hake are smaller, it is probably more worthwhile processing the non-hake bycatch component. This hypothesis is supported by the fact that hake discarding decreased with increasing depth. The increase in non-hake bycatch utilisation seen with increasing catch size was somewhat unexpected, since one would expect that with a large catch there would be less time available to process the non-hake bycatch. The observed increase in bycatch utilisation with increasing percentage of bycatch is expected, since it is probably more worthwhile processing a large bycatch catch than a small one.

Differences in the size distribution of discarded hake were observed for the three fisheries and these may also have implications for management. On the West Coast, the majority of hake discards were larger than 25 cm *TL* and of that size-group, 75% of the discards were 26 - 31 cm *TL*. These fish would fall into the second smallest of the commercial size categories used for grading hake (category 1) and, therefore, they were of a marketable size. It is possible that these fish were discarded as a result of high-grading. Given that fish in the 26 - 31 cm *TL* length class only fetch 81% of the price of those in the 32 - 36 cm *TL* class and 77% of those in the 36 - 42 cm *TL* class (Stuttaford 2001), the economic reasons for high-grading become clear. If high-grading is indeed taking place, the scale of the problem must be determined. Information on the size-structure of the retained hake catch is required to determine what proportion of the smaller size categories are being discarded. If the hake discards represent all of the small, but economically viable hake caught, this could be a major problem. However, if the majority of economically viable >25 cm *TL* fish are being retained and the discards represented only a minor portion of the catch, the problem may not be serious. Unfortunately, the observers did not have sufficient time to measure the retained hake along with the discards.

In contrast to the West Coast, the majority of hake discards on the South Coast fell into the 18 - 25cm *TL* and >25cm *TL* groups, possibly because fishing takes place in shallower water. Hake discarding in this fishery is therefore an issue of gear selectivity rather than fisher selectivity.

The fact that the majority of hake discarded in the sole fishery were of the >25cm *TL* size category is of interest since this fishery uses a smaller mesh size than that used by the offshore fisheries of the South and West coasts. One may, therefore, expect that the majority of discards would have fallen into the smallest size category. However, this may be a reflection of high-grading where the discarding of small economically viable hake outweighs the proportion of smallest individuals caught.

The data presented in this chapter suggest that many factors affect the fate of bycatch in trawls and that the effect of these factors is often unclear. This is further compounded by limitations of the data, which provided an incomplete picture of the influences on bycatch and discarding behaviour. Only 397, 320 and 279 trawls were observed for the West Coast, South Coast and sole-directed fisheries, respectively, and in many cases, there were few observations at the extremes of the covariates analysed. In addition, data for several years were combined to give one data set for each fishery. Finally, no environmental data were included in the analysis and, as reported by Millar (2000), factors such as water temperature may have a significant effect on the distribution (and therefore catch) of demersal species. The degree to which these results can be incorporated into a management plan is unclear. They may be able to give direction, but not provide specific answers to questions. For example, although an increase in hake discarding with an increase in catch size has been observed, it would be totally impractical to suggest that catch size should be limited to minimise discarding.

The most useful application of the results probably comes from the spatial (latitude, longitude and depth) and temporal covariates (month). Prior to the analysis, it was expected that month would play an important part in hake discarding and bycatch utilisation. This is because fishing strategies change as the allocation is used up. However, the time of year only appeared to significantly affect hake discarding in the inshore South Coast hake-directed fishery. It is likely that the size or class of allocation, which was not investigated, will also affect discarding practices. The absence of a trend in West Coast vessels may reflect the fact that the data were obtained from large companies with bigger allocations. These companies are able to divert vessels to different areas or species when hake catch rates are high, giving them more control over their bycatch management than the smaller companies observed on the South Coast. To clarify this, the effect of allocation on discarding behaviour should ideally be investigated.

It is clear that the dynamics of bycatch utilisation and discarding is extremely varied and many factors affect whether a given fish is retained or discarded. Although some factors affecting bycatch utilisation were investigated, many other factors such as the size structure of the hake catch, the fishing strategy of a given company or the value of a particular bycatch species in a given month may also play a role. To fully understand the dynamics of bycatch and discarding, these factors should ideally be included in future programmes.

An understanding of the dynamics of bycatch utilisation and discarding is an important aspect of effective bycatch management. The previous two

Chapters outlined the scale of the bycatch "problem", and this Chapter described and explained some of the factors affecting the fate of the bycatch component. The following Chapter will investigate the biology and stock status of monkfish, an important bycatch species, to illustrate the impact of fishing on non-target or bycatch stocks. The knowledge gained will be used to suggest some ways to manage bycatch in the South African demersal trawl fishery (Chapter 6).

Chapter 5 - The biology, distribution and preliminary stock assessment of the monkfish *Lophius vomerinus* in South Africa.

Introduction

The monkfish *Lophius vomerinus* is the most common of the five Lophiid species that occur in South African waters (Smith and Heemstra 1986). It has been recorded in 64.0% and 34.3% of research trawls that have been undertaken on the west and south coasts of South Africa (Marine and Coastal Management (MCM), unpubl. data), respectively. Although no formal directed fishery currently exists for this species in South Africa, it is a sought after bycatch species in the hake-directed demersal trawl fishery. Approximately 7 000 tons is landed per annum (compared to some 150 000 tons of hake). Due to the high price commanded by monkfish, and the fact that no catch limit has been issued for this species, small operators with limited hake allocations commonly target it. Periodically, larger operators may divert one or two vessels to target monkfish when hake availability is high, to ensure that their processing plants are not over-supplied with hake.

Historically, there has been some confusion regarding the taxonomic status of the Southern African taxon of *Lophius*. Prior to the revision of the genus by Caruso (1983, 1985), it was regarded as a sub-population of the European monkfish *Lophius piscatorius*. Caruso (1983, 1985) concluded that the South African monkfish was a distinct species that was separate from *L. piscatorius*, and therefore assigned it to *Lophius upsicephalus*, Smith. Leslie and Grant (1990, 1991) - using molecular genetic techniques - confirmed that the South

African monkfish was not *L. piscatorius*. They further concluded that *Lophius upsicephalus* was a junior synonym of *Lophiomus setigerus* and therefore assigned the South African monkfish to *L. vomerinus*, Valenciennes. As a result of this taxonomic confusion, some of the literature refers to *L. vomerinus* as *L. piscatorius* and *L. upsicephalus*. To avoid confusion the name *L. vomerinus* will be used throughout this thesis and, where a different name was used in a cited reference, that name will be given in parentheses with the citation.

Despite the abundance of *L. vomerinus*, little is known about its general biology in South Africa. It is found around the South African coast from the Orange River in the west, to Durban on the East Coast. The species is generally found over sandy substrates at depths ranging between 50m and 500m (MCM, unpublished. data). Griffiths and Hecht (1986: *L. upsicephalus*) used ground sagittal otoliths to make a preliminary investigation into the age and growth of monkfish on the South Coast. They found the otoliths difficult to interpret, due to the recurrence of irregular numbers of translucent and opaque zones within each annulus. Maartens *et al.* (1999) investigated several techniques for ageing monkfish off Namibia, and concluded that the illicium was the best structure for ageing the species. Field (1966: *L. piscatorius*) described the feeding mechanism and Benincasa (1983: *L. upsicephalus*) and Macpherson (1985: *L. upsicephalus*) investigated the feeding biology. Based upon survey data, Badenhorst and Smale (1991) described the length-frequency distribution and abundance of the species off the South Coast.

This chapter describes the age and growth parameters, reproductive and feeding biology and distribution of monkfish in South African waters. Due to the paucity of biological information, no stock assessment has previously been undertaken for this species. Therefore, a basic per-recruit model for the West Coast stock is also presented.

Material and methods

Observers aboard commercial trawlers operating along the west coast of South Africa (between Hondeklip Bay and Cape Agulhas, Fig. 5.1), from January 1997 to December 1998, made monthly collections of specimens for biological analysis. The specimens were kept on ice for the duration of the trip and either dissected on the day of landing or frozen for later analysis. Date, trawl position and depth were recorded for each sample. Additional samples were collected during routine biomass surveys aboard the FRS *Africana* during April and September 1997 (on the South Coast between Cape Agulhas and Port Alfred - 33°35'S, 26°53'E) and January and February 1998 on the West Coast. Commercial trawlers operating on the West Coast use a codend mesh of 110 mm. On average, trawling duration was 120 minutes. The FRS *Africana* uses a 180-ft (55 m) German bottom trawl with a codend liner of 35 mm mesh and, when possible, the trawls last 30 minutes. Badenhorst and Smale (1991) described the research survey areas and sampling procedures.

A total of 1259 *L. vomerinus* was sampled from commercial catches on the West Coast between January 1997 and December 1998 and during the

January / February 1998 research survey. In all, 81 samples were obtained during the April and September 1997 research surveys on the South Coast. All commercial sampling locations are presented in Fig. 5.1, and a summary of the size range of males, females and unsexed animals from each source is presented (Table 5.1).

Total mass (*TM*, g) and total length (*TL*, mm for commercial samples and nearest cm *TL* for survey samples), measured from the lower jaw symphysis to the tip of the tail (with the mouth held shut), were recorded for each fish. The illicium was removed and stored dry in a manila envelope. Each specimen was sexed, the gonads and liver removed and weighed to the nearest gram and the gonads visually staged. Maturity stages were assigned and based on gonad colour, size, degree of vascularisation and the presence or absence of eggs or sperm (Table 5.2).

The remaining viscera were removed and the eviscerated animal was re-weighed (eviscerated mass, *EM*, g). Finally, the head was removed posterior to the 3rd cephalic spine and pectoral fins, and the headed length (*HL*, mm) and weight (*HM*, g) and anus-tail length (*ATL*, mm) were recorded.

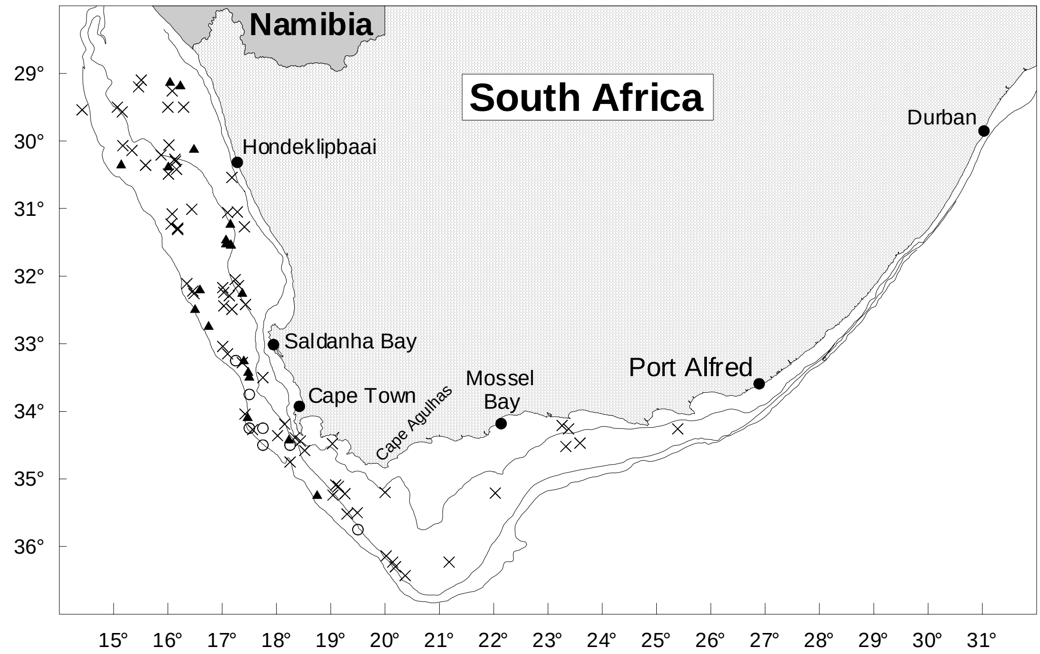


Fig. 5.1: Map of the South African coast, including the sampling locations of *L. vomerinus* collected for this study.
Symbols indicate the number of individuals sampled at each location. (× = 0-10 individuals, ▲ = 11-30 individuals, ○ = 31-120 individuals). Contour lines indicate the 100 m, 200 m and 500 m isobaths.

Table 5.1: The number, total length (*TL*, cm), mean and standard error of male, female and unsexed *L. vomerinus* obtained by observers aboard commercial trawlers between January 1997 and December 1998 and during research surveys aboard the *FRS Africana* in April and September 1997 on the South Coast and January and February 1998 on the West Coast, as well as historical data collected by the *FRS Africana* between 1986 and 1998 on the west and south coasts of South Africa.

Sample source	Sex	*N*	Size range (cm)	Mean ± *se*
Samples collected for this study (commercial and survey)				
West Coast	Female	479	10.2 – 82.5	38.3 ± 0.6
	Male	707	13.3 – 62.5	38.0 ± 0.4
	Unsexed	73	6.0 – 24.8	12.0. ±0.5
South Coast	Female	54	31.0 – 96.0	60.4 ± 1.8
	Male	27	22.0 – 72.0	48.8 ± 2.2
Historical survey data				
West Coast	Female	746	14.0 – 101.0	44.1 ± 0.6
	Male	642	17.0 – 67.0	40.5 ± 0.4
	Unsexed	7	8.0 – 17.0	10.7 ± 1.2
South Coast	Female	302	18.0 – 96.0	51.9 ± 0.8
	Male	219	16.0 –72.0	46.3 ± 0.6

Table 5.2: Description of the maturity stages of the gonads of male and female monkfish based on macroscopic observations.

Stage	Description
	Females
Immature	White, relatively small, ribbon-like, appear empty, no vascularisation
Developing	White, ribbon-like, vascularisation begins
Active	Turning orange, small eggs begin to form inside the tissue
Ripe	Ovary is full of gelatinous egg mass. Eggs approximately 2 mm in diameter. Ovaries fill body cavity
Spent	Highly vascularised, tissue appears very granular
Spent/ inactive	Similar to developing but distinctly orange, vascularisation clearly seen
	Males
Immature	Small and white, very soft, distinct grove along dorsal edge
Developing	Creamy-white, large and firm, vascularisation begins
Active	Blotchy cream, sections of testis become splotchy and vascularised, small amount of sperm present when testis is dissected
Ripe	Dark cream. Testes are distorted in shape, like an overfilled sausage. Highly vascularised, copious amount of sperm present
Spent	Dark cream in colour, highly vascularised. Small amount of sperm present
Spent/ inactive	Creamy-white, vascularised, small amount of sperm present

The *L. vomerinus* collected by observers aboard commercial vessels were stored whole on ice, which was not cold enough to arrest digestion. As a result, the stomach contents of these specimens could not be identified. Therefore, the analysis of diet was based on the stomach contents of specimens collected during research surveys. Biological information including length (cm *TL*), weight (g), sex and stomach contents was extracted from the survey database for 1395 West Coast individuals (from surveys between 1986 and 1997) and 521 South Coast individuals (from surveys between 1988 and 1996). Stomach contents were identified to the lowest possible taxon and for each prey group, the mass and number of items was recorded. Where possible, individual prey items were weighed and measured. A stomach containing multiple items of the same species was classed as containing multiple items.

Length frequency information was also extracted from the survey database for 1112 and 792 West and South Coast individuals, respectively.

Length-weight regressions

In order to investigate the morphometric relationships of *L. vomerinus*, headed length, anus-tail length, total mass, headed mass and eviscerated mass were regressed against total length for male, female and both sexes combined. The total mass was regressed against the eviscerated mass and headed mass. A likelihood ratio test was used to determine whether significant differences existed between males and females.

Age and growth

Griffiths and Hecht (1986; *L. upsicephalus*) found monkfish otoliths difficult to interpret, because of the recurrence of irregular numbers of translucent and opaque zones within each annulus. Given these problems, and the success reported by Maartens *et al.* (1999) using illicia, a modified first dorsal fin spine, the illicium was selected to age the South African population. Illicia were collected from 995 individuals (626 males, 133-890mm *TL*; 369 females, 105-930mm *TL*) from the West Coast and 80 individuals (27 males, 53 females) from the South Coast (from commercial and research catches). South Coast individuals ranged in size from 220-960 mm *TL*.

Illicia were trimmed to approximately 2 cm in length from the base, skinned and embedded in a clear casting resin. Each illicium was sectioned 0.5 cm from the base with a double-bladed diamond-edged saw. The section (approximately 0.2-0.5 mm thick) was mounted in DPX on a microscope slide (Maartens *et al.* 1999), and viewed under transmitted light using a compound microscope at 40X magnification.

The age of each fish was estimated by counting the concentric dark and light ring band pairs in the illicia. The periodicity of band formation was investigated by noting the optical characteristics of the illicium edge (Maartens *et al.* 1999). Illicia were aged by 2 independent readers and the reproducibility of the counts was measured using the index of average percentage error *(IAPE*) method, which enables the consistency between the age readings to be assessed (Beamish and Fournier 1981). Each reader counted the illicia bands twice without reference to fish size or previous counts. If the two counts differed, a third count was taken. If the third count corresponded to either of the first two, that count was accepted. If all three counts were different but consecutive the middle reading was taken, otherwise the specimen was rejected.

Band counts were obtained from 386 West Coast males and 236 West Coast females and from 50 South Coast animals. Due to the small sample size obtained on the South Coast, the sexes were pooled. The PC-Yield 2.2 (Punt 1992) package was used to estimate the growth parameters and their variance. PC-Yield tests the residuals for randomness using a non-parametric, one sample runs test (Draper and Smith 1966) and for homoscedasticity using a Bartlett's test (Bartlett 1937). Variance estimates were calculated using (conditioned) parametric bootstrap sampling (Efron 1981), with 500 bootstrap iterations. Standard errors and 95% confidence intervals were constructed from the bootstrap data using the percentile method described by Buckland (1984).

Two growth models were fitted to the data:- the von Bertalanffy growth model:

$$L_t = L_\infty (1 - e^{-K(t - t_o)}) \quad (1)$$

and the four-parameter Schnute growth model (Schnute 1981):

$$L_t = \left[L_1^{\,b} + \left(L_2^{\,b} - L_1^{\,b} \right) \left(\frac{1 - e^{a(t - t_1)}}{1 - e^{a(t_2 - t_1)}} \right) \right]^{1/b} \tag{2}$$

where:

K is the Brody growth coefficient

L_∞ is the theoretical maximum (asymptotic) length

t_0 is the theoretical length at age zero

L_t, L_1 and L_2 are the lengths at *t*, t_1 and t_2, respectively

a and *b* are the Schnute growth parameters

t_1 and t_2 are the youngest and oldest ages recorded in the sample respectively. The von Bertalanffy parameters (L_∞, *K* and t_0) were calculated for the Schnute fits using the equations provided by Schnute (1981):

$$K = a \tag{3}$$

$$t_0 = t_1 + t_2 - \frac{1}{a} Ln \left[\frac{\left(e^{at_2} y_2^{\,b} \right) - \left(e^{at_1} y_1^{\,b} \right)}{y_2^{\,b} - y_1^{\,b}} \right] \tag{4}$$

$$L_\infty = \left[\frac{\left(e^{at_2} y_2^{\,b} \right) - \left(e^{at_1} y_1^{\,b} \right)}{e^{at_2} - e^{at_1}} \right]^{\frac{1}{b}} \tag{5}$$

The most suitable growth model was chosen based upon the randomness of residuals, and the lowest sum of squares using absolute and relative error structures (Punt 1992).

Reproduction

Some fish build up fat and protein reserves in the liver prior to spawning (Hoar 1957). Therefore, preparation for spawning could be accompanied by an increase in the relative weight of the liver and gonads, and at the onset of spawning, there may be a decline in the relative weights of both. In order to investigate reproductive periodicity, the monthly gonadosomatic index (*GSI*) and hepatosomatic index (*HSI*) were calculated. These were defined as:

$$GSI = \frac{GM}{TM} \times 100 \qquad (6)$$

$$HSI = \frac{LM}{TM} \times 100 \qquad (7)$$

where *GM* was the gonad mass (g), *LM* was the liver mass (g) and *TM* was the total mass (g). Immature animals were excluded from this analysis. Livers were excised from 276 males and 148 females and gonads from 323 males and 194 females.

Length-at-maturity was modelled using a 2-parameter logistic ogive, which was described as:

$$P_l = \frac{1}{1 + \exp^{-(L - L_{50})/\delta}} \qquad (8)$$

where P_l was the percentage of mature fish (stages two to five) at length L, L_{50} was the length at which 50% of the fish were sexually mature and δ was the width of the ogive.

Diet

No single method of assessing prey importance is wholly unbiased (Hynes 1950; Windell and Bowen 1979; Hyslop 1980). Numerical methods are biased towards small organisms eaten in large numbers and gravimetric measurements are biased towards large, heavy prey items. Frequency of occurrence is biased towards prey items that take longer to be digested, e.g. large items and those with hard parts such as otoliths. Prey importance was assessed by: percentage frequency of occurrence (*%FO*), which provided an indication of how often a particular prey item is ingested; percentage by mass (*%M*), which gives a measure of the energy contribution of a prey item; and percentage by number (*%N*), which gives an indication of the availability of the prey item. An index of relative importance (*IRI*), which allows for comparisons between the various prey components, was calculated by multiplying the *%FO*, *%M* and *%N*.

Meyer and Smale (1991a, b) demonstrated that for many South African demersal species there is a strong correlation between predator and prey size. Therefore, change in the diet with increasing predator size was investigated. Three size categories, based upon the maturity ogives estimated in the reproductive study, were defined. These categories were juveniles (< L_{50}, 37 cm *TL*), sub-adults (L_{50} - L_{100}, 37-47 cm *TL*) and adults (> L_{100}, 47 cm

TL). In addition, the relationship between predator size and the size of its hake prey (the most common prey species) was investigated. Unfortunately, there was insufficient data available to investigate predator/prey size relationships for other species.

Distribution

Monkfish distribution was investigated using length frequency data collected on research surveys. For each trawl, the abundance (number caught per hour) was calculated for each of the three life history stages defined in the diet study (juvenile, sub-adult and adult). Trawls were grouped by coast and survey month – West Coast Jan/Feb, West Coast June/July, South Coast April/May and South Coast Sept/Oct and plotted using ArcView 3.2.

Per-recruit analysis

Several methods for assessing stock status are available. Most of these *e.g.* biomass dynamic models require an abundance index, such as annual catch rate (CPUE). However, estimating CPUE for bycatch species is problematic, as apparent trends may be a reflection of changes in factors such as fishing strategy, (*e.g.* changes in the relative proportion of effort spent fishing in areas of high bycatch abundance), the distribution of the target species, or fishing gear. In addition, the proportion of the bycatch species landed fluctuates with market demand, although this may not apply to a high-value species such as monkfish.

A preliminary study aimed at deriving a CPUE series for monkfish did not yield realistic results (Leslie, unpubl. data). A more detailed study of kingklip, another high-value bycatch species in this fishery, was also unable to derive a usable CPUE series (Robertson and Butterworth 2002). Therefore, simple yield-per-recruit (YPR) and spawner biomass-per-recruit (SBR) models were used, as they do not require an abundance index. Stock assessment was undertaken for the West Coast only, where approximately 92% of monkfish were landed (Stuttaford 2001). There was paucity of biological information from the South Coast.

General

Basic data used for the per-recruit analysis in this study included:

- Total length measurements of monkfish landed by commercial trawlers during 1993, 1994 and 1996, collected by MCM personnel. Due to technical problems, there were few landings measured in 1997 and 1998.
- The age length-key presented in Table 5.3. This was based upon the age and growth information collected during the biological study, the length/mass relationship, von Bertalanffy growth curve and size-at-maturity information presented in this chapter.
- Information on the length frequency of monkfish caught, but subsequently discarded - as recorded by observers and extracted from the SANCOR observer database.

Total mortality Z was estimated using a catch curve analysis (Ricker 1975) and the following equation described by Butterworth *et al.* (1989):

$$Z = \ln\left[1 + \frac{1}{(a_m - a_f)}\right] \tag{9}$$

where a_f is the age at full recruitment and a_m is the mean age of all fully recruited fish sampled. An average of the two values of Z was used in the subsequent analysis.

Natural mortality (M) was estimated using three methods. The most commonly used method is that of Pauly (1980), which is based largely on the parameters of the von Bertalanffy growth equation:

$$\ln M = 0.0152 - 0.279 \ln L_\infty + 0.6543 \ln K + 0.463 \ln T \tag{10}$$

where L_∞ is the theoretical maximum (asymptotic) length, K is the Brody growth coefficient, and T is the temperature at the sea bed (estimated to be 9°C on the west coast of South Africa). The following two equations were also used to obtain estimates of M:

$$\ln M = \ln 3 + \ln L_\infty + \ln K + \ln\left(1 - \frac{L_t}{L_\infty}\right) - \ln L_t \quad \text{(Roff 1984)} \tag{11}$$

$$\frac{M}{K} = 1.5 \quad \text{(Jensen 1996)} \tag{12}$$

where:

L_t is the size at 50% maturity, and other symbols are as previously defined. An average value of M from the three methods was used in the subsequent analysis.

Age-at-maturity was calculated by using the length-at-maturity ogives that were derived from the reproductive study. These were converted to age-at-maturity and the percentage maturity averaged from males and females was used as the percentage maturity for any given age class. Fishing selectivity was estimated using data derived from retained and discarded monkfish samples collected by observers.

Yield per recruit (YPR), spawner biomass at age *t* (SBR_t), and spawner biomass per recruit (SBR) were determined according to the following equations:

$$YPR = \sum_{t=0}^{t_{max}} \frac{(S_i \times F)}{(S_i \times F) + M} \times \left(e - \sum_{i=0}^{t-1}((S_i \times F) + M) \right) \times \left(1 - e^{-((S_i \times F) + M)}\right) \times W_t \quad (13)$$

$$SBR_t = W_t \times \left(N_{t-1} \times e^{-(M + (F \times S_i))}\right) \times B_t \quad (14)$$

$$SBR = \sum_{t=o}^{t_{max}} SB_t \quad (15)$$

where W_t is the weight (g) at age *t* (calculated from the von Bertalanffy growth equation and length-weight data), N_{t-1} is the number of survivors from the previous age group, *M* is the natural mortality, *F* the instantaneous rate of fishing mortality, S_i is the fishing selectivity (see Table 5.4), and B_t is the proportion of mature fish at age *t* (see Table 5.4). Several biological reference points were calculated from the SBR and YPR analyses. These include the fishing rates corresponding to 25% and 40% of $SBR_{F=0}$ from the SBR analysis and $F_{0.1}$ from the YPR analysis.

Results

Length-weight regressions

Regressions of total mass versus total length, eviscerated mass and headed mass and eviscerated mass, headed mass, anus-tail length and headed length versus and total length for male and female and both sexes combined are shown in Table 5.5. Likelihood ratio tests demonstrated that there was a significant difference ($p < 0.05$) between males and females for all relationships, except for *logTL v. log HM* ($p > 0.05$). Although not used in this report, these relationships are reported here as they are useful to fisheries biologists.

Age and growth

An *IAPE* of 6.3% between the two readers' age estimates was calculated, indicating that the counts obtained for each fish by the readers were relatively similar. The relative error model provided the best fit to the data for West

Coast males and females, as well as for the data where the sexes were combined (West and South coasts). Parameter point estimates, standard errors (*SE*) and 95% confidence levels (*CI*) for parameters of both growth models are shown in Tables 5.6a & b. The error sum of squares was similar between the Schnute and von Bertalanffy models. As fewer parameters are required, the latter was used to model age. The observed data and fitted von Bertalanffy growth curves are presented in Figs. 5.2a & b. A likelihood ratio test (Draper and Smith 1966), using size-at-age data, showed a significant difference ($p < 0.05$) between males and females on the West Coast. The optical characteristics of the illicium edge suggested that one dark and one light band is deposited per annum (Fig. 5.3).

Reproduction

The gonads of *L. vomerinus* were similar those of other *Lophius* species (*e.g.* Armstrong *et al.* 1992). The sex of juveniles is difficult to determine, as both the ovaries and testes are small, transparent and elongate. The paired ovaries are long and ribbon-like and the tissue is highly coiled within the body cavity. In immature and resting individuals, the ovaries are extremely small. In contrast, the ripe ovary may take up the majority of the body cavity. A gonad mass of 2.7kg (35% of total body mass) was obtained for one female caught in September 1998 (*TL* 71 cm, *TM* 7.7 kg). The paired testes are long sausage-shaped organs. In immature males, these are soft and white, becoming firm and cream-coloured in adults.

Female monthly *GSI* values showed a peak in September, but a similar pattern was not seen in the males (Fig. 5.4). Length-at-50%-maturity was estimated at 376 mm and 369 mm *TL* for males and females respectively (Fig. 5.5). Monthly *HSI* values revealed no clear patterns for either sex (Fig. 5.4).

Diet

Of the 1395 monkfish sampled on the West Coast, 617 (44.2%) had stomachs containing food and 778 (55.8%) were empty. On the South Coast, of 523 animals, 220 (42.1%) had stomachs containing food and 303 (57.9%) were empty. Each stomach contained few prey items, and the average number of items per stomach was 1.0, 2.5 and 1.2 for West Coast juveniles, sub-adults and adults respectively, and 1.6, 1.7 and 1.9 for the respective South Coast juveniles, sub-adults and adults.

The effect of life history stage on the diet was investigated by classifying the animals by age as juvenile, sub-adult or adult (Tables 5.7a & b). Demersal fish such as hake and dragonet *Paracallionymus costatus* dominated the diet, with pelagic teleosts contributing the majority of the remainder. For both coasts, a shift from small prey species such as *P. costatus*, to large species such as hake, was observed with an increase in body size. A significant increase in the size of *Merluccius* sp. prey was observed with an increase in monkfish body size ($F = 76.591$, $df = 1,78$, $p < 0.05$). Cannibalism was limited to three observations on the West Coast and one observation on the South Coast.

Distribution

The abundance of monkfish during April/May and Jan/Feb on the south and west Coasts of South Africa, respectively, is presented in Figs 5.6 and 5.7. Since the observed abundance for these two periods was similar to that of the Sept/Oct and June/July periods, no additional figures are provided.

Per-recruit analysis

Age distributions and the corresponding catch curves are presented in Fig. 5.8. Values of Z calculated for 1993, 1994 and 1996 (separately) using catch curve analysis gave similar results (0.52 yr^{-1}, 0.58 yr^{-1} and 0.54 yr^{-1}, respectively) and data were pooled. Z was estimated at 0.54 yr^{-1} using the catch curve analysis and 0.58 yr^{-1} using the equation of Butterworth *et al.* (1989), giving an average total mortality estimate of 0.56 yr^{-1}. The estimates of M obtained were 0.20 yr^{-1}, 0.29 yr^{-1} and 0.17 yr^{-1} using the equations of Pauly (1980), Roff (1984) and Jensen (1996), respectively, giving an average of 0.22 yr^{-1}. The current fishing mortality was estimated to be 0.36 yr^{-1}. Since the estimation of natural mortality can be difficult, the per-recruit analysis was performed using additional values for M of 0.15 yr^{-1} and 0.25 yr^{-1} (Griffiths 1997b).

Spawner biomass per recruit and yield per recruit curves for monkfish for the three levels of natural mortality can be found in Fig. 5.9a & b. Spawner biomass declined rapidly with increasing F. Although the maximum SBR values varied widely for the three values of M, there was little variation in the estimates of F_{SB40} (0.13-0.15 yr^{-1}) and F_{SB25} (0.12-0.24 yr^{-1}). Current SBR was estimated at 14.8%, substantially below the biological reference-point threshold level of F_{SB35}. The value of $F_{0.1}$, the fishing mortality rate where the slope of the YPR function is 0.1 times the initial slope was calculated as 0.22 yr^{-1}.

Table 5.3: Age-length key for monkfish sampled from the west coast of South Africa between January 1997 and December 1998.

Size class (cm)	Number of fish at age (years)																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
0-7	1																
8-9																	
10-11	3																
12-13	3	1	1														
14-15		2															
16-17		5	3					1									
18-19		2					1										
20-21			2	2			1										
22-23		2	6	7	1		1										
24-25		1	7	12	2												
26-27			4	19	10	2	2										
28-29			4	11	11	6	5	1	1								
30-31			5	16	19	12	6	3	1								
32-33			1	7	12	10	8	3	1								
34-35				4	12	16	3	2	3	2							
36-37					3	7	15	4	5	1							
38-39			1	1	5	4	8	9	5	2	1						
40-41				1	1	8	6	13	15	2	1						
42-43					2	3	7	14	13	4	2						
44-45					2	7	6	7	12	4	4						
46-47				1	1	4	5	6	8	3	3						
48-49			1		1	2	1	5	8	6	3	1					
50-51				1		1	1	5	9	7	2			1			
52-53						1	1	5		5	2		3	1			
54-55					1		1	3	4	5	4	1	1				
56-57						1			1	4	3	1		2	1		1
58-59						1	1	1	2	6	2	1					
60-61									2	3	2	2			1		
62-63								2	2	2		1	1	3			
64-65										2	1	1			1		
66-67									1			1					
68-69							1			1		2					
70-71										1	1		1				
72-73											2	1					
74-75																	
76-77																	
78-79													1				

Table 5.4: Proportion-at-age (where 1 refers to 100% mature) of mature monkfish determined using length-at-maturity ogives and age-at-maturity data and the fishing selectivity-at-age (where 1 refers to 100% selection by the net) determined from information on the length frequency of discarded individuals.

Age (years)	Proportion of fish mature	Fishing selectivity
1	0	0.01
2	0	0.1
3	0	0.18
4	0.05	0.38
5	0.2	0.63
6	0.5	1
7	0.75	1
8	0.9	1
9	1	1
10	1	1
11	1	1
12	1	1
13	1	1
14	1	1
15	1	1
16	1	1
17	1	1

Table 5.5: Summary of the parameters obtained from the regression analysis of total length (*TL*) eviscerated mass (*EM*) and headed mass (*HM*) against total mass (*TM*), and total length against eviscerated mass, headed mass, anus-tail length and headed length for male, female and both sexes combined for monkfish.
* indicates that there was a significant difference between males and females ($p < 0.05$).

Parameter	Relationship	r^2	*n*	Range (*TL* mm)	Mean (*TL* mm) ± *se*	Significance
Total mass						
Female	$0.00001\ TL^{3.0346}$	0.97	322	102-767	365.3 ± 6.9	
Male	$0.00002\ TL^{2.9604}$	0.97	516	164-623	381.9 ± 4.0	
Combined	$0.00001\ TL^{3.0204}$	0.96	838	102-767	375.5 ± 3.6	*
Total mass						
Female	1.183 *EM* + 11.838	0.99	157	152-767	386.0 ± 8.9	
Male	1.150 *EM* + 34.220	0.96	373	177-596	399.4 ± 4.1	
Combined	1.169 *EM* + 20.205	0.98	534	142-767	394.1 ± 4.0	*
Total mass						
Female	3.499 *HM* + 10.862	0.98	309	149-767	362.1 ± 6.9	
Male	3.162 *HM* + 57.162	0.95	508	164-623	381.6 ± 4.0	
Combined	3.379 *HM* + 16.385	0.97	862	67-767	361.1 ± 4.0	*
Eviscerated mass						
Female	$0.00008\ TL^{3.0611}$	0.98	309	152-825	401.5 ± 7.5	
Male	$0.00003\ TL^{2.8536}$	0.95	550	133-625	391.2 ± 3.8	
Combined	$0.00001\ TL^{2.9582}$	0.96	859	133-825	394.9 ± 3.6	*
Headed mass						
Female	$0.00002\ TL^{3.0812}$	0.98	312	102-767	364.4 ± 7.0	
Male	$0.00003\ TL^{3.0582}$	0.97	518	164-625	384.6 ± 4.0	
Combined	$0.00003\ TL^{3.0683}$	0.97	830	102-767	377.0 ± 3.7	
Anus-tail length						
Female	0.428 *TL* + 9.337	0.99	316	149-767	365.1 ± 7.0	
Male	0.444 *TL* + 5.233	0.98	522	164-625	384.5 ± 4.0	
Combined	0.442 *TL* + 7.665	0.98	838	149-767	377.2 ± 3.7	*
Headed length						
Female	0.649 *TL* + 0.723	0.99	313	149-767	365.6 ± 7.1	
Male	0.661 *TL* – 1.264	0.99	519	164-625	384.3 ± 4.0	
Combined	0.645 *TL* + 0.209	0.99	832	149-767	377.3 ± 3.7	*

Table 5.6: Growth parameter point estimates, associated standard errors (*SE*) and 95% confidence intervals (*CI*) for a) male, female and combined sex data collected off the West Coast and b) combined sex data collected off the South Coast for *Lophius vomerinus* using the Schnute and von Bertalanffy growth models.
See text for definition of symbols.

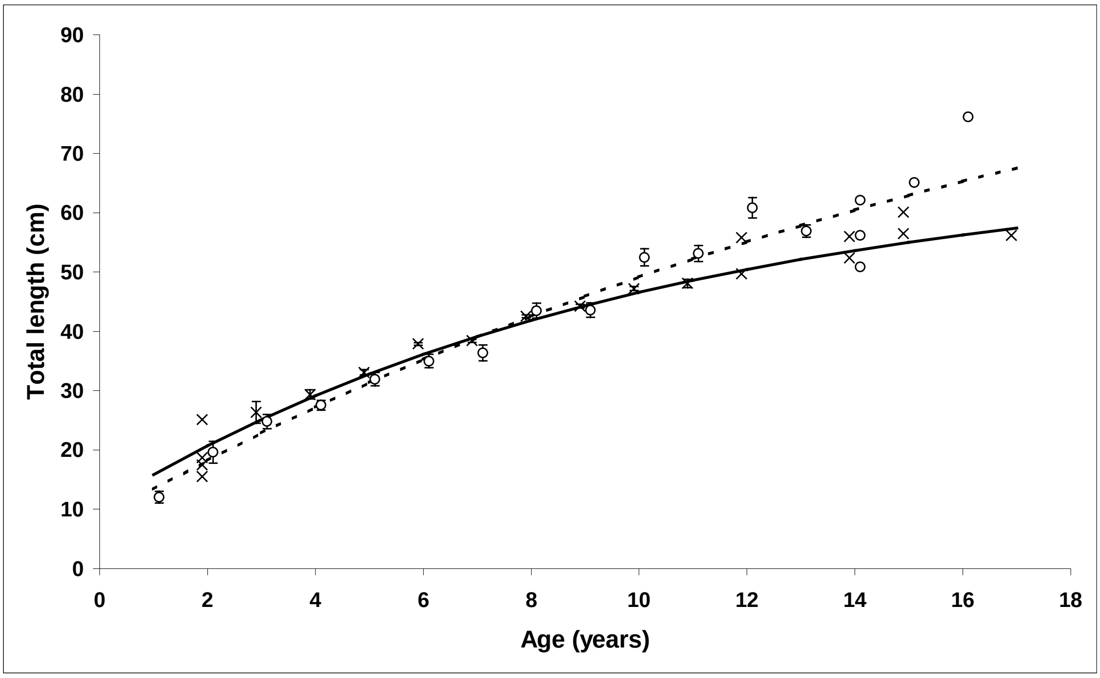
a)

	4-parameter Schnute growth curve			**von Bertalanffy growth curve**		
Parameter	Estimate	SE	*CI*	Estimate	SE	*CI*
Females (*n*=236)						
L_∞	98.06			110.23	5765.02	[83.55, 27229.13]
t_o	-1.82			-1.54	0.09	[-4.00, -1.05]
K (= a)	0.07	0.09	[-0.13, 0.25]	0.05	0.02	[0.000102, 0.08]
b	0.90	0.77	[-0.48, 2.43]			
L_1	13.43	0.79	[12.15, 15.00]			
L_2	64.52	3.76	[57.87, 72.68]			
t_1	1					
t_2	16					
Males (*n*=386)						
L_∞	81.41			68.50	911.97	[56.00, 119.47]
t_o	-0.28			-1.69	0.90	[-3.74, -0.51]
K (= a)	0.05	0.03	[0.02, 0.11]	0.10	0.03	[0.04, 0.16]
b	1.57	0.25	[1.22, 1.66]			
L_1	20.24	1.10	[18.21, 22.53]			
L_2	58.40	2.47	[53.85, 63.08]			
t_1	2					
t_2	17					
Combined (*n*=622)						
L_∞	85.45			70.12	4.62	[63.39, 80.95]
t_o	0.06			-0.80	0.18	[-1.19, -0.51]
K (= a)	0.07	0.05	[-0.04, 0.18]	0.11	0.01	[0.08, 0.13]
b	1.45	0.38	[0.65, 2.10]			
L_1	11.05	0.63	[10.02, 12.40]			
L_2	61.13	28.60	[55.61, 66.41]			
t_1	1					
t_2	17					

b)

Parameter	4-parameter Schnute growth curve			von Bertalanffy growth curve		
	Estimate	SE	*CI*	Estimate	SE	*CI*
South coast, combined (*n*=50)						
L_∞	119.74			77.97	1525.40	[68.53, 106.54]
t_o	3.33			1.64	0.62	[0.23, 2.48]
K (= a)	0.03	0.13	[-0.14, 0.35]	0.15	0.04	[0.08, 0.23]
b	2.41	1.37	[-0.79, 4.00]			
L_1	22.13	2.49	[17.62, 27.59]			
L_2	72.10	3.12	[65.23, 78.28]			
t_1	4					
t_2	17					

a)



b)

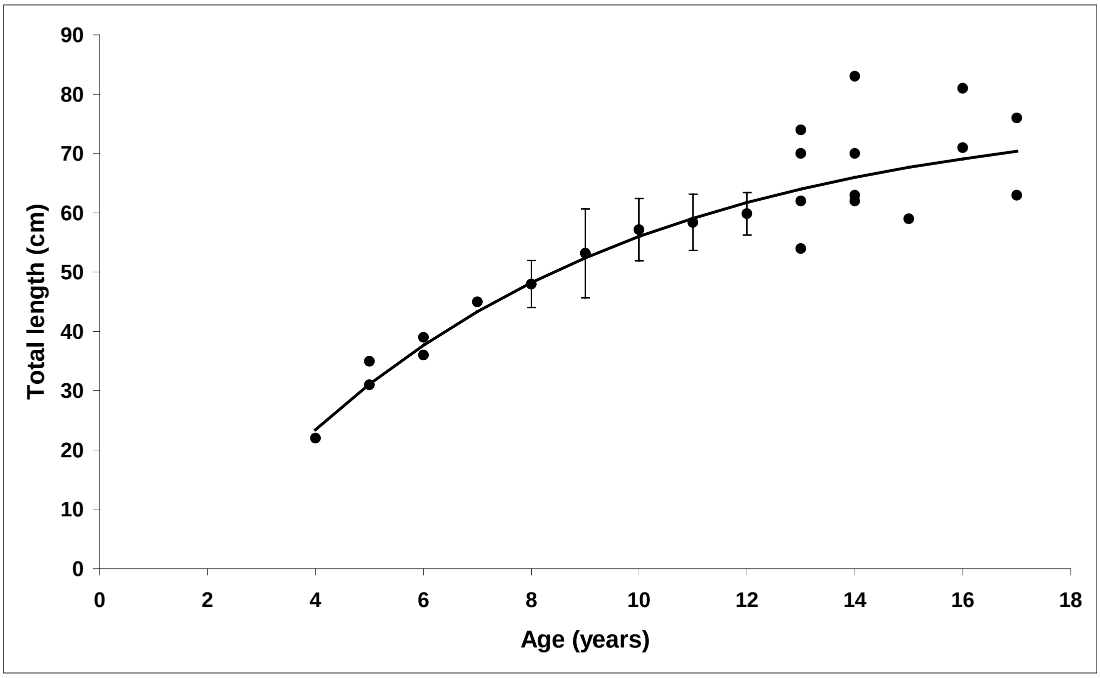


Fig. 5.2: Mean observed lengths-at-age and 95% confidence intervals of monkfish a) males (cross, *n* = 415) and females (open circle, *n* = 252) sampled off the west coast of South Africa and b) sexes combined (*n* = 50) sampled off the south coast of South Africa using sectioned illicia.
Growth models for males (solid line) and females (dotted line) and sexes combined were fitted using the von Bertalanffy growth model. For observations *n*<5, individual lengths-at-age were plotted.

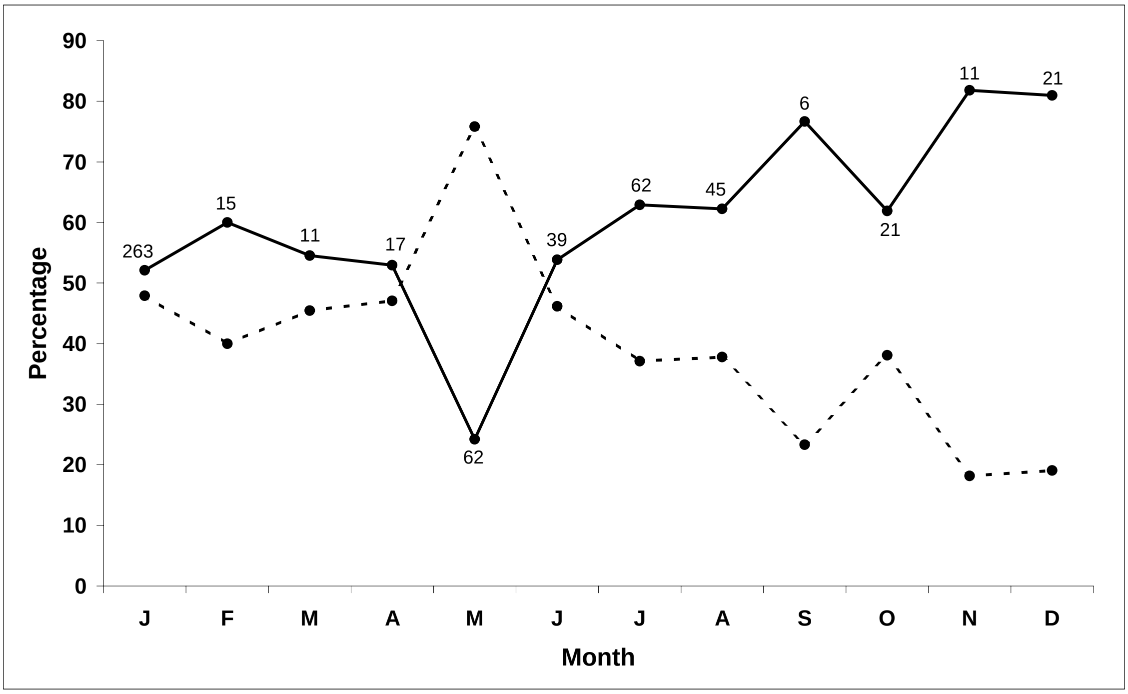


Fig. 5.3: Growth characteristics of the illicium edge for west coast monkfish, indicating the percentage of the monthly sample with a light edge (solid line) and a dark edge (dotted line).

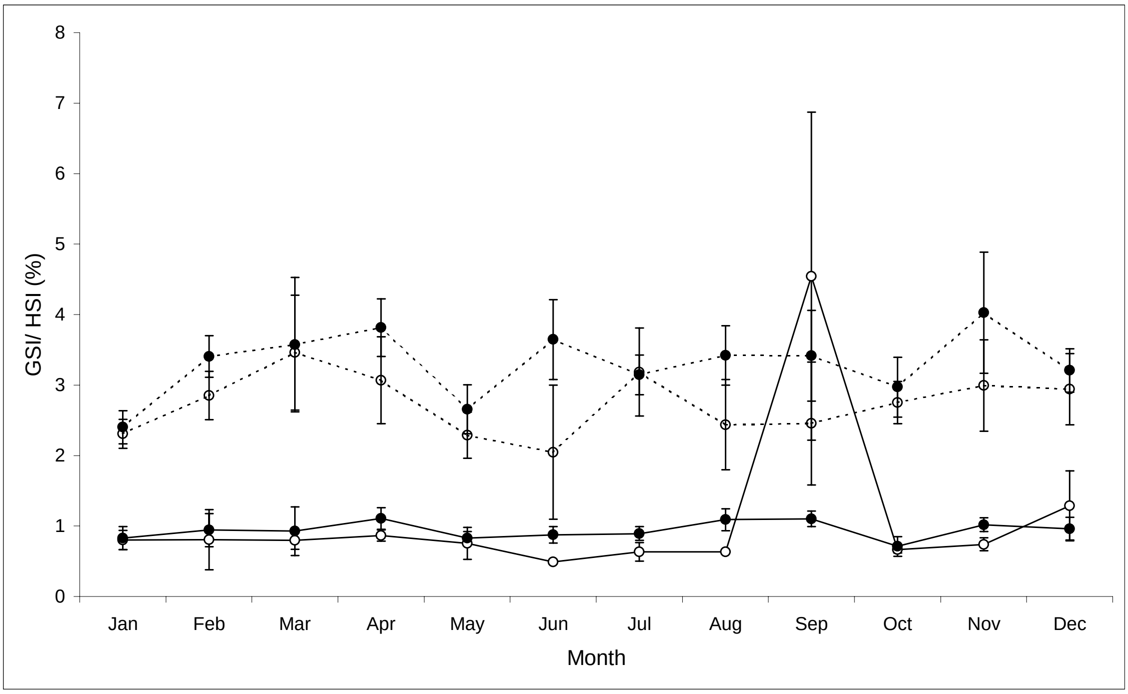


Fig. 5.4: Mean monthly gonadosomatic index (*GSI*, solid line) and hepatosomatic index (*HSI*, dotted line) values for male (closed circle and female (open circle) monkfish.
Vertical bars indicate 95% confidence intervals.

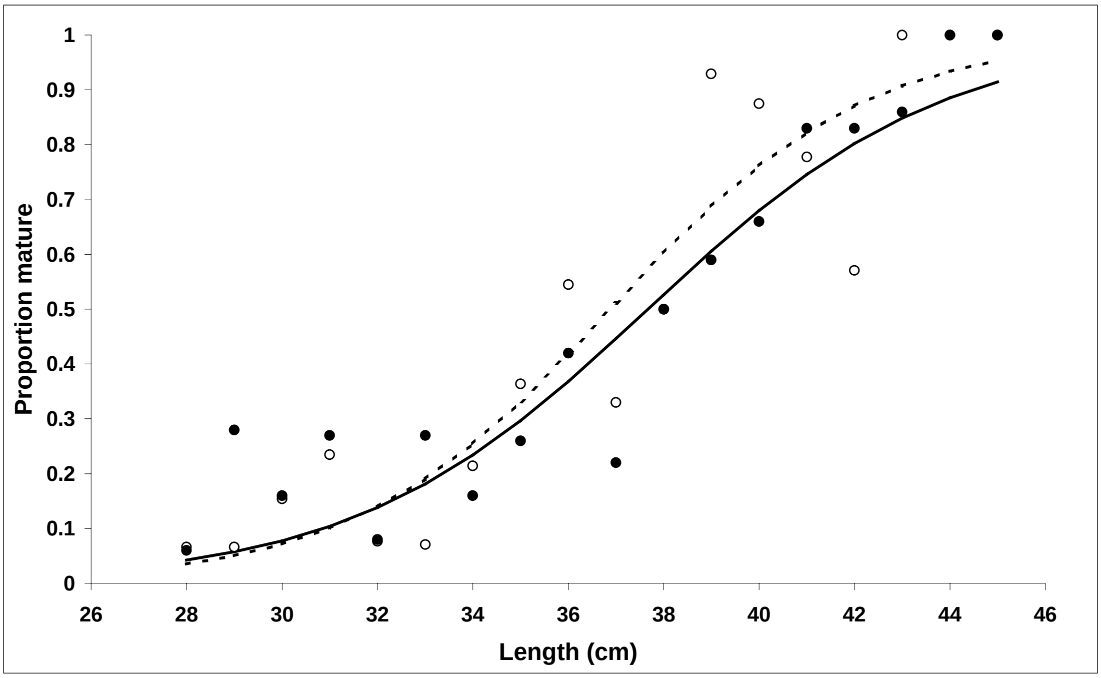


Fig. 5.5: Length-at-maturity ogives for male (solid line, closed circle; L_{50} = 376mm*TL*; δ = 3.09; *n* = 692) and female (dotted line, open circle; L_{50} = 369mm *TL*; δ = 2.68; *n* = 461) monkfish.

Table 5.7: Diet composition by percentage frequency of occurrence (*%FO*), percentage by mass (*%M*), percentage by number (*%N*) and Index of Relative Importance (*IRI*) for monkfish on a) the West Coast and b) the South Coast.
a) West Coast

	Juveniles (<37cm *TL*, n = 283)				Sub-adult (37-45 cm *TL*, n = 129)				Adult (>45 cm *TL*,n = 194)			
	%FO	*%M*	*%N*	*IRI*	*%FO*	*%M*	*%N*	*IRI*	*%FO*	*%M*	*%N*	*IRI*
TELEOSTEI												
Demersal												
Unid. demersal fish	22.3	7.3	13.8	470.6	16.3	4.4	9.8	231.1	22.2	7.3	19.8	601.2
Merluccius sp.	7.4	8.7	4.3	96.4	17.8	19.6	9.8	524.1	18.6	20.6	10.3	573.6
Merluccius paradoxus	9.5	19.2	17.1	345.6	13.2	25.6	9.4	461.3	8.2	10.4	5.7	132.5
Merluccius capensis	0.4	1.7	0.2	0.7	1.6	1.4	0.9	3.5	3.1	14.3	1.9	50.0
Paracallionymus costatus	19.1	5.9	16.8	433.3	12.4	2.7	8.0	133.0	3.6	0.5	5.4	21.4
Helicolenus dactylopterus	2.8	4.2	1.7	16.9	2.3	1.3	1.3	6.1	5.7	4.9	3.5	47.6
Gnathophis sp.	3.5	4.4	7.6	42.1	5.4	2.6	17.0	106.4	1.5	0.7	0.8	2.4
Unid. eel	-	-	-	-	-	-	-	-	0.5	1.7	0.3	1.0
Cynoglossus zanzibarensis	6.0	12.7	7.3	120.4	3.9	4.5	2.2	25.9	2.1	0.8	1.1	3.8
Austroglossus microlepis	0.7	0.9	0.4	0.9	-	-	-	-	-	-	-	-
Unid. macrourids	-	-	-	-	-	-	-	-	0.5	0.1	0.3	0.2
Caelorhinchus sp.	0.7	0.2	0.6	0.6	-	-	-	-	0.5	0.2	0.3	0.2
Caelorhinchus simorhynchus	1.8	1.8	1.1	5.0	2.3	4.4	1.3	13.3	4.1	3.1	2.2	21.8
Caelorhinchus braueri	-	-	-	-	-	-	-	-	0.5	0.1	0.3	0.2
Malacocephalus laevis	-	-	-	-	-	-	-	-	0.5	1.9	0.3	1.1
Trachurus trachurus capensis	1.1	2.0	0.6	2.8	4.7	11.6	2.7	66.3	5.7	8.2	3.0	63.2
Nemichthys sp.	-	-	-	-	-	-	-	-	0.5	0.0	0.3	0.2
Callanthias legras	-	-	-	-	-	-	-	-	0.5	0.2	0.3	0.3
Emelichthys nitidus nitidus	-	-	-	-	-	-	-	-	1.5	0.9	1.4	3.5
Sufflogobius bibarbatus	0.7	0.2	0.9	0.8	2.3	0.4	1.8	5.0	2.6	0.1	1.6	4.5
Physiculus sp.	0.4	0.2	0.2	0.1	-	-	-	-	-	-	-	-
Tripterophysis gilchristi	0.4	0.2	0.2	0.1	-	-	-	-	-	-	-	-
Lophius vomerinus	0.7	0.3	0.2	0.4	-	-	-	-	0.5	1.8	0.3	1.0
Chelidonichthys capensis	-	-	-	-	-	-	-	-	0.5	1.6	0.3	1.0

	%FO	*%M*	*%N*	*IRI*	*%FO*	*%M*	*%N*	*IRI*	*%FO*	*%M*	*%N*	*IRI*
Pelagic												
Unid. pelagic fish	2.5	2.9	1.5	11.0	3.1	1.6	1.8	10.4	5.2	1.7	2.7	22.6
Etrumeus whiteheadi	3.5	9.9	2.4	43.5	5.4	11.8	3.6	83.2	6.7	6.7	7.3	93.8
Engraulis capensis	2.8	3.0	3.0	17.0	4.7	5.8	10.7	77.0	2.6	4.2	15.5	50.7
Scomber japonicus	-	-	-	-	-	-	-	-	1.0	1.7	0.5	2.3
Unid. Pelagic larvae	-	-	-	-	-	-	-	-	0.5	0.3	5.4	3.0
Mesopelagic												
Photichthys argenteus	-	-	-	-	-	-	-	-	0.5	0.1	0.3	0.2
Epigonus sp.	-	-	-	-	-	-	-	-	0.5	0.3	0.3	0.3
CEPHALOPODA												
Unid. Cephalopod remains	0.4	0.1	0.2	0.1	1.6	0.0	0.9	1.4	-	-	-	-
Unid. Squids	0.7	0.2	0.4	0.5	-	-	-	-	4.1	0.3	2.7	12.4
Sepia sp.	1.4	0.2	1.1	1.8	3.1	0.5	9.4	30.5	1.0	0.2	0.5	0.8
Sepia australis	11.3	7.2	7.3	164.1	2.3	0.5	1.8	5.4	0.5	0.5	0.5	0.6
Loligo vulgaris	-	-	-	-	-	-	-	-	0.5	0.5	0.3	0.4
Todaropsis eblanae	-	-	-	-	0.8	1.0	0.4	1.1	1.5	1.1	0.8	3.0
Todarodes angolensis	-	-	-	-	-	-	-	-	0.5	2.1	0.3	1.2
Austrorossia mastogop	1.8	1.4	1.1	4.4	-	-	-	-	1.5	0.7	0.8	2.4
Inioteuthis capensis	-	-	-	-	0.8	0.1	0.4	0.4	-	-	-	-
Lolliguncula mercatoris	-	-	-	-	0.8	0.0	0.4	0.4	-	-	-	-
Unid. octopod	0.4	0.3	0.2	0.2	-	-	-	-	-	-	-	-
CRUSTACEA												
Unid. crustacean remains	0.7	0.1	0.4	0.3	0.8	0.0	0.4	0.3	-	-	-	-
Funchalia woodwardi	1.8	0.4	1.1	2.6	3.1	0.2	1.8	6.3	2.6	0.2	1.4	3.9
Pterygosquilla armata capensis	-	-	-	-	-	-	-	-	1.5	0.1	0.8	1.4
Unid. mysiids	-	-	-	-	-	-	-	-	0.5	0.0	0.3	0.1
Unid. amphipod	0.4	0.0	0.6	0.2	0.8	0.1	3.1	2.5	-	-	-	-
Parapagurus sp.	-	-	-	-	1.6	0.1	0.9	1.5	-	-	-	-
ANNELIDA												
Annelid worm	-	-	-	-	-	-	-	-	0.5	0.0	0.3	0.2

b) South Coast

	Juveniles (<37cm *TL*, n = 23)				Sub-adult (37-45cm *TL*, n = 50)				Adult (>45cm *TL*, n = 147)			
	%FO	*%M*	*%N*	*IRI*	*%FO*	*%M*	*%N*	*IRI*	*%FO*	*%M*	*%N*	*IRI*
TELEOSTEI												
Demersal												
Unid. demersal fish	30.4	9.6	28.0	1145.3	8.0	1.3	6.5	61.7	16.3	2.5	16.3	306.4
Merluccius sp.	-	-	-		-	-	-	-	4.1	2.7	3.5	25.3
M. paradoxus	-	-	-		6.0	17.4	4.8	133.3	2.0	2.3	1.7	8.3
M. capensis	4.3	25.0	4.0	126.0	-	-	-	-	4.8	12.7	4.1	79.7
Paracallionymus costatus	17.4	3.9	16.0	346.8	-	-	-	-	1.4	1.2	1.7	4.0
Helicolenus dactylopterus	8.7	21.0	8.0	252.5	8.0	19.4	9.7	232.9	8.8	6.2	7.6	121.9
Gnathophis sp.	8.7	1.5	8.0	82.6	16.0	3.6	12.9	264.5	3.4	0.4	3.5	13.1
Gnathophis capensis	4.3	5.1	4.0	39.6	2.0	0.8	1.6	4.9	2.0	0.3	1.7	4.1
Cynoglossus zanzibarensis	8.7	3.3	8.0	98.4	10.0	5.5	8.1	136.1	4.1	1.7	3.5	21.0
Austroglossus pectoralis	-	-	-	-	-	-	-	-	0.7	0.0	0.6	0.4
Caelorhinchus simorhynchus	-	-	-	-	-	-	-	-	1.4	0.4	1.2	2.1
Trachurus trachurus capensis	-	-	-	-	16.0	37.0	12.9	798.3	29.3	35.2	26.2	1795.8
Lophius vomerinus	-	-	-	-	-	-	-	-	0.7	1.2	0.6	1.2
Chelidonichthys capensis	-	-	-	-	-	-	-	-	0.7	0.6	0.6	0.8
Genypterus capensis	-	-	-	-	2.0	6.2	1.6	15.7	1.4	4.8	1.2	8.1
Pterogymnus laniarius	-	-	-	-	-	-	-	-	2.0	5.6	1.7	14.9
Gonorhynchus gonorhynchus	-	-	-	-	-	-	-	-	0.7	0.6	0.6	0.8
Notopogon macrosolen	-	-	-	-	-	-	-	-	0.7	0.0	0.6	0.4
Amblyrhynchotes honkenii	-	-	-	-	-	-	-	-	0.7	1.2	0.6	1.2
Pelagic												
Unid. pelagic fish	-	-	-	-	2.0	0.7	4.8	11.1	4.8	2.5	4.1	31.5
Etrumeus whiteheadi	-	-	-	-	2.0	2.9	1.6	9.0	5.4	5.2	9.3	78.7
Scomber japonicus	-	-	-	-	-	-	-	-	9.5	19.4	8.7	268.3
Sardinops sagax	-	-	-	-	-	-	-	-	0.7	0.3	0.6	0.6
Unid. pelagic larvae	4.3	24.7	4.0	124.7	-	-	-	-	-	-	-	-
CHONDRICHTHES												
Squalus megalops	-	-	-	-	4.0	1.3	3.2	18.0	3.4	3.9	3.5	25.1

	%FO	%M	%N	IRI	%FO	%M	%N	IRI	%FO	%M	%N	IRI
CEPHALOPODA												
Unid. squid remains	-	-	-	-	-	-	-	-	2.0	0.2	1.7	4.0
Sepia sp.	-	-	-	-	2.0	0.2	1.6	3.7	-	-	-	-
Sepia australis	17.4	14.6	28.0	740.3	6.0	0.5	6.5	41.7	1.4	0.0	1.2	1.6
Loligo vulgaris reynaudii	4.3	1.8	4.0	25.1	2.0	0.3	1.6	3.8	0.7	0.0	0.6	0.4
Todaropsis eblanae	-	-	-	-	2.0	2.3	17.7	40.2	0.7	0.4	1.2	1.1
Todarodes angolensis	-	-	-	-	-	-	-	-	1.4	0.8	1.2	2.7
CRUSTACEANS												
Pterygosquilla armata capensis	-	-	-	-	2.0	0.2	1.6	3.5	-	-	-	-
Funchalia woodwardii	-	-	-	-	4.0	0.4	3.2	14.4	0.7	0.0	0.6	0.4

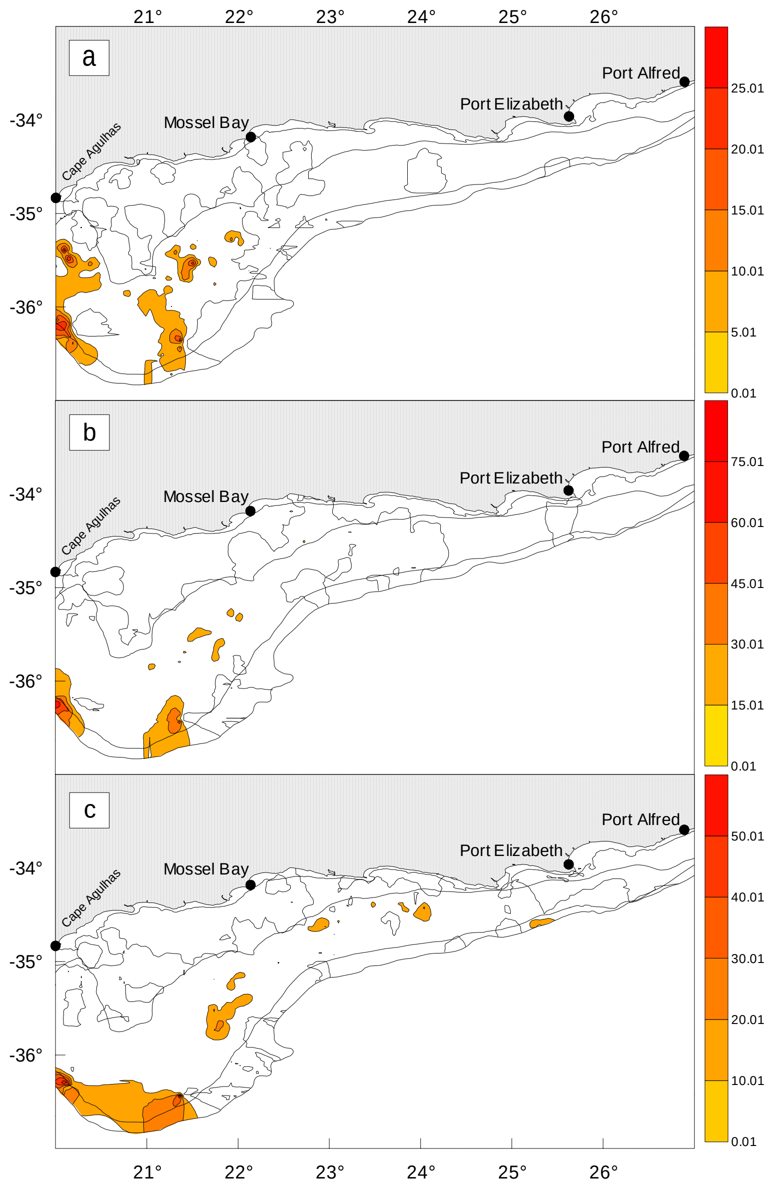


Fig. 5.6: Abundance (number caught per hour) of a) juvenile (< L_{50}, 37 cm *TL*), b) sub-adult (L_{50} - L_{100}, 37-47 cm *TL*) and c) adult (> L_{100}, 47 cm *TL*) *L. vomerinus* in autumn (April/ May) as estimated from data collected during research surveys (*n* = 792) on the south coast of South Africa between 1988 and 1996.
Isobaths are 100 m, 200 m and 500 m.

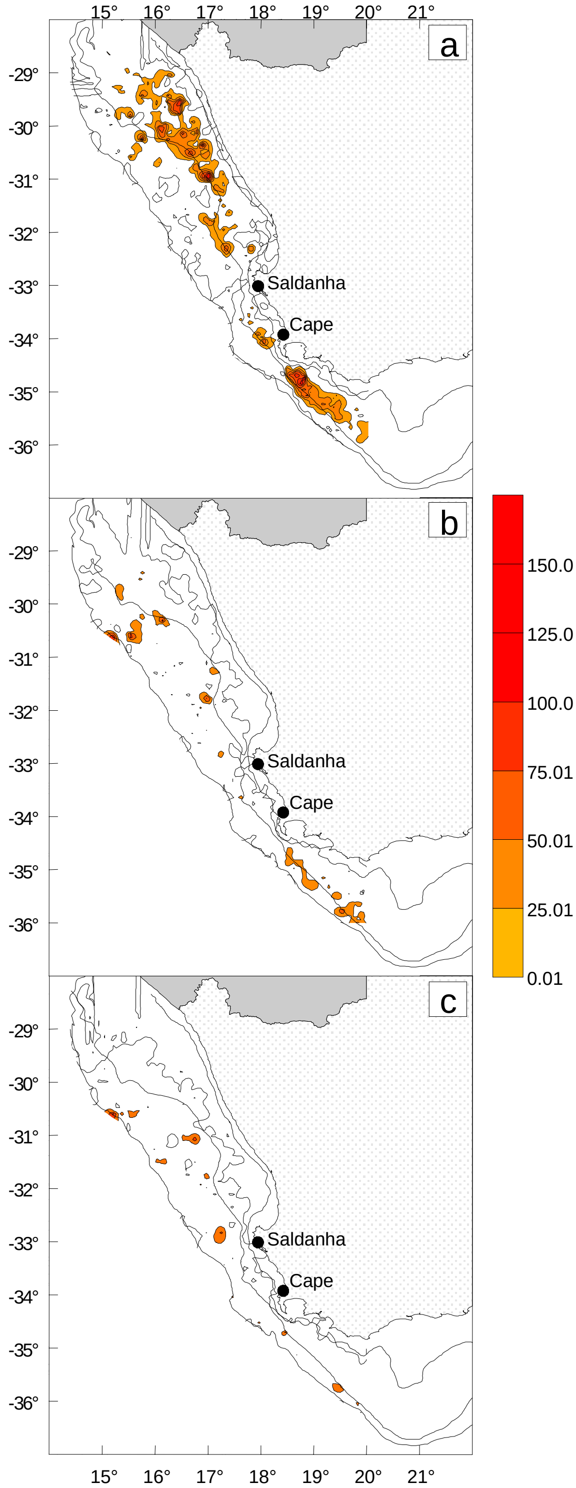


Fig. 5.7: Abundance (number caught per hour) of a) juvenile (< L_{50}, 37 cm *TL*), b) sub-adult (L_{50} - L_{100}, 37-47 cm *TL*) and c) adult (> L_{100}, 47 cm *TL*) *L. vomerinus* in summer (Jan/ Feb) as estimated from data collected during research surveys (n = 1112) on the west coast of South Africa between 1986 and 1997.
Isobaths are 100 m, 200 m and 500 m.

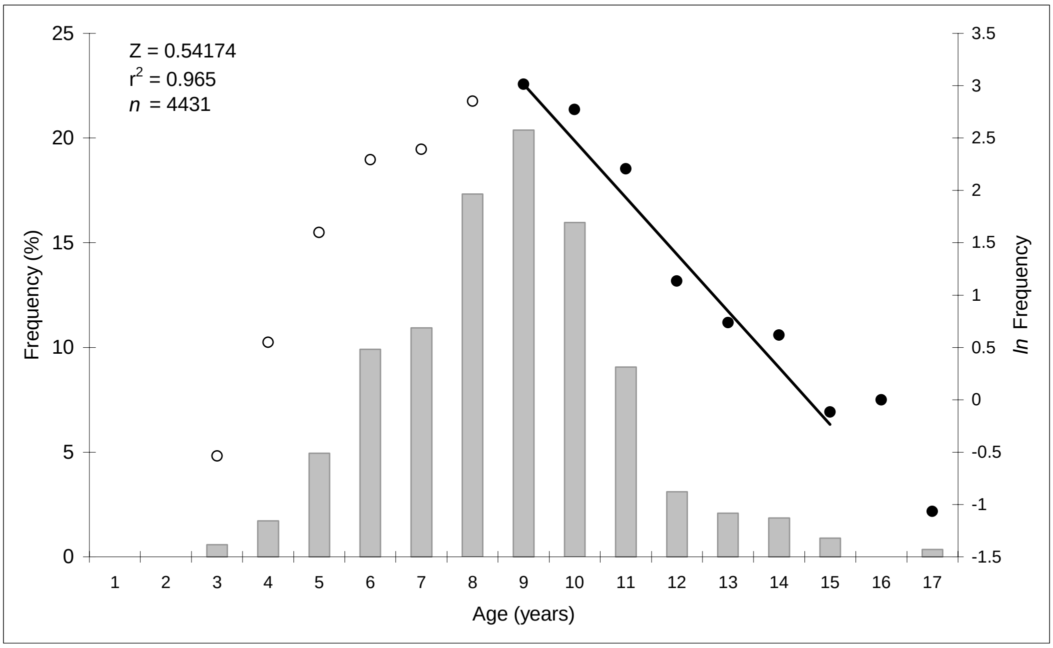
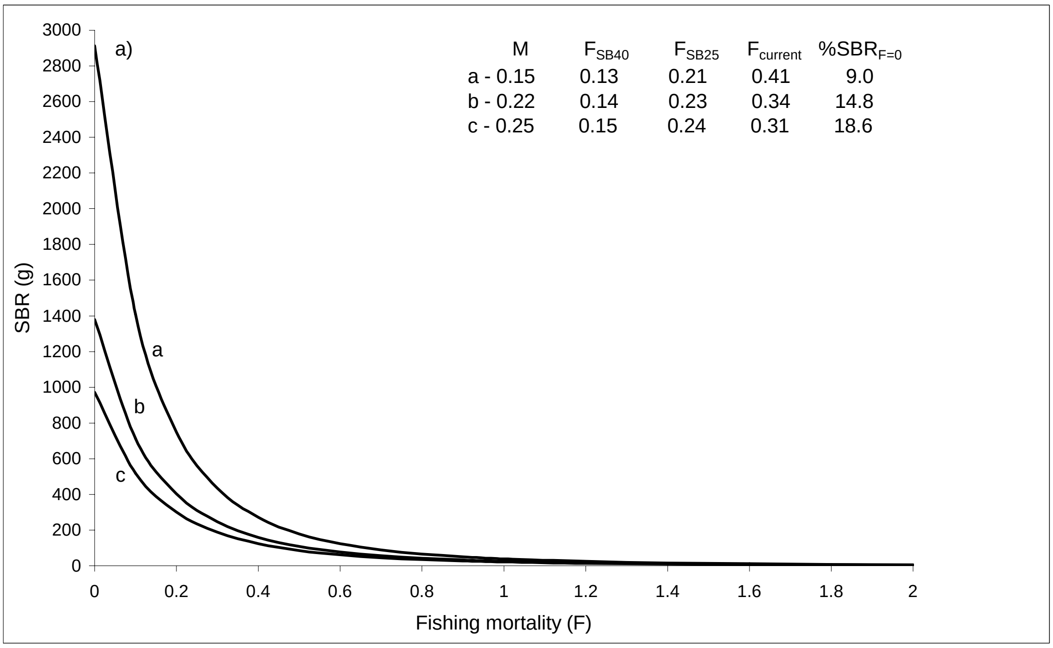


Fig. 5.8: Age distributions and catch curve of *Lophius vomerinus* landed by commercial trawlers on the west coast of South Africa during 1993, 1994 and 1996.
Total mortality (Z) was determined from the slope of the descending limb of the catch curve.

a)



b)

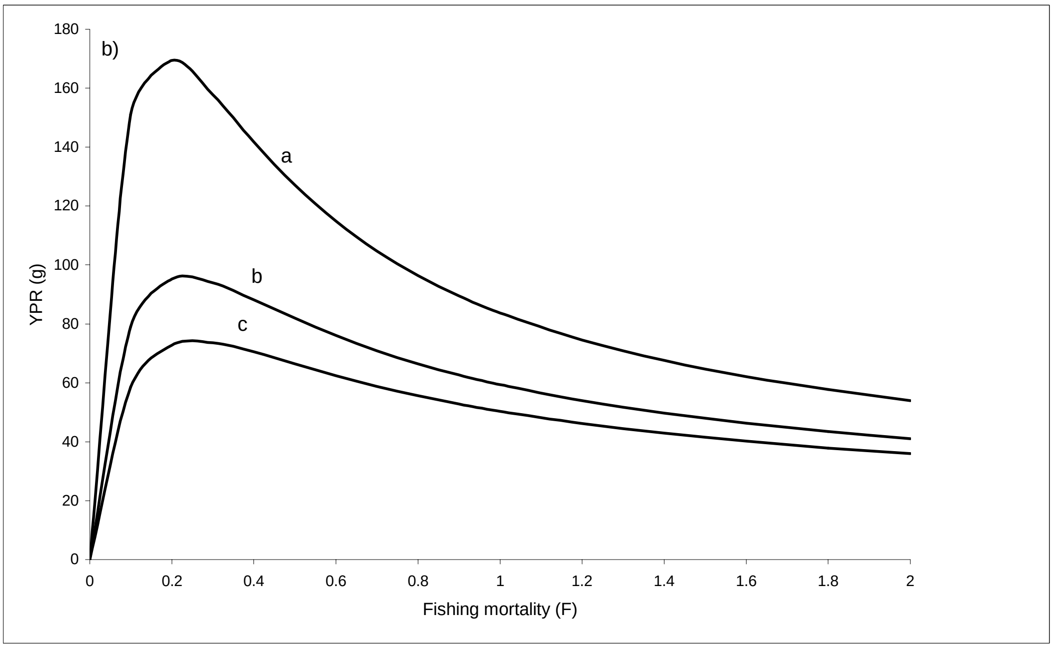


Fig. 5.9: Relationship between a) spawner biomass per recruit (SBR) and b) yield per recruit (YPR) at different levels of fishing mortality for *Lophius vomerinus*. Biological reference points and current SBR, expressed as a percentage of $SBR_{Fcurrent}$ are also given.

Discussion

Representatives of the genus *Lophius* are common to Atlantic demersal fish communities. Fisheries exist for most monkfish species, and landings worldwide have increased from 42 800 tons in 1970 to 105 246 tons in 1999 (FAO 1975, 1999). Off South Africa, monkfish are caught mainly as bycatch in the hake-directed trawl fishery. However, catches have increased over the last few years, apparently due to increased targeting, especially by small companies with limited hake allocations. Even though monkfish is a bycatch species, it is essential that the appropriate management measures are in place to utilise the stock in a sustainable manner.

Many of the life history parameters required to assess stock status, such as growth rate, require reliable estimates of age. The problems of using otoliths to age *Lophius* sp. are well documented (*e.g.* Tsimenidis and Ondrias 1980, Tsimenidis 1984, Griffiths and Hecht (*L. upsicephalus*) 1986, Crozier 1989) and researchers have turned to other hard structures such as vertebrae (Armstrong *et al.* 1992) and illicia (*e.g.* Dupouy *et al.* 1986, Duarte *et al.* 1997, Landa *et al*. 1998, Quinococes *et al*. 1998a, b). However, although Maartens *et al.* (1999) found that for *L. vomerinus* the best results were obtained using the illicium, the translucent band often splits into multiple rings making counting difficult. In the present study, this resulted in the rejection of approximately 30% of the specimens, which compared poorly with the Namibian population (12%; Maartens *et al*. 1999). However, the *IAPE* of 6.3% calculated in this study compared well with the value of 10.4% for the

Namibian population. This suggests that even though a high proportion of illicia from the South African population was rejected, there was good agreement between the two readers for those that were retained. The reasons for the high rejection rate are unknown.

Estimates of annual ring deposition are vital for verifying the age of a given species. The optical characteristics of the illicium edge indicated that one dark and one light band are laid down annually, confirming that the illicium can be used to age this species. This is the first time that age estimates using illicia have been verified for this species in South Africa.

The data indicated that growth is slow. The species attains a large asymptotic size and may live in excess of 20 years - characteristics shared by many *Lophius* species (Dupouy *et al.* 1986, Armstrong *et al.* 1992, Yoneda *et al*. 1997, Quinococes *et al*. 1998b, Landa *et al.* 2001). The results obtained were similar to those obtained by Griffiths and Hecht (1986; *L. upsicephalus*) using otoliths to age animals on the South Coast. In comparison with the Namibian population, the South African population grows slower and reaches a smaller asymptotic size, possibly as a consequence of environmental factors, such as water temperature or food availability. These growth characteristics may have significant implications for stock status, if the slow growth is coupled to late maturity or high fishing mortality.

Length-at-maturity ogives indicated that *L. vomerinus* matures late, a characteristic shared with *L. americanus* (Armstrong *et al.* 1992, Almeida *et* *al.* 1995); *L. piscatorius* (Afonso-Dias and Hislop 1996, Duarte *et al.* 2001); *L. litulon* (Yoneda *et al.* 1997) and *L. budegassa* (Duarte *et al.* 2001). Maartens (1999) reported that the L_{50} for the Namibian population of *L. vomerinus* was 40.8 cm *TL* for males and 61.8 cm *TL* for females, which is larger than the South African population. This is not surprising given that growth in the Namibian population is slower than that of the South African population. Of interest however, is the fact that South African *L. vomerinus* did not demonstrate a large difference in L_{50} between males and females. For many *Lophius* species, females tend to mature at a significantly larger size than males (*e.g.* Armstrong *et al.* 1992, Quinococes *et al.* 1998 a, b, Maartens *et al.* 1999). Why *L. vomerinus* does not follow this pattern is unclear, but it is possible that sampling difficulties, which resulted in a paucity of mature animals, may have skewed the estimates.

The data for female *L. vomerinus* suggested that spawning may take place in September (the austral spring). Sadovy (1996) reports that ovaries best reflect the duration of the spawning season, because testes tend to mature in advance of the ovaries, yielding estimates of longer reproductive seasons. The spring would be advantageous for spawning since the larvae can benefit from the spring plankton bloom. Many northern hemisphere *Lophius* species spawn in the boreal spring and early summer months (Armstrong *et al.* 1992, Quinococes *et al.* 1998 a, b, Duarte *et al.* 2001) or mid-winter to spring (Afonso-Dias and Hislop 1996), presumably to benefit from the plankton blooms.

Of interest is the lack of significant changes in male *GSI* throughout the year and the female *GSI* values themselves. Even though extremely high *GSI* values were obtained for some females in September, most ovaries from mature animals were either ribbon-like and flaccid, or full of hydrated eggs (and therefore presumably close to spawning). There was a paucity of fish with developing ovaries. Similarly, few males with developing testes were sampled. Little is known about the spawning behaviour and early development of *Lophius* species, but Hislop *et al.* (2001) reported that spawning takes place in deep water and that the pelagic stage may be prolonged (~ 120 days for *L. piscatorius*). It is possible that *L. vomerinus* spawns in deep water away from the commercial or survey trawling areas, resulting in few developing ovaries and testes being sampled. Unfortunately, there are no data available on spawning locations for *L. vomerinus*.

L. vomerinus is highly piscivorous, feeding primarily on demersal fish species. It is assumed that like other *Lophius* species*, L. vomerinus* is an ambush predator, lying motionless on the seabed and using flicking motions of the illicium to attract prey (Wilson 1937). Video footage of the West Coast commercial trawl grounds taken by the submersible Jago, showed monkfish well camouflaged in the soft sediments (De Beers Marine 1999), supporting the ambush theory. The diet of *L. vomerinus* showed a shift from small prey species to large prey species with increasing predator size. The high proportion of empty stomachs observed suggested that monkfish only attempt to capture prey when guaranteed of a return and that they do not eat again until the prey is almost completely digested. These are common strategies among *Lophius* species (Kosaka 1966; Benincasa 1983; *L. upsicephalus,* Crozier 1985, Macpherson 1985; *L. upsicephalus*) and could be a means of ensuring the maximum return for the energy expended.

The occurrence of flatfish such as *C. zanzibarensis* in the diet seems strange if it is assumed that *L. vomerinus* only captures prey by using its lure. *C. zanzibarensis*, is a benthic feeder, preying upon polychaete worms, crustaceans and amphipods (Meyer and Smale 1991b) and is unlikely to be attracted by the waving lure. The occurrence of flatfish within the *Lophius* diet has previously been reported by Wilson (1937), Benincasa (1983; *L. upsicephalus*) and Crozier (1985). This could suggest that *L. vomerinus* has an alternative means of capturing prey, such as lying the illicium flat upon the seabed so that the fleshy tip looks like a benthic worm. Alternatively, the flatfish may be more active than expected in the water column.

Lophius species have been recorded as bycatch in pelagic longliners of Iceland (Olafdottir, pers com.) and pelagic trawls and longlines in the northern North Sea (Hislop *et al.* 2000), suggesting that they are able to feed off the bottom (Hislop *et al.* 2000). During the course of the study, five individuals (three females, two males) without illicia were dissected. For these individuals the pterygophore was present suggesting that the illicium had been lost by accident - as opposed to a genetic deformity. Calculation of eviscerated mass using length-weight regressions indicated that the observed weight compared well with the predicted weight for all 5 individuals. This suggests that the loss of the illicium may not have affected the ability to capture prey.

The life history characteristics obtained during this study indicate that there may be cause for concern regarding the increased targeting of this species. Distribution data showed that although smaller individuals tended to be found at shallower depths, there was a large overlap in the distributions of the three size classes. This suggests that all size classes will be exposed to fishing. Data on the size structure of monkfish retained from monkfish-directed trawls (obtained by observers) and from hake-directed trawls (MCM, unpublished data) indicated that 26.8% (n = 347) and 10.7% (n = 9012) of landed monkfish were below 37 cm *TL* (the size of 50% maturity), respectively. In addition, data on the size of monkfish discarded from hake-directed trawls indicated that individuals as small as 15 cm *TL* were captured by trawl nets. Although these fish were subsequently discarded, it is likely that a high proportion would not have survived.

The slow growth rates and late maturity displayed by this species confirm that a proportion of the fish captured by the fishery would not have spawned, which if unmanaged could lead to recruitment overfishing. In addition, the differential growth rates observed suggested that the majority of the larger fish captured were females. This may increase the fishing mortality on the female component and lead to skewing of the sex ratios. In recent years increasing number of companies with limited hake allocations have entered the demersal fishery. It is possible that in order to remain economically viable these companies may increase their targeting of monkfish. Given the life history characteristics, it is unclear whether *L. vomerinus* stocks can sustainably cope with such an increase in fishing mortality.

The stock assessment data suggest that these concerns may be valid. Preliminary results indicated that the spawner biomass per recruit of this species is currently at ~15% of the pristine level. Stock assessment models use biological reference points to determine whether a given stock is over or under-exploited, and to provide targets for management (Clark 1991). Common reference points include 20% and 35% of pristine spawner biomass and $F_{0.1}$ (Mace 1994). However, the suitability of a given reference point is highly dependent on the life history characteristics of the species being studied (Mace 1994). Using a variety of growth, maturity and selectivity parameters to model a "typical" species, Clark (1991) suggested that a fishing mortality that would reduce the spawner biomass per recruit to 35% of pristine, should be used as a catch limit for groundfish. Mace (1994) suggested that reference points calculated using SBR are likely to be superior to those derived from YPR, as in addition to growth and selectivity parameters, they account for maturity. The value of 14.8% calculated for *L. vomerinus* is significantly below the level proposed by Clark (1991), suggesting that a catch limit should be introduced for this species as a matter of urgency. Further, the SBR analysis indicated that to attain the $F_{SBR35,}$ the $F_{CURRENT}$ (current fishing pressure) should be reduced by 42%. This would require the annual landing of approximately 7 000 tons to be reduced to approximately 4 060 tons.

The SBR value of ~15% of pristine is extremely low and this figure has been refuted by members of the fishing industry, based upon their CPUE information. Cognisance must, therefore, be taken of any short-comings in the data in order to determine the level of confidence that can be placed in this value. Of concern are the period of data collection and quantity of data collected. The collection of biological data upon which the age and growth analysis was based took place during 1997 and 1998 and the sample size was limited. In contrast, the data on the size-frequency of landed monkfish was available for the years 1993, 1994 and 1996 only. As a result, only one age-length key could be constructed and possible changes in the age-structure of the population may not have been reflected in the analysis. This is particularly true considering the fact that the largest monkfish landings were recorded in years for which there was no information on the size-frequency of landings. Despite this limitation, the SBR analysis does suggest that concern for the monkfish stock is warranted.

Whether or not the stock is as seriously depleted as the SBR analysis suggests, it would be prudent to limit or reduce landings. Exactly how this should take place is unclear - monkfish is a bycatch species and it is not feasible to close the associated hake fishery. Distribution data presented in this study indicated that although there is a trend of adults migrating to deeper water, sub-adults and even some juveniles may be found at hake target depths. As a result, it is unlikely that the closure of nursery areas would afford adequate protection to the younger individuals. Since this is a bycatch species, it is unlikely that an increase in mesh size would be feasible. This is exacerbated by the fact that due to its large head and many teeth, the monkfish tangles easily in the net, and it would require a significant increase in mesh size to effectively decrease the catch.

One method of managing catches would be to ban night fishing. During the night, hake move up the water column to feed and in doing so become less vulnerable to the trawl net. As a result, targeting monkfish at night allows an operator to catch a higher proportion of monkfish for his hake allocation. This is clearly reflected in the fact that night trawls contained almost double the proportion of monkfish compared with day trawls. Banning night fishing would remove the opportunity of targeting monkfish in this manner.

Another solution would be to ban fishing gear that is designed for targeting monkfish. These gears use a lower mouth opening height than hake-directed gear. Since hake swim higher in the water column than monkfish they are therefore less available to the net, and thus a higher proportion of monkfish for the hake allocation can be caught. Comparing West Coast monkfish-directed catches with hake-directed catches made at the same depth range, monkfish contributed 32.8% to monkfish-directed catches, compared with 2.4% in hake-directed catches (Chapter 3). Banning the use of such gear would reduce the monkfish catches.

Although these strategies would remove the advantage of catching more monkfish for a given hake allocation, they would not limit the monkfish catch *per se*. A simple method of limiting monkfish bycatch may be the introduction of a percentage limit. In such a case, a given proportion of the hake allocation may be landed as monkfish. Although compliance would be relatively easy to assess from log book returns, it could encourage discarding of less valuable hake - in order to retain the more valuable monkfish bycatch. An alternative solution would be the issuing of rights to individual companies and allowing trading of monkfish. This would allow operators who rely on their monkfish catch to remain economically viable, to buy rights from companies that are not so dependent.

Whatever management strategy is developed for monkfish, it is clear from the life history parameters and stock assessment data, that the assumption that bycatch species are sustainable simply because they are not targeted, appears to be invalid. The South African demersal trawl fishery has historically been managed for hake and sole and there have been no regulations for bycatch species such as monkfish. The monkfish was chosen for this particular study as it is a common and valuable bycatch species. The results indicate that issues pertaining to the capture of other bycatch species, such as kingklip, need to be addressed as a matter of urgency.

Chapter 6 -
Managing South Africa's trawl bycatch

Introduction

Many concerns exist regarding the effect that bycatch and discarding have on marine systems (ICES 1995, Dayton *et al.* 1995, Alverson 1998, Pauly *et al.* 2002). These include the generation of skewed effort estimates for quota-regulated and bycatch species in the absence of bycatch information; the over-exploitation of the bycatch species (Alverson *et al.* 1994); impacts on other fisheries (Alverson 1998); and biodiversity issues.

Economically, discarding represents a waste of protein and other resources, such as time and manpower, which are required to sort and discard the unwanted portion of the catch (Crowder and Murawski 1998). In addition, fishing strategies adopted by the industry generally work towards achieving the maximum economic yield, which may lead to high-grading (Arnason 1994). Even where non-target (bycatch) fish are utilised, for many fisheries information pertaining only to the landed or retained portion is recorded. Thus, the total catch (and hence fishing mortality) is unknown, which increases the uncertainty regarding the total fishing-related mortality. This, in turn, makes it more difficult to assess quota-regulated stocks (NOAA/ NMFS 1998) and may lead to the over-exploitation of unregulated species.

The importance of assessing and managing bycatch has been recognised only over the last three decades (Saila 1983, Hall 1996) and this is reflected in the lack of detailed historic bycatch information for many fisheries (Alverson *et* *al.* 1994). For demersal trawl fisheries, bycatch investigations have been sporadic, with data collection taking place over one or two years only. Management measures have generally been implemented for individual species when they become cause for concern and not as the product of a directed programme (Table 1.1, Chapter 1). Also, it is often difficult to gauge the success of these management measures largely because for many fisheries bycatch data only cover a few years (often the years following the introduction of the measures) and there is a lack of baseline information. The formulation of bycatch management plans is further complicated by the management needs of the various catch components. For example, it might be necessary to minimise the incidental catch of one group of species, while at the same time increasing the utilisation of another.

Although the issue of bycatch in South African trawl fisheries has been recognised for two decades (Japp 1996), research to quantify this component of the catch has been more recent. The only comprehensive estimates of bycatch and discards for the demersal trawl fishery are those of Japp (1996), based on bycatch ratios determined from research survey data. However, surveys use different gear to commercial trawlers, take place at limited times of the year and cover non-commercial and commercial trawling grounds. As Japp (1996) acknowledged, these factors may bias the estimates obtained.

Increased awareness of bycatch issues in South Africa coincided with a period of transformation in the fishing industry, following the election of the first democratic government in 1994. In 1998, after a period of consultation with all stakeholders, South Africa adopted a new policy for managing its marine resources - the Marine Living Resources Act (MLRA 1998) (Cochrane and Payne 1998, Hersoug and Holm 2000). This Act not only aims to redress the imbalances of the past, but it also recognises the need to fully utilise South Africa's resources and to manage them in a sustainable manner. One of the primary areas highlighted for attention was bycatch.

Background

According to Kennelly (1997), bycatch problems can be solved by following six steps that start with defining the problem and end with actions to address the concerns raised (Fig. 6.1). This process should include fishermen as well as scientists (Kennelly 1997), recognising the theoretical benefits of a co-management approach to management. These include increased legitimacy, more robust management and increased compliance (Lim *et al.* 1995, Hughey *et al.* 2000, Jentoft 2000). In order to solve bycatch problems in the South African trawl fishery, the model proposed by Kennelly (1997) was followed.

Debate on bycatch issues has been clouded by terminology and the term has been applied to the portion of the catch discarded at sea, the retained and sold non-target portion of the catch and more recently has become a general term for "waste" by the world's fisheries (Alverson *et al.* 1994, Hall 1996). Therefore, the term bycatch, as used in this study, was defined prior to beginning work. The definition was similar to that of Saila (1983, p1);

"That part of the gross catch which is captured incidentally to the species toward which there is directed effort. Some, all or none of the by-catch may become the discard catch."

but undersized individuals of the target species were included as part of the bycatch (Fig. 6.2).

The first step was data collection and analysis and assessment of the scale of the problem. This was done using a limited (pilot) observer programme. The levels of data collection and coverage were evaluated and gaps in the data identified. Economic data were collected to determine the reliance of the fishery on bycatch revenue and to assess the possible impact of bycatch management measures on this revenue. In addition, the potential for creating additional revenue through increased bycatch utilisation was investigated.

The pilot observer programme operated between 1995 and 2000 and a full description of the trawl locations and number of trawls observed can be found in Chapters 2 and 3. Briefly, on the west coast (Fig 6.3) two observers were employed to complete two trips to sea per month, one with each of the two main trawling companies. On the south coast, one observer was employed to complete one trip aboard a sole-directed vessel and one trip aboard a hake-directed vessel per month. In addition, a total of two trips were completed on a vessel targeting monkfish on the west coast. The choice of vessel was based upon the willingness of companies to have observers aboard and on vessel availability. The observers had no influence on the ground fished.

For each trawl, the discarded portion of the catch was sampled. The discards were sorted to species, weighed and the length composition was recorded. If the catch was large, the discards were sub-sampled. On west coast vessels, which tend to be large stern trawlers, the catch enters the factory from a holding pond via a conveyor belt. Fish for processing are removed from the belt and the discards are carried back to the sea via a chute. Therefore, the total discards were estimated from sampling time (the time during which discards were removed from the belt) and total time of belt operation. On the south coast vessels (generally small side trawlers), the catch is emptied from the cod end onto the deck. Fish for processing are removed, and the discards are shovelled overboard. Thus, the proportion of the sub-sample was estimated visually. For both coasts, information on the retained catch was obtained from the factory manager. By combining the retained and discard information, the composition of the trawl was calculated (Chapters 2 and 3).

A full description of the analyses undertaken can be found in Chapters 2 and 3. Briefly, the composition of west and south coast catches was calculated. The community structure was investigated using the PRIMER package (Version 5.1.2, Plymouth Marine Labs, 2000) and differences in catch composition between areas were assessed. In addition, the annual level of bycatch and discarding was estimated for each coast. Finally, the spatial distribution of bycatch was investigated using a GIS and factors affecting bycatch and discarding were investigated using GAMs.

The second step was to identify solutions to the many challenges highlighted by the study. Information documents were produced that formed a platform for debate between fisheries managers, biologists and industry representatives. Initial discussions were held between a small group of representatives in order to list all possible solutions, before a workshop was held with industry representatives, where the documents were presented and discussed. The results of the observer programme, additional data and discussions were used to propose immediate management measures and medium-term targets to solve the issues raised.

The problem: Concern over a particular bycatch issue

1. Identify and quantify the problem through observer programme
- scientists working with fishermen on typical fishing trips

↓

2. Think of alternatives to solve the problem (i.e. reduce bycatch)
- scientists' ideas from others in the literature; fishermen's ideas from the knowledge of their gear and practices

↓

3. Test these various ideas to identify the best solutions
- scientists doing field experiments onboard fishermen's vessels; scientists analysing the data for the best solution; fishermen making it practical for their operations

↓

4. Publicise the solutions through the fleet
- scientists doing talks, videos and articles, papers for fishermen not involved in the tests; fishermen discussing and teaching others how to use the modification

↓

5. Publicise this adoption to those concerned
- fishermen and scientists making various interest groups aware of the solutions through the media, meetings *etc.*

↓

6. and so reduce the concern, solving the problem

Fig. 6.1: A framework to address bycatch problems (after Kennelly 1997)

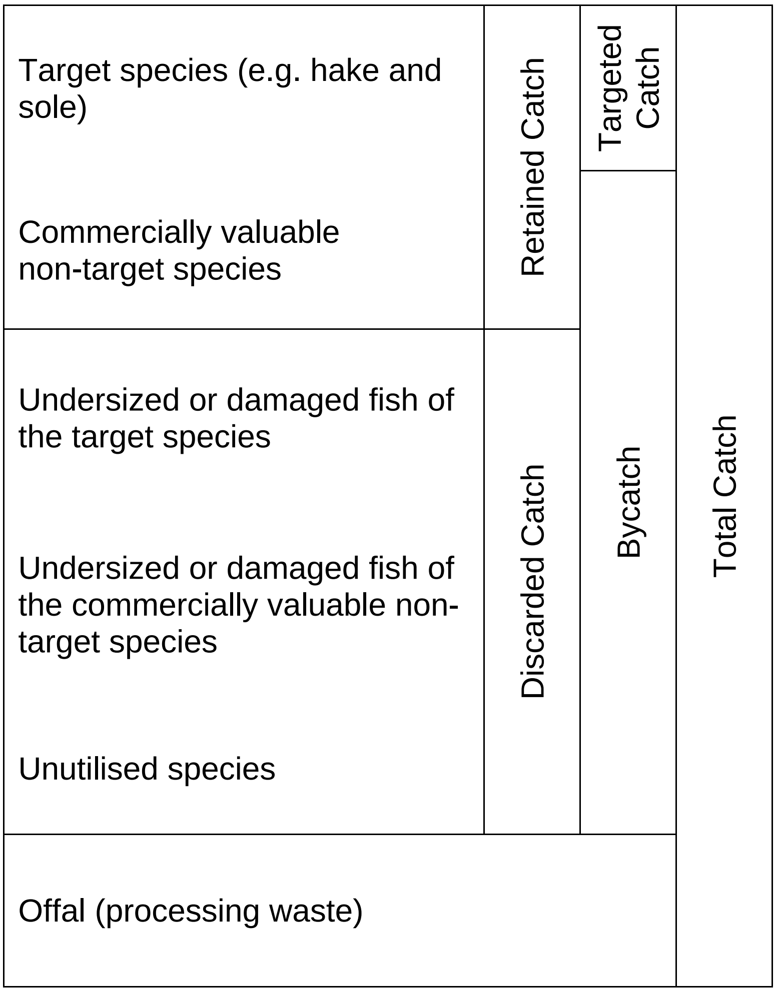


Fig. 6.2: Graphic illustration of the components of the catch as defined in the text. (Note that if nominal retained values are given, then the offal component is included in the total catch).

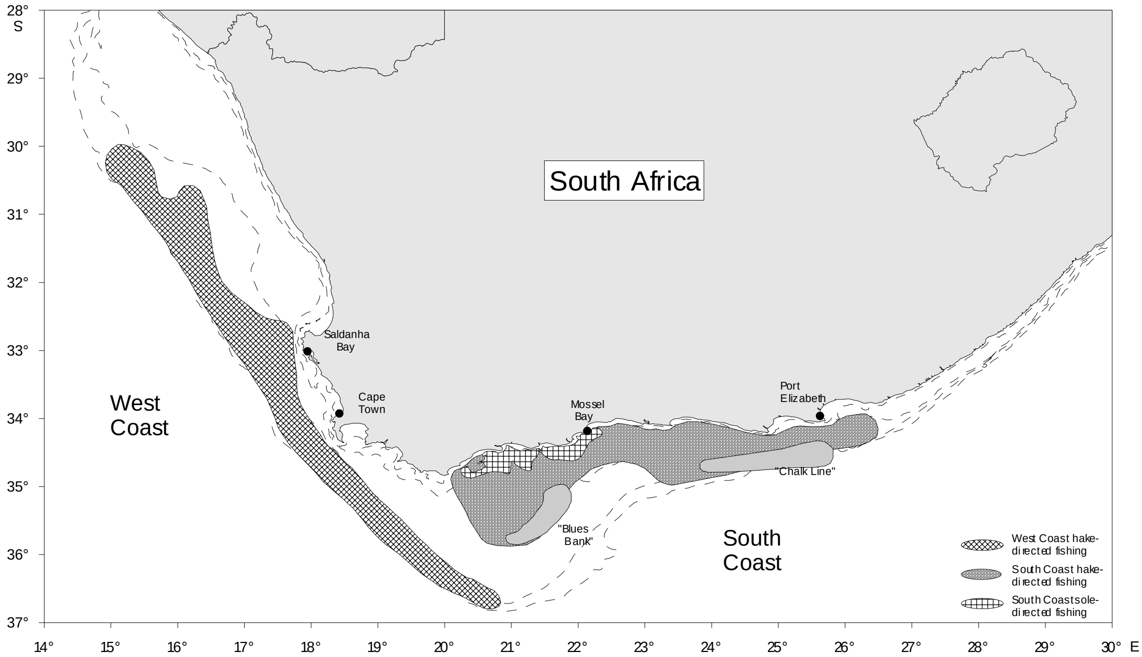


Fig 6.3: Map of South Africa showing the main demersal fishing grounds, the Blues Bank and Chalk Line areas and places mentioned in the text. Dotted lines indicate the 100m, 200m and 500m isobaths.

Discussion

The pilot observer programme collected data from 1093 trawls, providing the first comprehensive data on actual trawl catches (as opposed to landed catches). Full details of the sampling procedures, data analysis and results are given in Chapters 2 - 5. A summary of the results is given in Table 6.1.

The results indicated that the fishery is not homogenous and it can be split into several, characteristically different sectors (Fig 6.3, Chapters 2 & 3). These sectors are defined by the community structure of the fishing area, which largely determines the catch composition, the levels of bycatch and the fishing strategy utilised. For example, Cape hakes dominate the west coast demersal community and as a result, the west coast fishery is characterised by large companies with shore-based factories geared towards hake processing (Chapter 3). In contrast, the community structure of the south coast is more diverse and as a result, the fishery is largely composed of smaller companies that utilise many species (Chapter 2). The differences in community structure not only affect the patterns of catch and discarding but also have implications for the introduction of management measures.

As expected, levels of bycatch and discarding differed markedly between the two coasts. On the west coast, hake dominated and accounted for about 90% of the catch. The remainder of the catch was generally composed of species such as small macrourids that cannot be easily utilised. In contrast, although hake accounted for only 49 - 69% of the total south coast catch, a greater proportion of the bycatch was utilisable. Consequently for both coasts, the level of catch utilisation was high, with approximately 90% of the catch being processed and utilised. Nonetheless, it was still estimated that the fleet discarded 25 000 - 36 000 tons of fish and 40 000 - 59 000 tons of offal annually. These estimates were lower than those obtained by Japp (1996), possibly as a result of the bias inherent in extrapolating the research data to the commercial fleet (Chapters 2 and 3).

A total of 118 species were identified in trawl catches, indicating that trawling directly impacts a substantial part of the demersal ecosystem. Although some species were caught infrequently or in small numbers other species, such as the macrourids *Caelorinchus braueri* and *C. symorhynchus*, were caught often and the levels of catch and discarding were high. Given the need to manage South Africa's marine resources in a sustainable manner (MLRA 1998), the impact of trawling on all these species must be considered.

Many factors affect the discard rate of the various species. Although target and high value bycatch species are generally always utilised, lower value bycatch species may be retained or discarded depending on factors such as the current market value, market demand, hold space and the composition of the catch. Preliminary analysis using GAMs (Chapter 4) indicated that the latter was one of the most important factors affecting discarding. When the catch was predominantly composed of the target species, the proportion of bycatch retained was lower than when the proportion of the target species was low.

Although the use of GAMs and GIS was limited by the small dataset, the results nevertheless indicated the potential of these tools for exploring factors influencing patterns of bycatch and discarding. When more data become available through the full-scale observer programme, it is likely that these techniques will reveal other factors that influence the fishers selection of the component of the catch to retain.

Different bycatch components

The results of the pilot observer programme indicated that bycatch and discards generally fall into one of three categories, namely discarded bycatch, retained bycatch and processing waste (offal). Each category presents different management problems, requiring different management approaches. In addition, the introduction of new management strategies must considered in conjunction with the issues of economics and compliance.

Discarded bycatch

Discarded bycatch is composed of two types - undersized fish of the target (*e.g.* hake) and non-target species (*e.g.* ribbonfish) and species that are unutilisable (*e.g.* macrourids). Ideally, this component of the catch should be minimised, as the stock status of the species may be negatively affected by fishing. In terms of good fishing practice we should aim to avoid unnecessary fishing mortality. The pilot observer programme indicated that hake discarding in particular might be cause for concern.

Using a landings-based extrapolation method (Chapter 2), it was estimated that 7 000 tons and 2 000 tons of hake were discarded annually on the west and south coasts, respectively (Tables 2.7 & 3.7). Possible reasons for hake discarding are because the fish are too small to market or because of high-grading. Incorrect estimates of hake discarding may have implications for stock assessment. If information is available only for the landed catch, then the actual catch and true fishing mortality will be underestimated. However, if the proportion of hake discarded remains constant over time although CPUE will be underestimated, the relative trend will not be affected and CPUE could be used as an abundance estimate. When used with simple biomass dynamic models, the CPUE trend will underestimate hake productivity, resulting in lower TAC recommendations, thereby compensating for the unrecorded mortality. However, the discarding rate for small hake is probably driven by economic forces (e.g. market demands, high-grading etc.) and is unlikely to remain constant. If the proportion of the catch that is landed increases or decreases over time, then the CPUE estimated from the landed portion of the catch will change independently of changes in abundance. Thus, using this CPUE time-series as an index of abundance could lead to biased TAC recommendations.

Catch-at-age (CAA) estimates derived from landed catches underestimate the mortality on younger age classes and the effect of unrecorded discarding of hake will be compounded when CAA and CPUE estimates based on landed catches alone are used in age-structured models.

Although the current Operational Management Procedure (OMP) used to provide management advice for South African hake uses a biomass dynamic model to estimate the TAC, it was tested against an age-structured operating model. It is unclear what effect unrecorded hake discarding could have on the OMP, although it should be noted that the sensitivity to various assumptions of both CAA and CPUE data was tested during the OMP development and the OMP was found to be relatively robust to assumptions regarding levels of discards (Rademeyer, 2003).

Retained bycatch

Retained bycatch presents a different management problem to discarded bycatch. Although the demersal fishery is managed as though it is a single species fishery directed at the Cape hakes, in reality it is a multi-species fishery. Many of the bycatch species are processed and retained, and some species are sought after. It would be impractical to introduce single species fisheries on each of these species. Therefore the management objective should be to exploit these species in an optimally sustainable manner. However, exploitation of these species is not currently managed and it is possible that the exploitation of high value species may be increasing beyond sustainable levels. Also, the utilisation of other incidental species may be affected by market demand *etc.*, and this is not maximally utilising the catch.

The incidental capture of non-target species is an inherent feature of unselective fishing methods such as bottom trawling and throughout the history of the South African trawl fishery, markets for various bycatch species have developed then declined. However, recent changes to the industry structure may have brought about an increase in bycatch targeting. During its development, the capital-intensive nature of the deep-sea demersal trawl sector favoured large conglomerates and by 1978 three companies shared approximately 80% of the offshore hake trawl allocation. The remainder was shared between approximately 30 other companies (Kleinschmidt *et al.* 2003). As a result of the transformation process initiated in 1994, the allocations to these three large conglomerates had declined to less than 60% of the TAC by 2001 and the number of participants had increased to 57 (Kleinschmidt *et al.* 2003). However, the new participants have limited hake allocations and there are concerns that they may be encouraged to target bycatch and high-grade hake in order to maximise the economic return on their allocation. These concerns arise from the recent increase in the landings of two high value species - monkfish, stocks of which may already be under pressure (Chapter 5) and kingklip, which is recovering from a stock collapse.

Monkfish is a slow-growing, long-lived species that matures at around 6 years of age (Chapter 5). Annual landings have historically been around 3 000 tons, but catches increased in the last decade, peaking at over 7 000 tons in 1998 (Stuttaford 2001). Estimating monkfish abundance and CPUE trends is difficult, because monkfish-directed effort is usually recorded as hake-directed effort in logbooks. Therefore a re-direction of effort within the demersal fleet to target monkfish could lead to a substantial increase in monkfish landings with little or no increase in total effort. Thus, the nominal monkfish CPUE is unusable as an abundance index and attempts to standardise the CPUE series have been unsuccessful. Per recruit models suggest that the spawner biomass per recruit is currently at ~15% of pristine (Chapter 5), although relative biomass estimates for west coast monkfish suggest that the stock is increasing (MCM, unpublished data). Replacement yield models however, suggest that the stock is sustainable at landings of 6 500 and 800 tons on the west and couth coasts, respectively (Booth 2004). Better data are required to resolve this issue.

The kingklip is also slow-growing and may reach 24 years of age (Punt and Japp 1994). Trawl landings increased from approximately 1 500 tons at the beginning of the 1960's to approximately 4 000 tons in 1982. In 1983 an experimental longline fishery was instigated and by 1986 catches had increased to 11 000 tons. The stock could not sustain this increase and by 1990 catches had dropped to 2 500 tons and the longline fishery was closed. Subsequent assessment of the kingklip resource by Punt and Japp (1994) indicated that the resource was already under pressure as bycatch in the trawl fishery prior to the initiation of the longline fishery. Although relative biomass estimates suggest that the west coast stock is increasing (MCM, unpublished data), stock assessments indicate that the spawner biomass is at less than 50% of pristine, the west coast stock is close to maximal exploitation and the south coast stock is over-fished (Mori and Butterworth 2002). A further cause for concern is that the bycatch of kingklip by south coast trawlers is increasing (Mori and Butterworth 2002). Finally, the last few years have seen the instigation of a hake longline fishery to provide access for those with less investment capital than that required for trawling. Although the gear is deployed differently when hake longlining, there is potential for substantial kingklip bycatch.

Trawl catches contain a variety of other species whose fate depends on factors such as the catch size, market forces or the fishing strategy of the operator. These species have a variable economic value, which may be less than the processing and landing costs or which may make it worthwhile landing them. In addition, there is currently little or no information available on the stock status of many of these bycatch species and it is impossible to determine whether catches are sustainable. Given the difference in potential revenue that exists between bycatch species and hake, it is easy to see why they are discarded. However, the development of lucrative export markets in Europe has caused the price on the South African market to increase substantially and hake is no longer a source of relatively cheap protein. This could create a demand for lower value species to satisfy the local demands for cheaper protein and may lead to the increased utilisation and possibly increased targeting of these bycatch species. A study on bycatch economics suggested that the need to maximally utilise decreasing allocations would encourage the landing and marketing of bycatch species in the future (Erstadt 2002).

One of the major concerns highlighted by the inshore south coast data was the incidental capture of juvenile linefish such as kob (Chapter 3). Although linefish are generally retained and utilised when they are captured, many South African linefish stocks are collapsed or overexploited (Griffiths 1997a, Griffiths 2000). It is therefore unknown whether the linefish caught by trawlers are being fished in a sustainable manner.

Processing waste

Processing waste is an unavoidable part of fishing operations and the observer data indicated that a substantial mass of offal is discarded annually. However, the utilisation of offal is largely maximised by fishing companies, who retain the tongues, cheeks and roes because of their high value and heads for rock lobster bait. Although it is recommended that investigations into the enhanced utilisation of offal should take place, offal discarding is not considered an immediate concern.

Bycatch economics

Two investigations were made into bycatch economics. The first examined the importance of bycatch revenue to trawling companies and the second involved interviewing industry representatives and small-scale processors to determine their attitudes to bycatch. Two important points were revealed:

a) The south coast fishery is more dependent on its bycatch revenue than the west coast. The west coast fishery, which is dominated by hake, derived 7% of its revenue from bycatch, whilst the more diverse south coast fishery derived between 15 and 36% of its revenue from bycatch (Erstadt 2002).

b) Although small-scale processors would be able to sell bycatch to locals if it was available, for operators the cost of sorting and packing bycatch is often greater than the landed value. Thus, even if a market exists, it is often not worthwhile landing the fish. (Karaan *et al.* 2001).

These factors highlight the importance of considering the economic implications for fishing companies when formulating a management strategy. In the case of the south coast, regulations to reduce bycatch could result in fishing becoming unviable and must therefore be carefully considered. If a no discards policy was introduced to provide processors with bycatch, it must take place in conjunction with additional plans for creative marketing or value adding to ensure that the catch is viable for operators to land.

Compliance considerations

There is little point in introducing additional measures to manage bycatch if they cannot be enforced. In 1999 an MCM task group reported that several areas of concern existed with regard to compliance. These included a lack of monitoring at sea (with respect to mesh size and the discarding of regulated species), problems with high-grading, the under-reporting of bycatch and the lack of monitoring at off-loading points (Department of Environmental Affairs and Tourism 2000). Within MCM problems included poor routines and legislation, lack of response to violations, lack of leadership and low morale. Since the release of this report, MCM has gone some way to rectifying the concerns, particularly with respect to the problems within the institution itself. A collaborative bycatch management approach should increase industry responsibility towards the sustainable utilisation of the resource, and encourage adherence to the rules.

All trawlers are now required to carry a Vessel Monitoring System (VMS), which will allow the monitoring of closed areas. In addition, the introduction of real-time electronic logbooks has been proposed and may be implemented. Currently skippers could complete two logbooks, one declaring the full catch, the other only part of the catch. They can then decide which logbook to hand in, depending on whether or not they are inspected. With electronic logbooks, they would have to declare their catch prior to docking and would therefore have to decide in advance whether to take a chance that they will not be inspected.

Table 6.1: Summary of catch composition data collected by observers aboard commercial fishing vessels on the west and south coasts of South Africa between June 1995 and September 2000.

All results represent the total catch (or percentage of total catch) from all trawls sampled in each area for all years combined. Data for the West Coast hake-directed trawls represent the range of results obtained for 4 depth ranges (0-300m, 301-400m, 401-500m and >500m) and data for the South Coast hake-directed trawls represent the range of results obtained from 3 areas (Blues Bank, Chalk Line and inshore). (Note that if monkfish or sole is the target species, hake becomes a bycatch species). All data are summarised from the results presented in Chapters 2 and 3

	West Coast		South Coast	
	Hake-directed	Monkfish-directed	Hake-directed	Sole-directed
Number of trawls observed	430	49	320	294
Total observed catch (tons)	2 073	137	537	138
Percentage of total catch retained	86 - 92	96	94 - 96	81
Percentage of total catch discarded	9 - 15	4	4 - 7	20
% contribution of selected species to the total observed catch				
hake	65 - 92	62	53 - 70	62
monkfish	2 - 4	33	1 - 2	0.2
sole	<0.1	<0.1	0.0 - 0.5	18
% contribution of selected species to the landed catch				
hake	59 - 89	59	51 - 69	49
monkfish	1 - 4	33	<0.1	<0.1
sole	<0.1	<0.1	<0.1 - 1	17
Percentage of the landed value from bycatch	2 - 24	73	15 - 37	47
Estimated annual discards (tons)	29 619		5 722	
Hake	6 915		2 003	
Ribbonfish	14 198		649	
Monkfish	254		214	
Horse mackerel	159		179	
Jacopever	426		649	
Other	7 667		2 028	
Offal discards (tons)	29 859		13 423	
General characteristics	• Large proportion of the bycatch unutilisable e.g. macrourids • 71 spp. caught, of which 19 were retained • Decrease in the percentage of bycatch in the catch with increasing depth		• Large proportion of the bycatch utilisable e.g. panga and horse mackerel • 74 spp. caught of which 32 were retained • The sole-directed fishery discards ~20% of the hake that it catches	

Evaluation of the pilot observer programme

The observer programme described in this thesis was initiated as a pilot study to assess the potential of using observer data to help solve bycatch issues and to provide the basis for a National Observer Programme. In order to determine the success of the pilot programme, consideration must be given to whether or not the original goals were achieved. The primary goal was to assess whether data collected by observers could be used to provide the basis for the formulation of a bycatch management plan in the South African demersal trawl fishery. In this, the pilot observer scheme was undoubtedly successful and has:

- provided the first estimates of bycatch and discarding based on data from the fishery;
- provided insights into the dynamics of the demersal trawl fishery, and;
- shown that fishing strategy, catch rates and catch composition differ amongst the trawl grounds, indicating the need to stratify observer coverage to increase the precision of discard estimates.

In addition, there were a number of subsidiary aims. The first of these was to provide basic estimates of bycatch and discarding for the fleet, to identify areas of immediate concern and to propose management solutions. Estimates of bycatch and discarding by the fleet were calculated, and they represent the first estimates based on data collected from the fishery. However, potential users of these estimates should be aware of the limitations of the estimates in both precision and bias. As is generally the case with pilot studies, the sample size was severely limited and only an estimated 0.49% of west coast and

0.62% of south coast trawls in were observed in 1997, which was the year of highest observer effort (Chapter 3). Sources of bias were: (i) it is not known to what extent the presence of an observer affected fishermen's behaviour (with respect to fishing strategy and discard practices), and; (ii) on the West Coast observers were deployed only on vessels from the two main fishing companies. It is unlikely that the smaller and the newer companies would follow the same fishing strategy as the two large companies, therefore placing observers on vessels from these companies should be a high priority target for the National Observer Programme.

The study also aimed to provide representative data from the observed trawls. Several possible sources of bias were identified in the methodology. These include the distribution of observer effort, the method of scaling-up the sub-sample to produce an estimate for the whole fleet and observer bias (Chapter 3). These sources of bias must be considered when interpreting the data and when formulating sampling protocols for future programmes.

The final (and perhaps most important) aim was to use the lessons learnt from the pilot programme to design the first stage of the National Observer Programme The most urgent areas for improvement are the level and distribution of observer coverage and the sampling protocols used. The simplest method of achieving better observer coverage is to aim for a particular sampling level (such as 5 or 10% of all trawls) that will provide representative data for the fleet. Legislating that all vessels must carry an observer for a given percentage of their fishing time will ensure that the entire fleet is sampled. However, due to the small number of trawls observed by the pilot programme, it was impossible to determine the level of observer coverage that is required to provide representative discard data with 95 or 99% confidence limits. Given the results obtained, it is suggested that a national programme should initially aim for a basic coverage of 10% of all trawls.

Such blanket coverage does not, however, account for differences in the composition of catches taken in different fishing areas or by using different gears. Fewer samples are required to provide representative catch data from a fishing area where the variance in catch composition is low, compared with an area where the variance is high. If large differences in variance exist, the observer effort can be stratified accordingly. To assess the variation in discarding levels in the pilot programme, the mean discard rate (kg/km^2 trawled), standard deviation (sd) and coefficient of variation (CV) of hake, monkfish and sole were calculated for each of the fishing areas defined. The discard rate was calculated using the formula:

$$D = \frac{Wt}{MW \times V \times D}$$

where D = Discard rate (kg/km^2), Wt = weight of the discard species (kg), MW = trawl mouth width (km), V = trawl speed (km/h) and D = trawl duration (h).

The CV's were high for all areas (Table 6.2), but particularly so for the inshore hake-directed and Chalk Line areas on the south coast and the 0-300m and

401-500m depth ranges on the west coast, i.e. the areas with greatest species diversity. Although the data set from the pilot study is small, it can be used as a basis for determining the initial stratification of observer effort to account for differences in sampling variability. The level of observer coverage per stratum should be re-assessed at regular intervals for the first few years.

In addition to stratifying on the basis of sample variance, sampling effort can be stratified to take account of areas with highly variable discard rates, high species diversity or that have been poorly sampled. The results from the pilot programme suggested that the south coast (which has higher species diversity than the west coast); the monkfish-directed fishery (for which only 2 sampling trips were completed); smaller offshore companies (not included in the pilot study); and the <300m and 400-501m west coast depth bands (where the CV's were very high) should be allocated additional sampling effort. One method would be to use a metier approach, such as is used in some European fisheries. Such an approach groups vessels or fleets with similar characteristics and sets sampling targets for each group, based on some pre-determined criterion. This could be the proportion of total annual fishing effort expended by each metier or the proportion of the annual catch of the target species taken by each metier.

In addition to the concerns raised regarding the level and distribution of observer effort of the pilot programme, concern was raised regarding the method used to scale up the sub-sample on west coast vessels. It is difficult to provide an alternative to the protocol used, because due the complete catch is never observed. This makes visual estimation of the sample size impossible. Observers aboard UK vessels with conveyor mechanisms also base their estimate of the sub-sample size on the time spent filling baskets with discards. However, their estimate is improved by being able to see the entire catch in holding ponds on the deck (pers. obs.).

The best solution would be to collect all the discards into baskets before sub-sampling and estimate the proportion of the sub-sample from the total number of baskets. However, given the space limitations in the factory, this method will be impractical for large catches. The present method of using the time of conveyor belt operation would appear to be the most practical.

Other concerns regarding the pilot programme involve the data collection. Due to time and logistical constraints, no information on the length distribution of the retained catch or the benthic component of the catch was recorded. Future work must ensure that these components are quantified to produce a more realistic picture of the trawl catch. In addition, the percentage of the discards sub-sampled was often small (10 – 100% for west coast and 50 – 100% for south coast catches), increasing the sampling error. Future work must aim towards sampling a greater percentage of the discards (ideally 100%). This might be achievable for south coast catches but for large west coast catches is probably impossible and a lower target should be set. Increased data collection will allow individual sampling variability to be estimated in order to determine what level of sub-sampling is appropriate.

Table 6.2: Mean mass (kg/km^2 trawled) of hake, monkfish and sole discarded in each of the nine fishing areas defined from trawls observed between 1995 and 2000 on the south and west coasts of South Africa. *n* = number of trawls observed, *s.d.* = 1 standard deviation, *C.V.* = Coefficient of Variation

		Hake			**Monkfish**			**Sole**		
	n	mean	*s.d*	*C.V.*	mean	*s.d*	*C.V,.*	mean	*s.d*	*C.V.*
South Coast										
Blues Bank	139	60.9	113.1	209.9	0.03	0.3	2.1	0.2	1.3	11.2
Chalk Line	41	100.0	242.3	586.6	40.3	93.1	214.8	0.1	0.3	2.2
Inshore hake-directed	140	135.2	253.4	474.9						
Inshore sole-directed	294	251.9	294.6	344.6	0.01	0.1	1	7.6	13.5	23.9
West Coast										
0-300m	52	1003.6	1300.2	1684.3	18.1	33.2	60.9			
301-400m	142	1488.1	157.2	16.6	17.0	54.7	176.1			
401-500m	201	1270.4	2279.9	4091.6	56.2	217.4	840.7			
>500m	35	188.6	368.8	721.3	121.2	227.4	427.0			
Monkfish-directed	49	288.5	237.4	195.3						

Bycatch management

Solving bycatch problems is an adaptive process that follows a series of steps, *viz*: the collection and analysis of data, the assessment of possible solutions, the introduction of precautionary measures or mitigating regulations and the collection and review of new data (Fig 6.4). The efficacy of the initial measure or regulation is assessed and, depending on its success or failure, the solution is fully implemented, modified or abandoned. The process continues and management measures become more refined as data coverage increases.

In order to assess the success of a solution, it must be measured against a pre-determined target. However, it is extremely difficult to establish bycatch targets (Buxton and Eayres 1999), particularly if the initial data are limited. For example, if the aim is to reduce the incidental catch of a given species to a sustainable level, it may be difficult to determine what level is sustainable or how much of a reduction is enough. Alternatively, it is difficult to set an expected level of bycatch reduction when using an exclusion device if there are no data on the efficacy of the device on the species or fishery in question. Thus, not only are management measures adaptable, so are the targets.

The pilot observer programme data and the discussions with the fishing industry highlighted several areas of concern with regard to bycatch and areas that require management attention. To address these concerns, a bycatch action table similar to those proposed for Australian trawl fisheries (AFMA 2002b, c), has been formulated (Table 6.3). This table lists the problems identified, proposes some targets that could alleviate the problems and suggests solutions that may be used to achieve those targets. One of the most important concerns was the lack of a co-ordinated approach to bycatch management. If bycatch is to be accorded the same status as target species, it must be represented at all levels. Thus, the formation of a Bycatch Working Group (BWG), composed of representatives of all stakeholders and charged with developing management measures is required as soon as possible.

With regard to specific bycatch components, the most important is the capture of juvenile hake because of the potential loss of yield and the effect of unknown juvenile mortality on stock assessments. For demersal fisheries, a minimum mesh size is often set to determine the size of first capture (Table 1.1, Chapter 1) and therefore the simplest and most common method of reducing the capture of juveniles of the target species is to increase the minimum mesh size (Armstrong *et al.* 1990). However, whatever the mesh size, the net will pull closed whilst fishing, capturing small individuals, which will be discarded. Thus, although increasing the minimum mesh size will reduce the number of juvenile hake boated, there is some doubt whether the juvenile hake that escape through the diamond mesh will survive. Therefore, alternative methods, such as exclusion devices, grid sorters and escapement panels should be investigated. Square mesh panels, which do not pull closed during trawling, have been successfully used in New South Wales (Broadhurst and Kennelly 1995b) and the Mediterranean Sea (Petrakis and Stergiou 1997), and rigid sorting grids, which provide a stable opening for fish to escape, have been used in prawn trawl fisheries (e.g. Eayres *et al.* 1997) and tested in the Norwegian Atlantic cod fishery (Larsen and Isaksen 1993). The use of such exclusion devices could also help to reduce the catch of other discarded bycatch species.

An alternative solution for reducing bycatch is the closure of sensitive areas such as nursery or spawning grounds, either permanently (marine protected areas) or during particular periods (time/area closures) (Gauvin *et al.* 1995, Stergiou *et al.* 1997, Witherell and Pautzke 1997, NOAA/ NMFS 1998, Machias *et al.* 2001). Historically there was some measure of self-policing in the South African demersal sector as companies avoided the nursery grounds off Slangkop Point as a "gentleman's agreement". With the entrance of new operators who were not party to, or may not know of such "gentlemen's agreements", more formal regulations should be considered. However, care must be taken when considering the position and timing of closures to ensure that they will sufficiently protect the sensitive portion of the stock.

The closure of sensitive areas can be refined by the abandonment of trawl grounds when the proportion of small individuals in the catch reaches a pre-determined limit, as happens in the Bering Sea (Gauvin *et al.* 1995) or in some Norwegian fisheries (Olsen 1995). In order for such a system to be successful, real-time monitoring is required to ensure that areas of high bycatch are closed immediately and that they are re-opened as soon as the proportion of bycatch decreases below the acceptable level. This requires a high degree of co-operation and trust between the authorities and the industry. In South Africa, the potential of submitting logbook data electronically via satellite in real time is being investigated. If such a system were to be implemented, it could facilitate the management of time/area closures that are triggered by threshold limits of vulnerable species (either target or incidental) or life-stages. Vessels are already required to utilise a Vessel Monitoring System (VMS), which will allow closed areas to be policed more effectively.

The problem of high-grading particularly by smaller operators, remains a cause for concern. A possible approach may be to randomly scrutinise the landed hake catch. If the size distribution differs substantially from an expected value - perhaps the monthly average of all operators - then the operator concerned could be required to carry a compliance observer to record the fishing strategy employed. If the operator is unable to repeat his catch, he could face disincentives such as fines or other measures.

Managing the retained bycatch requires alternative solutions to ensure that catches are sustainable and maximally utilised. High value bycatch species such as monkfish and kingklip are unlikely to be managed by an increase in mesh size, as this would affect the capture of the target species. The introduction of a bycatch allocation, based upon the New Zealand example could be considered, with each operator allocated a quantum of the catch limit (Batstone and Sharp 1999). If the operator exceeds his limit he should either pay a levy to land it or be able to buy/trade quota from other operators. Thus, operators wishing to target high value species can do so, providing that they are willing to pay for it. If not, they are forced to fish using methods that will ensure they do not target these species.

However, setting a monkfish catch limit is problematic given the uncertainty regarding the stock status. Per recruit models (Chapter 5) suggested that $SBR_{CURRENT}$ was 14% of pristine, significantly lower than the 35% of pristine recommended for groundfish species by Clarke (1991). To attain the $F_{SBR35,}$ the $F_{CURRENT}$ (current fishing pressure) should be reduced by 42%. This would require a catch limit of approximately 4 060 tons. Booth (2004) undertook a more rigorous assessment using a replacement yield (*RY*) model. He estimated that an *RY* of 6 500 and 800 tons may be suitable to maintain monkfish biomass at current levels on the west and south coasts, respectively, which would suggest that catches should be reduced to 71 - 89% and 65 - 79% of their 2000 - 2002 monkfish levels for the two coasts, respectively.

In addition to the problems with assessing the stock status, it is currently unclear what the level of inevitable bycatch of high-value species in purely hake-directed fishing operations is. This must be determined and taken into account when setting a catch limit. Small operators with limited hake allocations further complicate the management of high value bycatch species, as they target these species to remain economically viable. Therefore measures that substantially reduce their access to high value bycatch species could drive them out of business. Innovative solutions could be considered, for example an algorithm that allocates a higher proportion of bycatch to operators with small hake allocations, than to operators with larger allocations (Leslie, 2004).

Given that stocks of many linefish species are collapsed or overexploited (Griffiths 1997a, b, Griffiths 2000), it would seem prudent to reduce catches of these species, despite the lack of data on the impact of trawling on stocks. Reduction of juvenile linefish bycatch in the trawl fishery may help slow the decline of stocks and could reduce friction between the trawl and linefish sectors over the bycatch issue. The use of exclusion devices is likely to be the most practical means of reducing incidental bycatch. Broadhurst and Kennelly (1994, 1995a) report that square mesh netting in the anterior section of the cod-end allows a significant proportion of *A. hololepidotus* to escape from prawn trawls, suggesting that this device could be used to reduce catches of kob *A. inodorus*.

Realistically, irrespective of the management measure bycatch can only be minimised, not eliminated. If bycatch is unavoidable, consideration should be given to landing and utilising the catch. However, the South African fishery already utilises a great deal of the bycatch (particularly on the South Coast, Chapter 2). The remainder is discarded because it is not economically viable. In order to fully utilise bycatch, products and markets must be developed, requiring a greater understanding of South African bycatch economics.

The final issue that must be considered is that of compliance. There are various ways of ensuring better compliance including greater observer coverage at sea and at discharge points, stiffer penalties for transgressors and understanding by the industry of the need for regulations. Annala (1996) reports that transgressions in the New Zealand demersal fishery were substantially reduced by the implementation of penalties such as the loss of rights, vessels and equipment. In South Africa, all vessels are required to carry VMS, which will allow the monitoring of any closed areas. The adoption of new technology such as electronic logbooks and real-time recording, which would aid compliance officers to determine if the recorded catch tallies with the catch in the hold, is under consideration and should be encouraged. Finally, a collaborative management approach should increase industry responsibility towards the sustainable utilisation of the resource, encouraging adherence to the rules.

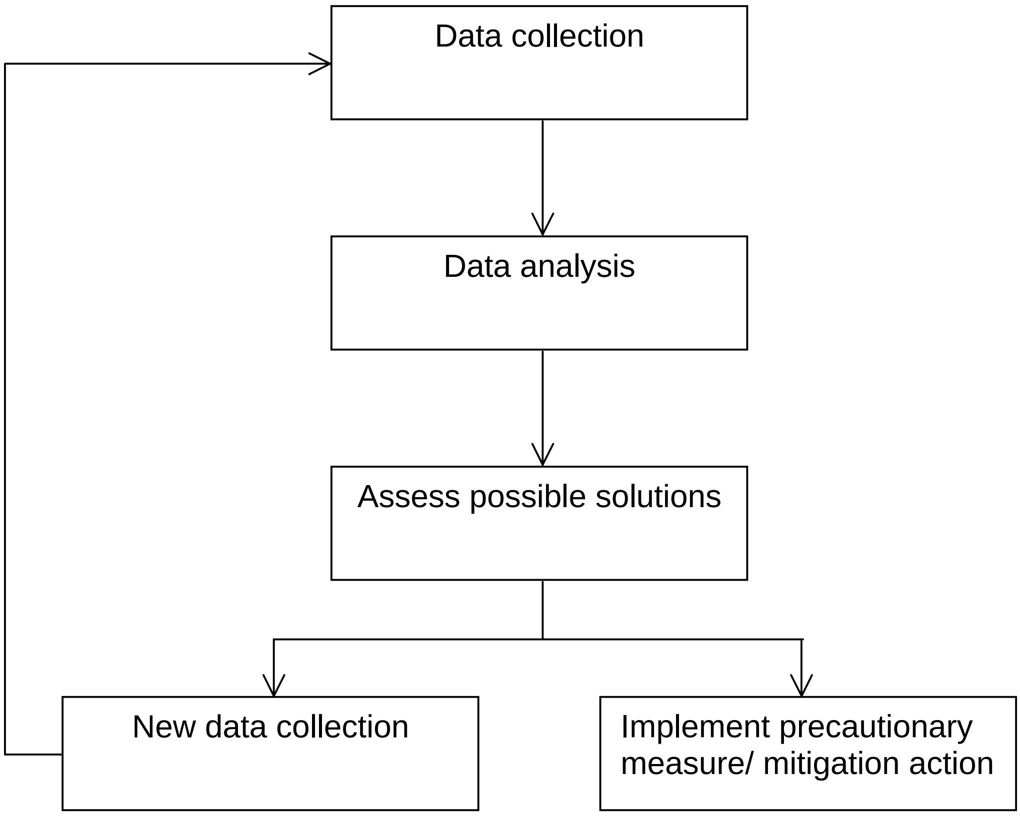


Fig 6.4: Flow chart showing the steps followed for an adaptive bycatch management plan.

Table 6.3: Bycatch action table for the South African demersal trawl fishery. Immediate concerns regarding bycatch are given with targets to reduce the concerns and solutions for achieving those targets.

Problem	**Target**	**Solution**
General There has been a lack of dialogue between management and industry regarding bycatch issues.	Better relationship between scientists and industry, leading to understanding about the importance of a structured approach to bycatch management.	Form a Bycatch Working Group with representatives from all stakeholders (by end 2005)
Data collection The pilot observer programme only managed to collect data from 0.49% and 0.62% of west coast and south coast trawls, respectively. This effort was unstratified and may be unrepresentative of the fleet. Concerns were also raised regarding the sampling methodology. Many bycatch questions remain unanswered and there is need for continued data collection to monitor the effects of bycatch regulations.	Representative data from all sectors of the fishery that can be used to answer many of the questions still remaining about the impact of trawling on target and non-target stocks.	Appoint a scientist dedicated to the analysis and interpretation of the bycatch data in order to direct future work (immediately). Specify a minimum of 10% coverage per right holder to ensure representative coverage (by end 2005). Stratify the observer effort using the proposed metiers based on the proportion of the total hake allocation for that metier (by end 2005). Bycatch scientist to review the data available from the new programme to assess the levels of variance within samples (as soon as possible). Re-evaluate the sampling protocols of the new observer programme.(as soon as possible) Fully utilise the data of the new observer programme (ongoing).
	The collection of more accurate effort data for non-hake species.	Educate skippers on the need to correctly fill in log books, especially with respect to indicating the target species. Disseminate results to skippers to aid in their

		understanding and increase interest in the science (ongoing).
Discarded bycatch Hake discarding It is estimated that nearly 7 000t of hake are discarded annually on the west coast (Chapter 3) and nearly 2 000t of hake are discarded on the south coast (Chapter 2). Sole-directed trawlers discard approximately 20% of the hake that they catch, much of which is <25 cm *TL* There is no information available on the potential loss of yield that this figure represents. In addition, no information is currently available on the possible increase of high-grading. Incidental species Undersized incidental (*e.g.* ribbonfish) and all unutilisable (*e.g.* macrourids) species are discarded. Ideally, this component of the catch should be minimised, as the stock status of the species may be negatively affected by fishing. In terms of good fishing practices we should aim to avoid unnecessary fishing mortality.	Understand the impact of fishing mortality on juvenile hake. Minimise the discarding of juvenile hake. Collect better data on high-grading. Minimise the catch of undersized retained bycatch and unutilisable species	Collect additional data so that more specific assessments can be undertaken (start Jan 2006). Formally close known nursery areas such as off Port Nolloth to ensure that new entrants unfamiliar with such areas, do not catch excess small hake (by end 2005). Experiment with exclusion devices (begin Jan 2006). Investigate the use of real-time reporting to assist in the closure of fishing areas when the proportion of small individuals exceeds a predetermined threshold level (begin Jan 2006). Use scientific observers to monitor the length-frequency of landed hake catch (ongoing). Experiment with exclusion devices (begin Jan 2006)
Retained bycatch		

High value bycatch species Monkfish and kingklip landings have increased (Stuttaford 2000) but there is no catch limit or management strategy for these species. Stock assessments suggest that the monkfish stock is at <20% of pristine spawner biomass (Chapter 5) and that kingklip is at <50% pristine biomass (Mori and Butterworth 2002). The recommended minimum level of spawner biomass for long-lived demersal species is 35% of pristine (Clark 1991).	Better stock assessment for monkfish. Ensure that catches are sustainable. Data on the basic bycatch levels of these species by hake-directed trawling.	Collect the data necessary to run more complex stock assessments for monkfish (ongoing 2005). Given the current assessments for both species, set a precautionary catch limit for these species. The PCL should be set at the historical average of landings (begin Jan 2006). Use observer and commercial landings data to determine the levels of monkfish and kingklip bycatch that result from normal hake-directed fishing operations (begin Jan 2006).
Other species Retained bycatch species should be maximally utilised and their catches should be sustainable. There is little information on their stock status to determine these levels. Also, the current utilisation of bycatch is largely dependent on market forces. Changes to the market could cause changes to discarding practices.	Better information on the stock status of retained bycatch species.	Collect biological and catch information on retained bycatch species (ongoing). Develop strategies to fully utilise bycatch (ongoing).
Linefish Juvenile linefish are caught incidentally, particularly by inshore trawlers (Chapter 2). Many linefish stocks are collapsed or overexploited (Griffiths 2000). There is no information on the impact of trawling on linefish stocks	Reduce the incidental catch of linefish species	Experiment with exclusion devices (begin experiments 2006) Determine whether linefish nursery grounds overlap trawling grounds and if so, investigate their closure to trawlers (ongoing).
Economics Bycatch economics and the impact of regulations on bycatch revenue are poorly	Fully understand the economic implications of bycatch measures	Initiate a large-scale programme to investigate the economics of bycatch (Instigate Jan 2006).

understood.		
Compliance It is reported that there are problems with compliance at sea (with respect to mesh size and discarding of regulated species), bycatch may be under-reported, and there is a lack of monitoring at all discharge points (Department of Environmental Affairs and Tourism 2000)	Increased compliance with regulations	Include the fishing industry in the management process to encourage a feeling of ownership of the resource (ongoing). Disseminate scientific information more widely , to allow fishers to understand why regulations exist (ongoing). Ensure that transgressors are properly punished. Ensure that the industry is made aware of these punishments as a warning to others (ongoing)

Design of the first phase of the National Observer Programme

Introduction

The primary aim of the pilot observer programme was to provide the basis for a National Observer Programme (NOP), taking into account the lessons learnt. The key findings were that (i) the observer coverage must be increased to provide realistic estimates of bycatch and discarding, (ii) the coverage must be stratified to account for differences in species diversity or fishing strategies and (iii) the sampling protocols must be re-evaluated to ensure that sampling bias is minimised. Table 6.4 shows the suggested level and distribution of coverage and the sampling methods that should be employed.

First, the observer coverage must be stratified. The results from the pilot programme indicated that metiers should be based on fishing grounds or depth ranges fished. However, it will be difficult, to implement observer coverage based on the metiers used in the initial analysis, although they could be considered when analysing the NOP data. Although the pilot study did not include coverage of the smaller offshore companies and the new operators, it seems likely that economic pressures will force smaller companies to adopt different fishing and bycatch strategies to the large established companies. A more practical approach may therefore be to divide the fishery into metiers based on a combination of: the coast fished; the main target species; the size of the hake allocation (large or small); and whether the company had inshore or offshore right. Large companies would be defined as those with individual allocations in excess of 10% of the offshore trawl sectorial allocation and small companies would be those with less that 10% of the offshore allocation.

Under this model there would be three west coast (monkfish-directed and large and small offshore hake-directed) and four south coast (sole-directed, inshore hake-directed and large and small offshore hake-directed) metiers.

Observer coverage

Given the results of the pilot programme, it is suggested that a blanket 10% observer coverage should provide adequate bycatch data for the fleet. However, this coverage could be modified to increase the sampling of some metiers and reduce sampling in others. For the west coast, 179 trawls were observed in 1997, equating to an estimated 0.49% of total effort. In order to provide 10% coverage, approximately 3650 trawls must be observed. Assuming that each trip lasts 7 days and that 4 trawls can be observed per day, 130 trips must be observed annually on this coast. However, it is suggested that the monkfish-directed and small offshore hake-directed metiers are allocated proportionally more of these trips to obtain enhanced coverage in these metiers (Table 6.4).

For the south coast inshore areas, 181 trawls were observed in 1997, equating to an estimated 0.55% of total effort. In order to provide 10% coverage, approximately 3290 trawls must be observed. Assuming that each trip lasts 10 days and that 4 trawls can be observed per day, 82 trips must be observed on this coast. It is suggested that sole-directed trawls receive a higher proportion of these trips (Table 6.4). For the south coast offshore areas, 101 trawls were observed in 1997, equating to an estimated 0.44% of total effort. In order to provide 10% coverage, approximately 2295 trawls must be observed. Assuming that each trip lasts 7 days and that 4 trawls can be observed per day, 82 trips must be observed on this coast. These should be split equally between large and small operators.

Sampling protocol

Since the primary aim is to collect data on the whole catch, it is vital that information is collected from the retained and discarded portions. Due to time constraints it is highly unlikely that length, weight and biological information can be collected from the retained and discards portion of every trawl. Thus, trawls should be sampled in one of four ways, a catch composition sample, a discard length frequency sample and a length frequency information and a biological sampling.

To determine the total catch composition, the mass and number of the retained and discarded portion of the catch must be determined. A sample of the unsorted catch must be retained and the proportion of the sub-sample must be estimated. On the west coast, it is suggested that the proportion of the discard sub-sample should be estimated recording the total time that the conveyor belt is in operation and the time spent removing the unsorted sample, as used in the pilot study. On the south coast, the method of visually estimating the proportion of the sub-sample is considered adequate. Although 100% of the sample should ideally be measured, this is impractical, particularly if the catch is large. Therefore it is suggested that approximately 3 - 5 baskets should be retained for sorting. The sample should sorted to species level (or for benthos, as far as possible) and each component weighed. The target species should be weighed first and passed to the crew for processing. Information on the trawl position, etc. must be obtained from the ship's log.

For length frequency sampling, approximately 3 - 5 baskets of discards should be collected once the retained catch has been removed. In addition, 1 - 2 boxes of the retained species should be obtained from the crew and measured. The discard sample should be sorted to species, weighed and in the case of priority discard species, measured. Priority discard species should be defined by MCM but should include discarded target species and any bycatch species usually retained. Other common discard species such as macrourids should also be measured in addition to any rare or unusual species. Information on the trawl position etc. should be obtained from the ship's log.

During biological sampling, approximately 20 fish representing the whole size range (retained and discards) of the sample species should be sampled. The length, weight (if possible) and other biological information (*e.g.* sex, maturity, otoliths) should be collected from each specimen. Again, information on the trawl position *etc.* should be collected from the ship’s log. Biological sampling should be undertaken at the direction of MCM.

It is suggested that catch composition and length frequency sampling should be alternated and that given the large number of trips proposed per annum, one biological sample per trip should be sufficient for each species required.

Table 6.4: Suggested distribution of effort, levels of coverage and sampling protocols for a national observer programme for the South African demersal trawl fleet, based on the results of the pilot programme.

Distribution of effort and levels of coverage	
Metier	Estimated number of trips required per year
West Coast	
Offshore (large allocation)	36
Offshore (small allocation)	47
Monkfish-directed vessels	47
South Coast	
Sole-directed vessels	47
Inshore hake-directed	35
Offshore (large allocation)	41
Offshore (small allocation)	41

Sampling protocols

Catch composition sampling

1) Collect 3 - 5 baskets of the catch, before the crew sorts it.
2) Estimate the size of the sub-sample. On the west coast, estimate the proportion of the sub-sample from the sampling time and time of conveyor belt operation. On the south coast, estimate the proportion of the sub-sample visually.
3) Sort the sample to species. Sort the benthos as far as possible.
4) Weigh each species starting with the target species, followed by the retained bycatch then the discard species.
5) Collect trawl information from the ship’s log.
6) Scale up the sub-sample to estimate the total catch composition by weight.

Length frequency sampling

1) Collect 3 baskets of discards after the crew has sorted it.
2) Collect 2 baskets of retained catch from the crew.
3) Measure the retained catch.
4) Measure the priority discard species
5) If time allows, measure any other discard species
6) Obtain information on the trawl position etc.

Biological sampling (to be collected only as required by MCM, one sample per trip)

1) Collect ~20 specimens of the sample species, covering all length classes.
2) Weigh, measure and collect relevant biological data (*e.g.* sex, maturity, otoliths).

Conclusion

At the beginning of 2002, medium-term rights of four year's duration were allocated in the demersal trawl fishery, recognising the need for stability and hopefully reducing uncertainty and promoting investment in the industry. This period will come to an end in December 2005. In January 2006 long-term rights will be allocated. This will be accompanied by the adoption of a new management policy and new operations manual for hake fisheries and by the establishment of a Management Working Group (MWG). The MWG, with representation by all stakeholders, will have the responsibility of implementing the policy document and the operations manual. It is essential that bycatch management issues are included in this process and hopefully, the bycatch action plan and the structure for the NOP proposed in this thesis will go some way to ensuring that this happens.

There are probably four key elements required for the development of a successful bycatch management plan. The first is that there must be agreement by all stakeholders on the importance of bycatch management and a sincere undertaking to co-operatively find solutions. Preliminary discussions have hopefully raised awareness of the issue, but all stakeholders should recognise the need to find ways of managing the fishery in a responsible and sustainable manner. Secondly, capacity must be available at all levels. One of the most important lessons learnt from the pilot observer programme was that the collection of bycatch data is costly and time-consuming. Without significant funding and personnel, the data obtained will be inadequate for answering specific questions. The new observer programme promises to provide the capacity to collect the necessary data. However, the full potential of the data can only be realised if the personnel are in place to ask the necessary questions, to determine how those questions should be answered and to analyse and interpret the data. Thirdly, the success or failure of bycatch management in South Africa will depend on the BWG itself. The BWG must understand all the needs (biological, social, economic, political and technological) that exist with regard to bycatch management and must have the innovative capacity to provide solutions that satisfy all those needs or to find appropriate compromises. In addition, the composition of the BWG must be such that it has the trust of all stakeholders. Lastly, the BWG must be given the freedom to undertake research, experiment with new ideas and technologies and to make recommendations that will be seriously considered at all levels.

Appendices

Appendix A: Checklist of all species observed caught by demersal trawlers operating off the south coast of South Africa

Class	Order	Family	Species name	Common name	CPUE (kg/hour)			
					Blues Bank	Chalk Line	Hake-directed	Sole-directed
OSTEICHTHYES								
	CLUPEIFORMES							
		Clupeidae	*Etrumeus whiteheadi*	Anchovy	0.0218	0.0000	0.5169	0.0000
			Sardinops sagax	Pilchard	0.1875	0.5748	0.0399	0.0000
		Engraulidae	*Engraulis capensis*	Red-eye	0.0000	0.0000	0.0923	0.0000
	GADIFORMES							
		Merluccidae	*Merluccius capensis*	Shallow-water hake	528.2167	856.2222	460.8829	72.6917
			Merluccius paradoxus	Deep-water hake	528.2167	856.2222	460.8829	72.6917
	LOPHIIFORMES							
		Chaunacidae	*Chaunax pictus*		0.0000	0.1011	0.0000	0.0000
		Lophiidae	*Lophius vomerinus*	Monkfish	10.8573	23.3794	8.3195	0.2506
	OPHIDIIFORMES							
		Ophidiidae	*Genypterus capensis*	Kingklip	4.6103	6.2058	6.4599	0.7684
	PERCIFORMES							
		Acropomatidae	*Synogrops japonicus*	Japanese splitfin	0.0000	0.0258	0.0000	0.0000
		Carangidae	*Trachurus trachurus capensis*	Horse mackerel	228.1356	183.5908	143.9001	2.6153
		Cheilodactylidae	*Cheilodactylus fasciatus*	Red fingers	0.0000	0.0000	0.0000	0.0010
			Cheilodactylus pixi	Barred fingerfin	0.0000	0.0000	0.0000	0.0012
			Chirodactylus brachydactylus	Two-tone fingerfin	0.0065	0.0000	0.0006	0.0019
			Chirodactylus grandis	Bank steenbras	0.0000	0.0000	0.0001	0.0000
		Gempylidae	*Thyrsites atun*	Snoek	1.8406	0.0000	0.4431	0.3364
		Haemulidae	*Pomadasys olivaceum*	Piggy	0.0000	0.0000	0.0000	0.0017
		Pomatomidae	*Pomatomus saltatrix*	Elf	0.0000	0.0000	0.0000	0.0006
		Sciaenidae	*Argyrosomus inodorus*	Kob	0.0000	1.7283	0.5812	2.2822
			Umbrina canariensis	Baardman	0.0000	0.0000	0.0776	0.2853

	Scombridae	*Scomber japonicus*	Mackerel	1.2649	7.3282	5.7173	0.4084
	Sparidae	*Argyrozona argyrozona*	Carpenter	3.0590	0.0281	0.5156	0.0471
		Atractoscion aequidens	Geelbek	0.0000	0.0000	0.1514	0.0180
		Cheimerius nufar	Santer/ Soldier	0.0000	0.0000	0.0000	0.0020
		Chrysoblephus gibbiceps	Red stumpnose	0.0000	0.0000	0.0000	0.0059
		Lithognathus lithognathus	White steenbras	0.0000	0.0000	0.0000	0.0017
		Pachymetopon aeneum	Blue hottentot	1.7917	0.0000	0.0665	0.2208
		Pagellus bellotti natalensis	Red tjor-tjor	0.0000	0.0000	0.0007	0.0673
		Pterogymnus laniarius	Panga	58.5437	23.5719	120.7491	0.7134
		Rhabdosargus globbiceps	White stumpnose	4.1629	0.0000	0.0829	0.3690
		Spondyliosoma emarginatum	Steentjie	0.0000	0.0000	0.0000	0.0146
	Trichiuridae	*Lepidopus caudatus*	Ribbonfish	0.1931	7.3190	0.1785	0.0000
PLEURONECTIFORMES							
	Bothidae	*Arnoglossus capensis*	West Coast sole	0.0003	0.0073	0.0000	0.0022
	Cynoglossidae	*Cynoglossus zanzibarensis*	Sandrat	0.0201	7.6137	4.1581	0.0511
	Soleidae	*Austroglossus pectoralis*	East Coast sole	4.4627	0.0067	3.3452	20.5706
SCORPAENIFORMES							
	Congiopodidae	*Congiopodus spinifer*	Spiny horsefish	0.1794	0.1230	0.7515	0.0184
		Congiopodus torvus	Smooth horsefish	0.7919	1.1905	0.5286	0.0106
	Peristediidae	*Satyrichthys adeni*	Armoured gurnard	0.0000	0.0141	0.0000	0.0000
	Scorpaenidae	*Helicolenus dactylopterus*	Jacopever	1.6472	40.5758	4.2904	0.0113
	Triglidae	*Chelidonichthys capensis*	Cape gurnard	12.2022	13.0189	8.9999	1.8172
	Triglidae	*Chelidonichthys queketti*	Lesser gurnard	4.7129	11.2780	14.0497	0.3463
SILURIFORMES							
	Ariidae	*Galeichthys feliceps*	White seacatfish	0.0000	0.0000	0.0096	0.6370
TETRAODONTIFORMES							
	Tetraodontidae	*Amblyrhynchotes honkenii*	Evileye blaasop	0.0000	0.0000	0.0037	0.0032
ZEIFORMES							
	Oreosomatidae	*Oresoma atlanticum*	Oxeye dory	0.0000	0.2652	0.0000	0.0000
	Zeidae	*Zeus capensis*	Cape dory	2.0599	18.9462	0.9131	0.2013
CHONDRICHTHYES							
CARCHARHINIFORMES							
	Carcharhinidae	*Carcharhinus brachyurus*	Bronze whaler	0.0000	0.0000	0.0000	0.0257

		Carcharhinus obscurus	Dusky shark	0.0000	0.0000	0.0000	0.0257
	Scyliorhinidae	*Halaelurus natalensis*	Tiger catshark	0.0026	0.0112	0.0479	0.0291
		Haploblepharus edwardsii	Puffadder shyshark	0.1401	0.0000	0.1473	0.1117
		Holohahaelurus regani	Izak	0.3424	0.1563	0.1985	0.0009
		Poroderma africanum	Pyjama shark	0.0000	0.0562	0.1681	0.5775
		Poroderma pantherinum	Leopard catshark	0.0534	0.3326	0.0000	0.0060
		Scyliorhinus capensis	Yellowspotted catshark	0.2392	0.2095	0.0754	0.0021
	Sphyrnidae	*Spyrna zygaena*	Scalloped hammerhead	0.0000	0.0000	0.0000	0.0300
	Triakidae	*Galeorhinus galeus*	Soupfin shark	3.6446	3.0773	3.1458	0.5818
		Mustelus mustelus	Houndshark	0.0000	0.1902	0.0036	0.0211
		Mustelus palumbes	Whitespotted houndshark	0.0042	0.0000	0.0012	0.0118
CHIMAERIFORMES							
	Callorhinchidae	*Callorhinchus capensis*	St Joseph shark	8.0189	1.1522	10.3071	1.2245
MYLIOBATIFORMES							
	Dasyatidae	*Dasyatis marmorata*	Blue stingray	0.0000	0.0000	0.0501	0.0175
	Gymnuridae	*Gymnura natalensis*	Diamond ray	0.0000	0.0000	0.0074	0.0000
	Myliobatidae	*Myliobatis aquila*	Bullray	0.0476	0.0000	0.0778	0.1127
		Pteromylaeus bovinus	Duckbill ray	0.0000	0.0000	0.0111	0.0034
PRISTIOPHORIFORMES							
	Pristiophoridae	*Pliotrema warreni*	Sixgill sawshark	0.0000	0.0000	0.0160	0.0000
RAJIFORMES							
	Rajidae	*Cruriraja parcomaculata*	Roughnose legskate	0.0000	0.7132	0.0000	0.0000
		Raja alba	Spearnose skate	0.5518	0.0169	1.1250	1.2544
		Raja caudaspinosa	Munchkin skate	0.0000	0.0000	0.0000	0.0009
		Raja miraletus	Twineye skate	0.0000	0.0000	0.0090	0.4710
		Raja pullopunctata	Slime skate	0.8249	0.0593	0.1054	0.0789
		Raja straelini	Biscuit skate	28.7862	3.4240	18.5819	6.5082
		Raja wallacei	Yellowspot skate	0.4328	3.6211	0.3820	0.1516
RHINOBATIFORMES							
	Rhinobatidae	*Rhinobatos annulatus*	Lesser guitarfish	0.0000	0.0000	0.0020	0.0649
SQUALIFORMES							
	Squalidae	*Squalus megalops*	Shortnose spiny dogfish	13.2927	4.1497	4.7936	0.3139
TORPEDINIFORMIDAE							

	Narkidae	*Narke capensis*	Onefin electric ray	0.0000	0.0000	0.0000	0.0841
	Torpedinidae	*Torpedo fuscomaculata*	Blackspotted electric ray	0.0000	0.0000	0.0074	0.1230
		Torpedo nobiliana	Atlantic electric ray	0.0000	0.0000	0.0337	0.2045
CEPHALOPODA							
OCTOPODA							
	Octopodidae	*Octopus magnificus*	Deepwater octopus	0.0000	0.0000	0.0369	0.0043
		Octopus vulgaris	Common octopus	(Values for octopus species are combined)			
TEUTHOIDEA							
	Loliginidae	*Loligo vulgaris reynaudii*	Chokka squid	15.1289	6.6151	25.1926	1.3092

Appendix B: Mass (kg) and number of fish and cephalopods estimated to be discarded annually by trawlers operating on the south coast of South Africa. Estimates were calculated using observer data collected during 1997 and extrapolated to the annual catch using a landings-based approach. Note that because the estimates were obtained using 1997 data, estimates for species recorded from years other than 1997 (and therefore listed in Appendix A) may not be available.

	Inshore		Offshore		Total	
	Mass (kg)	Number	Mass (kg)	Number	Mass (kg)	Number
Teleostei						
Merluccius sp.	565 947.5	2 408 528	1 436 721.7	5 081 912	2 002 669.2	7 490 440
Chelidonichthys queketti	157 003.7	732 016	657 438.2	3 012 467	814 441.9	3 744 483
Lepidopus caudatus	5 948.3	10 653	643 703.6	1 052 688	649 651.9	1 063 342
Helicolenus dactylopterus	975.3	3 602	647 490.0	2 777 650	648 465.2	2 781 252
Zeus capensis	42 856.1	227 449	442 893.6	955 459	485 749.7	1 182 908
Genypterus capensis	1 088.1	4 469	244 363.8	255 137	245 451.9	259 606
Lophius vomerinus	15.8	76	213 846.6	110 359	213 862.4	110 435
Trachurus trachurus capensis	5 557.2	53 724	173 832.1	277 608	179 389.3	331 331
Chelidonichthys capensis	24 024.1	72 567	141 417.5	289 494	165 441.6	362 062
Scomber japonicus	3 573.5	11 637	105 926.9	253 174	109 500.4	264 811
Congiopodus torvus	15 746.3	16 883	40 526.3	68 347	56 272.6	85 230
Galeichthys feliceps	35 591.6	53 044	0.0	0	35 591.6	53 044
Cynoglossus zanzibarensis	0.0	0	296 29.8	107 130	29 629.8	107 130
Austroglossus pectoralis	18 231.9	229 644	385.1	1 606	18 617.0	231 249
Oresoma atlanticum	0.0	0	15 150.8	52 941	15 150.8	52 941
Congiopodus spinifer	13 156.8	89 017	1 444.0	1 925	14 600.8	90 942
Argyrosomus inodorus	9 965.2	71 074	0.0	0	9 965.2	71 074
Chaunax pictus	0.0	0	5 775.8	9 626	5 775.8	9 626
Pterogymnus laniarius	5 568.4	33 682	0.0	0	5 568.4	33 682
Pagellus bellotti natalensis	3 728.6	24 120	0.0	0	3 728.6	24 120
Umbrina canariensis	2 747.0	10 822	0.0	0	2 747.0	10 822
Engraulis capensis	2 358.9	29 533	0.0	0	2 358.9	29 533
Synogrops japonicus	0.0	0	1 476.3	8 987	1 476.3	8 987

Argyrozona argyrozona	1 176.5	8 171	0.0	0	1 176.5	8 171
Pachymetopon aeneum	981.9	5 868	0.0	0	981.9	5 868
Rhabdosargus globbiceps	874.6	4 662	0.0	0	874.6	4 662
Satyrichthys adeni	0.0	0	850.3	4 252	850.3	4 252
Arnoglossus capensis	3.3	189	417.5	1 925	420.8	2 114
Chirodactylus brachydactylus	178.0	1 154	0.0	0	178.0	1 154
Thyrsites atun	73.7	368	0.0	0	73.7	368
Pomatomus saltatrix	53.3	533	0.0	0	53.3	533
Amblyrhynchotes honkenii	22.9	229	0.0	0	22.9	229
Chirodactylus grandis	3.4	94	0.0	0	3.4	94
Chondrichthyes						
Squalus megalops	265 405.1	649 471	816 531.0	695 539	1 081 936.2	1 345 010
Raja wallacei	16 572.8	28 158	474 522.7	202 886	491 095.4	2 31 044
Scyliorhinus capensis	0.0	0	413 800.8	434 762	413 800.8	434 762
Raja straelini	155 280.1	333 788	51 912.0	32 072	207 192.1	365 860
Raja pullopunctata	18 776.3	16 141	187 681.3	50 844	206 457.6	66 986
Holohahaelurus regani	6 452.7	6 528	143 618.3	270 379	150 071.0	276 907
Galeorhinus galeus	0.0	0	121 881.9	14 172	121 881.9	14 172
Cruriraja parcomaculata	0.0	0	79 176.9	137 353	79 176.9	137 353
Raja alba	73 193.7	15 526	0.0	0	73 193.7	15 526
Callorhinchus capensis	1 418.2	2 836	51 020.4	12 755	52 438.7	15 592
Torpedo nobiliana	17 273.0	33 839	15 943.9	1 772	33 216.9	35 610
Raja miraletus	22 821.8	37 497	0.0	0	22 821.8	37 497
Bathyraja smithii	0.0	0	16 197.0	4 049	16 197.0	4 049
Poroderma africanum	12 851.9	14 328	0.0	0	12 851.9	14 328
Mustelus mustelus	1 111.7	1 143	11 508.4	6 394	12 620.1	7 537
Myliobatis aquila	7 825.9	5 045	0.0	0	7 825.9	5 045
Narke capensis	6 563.0	66 992	0.0	0	6 563.0	66 992
Haploblepharus edwardsii	6 314.6	24 206	0.0	0	6 314.6	24 206
Poroderma pantherinum	2 933.4	8 741	0.0	0	2 933.4	8 741
Rhinobatos annulatus	2 313.8	8 231	0.0	0	2 313.8	8 231
Halaelurus natalensis	2 079.7	10 517	0.0	0	2 079.7	10 517

Dasyatis marmorata	1 227.9	1 448	0.0	0	1 227.9	1 448
Torpedo fuscomaculata	919.7	2 134	0.0	0	919.7	2 134
Mustelus palumbes	489.6	1 466	0.0	0	489.6	1 466
Pteromylaeus bovinus	38.1	76	0.0	0	38.1	76
Cephalopoda						
Loligo vulgaris reynaudii	0.0	0	15 073.9	67 074	15 073.9	67 074

Appendix C: Checklist of all species and the associated CPUE (kg/ trawl hour) recorded in trawls made by vessels operating on the west coast of South Africa between January 1996 and September 2000. (* in the species name column denotes the presence of that species in trawls targeting monkfish, [1] Species for which there was no positive identification but which is likely to have been one of those mentioned).

Class Order Family	Species name	Common name	CPUE (kg/hr)
PTERASPIDOMORPHII			
MYXINIFORMES			
Myxinidae	*Eptatretus hexatrema*	Sixgill hagfish	0.0009
OSTEICHTHYES			
ANGUILLIFORMES			
Anguillidae	*Conger wilsoni /Basanango capensis**[1]	Cape conger/ Hairy conger	1.1294
AULOPIFORMES			
Chloropthalmidae	*Chloropthalamus agassizi*	Greeneye	0.0609
BERYCIFORMES			
Berycidae	*Beryx splendens*	Alphonso	1.1098
Trachichthydae	*Hoplostethus atlanticus*	Orange roughy	0.0012
	Hoplostethus mediterraneus	Silver slime head	0.0521
CLUPEIFORMES			
Clupeidae	*Sardinops sagax*	Sardine	0.0201
GADIFORMES			
Macrouridae	*Caelorinchus braueri / C. karrae**[1]	Sharpnose grenadier species	1.6119
	*Caelorinchus symorhynchus**	Snub-nosed grenadier	13.5968
	Lucigadus ori / Negumia micronyerodon / N. umbricinta[1]	Blackspotted grenadier	0.0075
	*Malacocephalus laevis**	Purple grenadier	8.9092
Merluccidae	*Merluccius capensis*	Shallow-water hake	1734.7916
	*Merluccius paradoxus**	Deep-water hake	(combined)
Moridae	*Lepidion capensis*	Codlet	0.4008
	Physiculus capensis	Cape codlet	0.0031

LOPHIIFORMES			
Chaunacidae	*Chaunax pictus*	Batfish, red bloater	0.0064
Lophiidae	*Lophius vomerinus*	Monkfish	92.0081
MYCTOPHIFORMES			
Myctophidae	*Lampanyctus hectoris* / plus others[1]	Various lightfish species	0.0004
NOTOCANTHIFORMES			
Notocanthidae	*Notocanthus sexipinus*	Spiny eel	0.0004
OPHIDIIFORMES			
Ophidiidae	*Genypterus capensis**	Kingklip	12.0509
	Selachophidium guentheri	Pink brotula	0.0660
PERCIFORMES			
Apogonidae	*Epigonus telescopus / E. robustus*[1]	Epigonus sp.	0.0390
Bramidae	*Brama brama*	Angel	7.0734
Callionymidae	*Paracallyiomus costatus*	Dragonette	0.0002
Carangidae	*Trachurus trachurus capensis**	Horse mackerel	26.9267
Emmelichthidae	*Emmelichthys nitidus*	Red harder	0.4081
Gempylidae	*Ruvettus pretiosus*	Oilfish	0.1363
	Thyrsites atun	Snoek	34.0892
Scombridae	*Scomber japonicus**	Mackerel	2.6251
Stromateidae	*Centrolophus niger*	Black ruff	0.2070
	Schedophilus huttoni	Driftfish	0.0706
Trichiuridae	*Lepidopus caudatus*	Ribbonfish	17.5889
SCORPAENIFORMES			
Congiopodidae	*Congiopodus torvus*	Smooth horsefish	0.0243
Psychrolutidae	*Psychrolutes macrocephalus / M. inermis*[1]	Jelly belly	0.1062
Scorpaenidae	*Helicolenus dactylopterus**	Jacopever	23.1163
	Sebastes capenis	Cape scorpionfish	0.0157
Triglidae	*Chelidonichthys capensis / C. queketti**[1]	Cape gurnard / lesser gurnard	0.9857
STOMIIFORMES			

Sternoptychidae	*Maurolicus muelleri*	Lightfish	0.0003
Photichthydae	*Photichthyes argentius*		
SYGNATHIFORMES			
Macroramphosidae	*Notopogon macrosolen*	Orange trumpeter	0.0663
TETRAODONTIFORMES			
Tetraodontidae	*Amblyrhynchotes honkenii*	Evil-eye blaasop	0.1335
ZEIFORMES			
Oreosomatidae	*Allocyttus verucosus*	Oreo	0.0277
	Neocyttus rhomboidalis	Deepsea John Dory	0.1981
	Oresoma atlanticum	Oreo	0.0498
Zeidae	*Cyttus traversi*	Shortfin John dory	0.0828
	*Zeus capensis**	Cape dory	12.6568
CHONDRICHTHYES			
CARCHARHINIFORMES			
Scyliorhinidae	*Holohalaelurus regani**	Izak spotted shyshark	1.7357
	*Scyliorhinus capensis**	Yellowspotted catshark	0.9313
Triakidae	*Galeorhinus galeus*	Soupfin shark	0.1308
	Mustelus palumbes/ M. mustelus	Whitespotted smoothhound	0.2109
CHIMAERIFORMES			
Callorhinchidae	*Callorhinchus capensis*	St. Joseph shark	0.4230
RAJIFORMES			
Rajidae	*Raja wallacei*	Yellowspot skate	2.7340
	Cruriraja parcomaculata	Roughnose legskate	0.8865
	Raja alba	Spearnose skate	0.1253
	Raja straelini	Biscuit skate	0.7010
	Raja pullopunctata	Slime skate	0.6411
	Raja leopardus/ R. springeri/ R. caudaspinosa/ Bathyraja smithii	Various skate species	2.2473
SQUALIFORMES			
Squalidae	*Centroscyllium* sp./ *Etmopterus* sp.	Various deepwater dogfish species	0.5597

	*Squalus acanthias/ S. megalops/ S. mitsukurii**	Various spiny dogfish species	2.5793
TORPEDINIFORMIDAE			
Torpedinidae	*Torpedo fuscomaculata*	Black electric ray	0.0027
	*Torpedo nobiliana**	Atlantic electric ray	0.6411
CEPHALOPODA			
OCTOPODA			
Octopodidae	*Octopus magnificus*	Deep water octopus	1.8644
TEUTHOIDEA			
Loliginidae	*Loligo vulgaris reynaudii*	Chokka squid	0.2284
Ommastrepidae	*Todarodes angoliensis / Todaropsis eblanae*	Angolan flying squid / Lesser flying squid	7.3453

Appendix D: Mass (kg) and number of fish and cephalopods estimated to be discarded annually by trawlers operating on the south coast of South Africa. Estimates were calculated using observer data collected during 1997 and extrapolated to the annual catch using a landings-based approach. Note that because the estimates were obtained using 1997 data, estimates for species recorded from years other than 1997 (and therefore listed in Appendix C) may not be available.

	Mass (kg)	Number
Teleostei		
Lepidopus caudatus	14 197 915.4	19 929 663
Merluccius sp.	6 914 958.4	37 313 931
Caelorinchus symorhynchus	845 823.2	7 552 539
Scomber japonicus	754 470.3	474 757
Malaccocephalus laevis	579 282.0	1 129 666
Helicolenus dactylopterus	425 821.9	2 002 211
Zeus capensis	334 982.8	1 151 196
Lophius vomerinus	253 707.5	338 576
Trachurus trachurus capensis	159 067.3	466 855
Conger wilsoni	65 408.4	47 615
Caelorinchus braueri	51 700.3	491 250
Emmelichthys nitidus	30 747.0	67 595
Neocyttus rhomboidalis	26 040.5	89 751
Thyrsites atun	24 017.3	9 137
Centrolophus niger	22 892.9	5 104
Chelidonichthys capensis	16 892.7	52 313
Chloropthalamus agassizi	8 001.9	2 786
Schedophilus huttoni	7 091.1	4 771
Brama brama	4 808.8	4 182
Hoplostethus mediterraneus	4 427.7	13 272
Allocyttus verucosus	3 647.5	35 809
Genypterus capensis	3 547.3	1 182
Epigonus telescopus	3 447.6	2 758
Psychrolutes macrocephalus	2 396.7	8 081
Selachophidium guentheri	2 287.0	10 074
Notopogon macrosolen	2 190.3	9 115
Lepidion capensis	1 679.0	5 637
Sardinops sagax	1 650.5	8 403
Chaunax pictus	753.3	2 360
Beryx splendens	626.2	1 343
Physiculus capensis	405.2	1 573
Sebastes capenis	349.9	1 566
Oresoma atlanticum	154.8	308
Lucigadus ori	151.2	1 320
Lampanyctus hectoris	53.2	411
Chondrichthyes		
Raja wallacei	213 063.0	88 140
Squalus megalops/ S. acanthias/ S. mitsukurii	129 986.0	139 628
Holohahaelurus regani	102 536.3	180 978
Raja straelini	77 020.5	33 430
Various skate species	66 399.5	26 511
Torpedo nobiliana	33 875.0	5 143
Callorhinchus capensis	30 937.4	11 443

Cruriraja parcomaculata	30 371.5	31 396
Scyliorhinus capensis	28 096.2	22 546
Mustelus palumbes	25 204.8	2 160
Raja pullopunctata	16 395.5	8 928
Raja alba	5 030.9	1 264
Cephalopoda		
Todarodes angoliensis/ Todaropsis eblanae	4 105 731.2	37 515 091
Loligo vulgaris reynaudii	2 319.9	2 150
Octopus magnificus/ O.vulgaris	1 119.9	849

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