Biology and management of the Cape gurnard, *Chelidonichthys capensis* (Order Scorpaeniformes, Family Triglidae) in South Africa.

THESIS

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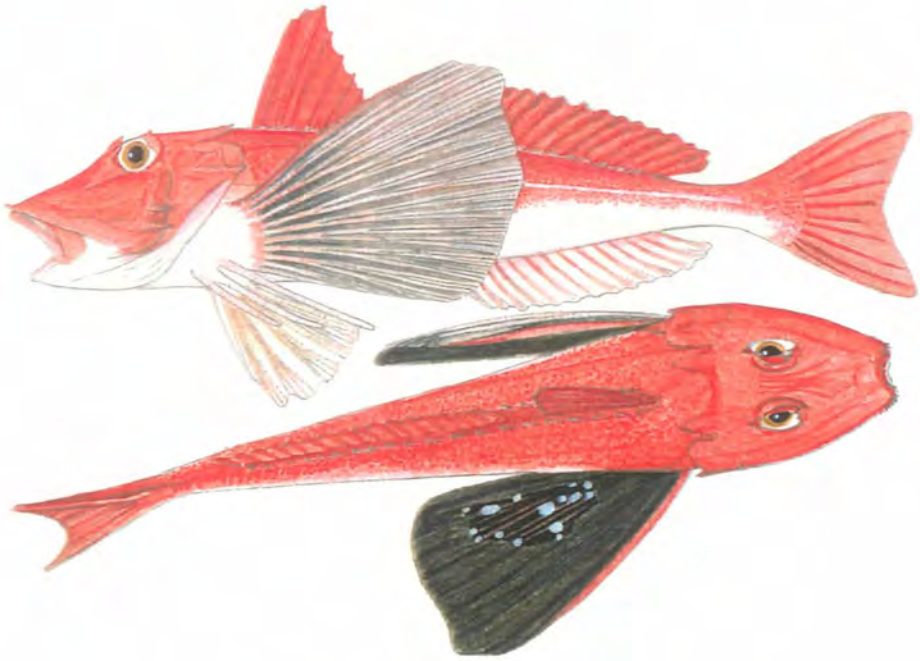
To Graeme and Retha, who put everything within my reach and made me who I am, thankyou.



Chelidonichthys capensis (Cuvier, 1829), 60cm TL (Port Alfred)

Artist: Mrs Elaine Heemstra

"Yet the wealth of the seas, vast though it is, is not inexhaustible, as has been proved by over-fishing problems that have arisen in some parts of the world in recent years. Fortunately in South Africa, with our rich fishing grounds, our long coastline and our absence of near neighbours, we have no serious over-fishing problem at present."

(Dr S.H. Skaife, 1949)

Biology and management of the Cape gurnard, *Chelidonichthys capensis* (Order Scorpaeniformes, Family Triglidae) in South Africa.

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IV. Acknowledgements

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V. Abstract

The South African demersal trawl fishery, as with most trawl-directed fisheries world-wide, has a substantial bycatch component. With increasing commercial emphasis being placed on retained bycatch, an urgent need has arisen to investigate these species. In the past the bycatch component has received little research or management attention. Members of the gurnard family Triglidae make up up to 2.4% of the South African hake-directed demersal catch and are thus considered an important bycatch species. The catch history and biology, including population structure, reproduction, feeding, age, growth and mortality, of the Cape gurnard, *Chelidonichthys capensis,* sampled from the Agulhas Bank, South Africa, were thus investigated.

Males (mean TL = 366mm) were significantly smaller than females (mean TL = 411mm). The sex ratio was close to parity, males being more dominant in commercial trawls and less dominant in research trawls. Gonad maturation and gonadosomatic indices showed this species to have an extended spawning period with peaks in reproductive activity during September, January and April. First approximations of size at 50% maturity were similar for females (349mm TL) and males (348mm TL) but differed significantly in terms of age (3.6 years and 4.6 years respectively). Otolith growth marks were validated as annuli using marginal zone analysis. The maximum age estimated was 16 years for a female of 675mm TL and recruitment to the commercial fishery was estimated as taking place in the fifth year of growth for both males and females. Gut content analysis showed *C. capensis* to be an opportunistic feeder preying preferentially on the benthic crustaceans *Goneplax angulata* and *Mursia cristimanus*.

Landings from the commercial linefishery were insignificant whilst those for the commercial trawl fishery ranged from 500 tonnes to 3250 tonnes between 1984 to 1995, and indicated that this species forms an important component of the South African trawl fishery bycatch. A first approximation of fishing mortality (0.36 $year^{-1}$) for the inshore commercial trawl fishery was higher than that of natural mortality (0.25 $year^{-1}$) suggesting some fishing pressure on this species on the Agulhas Bank. However this fishing mortality value was significantly less than that for $F_{0.1}$ (4.78 $year^{-1}$) that was estimated using a yield-per-recruit model.

Chapter 1 - General Introduction

For the goals of conservation, and sustained or enhanced utilisation to be achieved, sound information on the condition of fishery stocks, on fish population parameters, and on the effects of utilisation on fish stocks is required. The South African demersal trawl fishery is predominantly hake-directed (Botha 1985) and, as with most trawl-directed fisheries world-wide, has a substantial bycatch component (Japp *et al.* 1994). Indications are that greater commercial emphasis is being placed on retained bycatch species, most of which have previously been given little research or management attention. In addition to these, there is an unquantified number of discarded bycatch species that include the juveniles of target species such as hakes. The unknown proportion of "discards" as well as the poor biological knowledge of many of the retained bycatch species is the focus of one of the umbrella projects (Offshore Resources and Society) of an intensive research program within the South African Network for Coastal and Oceanic Research (SANCOR). The ultimate objective of this research is to assess the discarded and retained bycatch components of the South African fisheries, with a view to greater utilisation of the demersal resources in the future and ultimately, to assist with the social and economic upliftment of the fishing community as a whole.

A variety of retained and discarded bycatch species have been, or are currently being, investigated through the SANCOR program. For example redspotted tonguefish (*Cynoglossus zanzibarensis*), panga (*Pterogymnus laniarus*), lesser gurnard (*Chelidonichthys queketti)*, slime and blancmange skates (*Raja pullopuctata* and *R. wallacei* respectively*)*, smooth-hound shark (*Mustelus mustelus)*, bluntnose spiny dogfish (*Squalus megalops),* rattails (*Caelorinchus braueri, C. simorhynchus*, *Malacocephalus laevis*), butter snoek (*Lepidopus caudatus*), chubb mackerel (*Scomber japonicus*), pomfret (*Brama brama*), John Dory (*Zeus capensis*), and monkfish (*Lophius vomerinus*). Although several bycatch species within the South African trawl fishery may already be overexploited, for example the carpenter, *Argyrozona argyrozona*, biological data gathered for species that are not subject to targeted exploitation will provide valuable information on the likely implications of an increase in fishing effort on individual species, i.e. future targeting. This strategy is impractical unless research efforts, such as those being focused on in the SANCOR bycatch

programme, are concentrated on species with the greatest likelihood of increased utilisation in the future. One such species is gurnard. Gurnards are a significant bycatch species in many of the offshore trawl and line fisheries in South Africa (Smale & Badenhorst 1991; Japp *et al.*. 1994). Heemstra (1986) describes the Cape gurnard, *Chelidonichthys capensis*, as an important commercial species whilst Van der Elst (1988) regards it as one of the six most important fish trawled off the eastern Cape coast. Trunov & Malevanyy (1974) described two gurnard species, the lyre gurnard, *Trigla lyra,* and the Cape gurnard, *C. capensis,* as being of secondary commercial importance in the Namibian fisheries. Although only marketed occasionally, it is reported that gurnards have been used in the preparation of fishmeal (Marshall 1946; Trunov & Malevanyy 1974; Van den Heever 1995). However little recent biological or catch data exists with which to assess this resource in South Africa.

The gurnard family, Triglidae, is represented by some 50-60 species globally and is distributed in most of the world's oceans (Barnard 1927; Heemstra 1986). Triglids are medium sized fishes, often red in colour, with large, armoured heads (Leis & Trnski 1989). The lower three fin rays of the pectoral fins are detached and enlarged, often having a tactile function and being used as feelers (Smith & Heemstra 1986). Papaconstantinou (1983a) describes gurnards as demersal fishes living on a wide variety of substrate types, from muddy to rocky, and using pectoral fins to support themselves on the seabed. Four genera from this family are represented in the southern African marine fauna, namely *Trigloporus, Trigla, Lepidotrigla* and *Chelidonichthys* (Barnard 1927; Smith 1934; Heemstra 1982). Three members of the latter genus, *C. capensis*, *C. kumu, and C. queketti*, are found in the southern African region with the fourth member, *C. gabonensis*, located off the west coast of Africa (Smith & Heemstra 1986). The distribution of *C. capensis* was first described as "universal" (Trunov & Malevanyy 1974) whereas more recently Smith & Heemstra (1986) place it only from Namibia to Mozambique. Van der Elst (1988) also describes this species as endemic to the southern African coast, being found from the Orange River on the west coast to the Umfolozi River on the east coast of South Africa, in water up to 300m deep. Tsimenides *et al.* (1992), in a study on the distribution patterns of triglids on the Cretan shelf in Greece, describe similar wide variations in depth distributions for six species of gurnard (Table 1.1). *Lepidotrigla natalensis* in southern Mozambique is found largely between 50-100m (Brinca *et al.* 1983) but are reported from trawls as shallow as 30m and

as deep as 800m (Timochin 1984). Further examples of the wide vertical distribution range of gurnards from around the world are presented in Table 1.1.

Table 1.1 Depth distributions for various triglid species studied around the world.

Species	Common name	Area	Depth distribution (m) (preferred depth)	Author, Year
Aspitrigla cuculus	Red gurnard	Cretan Shelf, Greek Sea	36-278 (70-350)	Tsimenides *et al.*, 1992
Aspitrigla cuculus	Red gurnard	Saranikos, Thermaikos and Pagassitikos Gulfs, Greek Seas	120-200	Papaconstantinou, 1983
Chelidonichthys capensis	Cape gurnard	Agulhas Bank, South Africa	30-200	This study
Chelidonichthys capensis	Cape gurnard	Agulhas Bank, South Africa	28-424 (50-200)	Smale & Badenhorst 1991
Chelidonichthys capensis	Cape gurnard	Namibia	10-390	Bianchi *et al.*, 1993
Chelidonichthys capensis	Cape gurnard	Namibia	0-300	Konchina, 1989
Chelidonichthys capensis	Cape gurnard	Namibia	0-300 (50-200)	MacPherson & Mas Riera, 1987
Chelidonichthys capensis	Cape gurnard	Namibia	0-340 (±260)	Trunov & Malevanyy, 1974
Chelidonichthys capensis	Cape gurnard	East Coast, South Africa	0-120	Hecht, 1977
Chelidonichthys kumu	Red gurnard	Hauraki Gulf, New Zealand	10-180 (10-55)	Elder, 1976
Chelidonichthys queketti	Lesser gurnard	Agulhas Bank, South Africa	28-228 (50-150)	Booth, In press
Eutrigla gurnardus	Grey gurnard	Saranikos, Thermaikos and Pagassitikos Gulfs, Greek Seas	20-200	Papaconstantinou, 1983
Lepidotrigla cavillone	Large-scaled gurnard	Cretan Shelf, Greek Sea	30-295 (70-150)	Tsimenides *et al.*, 1992
Lepidotrigla cavillone	Large-scaled gurnard	Saranikos, Thermaikos and Pagassitikos Gulfs, Greek Seas	30-440	Papaconstantinou, 1983
Lepidotrigla dieuzeidei	Spiny gurnard	Cretan Shelf, Greek Sea	42-297 (150-350)	Tsimenides *et al.*, 1992
Lepidotrigla natalensis(faurei)	Prickly gurnard	southern Mozambique	30-800 (50-100)	Brinca *et al.*, 1983; Timochin, 1984
Trigla lucerna	Tub gurnard	Cretan Shelf, Greek Sea	26-185 (26-150)	Tsimenides *et al.*, 1992
Trigla lucerna	Yellow gurnard	Saranikos, Thermaikos and Pagassitikos Gulfs, Greek Seas	30-120	Papaconstantinou, 1983
Trigla lyra	Piper gurnard	Namibia	45-350 (150-350)	Konchina, 1989
Trigla lyra	Piper gurnard	Saranikos, Thermaikos and Pagassitikos Gulfs, Greek Seas	40-440 (80-160)	Papaconstantinou, 1983
Trigla lyra	Lyre gurnard	Namibia	0-200 (140-175)	Trunov & Malevanyy, 1974
Trigloporus lastoviza	Streaked gurnard	Cretan Shelf, Greek Sea	30-169 (26-70)	Tsimenides *et al.*, 1992
Trigloporus lastoviza	Rock gurnard	Saronikos Gulf, Greece	40-140	Papaconstantinou, 1986
Trigloporus lastoviza	Rock gurnard	Saranikos, Thermaikos and Pagassitikos Gulfs, Greek Seas	20-240	Papaconstantinou, 1983

In general, literature on gurnards deals chiefly with feeding habits, age, growth and reproduction, many of these studies originating from countries outside southern African, such as New Zealand (Staples 1971a; Staples 1971b; Elder 1976; Clearwater & Pankhurst 1994), New England (North America) (Marshall 1946) and Greece (Papaconstantinou 1981; 1982; 1983; 1984; 1986). Literature concerning the ecology and biology of *Chelidonichthys* spp. in South Africa is scarce. To the author's knowledge the only work done on *Chelidonichthys capensis* has been on distribution (Konchina 1989; Meyer & Smale 1991), feeding (Hecht 1977a; Konchina 1989; Meyer & Smale 1991), and age, growth and reproduction (Hecht 1977b). The most recent, complete biological results available therefore, are those from twenty years ago. Some work was done on the ecology of *C. capensis* in Namibia in the 1970's (Trunov & Malevanyy 1974) and more recently by MacPherson & Mas Riera (1987) who studied various aspects of the life history of the *C. capensis* in Namibian waters, concentrating on diet, abundance and distribution. There have therefore been no recent observations on the biology of *C. capensis* in South Africa and, with the increased likelihood of greater utilisation, it is essential that reliable data be obtained that can be used for the long-term management of gurnards in South Africa. Booth (in press) recently completed a biological study of the lesser gurnard, *Chelidonichthys queketti,* a sympatric gurnard species also found on the Agulhas Banks.

This project focused on the catch and biology of the largest and most frequently caught gurnard species, *Chelidonichthys capensis,* (Cape gurnard). In addition, the proportion in commercial landings and research catches of the two other *Chelidonichthys* species, *C. kumu* and *C. queketti,* also frequently caught in trawls (Japp *et al.* 1994), were investigated. Detailed objectives of this research were as follows:

1) To investigate the present utilisation patterns of the three gurnard species, *C. capensis, C. queketti* and *C. kumu*, in the hake-directed trawl fishery as well as in the longline, handline and other fisheries in South Africa;
2) To study the biology of *Chelidonichthys capensis*;
3) Given the information on their biology and utilisation, to consider their potential for future sustainable utilisation and management, either as a directed fishery or as a bycatch in the established commercial fisheries;

These objectives were achieved by:

i) Assessing the historical and current trends of gurnard landings (all three species);

ii) Investigating aspects of the population dynamics of the *C. capensis*, such as population structure and reproductive biology (sex ratios, spawning, including gonad maturation indices and gonadosomatic indices, and length/age maturation rates);

iii) Studying the feeding biology through the examination of stomach contents to determine diet, trophic level, and potential ecological impact of directed commercial utilisation on other species;

iv) Determination of age and growth rates using otoliths and length frequency data for application in resource assessment models;

v) Briefly discussing the potential of the resource as a directed fishery.

Chapter 2 - Exploitation

2.1 Introduction

The total catch taken by a set of fishing gear that reaches the deck of a fishing vessel, can be divided into target catch, that is, the main species towards which the effort was directed, and bycatch (FAO 1997). A commonly recognised definition of bycatch is that of Saila (1983):" ...bycatch is that part of the gross catch that is captured incidentally to the species towards which there is directed effort. Some, all or none of the bycatch may become the discarded catch.". Bycatch may either be retained and sold (retained bycatch) or discarded at sea (discarded bycatch). Retained bycatch is an economically very important component of many target fisheries as in many cases the target fishery would be marginal without the bycatch. A particular species can move from one category of the total catch to another depending on criteria such as size, market demand or season. Bycatch does not simply imply "trash fish" but includes juveniles of target species that are not economically worth keeping due to their small size, as well as target species of other fisheries and "innocent bystanders" such as seabirds, turtles and cetaceans (Ross & Best 1989; Rulifson *et al.* 1992; Alverson *et al.* 1994; Kennelly 1995; Wolf *et al.* 1995; Hall 1996).

Bycatch has become a concern in many of the world's fisheries, particularly since the decline in high value demersal resources has forced an increasing reliance on lower value species (Anon. 1995a). In 1995, a "shock report" by the Food and Agricultural Organisation of the United Nations revealed that between 17.9 and 39.5 million tonnes (an average of 27 million tonnes) of fish was being discarded in commercial fisheries each year (Anon. 1995b; Wray 1995). This amounts to some 20% of the world fisheries landings, of which the biggest component comes from the shrimp trawl fisheries (Anon. 1995b; Anon 1995c). Pender & Willing (1989) report trashing of up to 1.5 tonnes of bycatch per vessel per night in Australia's northern prawn fishery since its inception in the 1960's. Although in the bottom ten on the list of gear types with the lowest discard ratios (Anon. 1995b), demersal fisheries contribute their fair share, particularly if one considers the non-selective nature of the gear, the South African demersal trawl fishery being no exception. Bycatch

species include the species in this study, *Chelidonichthys capensis,* as well as others already mentioned (see Chapter 1).

Landed catch statistics for triglid species caught the world over are provided by the Food and Agricultural Organisation of the United Nations (FAO 1964; 1970; 1975; 1978; 1981 1984; 1993) and are provided in summary form in Table 2.1. Reported landings of *Trigla* spp. in the north eastern, eastern central and south eastern Atlantic, and in the Mediterranean and Black Seas, have been on the increase since the early 1930's and range between 100 tonnes per annum to well over 16 000 tonnes in 1992. Landed catches of West Atlantic searobins, *Prionotus* spp., was in excess of 17 000 tonnes in 1974 but have more recently been on the decline, with landings approximating 1000 tonnes per annum. The eastern Indian Ocean produces landings of latchet gurnard, *Pterygotrigla polyommata,* of up to 300 tonnes per annum, and together with the Northwest and Southwest Pacific, yields *Chelidonichthys kumu* landings of over 500 tonnes a year. It is interesting to note the peak in landed catches for most gurnard species, for example *Trigla* spp., *Eutrigla gurnardus*, *Prionotus* spp., *Chelidonichthys kumu* and *Trigla capensis,* in the mid 1980's to early 1990's, followed by a virtual collapse in these fisheries. Clearwater & Pankhurst (1994) describe the red gurnard, *C. kumu*, as both a recreationally and commercially important species in the Hauraki Gulf, New Zealand. Yunokawa (1961) reports large landings of the same species in the Yellow and East China seas and labels it an economically important bottom fish, but fails to provide any figures. Elder (1976) described *C. kumu* as an important commercial wet fish species for New Zealand in the early 1970's, ranking it fourth in importance in total landings and seventh in total value.

Table 2.1 Summary of annual landings (tonnes) for Family Triglidae provided by the Food and Agricultural Organisation of the United Nations, 1938-1993.

Area		27			34			37		47	
Area	All areas	Northeast Atlantic			Eastern Central Atlantic			Mediterranean and Black Sea		Southeast Atlantic	(South Africa)
Species	Triglidae	*Trigla* spp.	*Eutrigla gurnardus*	*Aspitrigla cuculus*	*Prionotus* spp.	*Trigla* spp.	*Trigla lyra*	*Trigla* spp.	*Trigla lyra*	*Trigla* spp.	*Trigla capensis*
1938	8500	-	-	-	-	-	-	-	-	-	-
1948	11700	-	-	-	-	-	-	-	-	-	-
1958	28000	-	-	-	-	-	-	-	-	-	-
1961	24400	-	-	-	-	-	-	-	-	-	-
1962	22900	-	-	-	-	-	-	-	-	-	-
1963	22100	-	-	-	-	-	-	-	-	-	-
1964	28000	2400	-	-	-	1100	-	-	-	100	-
1965	24000	2900	-	-	-	1100	-	-	-	100	-
1966	29200	2900	-	-	-	1100	-	-	-	100	-
1967	34300	2900	-	-	-	4000	-	2500	-	300	-
1968	34700	4100	-	-	0	600	-	400	-	400	-
1969	24700	3200	-	-	0	800	-	300	-	500	-
1970	31700	9900	-	-	-	700	-	400	-	400	-
1971	15400	11100	-	-	1700	800	-	800	-	0	-
1972	19000	10500	-	-	2200	700	-	900	-	200	400
1973	20600	11700	-	-	3400	1000	-	500	-	400	300
1974	30061	10382	-	-	6400	455	-	597	-	189	320
1975	26313	9354	-	-	3803	591	-	513	-	133	295
1976	21528	9450	-	-	1617	659	-	659	-	155	417
1977	22192	10303	-	-	-	576	-	657	-	181	515
1978	51497	10457	-	-	-	598	-	1316	-	782	539
1979	46815	10393	-	-	-	607	-	1200	-	1076	-
1980	41651	10238	-	-	-	651	-	1283	-	709	-
1981	40496	8561	-	-	-	728	-	1017	-	802	-
1982	21116	10240	-	-	-	975	-	760	-	3639	-
1983	18895	11350	-	-	-	933	-	1140	-	965	-
1984	27602	13576	3328	-	-	1364	-	1810	132	1290	726
1985	18927	6745	2801	191	-	1983	3	1496	129	404	782
1986	17106	7697	324	10	-	812	24	2137	514	369	1058
1987	68081	8299	47580	207	-	1624	-	2833	253	782	1658
1988	60349	8261	38400	201	-	2442	2	3413	120	862	1458
1989	49601	7707	26861	253	-	928	-	3864	102	1036	4095
1990	45594	8308	22188	169	-	1141	-	4384	75	179	3801
1991	34983	7873	14636	114	-	1513	-	4224	119	27	651
1992	31848	7944	8262	147	-	1589	-	7109	132	17	686
1993	23944	7816	984	36	-	2114	-	5523	197	0	1023

Table 2.1 (contd.)

Area	21	41	57		81			61		87
Area	Northwest Atlantic	Southwest Atlantic	Eastern Indian Ocean		Southwest Pacific			Northwest Pacific		Southeast Pacific
Species	*Prionotus*	*Prionotus*	*Pterygotrigla polyommata*	*Chelidonichthys kumu*	*Pterygotrigla polyommata*	*Chelidonichthys*	*Chelidonichthys kumu*	*Chelidonichthys*	*Chelidonichthys kumu*	*Chelidonichthys kumu*
1938	-	-	-	-	-	-	-	-	-	-
1948	-	-	-	-	-	-	-	-	-	-
1958	-	-	-	-	-	-	-	-	-	-
1961	-	-	-	-	-	-	-	-	-	-
1962	-	-	-	-	-	-	-	-	-	-
1963	-	-	-	-	-	-	-	-	-	-
1964	800	100	-	-	-	4400	-	19100	-	-
1965	200	0	-	-	-	4300	-	15400	-	-
1966	1800	0	-	-	-	3900	-	19400	-	-
1967	800	0	-	-	-	3500	-	20300	-	-
1968	9200	500	-	-	-	3000	-	16400	-	-
1969	2000	0	-	-	-	3000	-	14900	-	-
1970	400	0	0	-	100	3400	-	16400	-	-
1971	900	0	0	-	100	-	-	-	-	-
1972	3900	0	0	-	200	-	-	-	-	-
1973	3000	0	0	-	300	-	-	-	-	-
1974	11512	0	0	-	206	-	-	-	-	-
1975	4495	54	0	1	77	-	2226	-	4771	-
1976	1974	62	0	1	155	-	3161	-	3218	-
1977	3351	28	0	0	59	-	3747	-	2775	-
1978	85	28	1	0	150	-	3924	-	33617	-
1979	121	29	2	0	122	-	3634	-	29631	-
1980	28	27	1	1	178	-	3503	-	25032	-
1981	88	29	12	0	162	-	4067	-	25030	-
1982	37	17	4	-	143	-	3561	-	1740	-
1983	38	27	2	-	119	-	3961	-	359	1
1984	22	70	17	41	91	-	3930	-	1205	-
1985	11	194	15	43	96	-	3201	-	833	-
1986	31	650	21	61	135	-	2370	-	893	0
1987	23	1029	27	77	172	-	2815	-	702	-
1988	29	899	28	81	180	-	3317	-	656	0
1989	16	922	23	68	150	-	2828	-	748	-
1990	22	920	29	86	191	-	3130	-	971	-
1991	44	941	30	80	190	-	3331	-	1210	-
1992	34	930	22	0	120	-	3813	-	1043	-
1993	17	930	43	1	133	-	3948	-	1179	-

In South Africa, Hecht (1976b) noted an increase in the commercial trawl landings of the endemic Cape gurnard, *C. capensis,* along the east coast (Figure 2.1) between 1967 and 1970 from 20 tonnes to 42 tonnes. Landings from 1970 to 1975 are provided in Table 2.2.

Table 2.2 Annual landings, in metric tonnes, of the Cape gurnard, *Chelidonichthys capensis*, between Cape St. Francis and Bird Island on the South African east coast from 1970 to 1975.

Year	Landed Catch (metric tonnes)
1970	42
1971	163
1972	80
1973	58
1974	39
1975	42

Landings along the whole South African coast have been recorded in the range 295 tonnes in 1975 to 4095 tonnes in 1989. This chapter deals in further detail with the current and historical exploitation rates of the Cape gurnard in two of the South African commercial fisheries, the line and trawl fisheries, as well as catch rates in research surveys.

2.2 Methods

2.2.1 Commercial linefishery

In order to facilitate sampling and data analysis, Sea Fisheries Research Institute (SFRI), Cape Town has divided the South African coast into distinct areas, illustrated in Figure 2.1. Since 1982 catch and effort data have been collected from these port landing areas around the coast by SFRI personnel as well as scientists from the Oceanographic Research Institute (ORI), Durban. These data are stored on the National Marine Linefish System (NMLS), a database that enables capture and analysis of the diverse catch and effort data available for the South African recreational and commercial linefisheries (Penney 1993). Landings for gurnard and other linefish species were made available from the NMLS by Mr Chris Wilke of SRFI. Landed catch weights of snoek, mullet, kob, panga, shad, carpenter and geelbek were noted for comparison with gurnard landings.

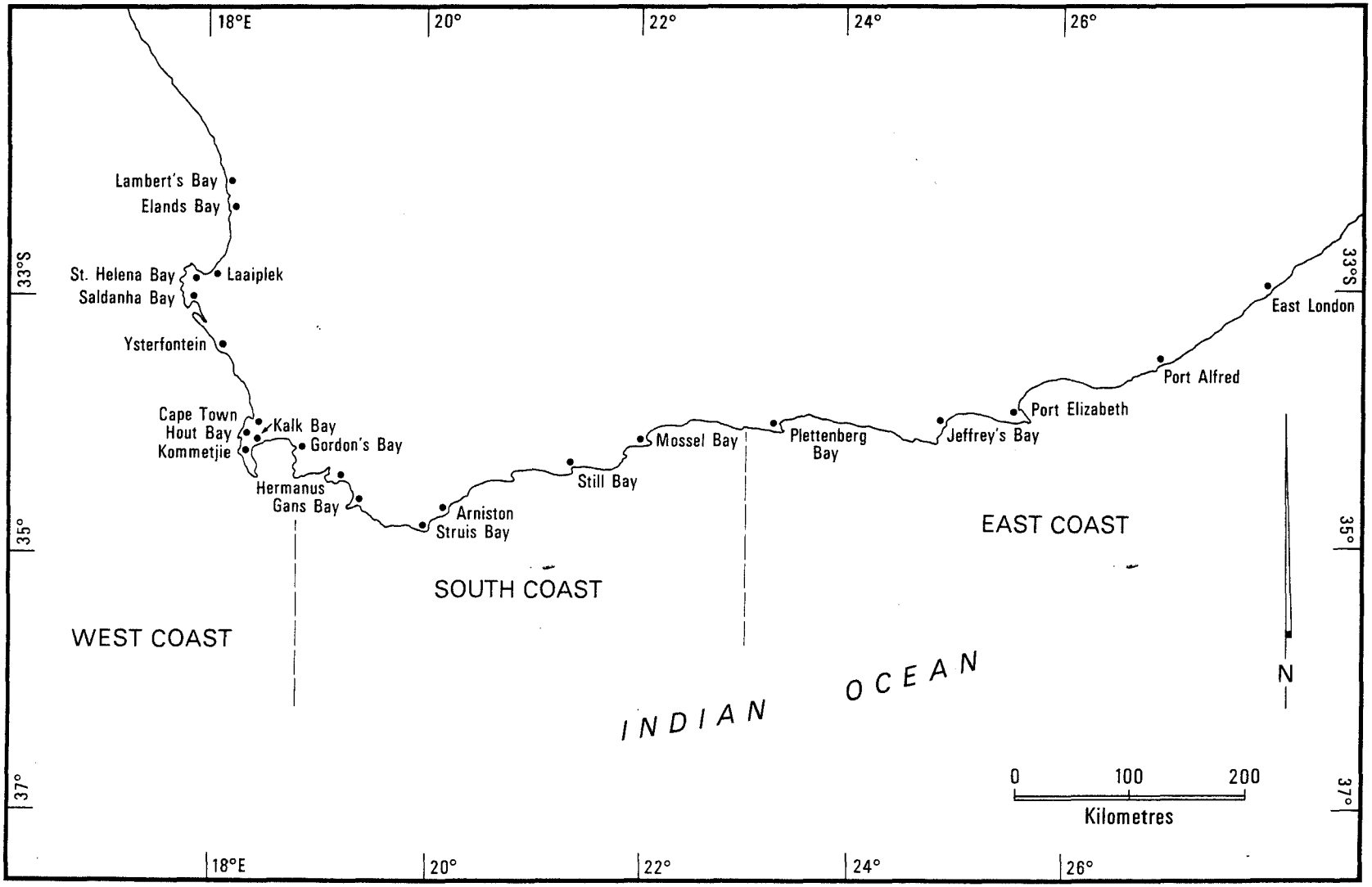

Figure 2.1 Map of the South African coast to show division of areas used for sampling by Sea Fisheries Research Institute, Cape Town, in the commercial linefishery, and the position of its major commercial linefish landing ports.

2.2.2 Commercial trawl fishery

Landed catch statistics for the South African commercial trawl fishery are available from 1979 to 1996. Data were, and are currently being, collected by SFRI personnel from fishery companies at commercial port landing areas around the coast, including the inshore and offshore trawling sectors. Inshore trawling vessels are typically small (± 20m long) and fish within the 110m depth contour using 75mm mesh codends. They are permitted to target on sole, hake or horse mackerel and spend approximately 10 days at sea at a time, keeping their catch fresh on crushed ice. There is no limitation on the size of offshore, or deepsea, vessels that are restricted to fishing outside of the 110m isobath with 110mm and 75mm mesh codends. Deepsea vessels are either wet deck or freezer trawlers, spending 7 days or up to 60 days at sea at a time, respectively (Japp *et al.* 1994).

Landed catch weights for gurnard (*Chelidonichthys capensis* and *C. queketti*) and other important bycatch species (maasbanker (*Trachurus trachurus*), monkfish (*Lophius vomerinus*), panga *Pterogymnus laniarus*), east coast sole (*Austroglossus pectoralis*), John Dory (*Zeus capensis*), skates (*Raja* spp.) and sharks (for example *Mustelus mustelus, Squalus megalops*) were made available for use in this project by Mr Dave Japp, Miss Sharon du Plessis and Mr John Prinsloo of SFRI.

Differences between inshore and offshore landings, as well as monthly differences in landings that may indicate some form of seasonal migration, were tested using analysis of variance with interactions and Tukey's multiple range analysis at the 95% confidence interval respectively.

2.2.3 Observer bycatch data

In January 1995 a project was initiated through SANCOR to quantify discarded and retained bycatch in the inshore and offshore commercial trawling sectors. Sea based observers were employed to work on board the commercial trawl vessels in order to collect biological and catch data on bycatch species. The data concerning gurnards were made available by SFRI for use in this project.

2.2.4 Research trawl surveys

Catch statistics from the research trawl surveys aboard *FRS Africana* are available from 1983 to 1995 from the database of the SFRI. For each trawl retrieved during the cruises the catch was sorted by species and weighed, then, for many species, the whole catch, or a sub-sample, was measured (TL, mm). Details of the methodology of research surveys are described in Badenhorst & Smale (1991). Data collected during these research surveys were made available for use in this project by Mr Dave Japp, Ms Sharon du Plessis and Mr John Prinsloo of SFRI.

2.3 Results

Statistics on gurnard landing available from the NMLS and the SFRI database, for the commercial line and trawl fisheries respectively, had to be treated with caution due to data lumping and unquantified discarding. Reported landings from both these fisheries included the three *Chelidonichthys* spp. as commercial fishermen tend not to differentiate between the species in their logbooks. Data lumping and unquantified discarding leads to obvious problems for accurate data analysis in that the proportion of landed catches by species is unknown. In addition, the collection of trawl fishery data is only monitored to a certain extent by the Sea Fisheries Inspectorate of the Chief Directorate: Sea Fisheries, thus it is largely left to the various fishing companies to report their landings honestly.

2.3.1 Commercial linefishery

Reported landings of gurnard in the South African commercial linefishery rarely exceeded two tonnes per annum between 1982 and 1995, suggesting that the *Chelidonichthys* spp. are not important catch species in this fishery (Figure 2.2). The highest landings to date have been in 1994 and 1995, 2.9 tonnes and 6.3 tonnes respectively.

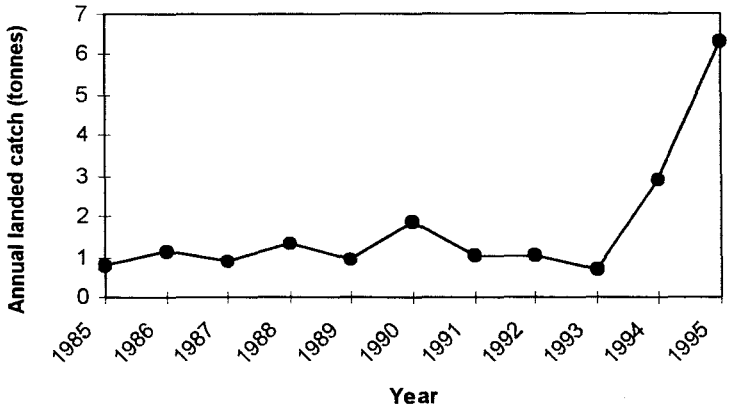

Figure 2.2 Annual landings (tonnes) of *Chelidonichthys* spp in the commercial linefishery on the South African coast between East London and Elands Bay from 1985 to 1995.

An extremely large landing of 4.5 tonnes in Elands Bay during 1995 contributed to the high landed annual catch for that year (Figure 2.2), although excluding this landing from the 1995 annual landing still resulted in an above average value for this year. Exclusion of this point however did result in a mean annual landed catch for Elands Bay more similar to those of Port Elizabeth and Mossel Bay (Figure 2.3b). Other areas with relatively large reported mean annual landings during the period 1985 to 1995, were Plettenberg Bay and Mossel Bay on the east coast, and Laaiplek on the west coast (Figure 2.3a).

Mean monthly landings for the period 1985 to 1995 appeared to be highest in March, May and September (Figure 2.4a). The high landing during September was again biased by the particularly high landing in Elands Bay in 1995. Exclusion of this point results in no significantly different peak at all during this month (Figure 2.4b)

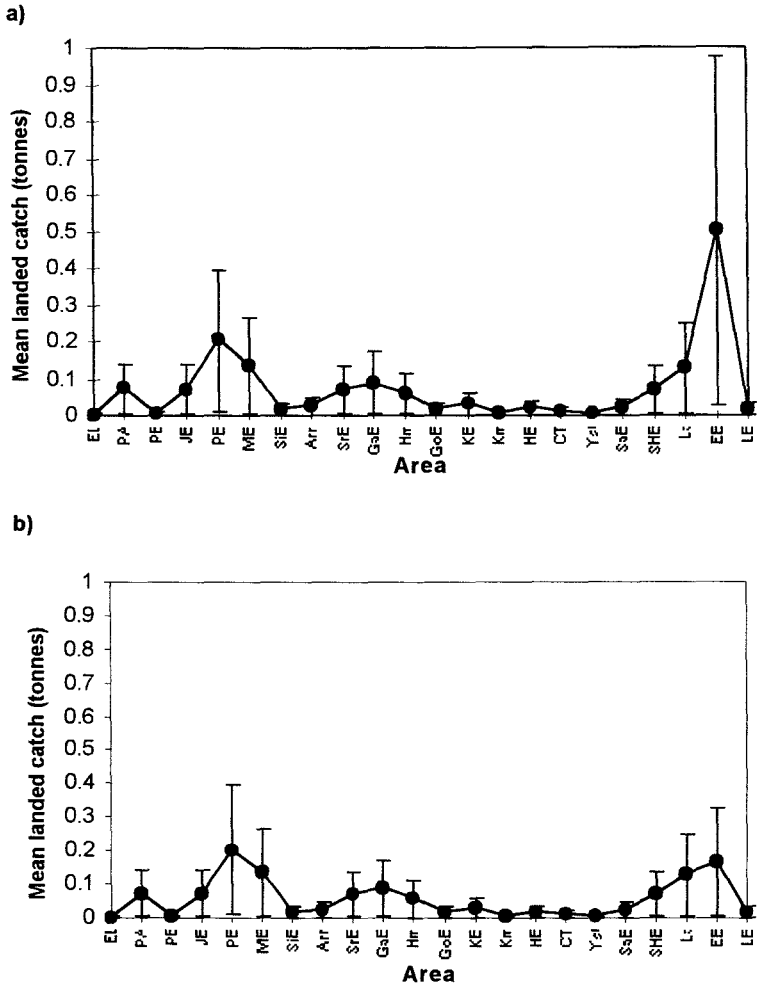

Figure 2.3 Mean annual landings (tonnes) of *Chelidonichthys* spp. a) including September 1995 landing in Elands Bay and b) excluding September 1995 landing in Elands Bay, in the commercial linefishery on the South African coast between East London and Elands Bay for the period 1985 to 1995 (error bars represent 95% confidence intervals) (EL-East London, PA-Port Alfred, PE-Port Elizabeth, JB-Jeffrey's Bay, PB-Plettenburg Bay, MB-Mossel Bay, SiB-Still Bay, Arn-Arniston, StB-Struis Bay, GaB-Gans Bay, Hm-Hermanus, GoB-Gordon's Bay, KB-Kalk Bay, Km-Kommetjie, HB-Hout Bay, CT-Cape Town, Yst-Ysterfontein, SaB-Saldanha Bay, SHB-St. Helena Bay, La-Laaiplek, EB-Eland's Bay, LB-Lambert's Bay).

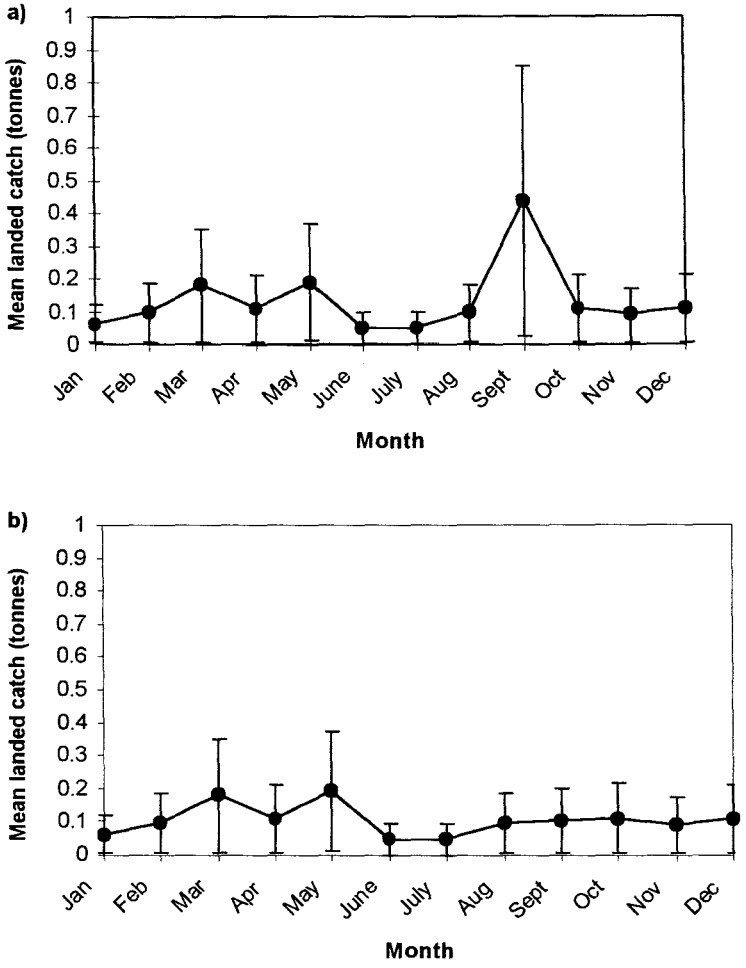

Figure 2.4 Mean monthly landings (tonnes) of *Chelidonichthys* spp. a) including September 1995 landing in Elands Bay and b) excluding September 1995 landing in Elands Bay, in the commercial linefishery on the South African coast between East London and Elands Bay for the period 1985 to 1995 (error bars represent 95% confidence intervals).

Gurnard landings were significantly lower that those of other linefish species such as snoek, carpenter and kob, rarely making up more than 0.01% of the total catch, a weight of between 1 and 1.8 tonnes per annum (Figure 2.5).

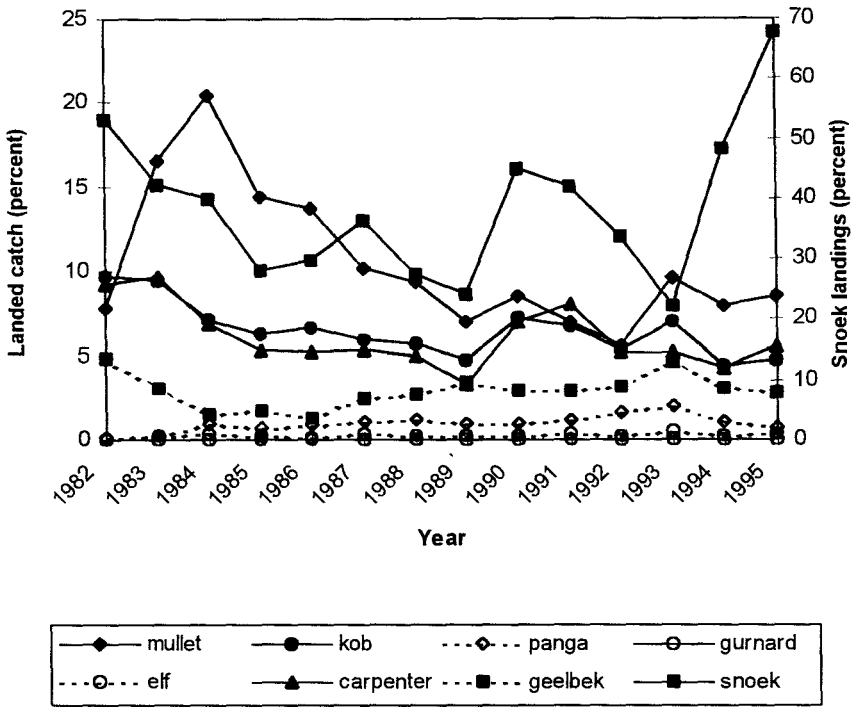

Figure 2.5 Annual landings of snoek (*Thyrsites atum*), mullet (various species), kob (*Argyrozomus japonicus*), panga (*Pterogymnus laniarus*), gurnard (*Chelidonichthys* spp)., elf (*Pomatomus saltatrix*), carpenter (*Argyrozona argyrozona*), and geelbek (*Atractoscions aequidens*) as a percentage of the total landings in the commercial linefishery between East London and Elands Bay from 1985 to 1995 (Note: snoek landings were considerably higher compared to those of other species so were plotted on the secondary y-axis to enable easier reading of species with small percentage contributions).

2.3.2 Commercial trawl fishery

On an annual basis, 1989 produced the highest total commercial landing of 3 250 tonnes; 1988 and 1990's landings were almost 2 500 tonnes (Figure 2.6). The landings in these three years were about five times higher than the average for the other eight years and could therefore have had a marked effect on the apparent trend in monthly landings. Generally annual landings were below 750 tonnes and mostly closer to 500 tonnes. Inshore and offshore landings differed significantly ($p<0.0001$, $F=23.0$), particularly from 1987 to 1990 when offshore landings were far greater than inshore ones. The distribution of these annual landings were quite distinct, most of the landed catch being taken in the offshore area of the west coast, and both the inshore and offshore areas of the southern Cape coast.

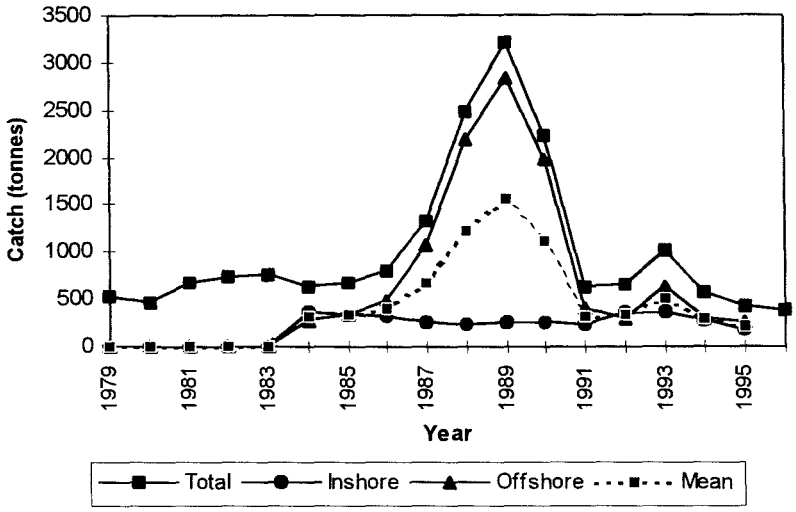

Figure 2.6 Annual inshore and offshore landings (tonnes) of *Chelidonichthys* spp. in the commercial trawl fishery on the South African coast from 1979 to 1995.

There were no significant differences between mean monthly landings for either the inshore or offshore trawl fisheries. Apparent monthly peak landings occurred during October in the inshore areas (<500 tonnes), and during March (1 250 tonnes), July (1 500 tonnes) and November (2 000 tonnes) in the offshore areas (Figure 2.7a). These peaks were comparable with those of the commercial linefishery during March, May and September, and again may indicate an increase in the availability of gurnard during these periods. Unusual monthly peaks during 1988 (November), 1989 (March and May) and 1990 (March, July and August) could have led to one or more of the apparent monthly peaks so mean monthly landings were also calculated excluding all landings for these years (Figure 2.7b). These results illustrated that the apparent monthly peaks were indeed an artifact of the large landings during these years.

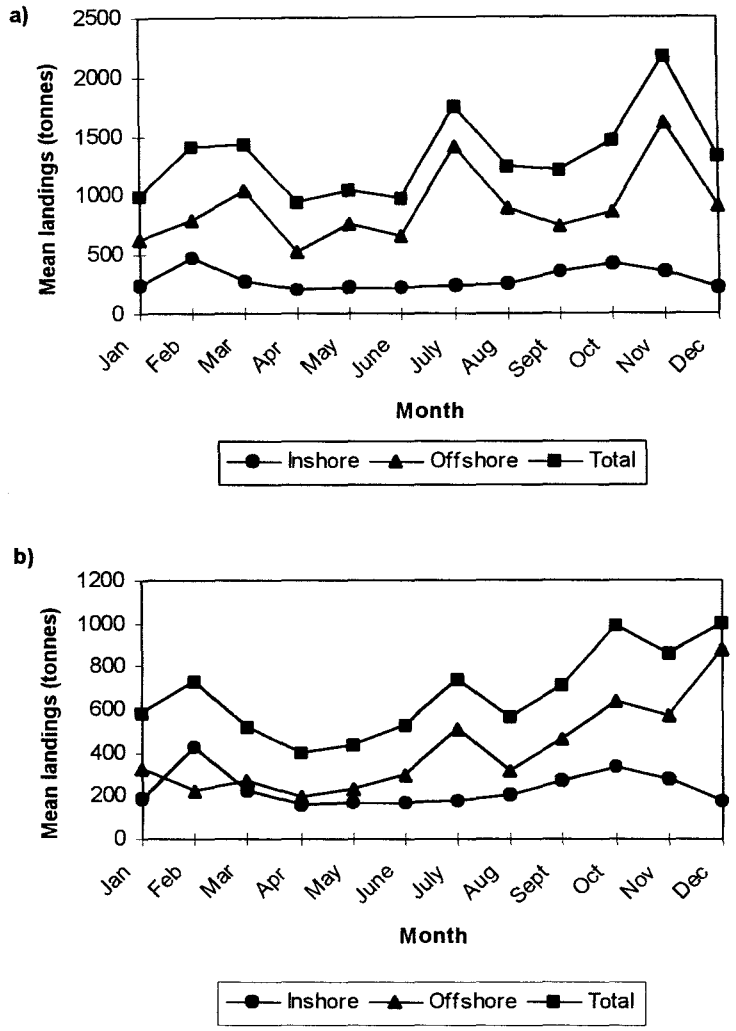

Figure 2.7 Mean monthly landings (tonnes) of *Chelidonichthys capensis* in the commercial trawl fishery on the South African coast for the period 1984 to 1995, a) including landings for 1988, 1989 and 1990, b) excluding landings for 1998, 1989 and 1990.

The high landings of gurnards over the period 1987 to 1990 were also noted for other bycatch species, particularly maasbanker, *Trachurus trachurs* (Japp, SFRI, pers. comm.). It is thought that abnormal environmental conditions prevailing on the Agulhas Bank that were noted at this time, including particularly warm water, had a marked influence on the availability of the fish stocks around the coast, and may have resulted in these large landings over this period (Figure 2.8).

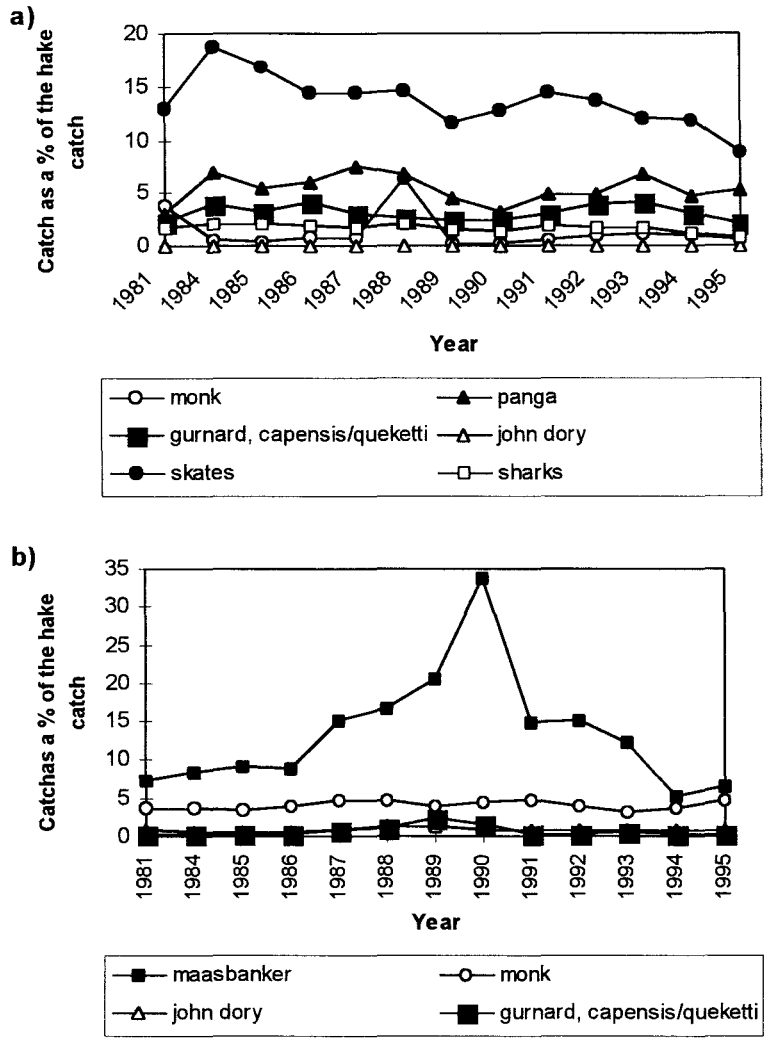

Figure 2.8 Annual landings (tonnes) for maasbanker (*Trachurus trachurus)*, monk (*Lophius vomerinus)*, panga (*Pterogymnus laniarus)*, gurnard (*Chelidonichthys capensis, C. queketti)*, east coast sole (*Austroglossus pectoralis)*, John Dory (*Zeus capensis)*, skates (*Raja* spp), and sharks (all species) as a percentage of the hake-directed catches along the South African coast for a) the inshore and b) the offshore commercial trawl fisheries from 1981 to 1995.

Gurnards rarely made up more than 2% of the hake-directed inshore trawl fishery landings between 1984 and 1995, a weight of approximately 1.5 tonnes (Figure 2.8a). Compared to other bycatch species this is considerably less than that for skates and soles, but more compared to monk and panga.

Although gurnard comprised only 0.2-2.4 % of the hake-directed landings in the offshore trawl fishery, the actual landings in tonnes were considerably higher than those of the inshore fishery, being between 200 and 3 000 tonnes (Figure 2.8b). In this case gurnard landings were again less than monk landings, and higher than panga landings.

2.3.3 Observer bycatch data

Gurnard catch statistics gathered by SFRI observers are presented in Table 2.3. On the west coast between June and October 1995, an observer recorded the catch composition for 143 commercial trawls. The total retained catch amounted to 1000 tonnes. Of this, 1.3 % was gurnard, a catch weight of nearly 13 tonnes that represents 74 % of the gurnard catch, or an average of 89 kilograms per trawl. The remaining 26 % that was discarded amounted to 4.5 tonnes, or an average of 32 kilograms per trawl.

Operating out of the Mossel Bay harbour in January 1996, an observer recorded similar data for 30 commercial trawls. Of the total retained catch of 30 tonnes, 222 kg or 0.74 % was gurnard. None of the gurnard catch was discarded despite the fact that this amounted to only 7.5 kilgrams per trawl.

Table 2.3. Gurnard catch statistics obtained from commercial trawlers through the SANCOR Observer Program on the south and west coasts of South Africa in 1995 and 1996.

	West Coast June-October 1995	South Coast January 1996
Number of trawls	143	30
Total retained catch, tonnes	1000	30
Gurnard catch (% of total catch)	1.3	0.74
Retained gurnard catch, tonnes (%)	13 (74)	0.22 (100)
Discarded gurnard catch, tonnes (%)	4.5 (26)	0 (0)
Mean discarded gurnard catch per trawl (kilograms)	32	0

2.3.4 Research trawl surveys

Catch statistics from hake-directed biomass surveys on the south coast indicate that gurnard landings were similar to those of monk and sole, making up 5-13 % of the hake landings (Figure 2.9a) from 1986 to 1996. The mean percentage catch composition for gurnards was 2% and represented a slightly higher value compared to that obtained from the commercial trawl data. Four possible reasons exist for the higher percentage of gurnards in the research surveys compared to the commercial landings. Firstly, the use of a fine mesh codend liner during research trawling possibly retains more smaller gurnards; secondly, the vertical mouth opening of the research trawl is much lower than that of the commercial trawl which may in proportionally higher catches of benthic species in research trawls; thirdly, research surveys include catches from non-commercial areas where gurnard may be more abundant compared to hake trawling grounds; and finally commercial data refers to landings, i.e. discards are

excluded, whereas research survey data is for actual catch. By comparison, data from the west coast showed that *C. capensis* constituted up to 27% of the hake-directed catch, a catch weight of just below 2 tonnes to up to almost 8 tonnes, and that gurnard were a key bycatch species in terms of landed mass (Figure 2.9b). Of particular interest were the consistent peaks during the June/July months between 1987 and 1990, strongly supporting the theory of an environmental influence on the landings during these months that was also apparent from the commercial data.

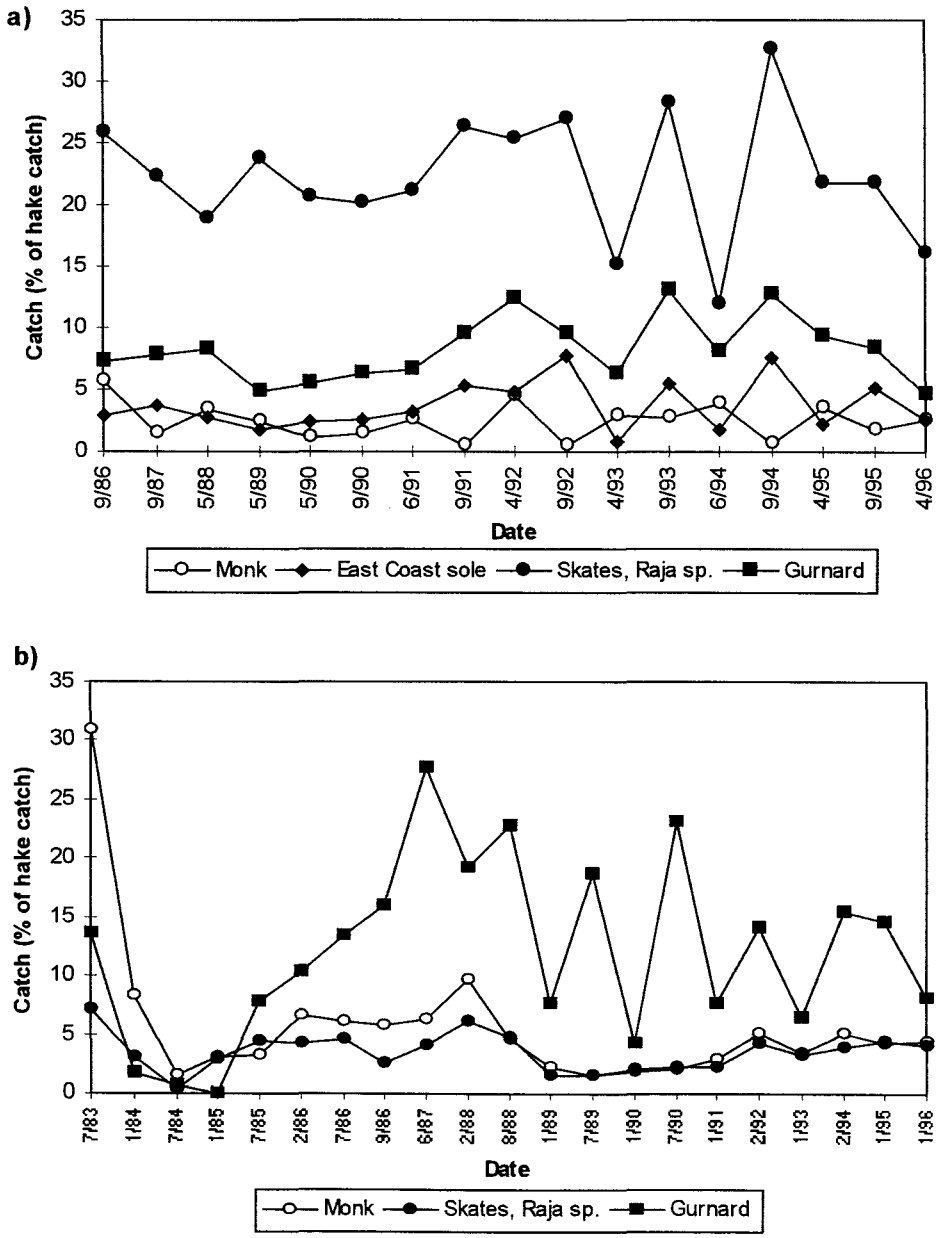

Figure 2.9 Research trawl landings of monk (*Lophius vomerinus*), east coast sole (*Austroglossus pectoralis*), skates (*Raja* spp.) and gurnards (*Chelidonichthys capensis, C. queketti*), as a percentage of the hake catch along a) the south and b) the west coasts of South Africa from 1983 to 1996.

Research survey biomass estimates calculated by Mr Dave Japp (SFRI) were made available for this study. Unfortunately standard error values were not available. The results are presented by depth strata (Tables 2.4 and 2.6) and by latitude (west coast) and longitude (south coast) strata (Tables 2.5 and 2.6). On the west coast the highest relative biomass estimate in terms of depth was from 101-200 metres (Table 2.4). In terms of latitude the greatest concentration of biomass was calculated to be between 34 and 35 degrees south, the area from Cape Town to Cape Agulhas (Tables 2.5a, 2.6).

On the south coast, the biomass estimates were also highest between 101 and 200 metres, however, the figures were much lower (Table 2.4). In terms of longitude, the area between Cape Agulhas and Cape Infanta appeared most productive (Tables 2.5b, 2.6).

Table 2.4 Biomass estimates (tonnes) by depth for *Chelidonichthys capensis* sampled during research cruises on the west and south coasts of South Africa, 1985-1995 (due to lognormal distribution of research survey biomass estimates, geometric means were calculated).

WEST															
Date	Jan	Jan	Feb	Jan	Jul	Jan	Jul	Aug	Feb	Jun	Jan	Jun	Jan	Jul	MEAN - all surveys
Depth, m	1995	1994	1992	1991	1990	1990	1989	1988	1988	1987	1987	1986	1986	1985	
0-100	42003	45179	15126	5189	8371	9616	14753	10810	12739	11217	27754	3209	9349	1724	11258.24
101-200	29301	28614	29760	20972	63771	29393	92912	62143	42192	71705	48255	32692	23951	14908	39921.23
201-300	5709	2754	4302	3597	23840	4514	12606	18712	3537	14341	2364	7055	2645	11918	5519.4
301-400	88	88	Missing data	53	Missing data	Missing data	Missing data	61	Missing data	Missing data	Missing data	Missing data	Missing data	49	Not calculated
401-500	11	Missing data	Missing data	Missing data	Missing data	Missing data	Missing data	Missing data	Missing data	Missing data	Missing data	Missing data	Missing data	Missing data	Not calculated
TOTAL (excluding 301-500)	77013	76547	49188	29758	95982	43523	120271	91665	58468	97263	78373	42956	35945	28550	62957

SOUTH															
Date	Sep	Jun	Sep	Apr	Sep	Apr	Sep	Jun	Sep	May	May	May	Sep	Sep	MEAN - all surveys
Depth, m	1994	1994	1993	1993	1992	1992	1991	1991	1990	1990	1989	1988	1987	1986	
0-50	1289	6394	1355	1269	1276	1266	703	1383	816	1033	40	2246	1952	1052	1092.74
51-100	5190	2855	3422	5362	3612	6315	2260	5229	3369	4062	3036	3889	3093	7786	4017.31
101-200	18071	10042	12552	12764	6954	10191	10162	7733	6564	7124	5601	7935	5517	7470	8683.90
201-500	Missing data	536	Missing data	Missing data	Missing data	Missing data	Missing data	1558	Missing data	Missing data	Missing data	Missing data	45	26	Not calculated
TOTAL (excluding 201-500)	24550	19291	17329	19395	11842	17772	13125	14345	10749	12219	8677	14070	10562	16308	14456.88

Table 2.5a Biomass estimates (tonnes) by latitude for *Chelidonichthys capensis* sampled during research cruises on the west coast of South Africa, 1985-1996 (due to lognormal distribution of research survey biomass estimates, geometric means were calculated) (values were not available for January 1993).

WEST														
LAT.	Jan 1996	Jan 1995	Feb 1992	Jan 1991	Jul 1990	Jan 1990	Jul 1989	Aug 1988	Feb 1988	Sept 1987	July 1986	Feb 1986	July 1985	MEAN - all surveys
29-30	8549	5120	8412	3912	2414	12649	9904	21	767	17581	113	5795	91	2198.03
30-31	6292	4735	3485	2373	1399	5306	4511	2639	1432	11501	230	792	1050	2355.14
31-32	5358	8307	1883	3784	1286	2513	4664	98	21	5415	6206	4134	712	2038.79
32-33	3099	18756	10308	3035	17016	634	11128	58	26	610	6214	458	1850	1808.00
33-34	3125	4948	8560	3600	22391	3891	52720	7	Missing data	8526	5100	182	9952	Not calculated
34-35	9818	42096	10849	3839	60380	9782	15606	Missing data	10	2607	8750	8589	1670	Not calculated
35-36	5546	8275	4896	8230	5597	7220	7455	200	834	10941	7122	5660	2062	4071.56

Table 2.5b Biomass estimates (tonnes) by longitude for *Chelidonichthys capensis* sampled during research cruises on the south coast of South Africa, 1988-1996 (due to lognormal distribution of research survey biomass estimates, geometric means were calculated).

SOUTH																
LONG.	April 1996	Sept 1995	April 1995	Sept 1994	June 1994	Sept 1993	April 1993	Sept 1992	April 1992	Sept 1991	June 1991	Sept 1990	May 1990	May 1989	May 1988	MEAN – all surveys
20-21	7135	12951	14876	15355	10538	7510	11488	3714	7422	7138	5425	4293	5555	3591	7338	7481.30
21-22	1318	2712	3205	2723	1903	1239	3387	1530	3935	767	1881	1117	2039	1855	1732	1905.34
22-23	3329	1573	1485	3531	1147	2720	2046	3310	1567	1478	3443	2073	1780	804	1225	1912.97
23-24	407	409	1252	806	953	899	1220	891	808	784	1496	1900	364	212	637	751.78
24-25	296	251	189	242	170	192	830	251	1048	424	272	283	187	313	1102	326.46
25-26	2359	1467	957	754	5390	446	1994	1720	2715	331	1683	265	1442	690	644	1117.42
26-27	415	1034	994	1431	301	1644	484	1027	1082	354	1136	152	85	126	786	534.74

Table 2.6 Mean biomass estimates (tonnes) by depth, and latitude or longitude for *Chelidonichthys capensis* sampled during research cruises on the west and south Coasts of South Africa, 1985-1995.

West Coast				South Coast			
Depth, M	Mean 1985-1995	**Latitude**	Mean 1985-1996	**Depth, M**	Mean 1986-1994	**Longitude**	Mean 1988-1996
0-100	11258.24	**29-30**	2198.03	**0-50**	1092.74	**20-21**	7481.30
101-200	39921.23	**30-31**	2355.14	**51-100**	4017.31	**21-22**	1905.34
201-300	5519.4	**31-32**	2038.79	**101-200**	8683.90	**22-23**	1912.97
301-400	Not calculated	**32-33**	1808.00	**200-500**	Not calculated	**23-24**	751.78
401-500	Not calculated	**33-34**	Not calculated		14456.88	**24-25**	326.46
		34-35	Not calculated			**25-26**	1117.42
		35-36	4071.56			**26-27**	534.74

2.4 Discussion

Since *Chelidonichthys queketti* form an insignificant part of the commercial linefish landings, and *C. kumu* are only caught on the west coast, the South African linefish gurnard landings consist mainly of *C. capensis*. These landings were low and, in the author's opinion, it is thus unlikely that these species will be targeted in the near future by this fishery. The increase in landings in 1994 and 1995 may reflect the beginnings of a trend in that the decline of other linefish target species is forcing fisherman to keep, and possibly target, less valuable bycatch species such as gurnard. Line fishermen tend to retain any fish that they are likely to sell and as such any change in the numbers of gurnard landed is also likely to be market-related. An alternate solution may be that the availability of other species, such as snoek and kob, were poor at this time due to environmental conditions with the result that gurnards were then kept. However, Smale & Buxton (1985) describe these species as rare amongst recreational ski-boat landings off the eastern Cape coast, South Africa, and Hecht & Tilney (1989) report insignificant landings of *C. capensis* in the Port Alfred commercial linefishery as compared to species such as kob, carpenter, panga and geelbek. The peaks in landings during March and May may indicate that either some form of migration is taking place, perhaps similar to that of New Zealand's Red gurnard, *Chelidonichthys kumu* which moves offshore to the deeper water during spring (Elder 1976), or that environmental conditions somehow increase the availability of the stock during these periods. However it appears that gurnards are not, as yet, an important commercial species in the South African linefishery.

Gurnard landings in the South African trawl fisheries, however, are comparable to those of other gurnard species that are commercially utilised around the world, and are more likely to become targeted on as catches of current target species continue to decline.

Biomass estimates from the west coast research surveys between 1985 and 1995 indicate a level comparable to that of another important bycatch species, the panga, *Pterogymnus laniarus*. Both are likely to become targeted in the near future (Booth &

Punt In press). Landed catches by the offshore sector on the west coast were significantly higher than those from the inshore sector in the east coast. This supports the research survey results showing that the highest biomass is in the 100-200m depth range.

Low oxygen levels have been reported between latitudes 20^0 S and 27^0 S in the Benguela System on the South African west coast by Bianchi *et al.* (1993). Macpherson & Mas Riera (1987) report a significant proportional correlation between benthic oxygen concentrations and *C. capensis* density. In addition, the results of their study showed that *C. capensis* is well-adapted to living in oxygen-deficient zones that cannot be inhabited by many teleost species. Van den Heever (1995) reported high biomass concentrations of *C. capensis* between Cape Town and Saldanha Bay in 150-200m depth, ranging between 95 983 tonnes and 29 810 tonnes from January 1990 to January 1995. The biomass estimates from the west coast of Macpherson & Mas Riera (1987) between January 1984 to August 1986 ranged between 36 100 tonnes in January 1984 and 24 303 tonnes in July 1986.

On the south coast, Smale *et al.* (1993), in a study of the demersal fish and cephalopod community on the Agulhas Bank, compared the distribution of *C. capensis* between the inshore, shelf, and shelf-edge/slope areas. Results showed inshore abundances to be far greater than shelf or slope estimates. The apparent variation in seasonal abundance of *C. capensis* landings, in both the commercial handline and trawl fisheries, may either be due to the availability of this species as a result of migration for spawning or feeding activity, or because preferred target species were not available during a certain season, the result being that the less valuable bycatch species were then targeted. Landings of one of the other South African gurnard species, the lesser gurnard, *C. queketti,* have been dealt with by Booth (1997), whilst those of the bluefin gurnard, *C. kumu,* were considered too low to warrant any special attention (Japp, SFRI, pers. comm.).

Papaconstantinou (1983) reported migration to spawning grounds and use of nursery areas by juveniles for many of the gurnard species found in the Greek Seas but results from the current study indicated that there were no significant differences between

monthly landings, suggesting no similar form of migration for *C. capensis*. Konchina (1989), in a study on the multi-species, epibenthic fish community in the Benguela System off Namibia, also described *C. capensis* as a non-migratory species but noted that larger fish were found deeper than smaller ones. Van den Heever (1995), however, reported biomass estimates, derived from data available from research cruises aboard *FRS Africana*, of 100 000 tonnes for July 1990 and 40 000 tonnes six months later in January 1991, and suggested seasonal catches for this species. Other reports of migration for triglid species include Elder (1976) on *C. kumu* in New Zealand, and Marshall (1946) on two sea robin species, *Prionotus carolinus* and *P. evolans strigatus* in southern New England waters.

At present an experimental gurnard fishery does exist on the west coast of South Africa and a brief description of this fishery follows.

History of the South African experimental gurnard-directed trawl fishery

In 1990, fishing permits for gurnard were issued to Visko Fishing, Mr C.P. Bodenstein, and Paternoster Fishery on the west coast, allowing them to catch gurnards as part of an experimental fishery. Landed catches were not high, ranging between 44 tonnes and 252 tonnes per company per year between 1990 and 1994, and returns were submitted erratically, making it a difficult fishery to monitor. It also appeared that fishermen were targeting St Joseph sharks, not gurnards. The SFRI was asked to make recommendations, at the end of each year, on the continuation of the fishery but found it difficult to asses due to the poor catch returns and inconsistent fishing. No further permits were issued until 1995 when it was decided, due to increased pressure from local fishermen, that one extra permit be issued to Elandia Fisheries. Neither Elandia nor Paternoster reported any gurnard catch for 1995 so all permit holders were then given an ultimatum: should they fail to activate their permits in 1996, then no permits would be renewed in 1997. At present one fishing company is still catching gurnards, the other permits having been withdrawn. Low oxygen concentrations however make this area ecologically sensitive and the experimental gurnard fishery could well be halted (Japp, SFRI, pers. comm.).

In conclusion then, *C. capensis* are an important bycatch species in the commercial trawl industry on the west coast and will more than likely become a target species in the future.

Chapter 3 - Population Structure and Reproduction

3.1 Introduction

Teleost fishes display a wide variety of reproductive strategies. Balon (1975) has provided one of the more flexible ways of classifying these strategies by organising them into eco-ethological guilds comprising non-guarders, guarders and bearers. These categories may be represented as alternative states from generalised (non-guarder) to specialised (bearer), with guarders being the intermediate category (Bruton 1989). Non-guarders would be open substrate spawners, perform little parental care and have high fecundity. At the other end of the scale the more specialised bearers exhibit intensive parental care, may build nests and produce few, well-developed young. Unpredictable environments normally favour open substrate spawners which, by producing a very large number of offspring, increase the chances that a few of their young may survive (Bruton 1989). Many marine teleosts exhibit this generalised form of reproductive behaviour and simply release many, small pelagic eggs into the water column. Pelagic spawning is true for many of the southern African seabream species such as the Red Roman, *Chrysoblephus laticeps*, and the santer, *Cheimerus nufar* (Nepgen 1977; Buxton 1987; Buxton & Garratt 1990). Leis & Trnski (1989) describe pelagic spawning for members of the gurnard genera *Chelidonichthys, Lepidotrigla* and *Pterygotrigla*, with eggs being spherical and of medium size (0.9-1.5mm diameter). Studies in southern African waters by Trunov & Malevanyy (1974), and Hecht (1977a), describe *C. capensis* as an intermittent, or asynchronous, spawner. Fecundity estimates of Trunov & Malevanyy (1974) were high, in the region 98 000 - 1 042 000 for *C. capensis* and 51 000-798 000 for the lyre gurnard, *Trigla lyra.*

Knowledge of reproductive biology may play an important role in determining conservation measures such as closed seasons and minimum sizes (Ricker 1975; Penney *et al* 1989). Closed seasons can be implemented during the months in which a species is known to spawn, or is known to migrate to a spawning area, during which time they may be vulnerable. Minimum sizes may ensure that the fish is given at least one chance to spawn before it is recruited into a fishery. It is also argued that older, long-lived fish are more fecund, producing more eggs that are larger with greater viability, points in favour of the implementation of a maximum size or

slot limit (Buxton 1994). An understanding of the reproductive process can also contribute towards explanations of large fluctuations in abundance, for example due to recruitment failure (Royce 1984). Exploitation may alter certain life history variables, including sex ratios and sizes at maturity (Garrod & Horwood 1984). Leaman (1991), in a study on the exploitation effects on several stocks of *Sebastes,* hypothesised that increased mortality of adults should lead to lowered age at first maturity and increased reproductive effort prior to ages at which mortality increases. This was shown to be the case for the Atlantic cod, *Gadus morhua,* where the median length and the age at sexual maturity declined by 50% over a period of 20 years during which time the stock came under heavy exploitation in the northwest Atlantic ocean (Beacham 1983). Bowering (1989) reported substantial changes in age composition, growth and maturation in flounder, *Glyptocephalus cynoglossus,* in the same area since the commercial exploitation of the species in the early 1950's. Similar effects have been reported for a number of South African sparid species, for example *Chrysoblephus puniceus* and *C. nufar*, by Garratt (1985) and *Chrysoblephus laticeps* and *C. cristiceps* (Buxton 1987).

A common secondary sexual characteristic of fishes is that females, carrying bulky eggs, are larger than males (Bond 1979). This has been hypothesised to facilitate the maximum possible egg production (Nikolsky 1978). Should this be the case, the implications for the resource will need to be assessed as increased fishing pressure may lead to a decreased number of females which in turn would have an effect on recruitment.

In Namibia, Trunov & Malevanyy (1974) have suggested that generally, the larger fish in commercial landings of *Chelidonichthys capensis* are predominantly female. Hecht (1977a) indicated an extended spawning period in the warmer months, November to March. Booth (In Press) reports iteroparity for the lesser gurnard, *Chelidonichthys queketti*, on the Agulhas Bank, South Africa, and year round spawning with peaks in reproductive activity in spring and late summer. Extended spawning periods have been reported for other gurnard species found around the world, for example *Chelidonichthys kumu* (Elder 1976; Clearwater & Pankhurst 1994), *Trigla lucerna* (Papaconstantinou 1984), and *Eutrigla gurnardus* (Baron 1985). Further examples are presented and discussed in Section 3.4.

In South Africa, the most recent, complete biological study on the Cape gurnard was twenty years ago (Hecht 1976b), thus it was deemed necessary to repeat the reproductive study to discover if any of the above mentioned changes had indeed occurred.

3.2 Methods

3.2.1 Sampling areas and strategy

Sampling for this study was carried out along the south and east coasts of South Africa, from inshore to a depth of 500m on the Agulhas Bank between Port Alfred and Cape Agulhas (Figure 3.1) during the period August 1995 to January 1997.

The Agulhas Bank, a triangular-shaped extension of the continental shelf south of Africa, is about 800km long and 250km wide (Hutchings 1994). Dropping steeply from the coast to 50m, the shelf slope then shallows out and deepens gradually to 200m. The western Agulhas Bank serves as a boundary area between the two major currents flowing along the coasts of Africa, the Agulhas Current down the east coast and the Benguela Current on the west coast. Warmer water in the upper layers, and bottom waters with an high oxygen content and only localised areas of slightly reduced oxygen, are characteristic of the Agulhas Bank and set it apart from the west coast shelf area (Hutchings 1994).

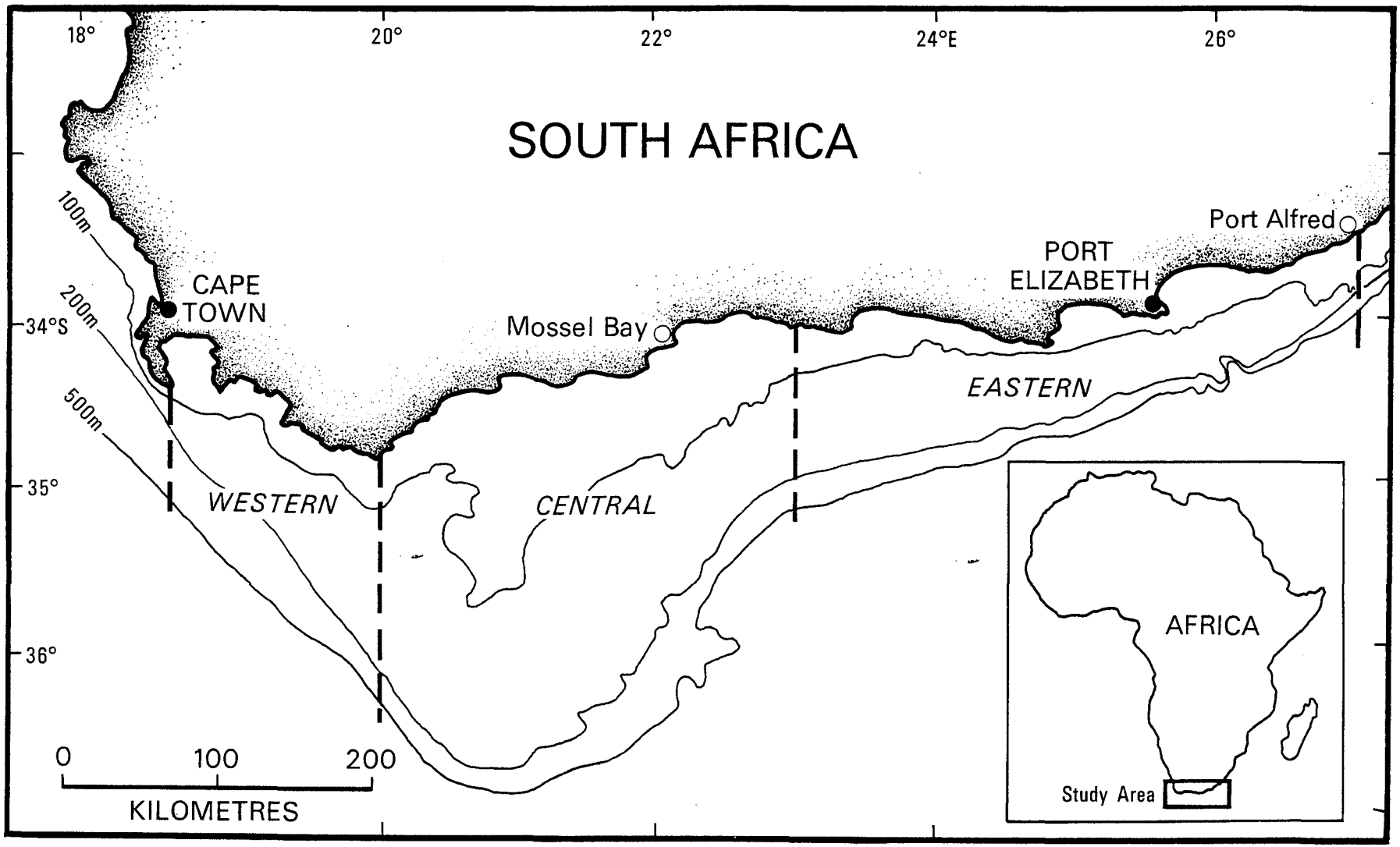

Figure 3.1 Map of the South African coastline to show the Agulhas Bank from which samples were collected during the sampling period August 1995 to January 1997.

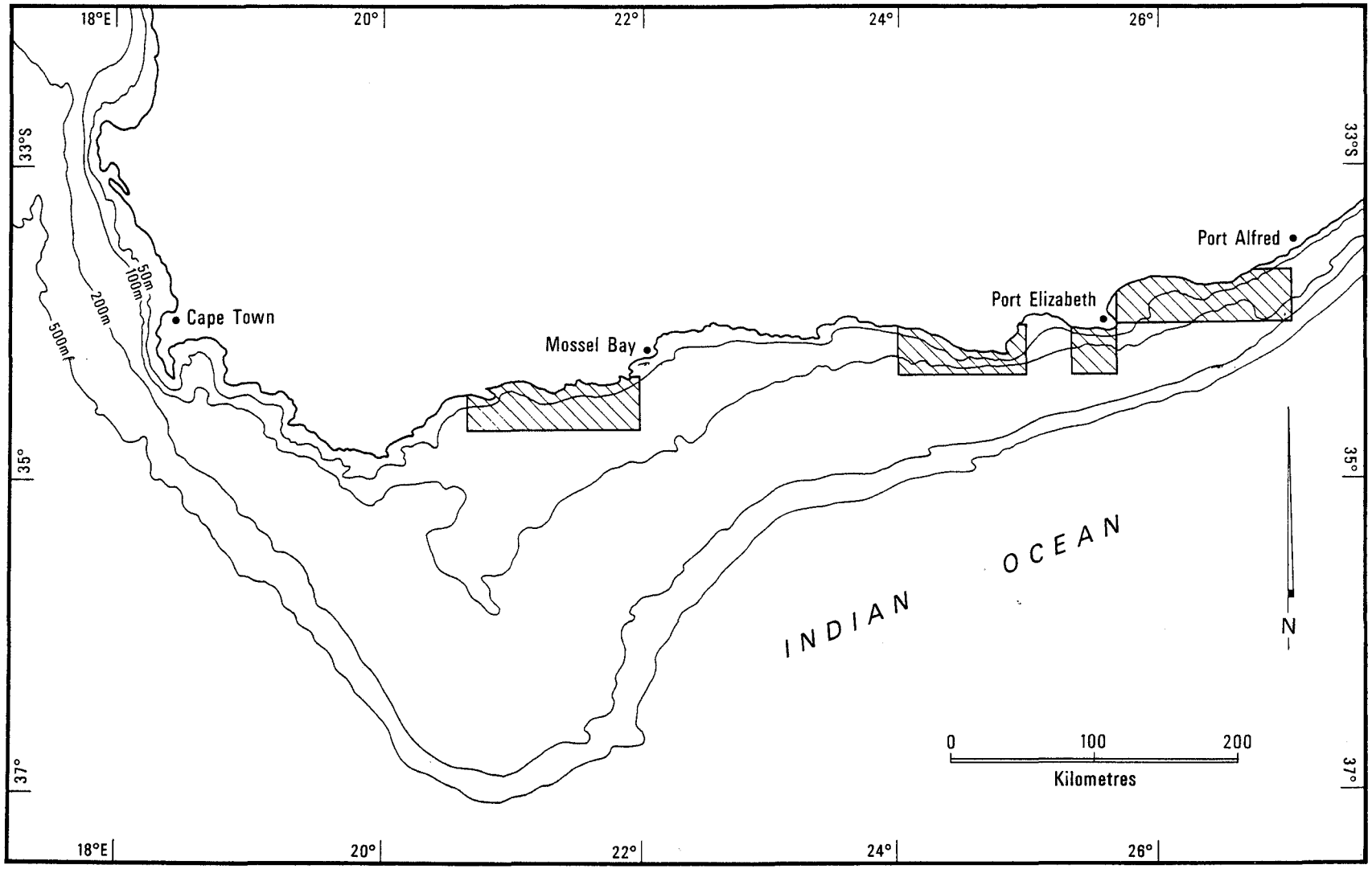

Figure 3.2a Map of the South African coastline to show areas on the Agulhas Bank from which commercial samples from inshore trawlers were collected during the sampling period August 1995 to January 1997.

Monthly samples were collected by SFRI observers aboard inshore trawlers operating from Port Elizabeth and Mossel Bay. These vessels use otter trawls with 75 mm stretched mesh codends. Areas from which samples were taken are shown in Figure 3.2a.

In addition, participation in two research cruises aboard *FRS Africana* in October 1995 and April 1996 helped to increase sample sizes. Research trawl operations are described in Badenhorst & Smale (1991). Trawl station positions were selected at random and included both commercial and non-commercial fishing areas. Samples collected during research surveys therefore covered a wider are area than those from commercial fishing vessels. A single sample from a research survey conducted on the west coast was collected by *FRS Africana* in January 1996. The reproductive and growth data obtained were not included due to significant environmental differences between the east and west coasts of South Africa (Shannon 1969), that may have an effect on reproductive seasonality, spawning and growth. As this was a single sample and numbers were low (n=145), it could not be statistically compared to samples collected on the east and south coasts.

The samples were collected from areas shown in Figure 3.2b. Catches were made using standard bottom otter-trawling gear, but with a 25mm stretched mesh codend liner thereby reducing escapement of smaller fish (Badenhorst & Smale 1991).

The longline fishery, and commercial and recreational linefisheries were not sampled as it was established from the SFRI personnel that very few gurnards are caught by these fishers (see Chapter 2).

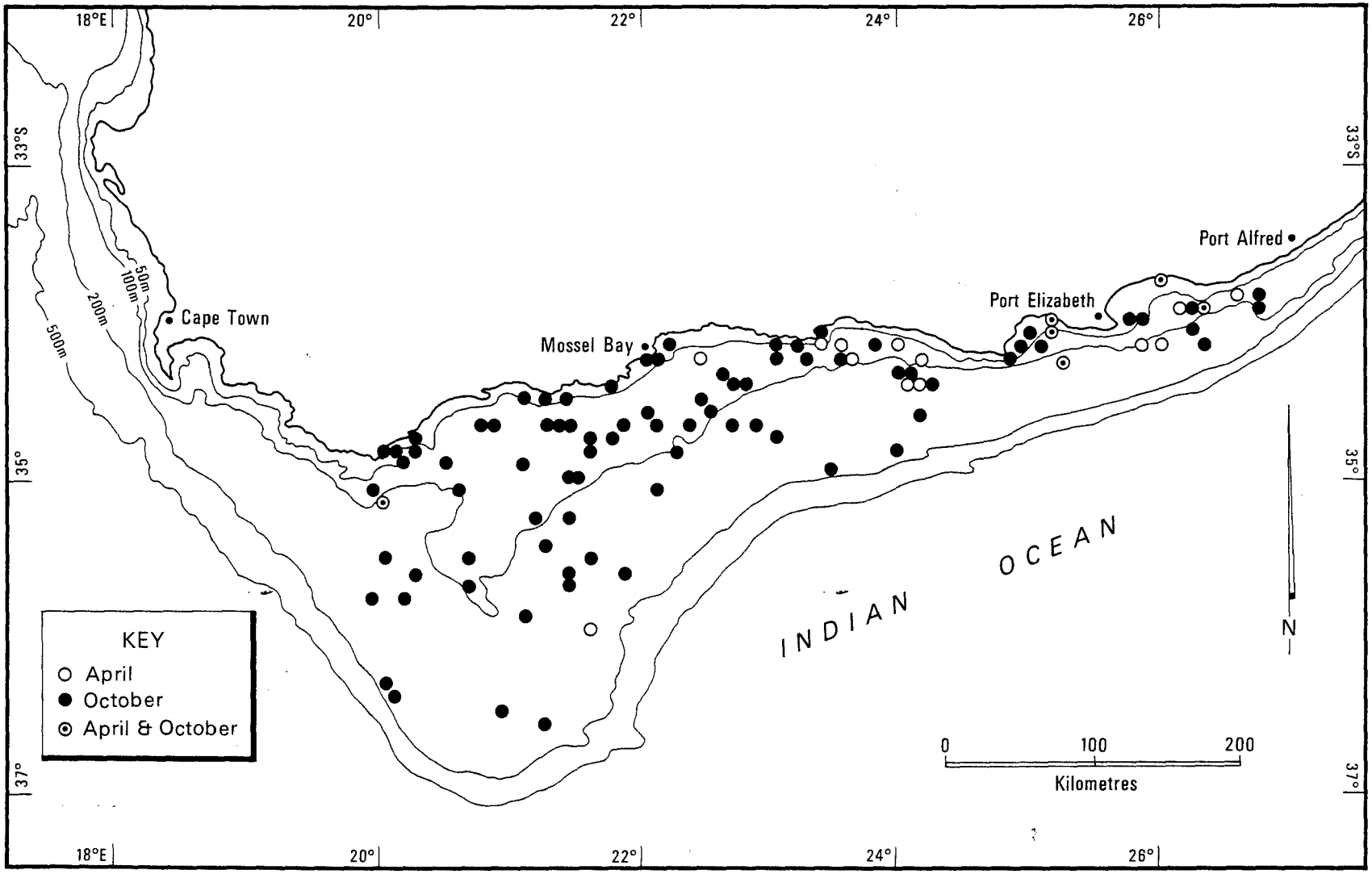

Figure 3.2b Map of the South African coastline to show areas on the Agulhas Bank from which research samples were collected during the sampling period August 1995 to January 1997.

3.2.2 Population Structure

3.2.2.1 Length Frequency

Length frequency data were obtained from monthly commercial landings in Port Elizabeth and Mossel Bay, and collected on the two research cruises in October 1995 and April 1996. Length frequency data in both cases were collected from whole fish and these were measured (TL) to the nearest mm below and sexed. Large research catches were generally sub-sampled for length frequency data, and the size of the sub-sample was determined by the number of fish measured to obtain a modal peak in the size frequency distribution. These data were used to determine percentage size frequency distributions. Mean lengths of males and females were compared using a Student's two sample t-test.

3.2.3 Reproduction

3.2.3.1 Sex Ratio

Sex ratios of *C. capensis* in commercial landings and research catches were determined. Research catches were sub-sampled, the size of the sub-sample depending on the number of fish measured to obtain a modal peak in the size frequency distribution.

3.2.3.2 Reproductive seasonality

The gonads of all Cape gurnards caught in the commercial trawls and sub-sampled from research catches were macroscopically examined and awarded a gonad maturation index (GMI). A simple maturation index chart was constructed to facilitate assigning GMI values in the field (Table 3.1). Virgin and resting stages were not distinguished as it was difficult to determine them accurately in the field.

The gonads of all sampled fish were removed and weighed (to the nearest 0.01g) to determine gonadosomatic indices:

$$GSI = \frac{\text{gonad mass (g)} \times 100}{\text{whole body mass (g)}}$$

Table 3.1 Classification of maturity stages for *Chelidonichthys capensis* (modified from Laevastu 1965, Nikolski 1978 and Buxton & Clarke 1986).

GMI	Stage	Description
1	Virgin and Resting	Ovaries and testis small and lying close under the vertebral column. Testes thread-like, opaque and white. Ovaries pinkish and translucent. No eggs visible to the naked eye.
2	Developing	Gonads larger, especially on long axis, and blood vessels present. Testis pale opaque yellow-grey and thick. Ovaries red-orange with opaque eggs visible to the naked eye
3	Active/Ripe running	Testis pinkish grey. Sperm runs freely out of sperm duct if pressure applied. Ovaries orange in colour, very large and swollen. Translucent eggs visible.
4	Post spawning	Testis becomes hard with frilly appearance, pale pink in colour. Ovaries flaccid and much decreased in size, reddish orange and bloodshot.

Gonads were used to determine temporal and spatial variability in reproduction and length and age at sexual maturity. Specimens showing little or no gonad development were considered undeveloped (stage 1), whilst those with developed gonads (stages 2-4) were considered mature. Significant differences in monthly gonadosomatic indices were tested for using one way analysis of variance and Tukeys' multiple range analysis at the 95% confidence interval in the StatGraphics statistical package.

3.2.3.3 Histology

Gonad tissue was only taken from research samples that were guaranteed to be fresh as commercial samples may have been defrosted and refrozen on more than one occasion, causing extensive cellular damage that would result in poor histological results.

Gametogenesis of male and female Cape gurnard have previously been described in detail by Hecht (1976b), thus it was not deemed necessary to repeat the work, the results of the histology study simply being used to confirm the correct assignation of the GMI values in the field.

Randomly selected gonad tissue from both males and females was fixed for 10 days in 10% formalin. After fixation, the gonad tissue was stored in 70% ethanol. Methods described by Sumner & Sumner (1969), Bernard & Hodgson (1988), and Hinton (1990) were employed to prepare the tissues for sectioning and are briefly described here. Tissue was trimmed to 0.5cm^3 blocks and dehydrated by passage though a series of ethanol solutions of increasing

concentrations (80%, 90% and 100% x2 aqueous ethanol) each for 1 hour. Dehydration is essential prior to embedding the tissue in paraffin wax as the wax will not penetrate tissue in the presence of water (Hinton 1990). To prevent cell shrinkage, the ethanol was then removed from the tissues by immersion in 100% chloroform for two hours. Embedding in paraffin wax took place overnight in a 60^{0}C oven. The samples were then blocked out and left overnight to harden. These were then trimmed, mounted and sectioned with a microtome to 5-8μm thickness. The resultant ribbons were floated onto a warm water bath (40^{0}C) and then attached to slides using Haupt's adhesive. The slides were placed in an oven at 37^{0}C overnight to dry and then stained using haematoxylin and eosin. Sections were protected with DPX mountant and a coverslip, and photographed under 4-40 times magnification.

3.2.3.4 Size at maturity

To eliminate possible bias, the size at sexual maturity was calculated by determining the proportion of reproductively active individuals (stages 2, 3 and 4) in each size class using the GMI values collected in the field during months of peak reproductive activity. A logistic ogive, described by the equation:

$$P_{(L)} = \frac{1}{1+\exp^{-(L-L50)/\delta}}$$

where $P_{(L)}$ is the proportion of mature fish at size L, L_{50} is the length at which 50% of the sample was found to be mature, and δ is the width of the ogive, was fitted using Newton's non-linear minimisation procedure (Zar 1996). The average length at sexual maturity was taken as the size at which 50% of the population was mature, as defined by several authors (e.g. Beverton & Holt 1957; King 1995), in addition to being the basis for most minimum legal sizes of fish in South Africa (Buxton & Clarke 1991). A likelihood ratio test was used to test for differences in the ages of maturity between females and males.

3.3 Results

3.3.1 Population structure

3.3.1.1 Length Frequency

Length frequency distributions for males and females were found to be significantly different (t-test, $p < 0.001$). The modal size for females was 449mm TL whereas that for males was 399mm TL. There was a significant difference between the size distributions of commercial and research caught females (t-test, $p < 0.05$) but not between males. Length frequency histograms are presented in Figure 3.3.

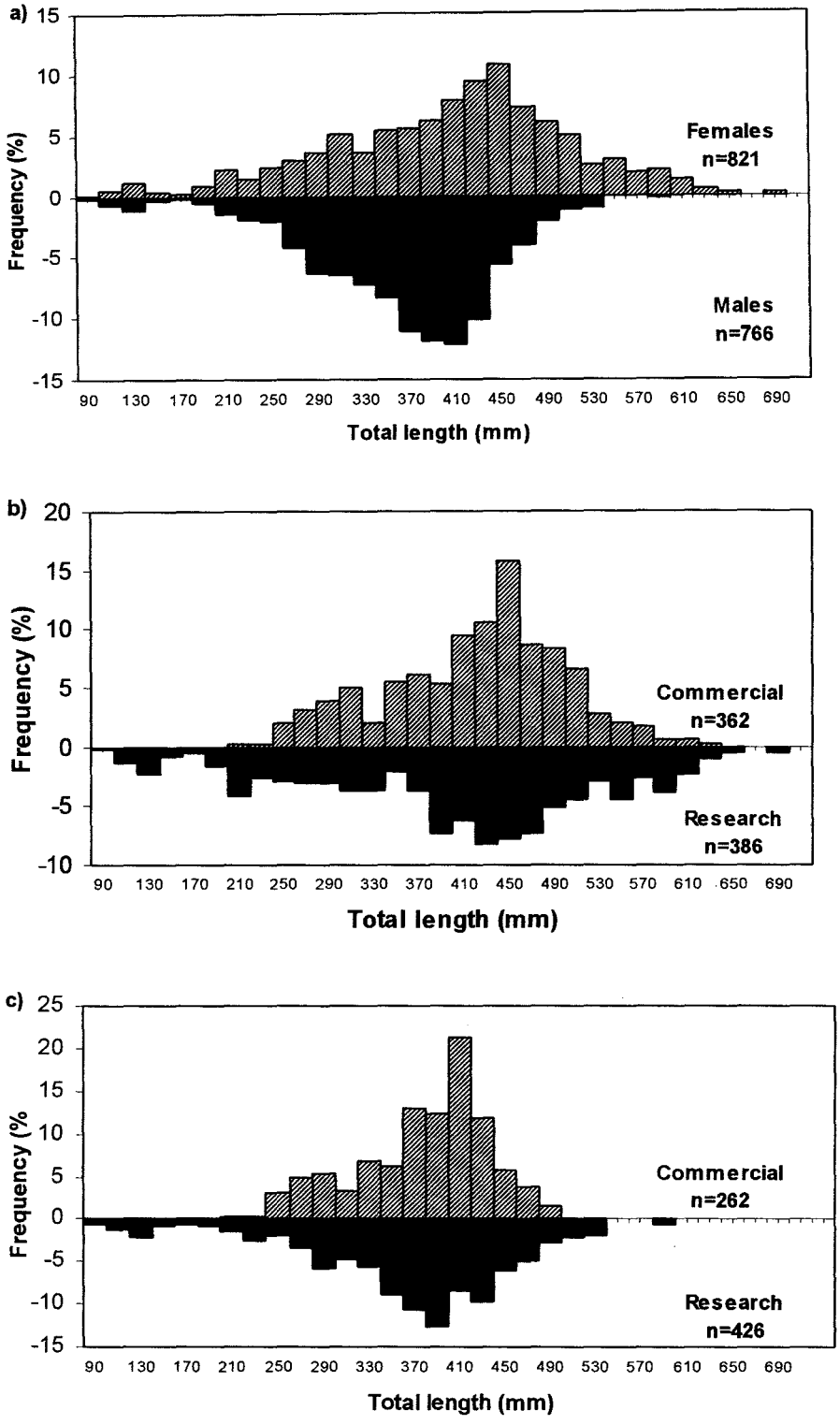

Figure 3.3 Size frequency histograms of *Chelidonichthys capensis* sampled on the Agulhas Bank from August 1995 to January 1997, a) all males and all females, b) commercial and research sampled females, and c) commercial and research sampled males (note that unsexed juveniles were included in figures b) and c) but not figure a)).

Mean lengths and standard deviations are presented in Table 3.2 as well as values for the largest males and females caught in research trawls or landed by the commercial fisheries. Males were significantly smaller than females ($p<0.001$). The mean size of females in the commercial landings (417mm TL) was significantly higher ($p<0.05$) than that from research catches (391mm TL), whereas there was no significant difference ($p>0.05$) in the mean size of males.

Table 3.2 Mean observed lengths and standard deviation, and maximum weights and lengths, for *Chelidonichthys capensis* sampled on the Agulhas Bank from August 1995 to January 1997.

Group	Mean TL length, mm	Standard deviation	Maximum TL length, mm	Maximum wet weight, g	n
Females					
Total	395	103	676	3300	821
Research	391	134	676	3300	386
Commercial	417	77	625	2835	362
Males					
Total	360	78	582	1100	766
Research	367	79	581	1100	462
Commercial	361	86	582	1061	262

3.3.2 Reproduction

3.3.2.1 Sex Ratio

The sex ratios were 1 male: 0.9 females and 1 male: 1.43 females for commercial and research data respectively.

3.3.2.2 Reproductive seasonality

Changes in gonad maturation indices for females and males are presented in Figures 3.4 and 3.5 respectively. Figures 3.6 and 3.7 illustrate the seasonal variation in gonadosomatic indices. Peaks in the numbers of spent females occurred in November 1995, March 1996, May 1996, and from October 1996 to January 1997 (Figure 3.6). Peaks in the GSI values occurred just before these periods, August to October 1995, January/February 1996, April/May 1996 and August/September 1996 (Figure 3.8), indicating periods during which females were spawning. A similar picture emerges for the males (Figure 3.7 and Figure 3.9). Peaks in November 1995, April/May 1996 and November 1996 in the numbers of spent males are preceded by peaks in GSI values in September 1995, January 1996, and August/September 1996. Male GSI values were considerably lower than those calculated for females. Wood (1998), in a study on egg and

larval dispersal in the Tsitsikamma National Park, noted high numbers of Cape gurnard larvae during July, August, October, and November 1995, and February, March, April and July 1996. The presence of these larvae strongly supports spawning during the period indicated by the GMI and GSI values.

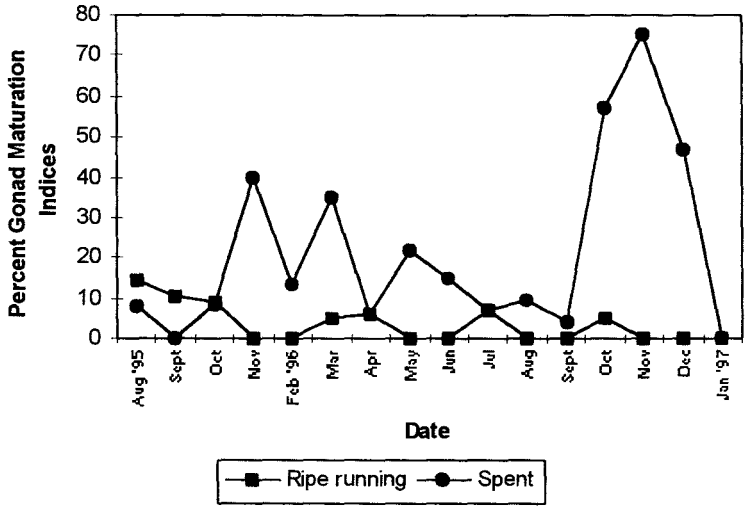

Figure 3.6 Monthly frequency distribution of ovaries of *Chelidonichthys capensis* in the ripe running and spent stages sampled on the Agulhas Bank from August 1995 to January 1997.

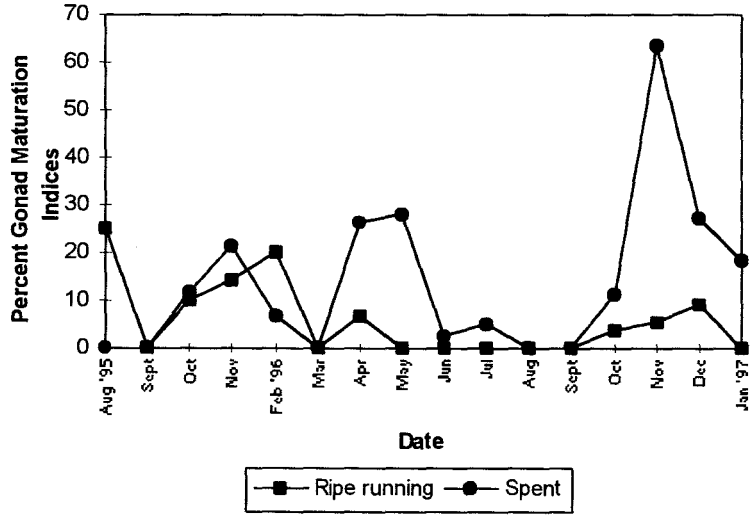

Figure 3.7 Monthly frequency distribution of testes of *Chelidonichthys capensis* in the ripe running and spent stages sampled on the Agulhas Bank from August 1995 to January 1997.

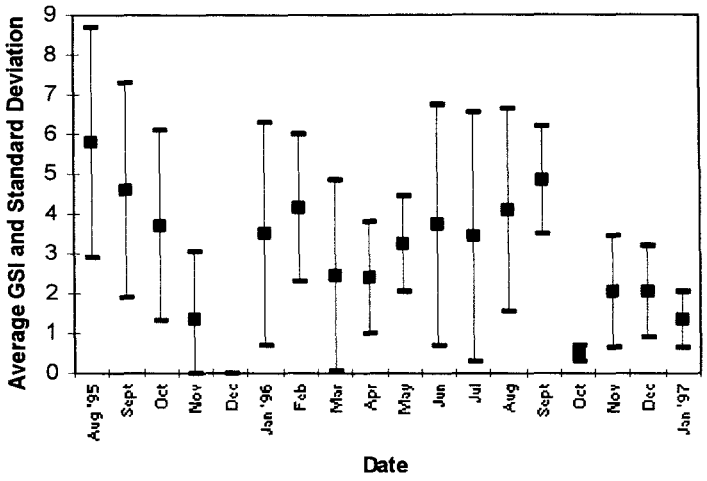

Figure 3.8 Monthly variation of individual gonadosomatic indices for female *Chelidonichthys capensis* sampled on the Agulhas Bank from August 1995 to January 1997 (error bars represent 95% confidence intervals).

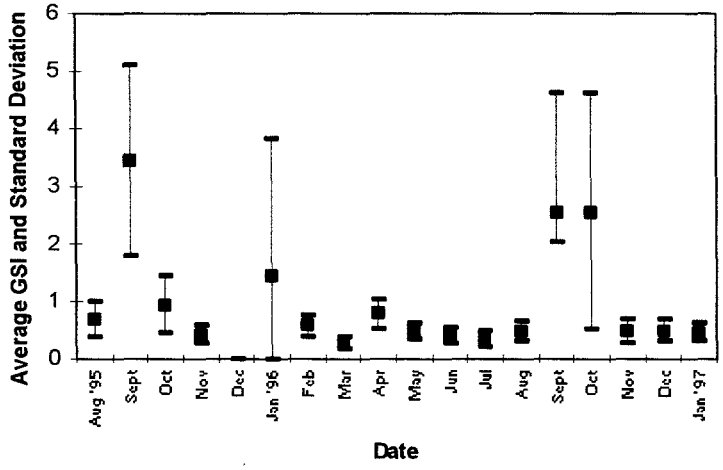

Figure 3.9 Monthly variation of individual gonadosomatic indices for male *Chelidonichthys capensis* sampled on the Agulhas Bank from August 1995 to January 1997 (error bars represent 95% confidence intervals).

Multiple comparison of mean monthly gonadosomatic indices using Tukey's multiple range analysis at the 95% confidence interval showed that GSI values from August 1995 differed significantly from October and November 1995, and January, March, April. May, June, July, October, November and December 1996 for female Cape gurnard (Table 3.3). No significant differences were found between any other months. For males, the mean monthly gonadosomatic indices from September 1995 significantly differed from all other months except November 1995, and those from January 1996 differed significantly from March, May, June, July,

October, November and December 1996 (Table 3.3). No significant differences were found between other months. These results suggest an extended spawning period for the Cape gurnard with peaks of reproductive activity in August, September and January of the study period. However interpretation in months with small sample sizes, such as November 1995, April 1996 and January 1997, was uncertain.

Table 3.3 Results of a multiple comparison of mean monthly gonadosomatic indices using Tukey's multiple range analysis at the 95% confidence interval for female and male *Chelidoncihthys capensis* sampled on the Agulhas Bank from August 1995 to January 1997. (months with bars (|) in common columns do not differ significantly from each other).

	Females		Males	
Month	n	Mean Gonadosomatic Index	n	Mean Gonadosomatic Index
August 1995	92	5.809 |	11	0.669 |
September	19	3.699 | |	14	3.437
October	155	4.596 |	200	0.947 |
November	5	1.351 |	12	0.423 |
January 1996	65	3.491 |	70	1.433 | |
February	16	4.148 | |	14	0.571 | |
March	20	2.458 |	15	0.262 |
April	9	2.410 |	8	0.783 | |
May	14	3.264 |	19	0.488 |
June	54	3.726 |	34	0.411 |
July	31	3.321 |	19	0.335 |
August	26	4.096 | |	9	0.479 | |
September	26	4.836 |	9	0.660 | |
October	21	2.564 |	27	0.506 |
November	12	2.061 |	19	0.478 |
December	15	2.050 |	22	0.492 |
January 1997	2	1.347 | |	12	0.459 | |

3.2.3.3 Histology

For the purpose of this study, ovarian and testicular tissue was divided into four stages of maturity based on the macroscopic appearance of the gonads as described in Table 3.1. The correct assignation of these stages was assessed by studying the microscopic structure of the gonads based upon the descriptions of Wallace & Selman (1981) and Crim & Glebe (1990).

Typically, immature female gonads (stage 1) are dominated by oogonia that develop into previtellogenic oocytes in the early stages followed by the late perinucleolar stages. Maturing, or vitellogenic, oocytes (stage 2) contain yolk granules that begin to aggregate peripherally and

then move towards the nucleus. Mature oocytes (stage 3) are large and filled with yolk whilst a spent, or atretic, ovary (stage 4) contains empty follicles and *corpora lutea.*

The testicular cycle begins with germ, or spermatogonial, cell proliferation (stage 1) followed by the appearance of spermatocytes (stage 2) that develop into spermatids. Once ripe (stage 3), the lumens of the testes lobules are filled with sperm and milt flows freely when the abdomen is compressed. After spawning (stage 4), residual sperm is resorbed and the cycle begins once again. It should be noted that oocytes or spermatocytes in various stages of development can be present at any one time, the maturity stage being identified by the dominant egg or sperm stage present.

Results of the histology study showed that 89% of the gonads had been correctly assigned gonad maturation indices and examples of some of the various gonad stages for males and females are presented in Figures 3.8 and 3.9.

3.2.3.4 Size at maturity

Percentage maturity for male and female Cape gurnard are presented in Figure 3.10. The smallest mature male sampled was 272mm TL, and female, 276mm TL. First approximations of sizes and ages at 50% maturity for males and females are presented in Table 3. A likelihood ratio test showed that males matured at significantly smaller lengths and ages (Chapter 5) compared to females ($F_{(2, 48df)} = 13.76$, $p<0.05$), 343mm TL (4.6 years) and 299mm TL (3.6 years) respectively (Table 3.5). The rates of maturation, as indicated by δ, for males (2.12 $year^{-1}$) and females (2.04 $year^{-1}$) were similar.

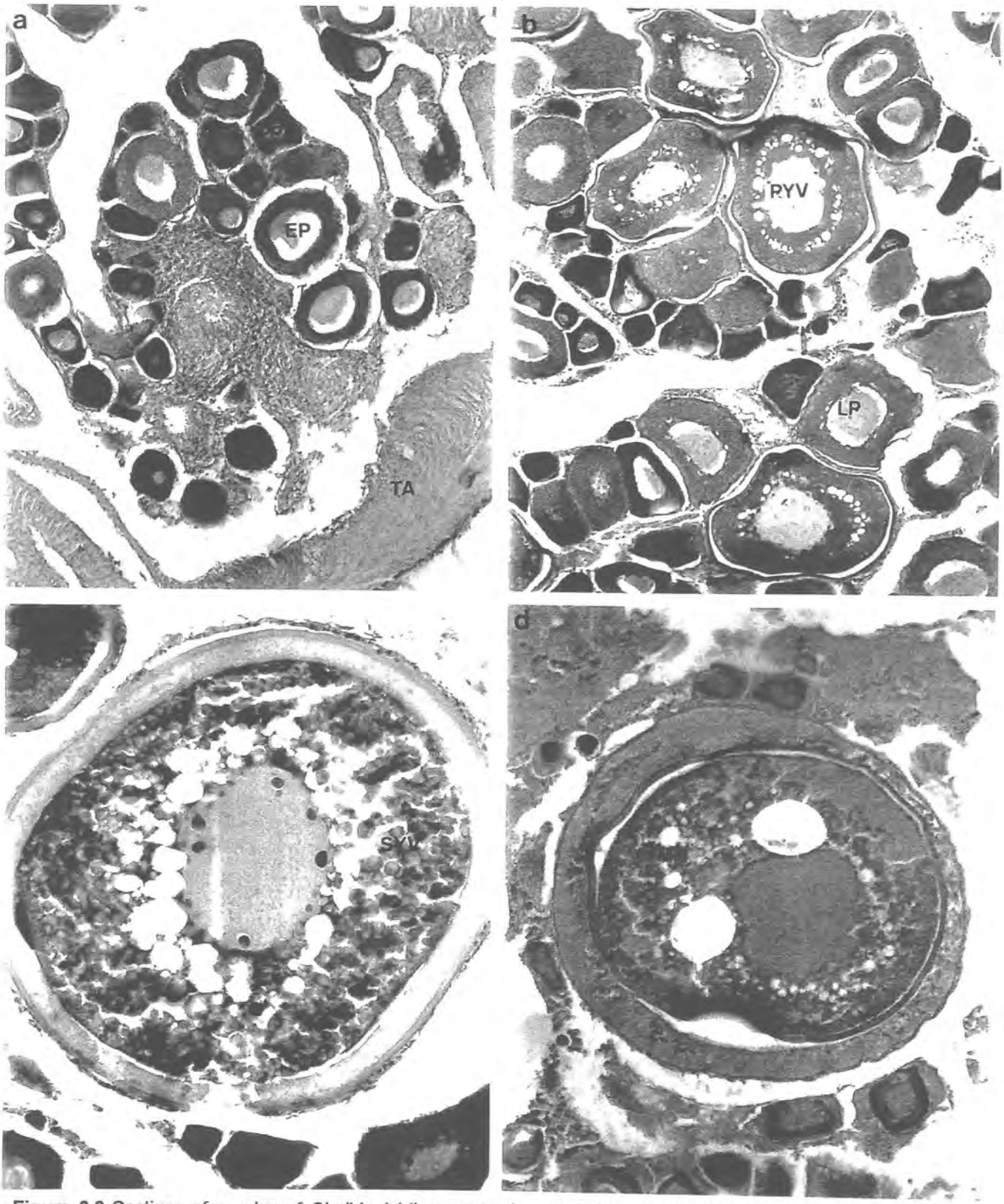

Figure 3.8 Sections of ovaries of *Chelidonichthys capensis* sampled on the Agulhas Bank from August 1995 to January 1997. a) stage 1: immature ovary with pre-perinucleolar (PP) and early perinucleolar (EP) oocytes. The tunica albuginea (TA), or ovary wall, is also visible. b) stage 2: maturing ovary with late perinucleolar (LP) and primary yolk vesicle (PYV) oocytes. c) stage 2: maturing ovary with secondary yolk vesicle oocytes (SYV). d) stage 3: mature ovary showing migratory nucleus oocyte (MN) with coalescence of yolk-globules in the anti-nuclear region.

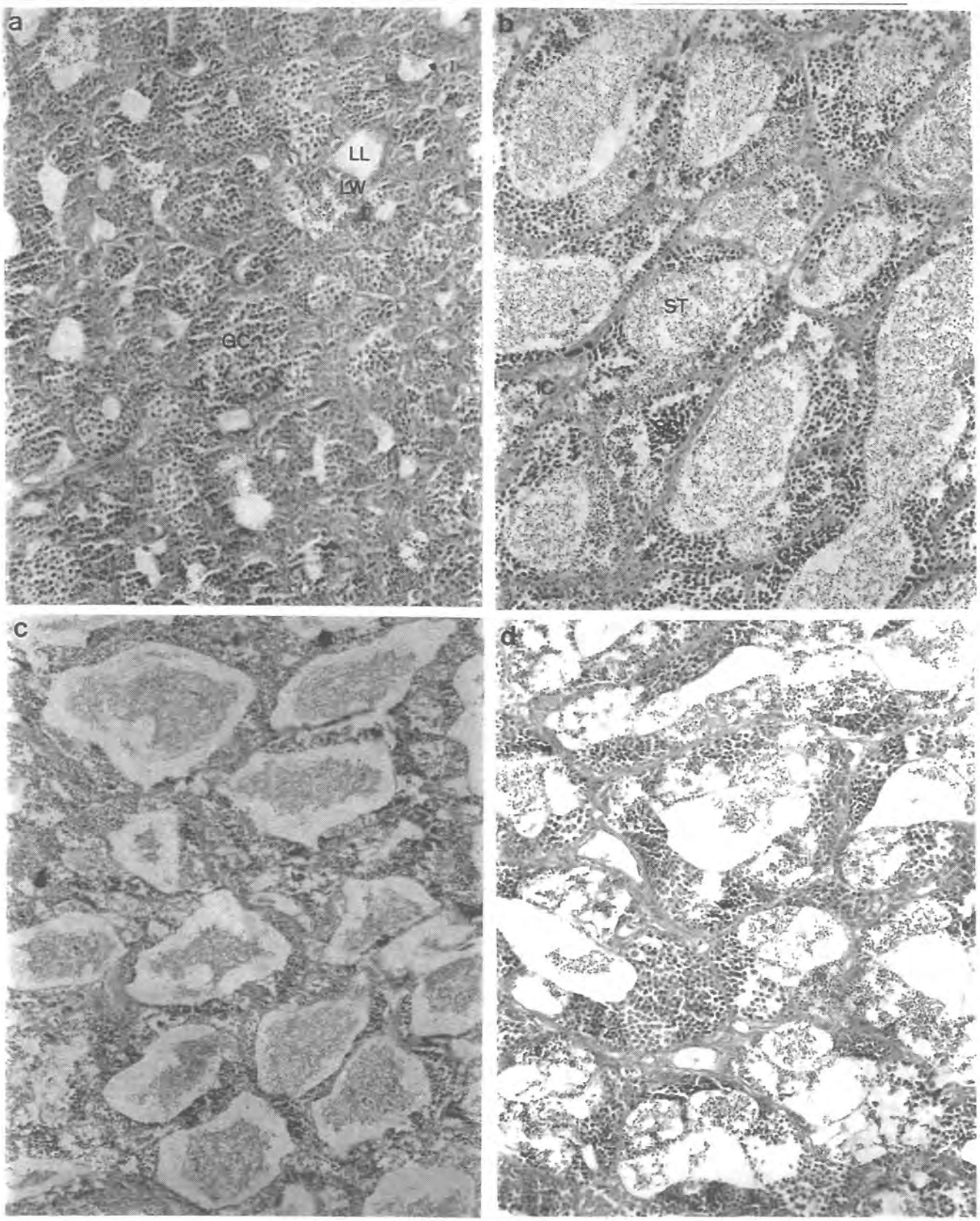

Figure 3.9 Sections of testes of *Chelidonichthys capensis* sampled on the Agulhas Bank from August 1995 to January 1997. a) stage 1: immature testes showing the lobule wall (LW) and lumen (LL), and germ cells (GC). b) stage 2: maturing testes with spermatocytes (SC) and spermatids (ST). The interstitial cells (IC) are also visible. c) stage 3: partially spawned testes with half-full lobules. d) stage 4: spent testes - very little sperm remains in the lobules.

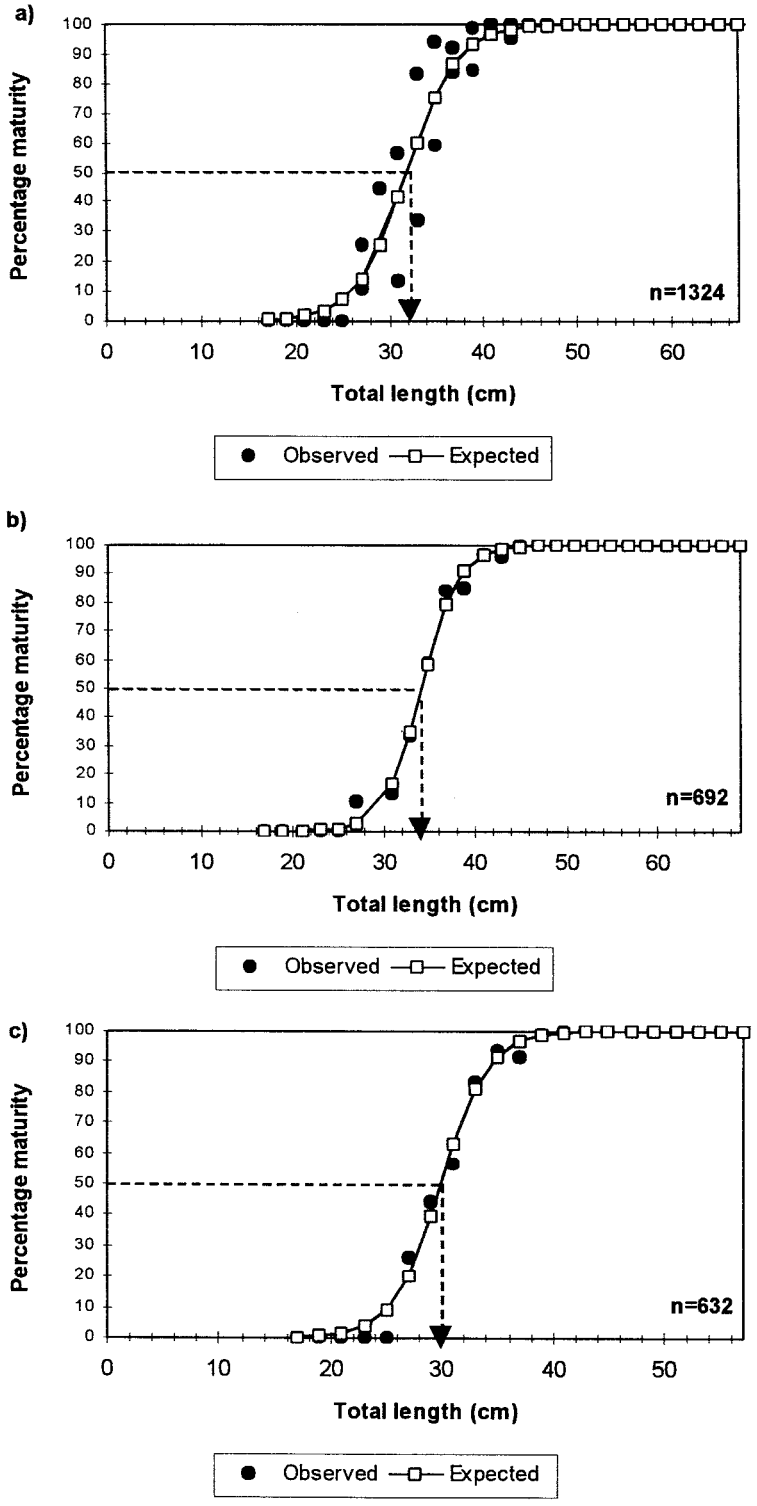

Figure 3.10 Percentage frequency of mature *Chelidonichthys capensis* in different length classes sampled on the Agulhas Bank from August 1995 to January 1997. The curve was fitted using a 2-parameter logistic ogive. a) all samples; b) females; c) males.

Table 3.4 First approximations of total length (L_{50} in mm) and age at 50% maturity (t_m in years) for *Chelidonichthys capensis* sampled on the Agulhas Bank from August 1995 to January 1997 (δ indicates the rate of maturation).

Group	L_{50}	t_m	δ	n
All	319	3.9	2.74	1324
Females	343	3.7	2.04	692
Males	299	3.6	2.12	632

3.4 Discussion

Results from various reproductive studies on triglid species around the world are presented in Table 3.5. The Cape gurnard is one of the larger gurnard species found with the largest male recorded at 582mm TL and the largest female at 676mm TL. These lengths were not inconsistent with previously recorded (515mm TL and 613mm TL for males and females respectively (Hecht 1976)) and theoretical (750mm (Bianchi *et* al 1993), 700mm (Smith & Heemstra 1986)) maxima. The average length of females in commercial landings (417mm TL) was larger than that in research catches (391mm TL), possibly due to smaller females being caught in research nets that are lined with fine mesh netting in order to sample entire size ranges. In addition, commercial vessels would tend to dump the smaller fish, increasing the bias further. No significant difference was found in mean lengths between males from commercial landings and research catches. However the low sample size from the commercial landings may account for this. It was not possible to increase sample sizes by using historical data gathered on research cruises due to a lack of sexual differentiation in these data. The length frequency samples from research surveys can later be used by management authorities to obtain estimates of the length distribution of the population, a potentially valuable piece of data that can be fed into various length-structured models, or converted into age distribution.

Sexual dimorphism is common amongst larger triglids, being previously reported for the Cape gurnard by Hecht (1976b), and Trunov & Malevanyy (1974), as well as for *C. kumu* (Elder 1976), *Trigla lucerna, Eutrigla gurnardus* and *Aspitrigla cuculus* (Baron 1985). In all instances females were larger than males. Booth (In Press), however, reports no significant size difference for lesser gurnard, *Chelidonichthys queketti*, a small triglid species with an L_∞ of 306mm TL.

Table 3.5 Results from reproductive studies on gurnard species around the world (- indicates that no data were available; superscripts c and r stand for commercial and research respectively).

Species	Length\weight equation	Length range, mm	Sex ratio m : f	Spawning period (peaks)	Size (Age) at maturity, mm	Study area	Author and Year
Aspitrigla cuculus	$6E\text{-}6FL^{3.12}$(f) $7E\text{-}6FL^{3.09}$ (m)	40-180FL	-	Jan, Jul	(2)(f) (1)(m)	Saronikos Gulf, Greece	Papaconstantinou 1983b
	-	40-240FL	1:1.1	Nov-Jun	-	Greek Seas	Papaconstantinou 1983a
	-	-	1:1.14	Dec-May	284(f) 270(m)	Douarnenez Bay	Baron 1985
Chelidoncihthys capensis	$8.6E\text{-}3TL^{3.02}$	251-515 (m) 309-599)f)	1:1.3	Nov-Jan,Mar-Ap	305 (3)(f) 340 (4)(m)	South Africa	Hecht 1977
	$3E\text{-}06TL^{3.179}$(f) $8E\text{-}06TL^{3.102}$ (m)	125-676 (f) 125-582 (m)	$1:0.9^{c}$ $1:1.43^{r}$	Oct-Mar, May	350TL (3.6)(f) 348TL (4.6)(m)	Agulhas Bank, South Arica	This study
	-	280-540TL	-	Year round (Dec-Mar)	350TL	Namibia	Trunov & Malevanyy 1974
Chelidonichthys kumu	$9.98E\text{-}3FL^{2.99}$	80-450FL	1:1	Aug-Dec	247FL (f) 220FL (m)	New Zealand	Elder 1976
Chelidonichthys queketti	$4E\text{-}5TL^{3.09}$	50-354TL	1:1.12	Aug-Oct,Jan-May	195TL (1.7)	Agulhas Bank, South Africa	Booth In Press
Eutrigla gurnardus	-	-	1:1.13	Dec-May	312 (f) 294 (m)	Douarnenez Bay	Baron 1985
	-	80-330FL	1:1.55	Feb-Jul	-	Greek Gulfs	Papaconstantinou 1983a
Lepidotrigla cavillone	-	45-163FL	-	Feb-Sept	-	Greek Gulfs	Papaconstantinou 1983a
Prionotus carolinus	$1.04SL^{2.99}$	-		Jun-Aug	140SL	Southern New England	Marshall 1946
P. evolans strigatus	$8.8E\text{-}3SL^{3.12}$	-	1:1	Jun-Aug	180SL	Southern New England	Marshall 1946
Trigla lucerna	$6E\text{-}6FL^{3.11}$ (f) $5E\text{-}6FL^{3.14}$(m)	100-767FL (f) 100-340FL (m)	1:1	Jan-May, Jul, Oct	(4) (f) (3) (m)	Thermaikos Gulf, Greece	Papaconstantinou 1984
	-	100-440FL	1.1:1	Year round	-	Greek Gulfs	Papaconstantinou 1983a
	-	-	1:1	Apr-Sept	401 (f) 355 (m)	Douarnenenz Bay	Baron 1985
Trigla lyra	-	40-460FL	1:1.73	Sept-Mar	-	Greek Gulfs	Papaconstantinou 1983a
	-	100-470TL	1:1	Dec-Mar, May, Sept, Oct	250TL	Namibia	Trunov & Malevanyy 1974
Triglaporus lastoviza	$1E\text{-}5FL^{3.054}$	30-300FL	1:1	Dec-Aug	(3) (f) (2) (m)	Saronikos Gulf, Greece	Papaconstantinou 1986
	-	50-300FL	1.42:1	Mar-Jul	-	Greek Gulfs	Papaconstantinou 1983a
	-	-	1:1.1	Apr-Sept	296 (f) 286 (m)	Douarnenez Bay	Baron 1985

The sex ratios determined for *C. capensis* from this study indicated a preponderance of females in research catches (1 male: 0.9 females - commercial; 1 male: 1.4 females - research). Hecht (1977a) reported a sex ratio of 1 male: 1.28 females for Cape gurnard sampled from commercial trawlers on the east coast of South Africa. These values suggest selective fishing of larger females in the past which has now resulted in a decline in their numbers. This is supported by the fact that there were significantly more females in research catches than in commercial landings. Similar sex ratios of approximately 1 male:1 female are not uncommon in many fish species (Nikolsky 1978) and have been reported for other gurnard species the world over. For example, Elder (1976) found a ratio of 1:1 for *C. kumu* in the Hauraki Gulf, New Zealand and Booth (In Press) found a sex ratio of 1:1.2 for the lesser gurnard, *C. queketti,* sampled on the Agulhas Bank, South Africa. With the exception of *T. lastoviza* in the Thermaikos Gulf, Papaconstantinou (1983) found a preponderance of males in the sex ratios for the 7 gurnard species he studied in the Greek Seas.

The histology results supported the correct assignation of gonad maturation indices in the field. The 11% misclassification is thought to indicate some bias resulting from the difficulty in distinguishing late stage 2 (developing) from early stage 3 (active). The GMI values indicated an extended reproductive season with peaks of reproductive activity during January/February and August/September, the summer and spring months respectively. Results from an egg and larval distribution study in the Tsitsikamma National Park showed concentrations in the number of *C. capensis* larvae to be highest during February, August and October, months directly following those of peak reproductive activity as indicated by this study (Wood, Rhodes University, pers. comm.). Spawning during these periods would increase the chances of survival of Cape gurnard larvae as upwellings, driven by easterly winds during the summer, bring the colder, nutrient-rich waters to the surface providing favourable environmental conditions (Hutchings 1994). Unpredictable environmental conditions in southern Africa's oceans are thought to force many fish species to spawn over wide areas and for extended periods of time (Crawford & Payne 1989). Bet-hedging is thought to allow an increase in the chances of the offspring surviving to maturity in unpredictable environments.

An extended spawning period is also not unusual amongst the gurnard species (Table 3.5). Papaconstantinou (1983) reports reproductive activity from September to March for *Trigla lyra, Trigloporus lastoviza* and *Lepidotrigla cavillone,* from November to June for *Aspitrigla cuculus,* from February to July for *Eutrigla gurnardus*, and year round spawning for the Yellow gurnard, *Trigla lucerna,* in the Greek Seas. Hecht's study (1977a) on *C. capensis* also indicated an extended spawning period from August to March.

The lower gonadosomatic indices for male *C. capensis* compared to females throughout the reproductive period confirmed that males invest less energy than females do in gamete production which is usual for many fish species (Baylis 1981).

Triglid males generally mature at a smaller size than females and in many cases at a younger age as well, e.g. *Aspitrigla cuculus* (Baron 1985), *Eutrigla gurnardus* (Baron 1985) and *Trigla lucerna* (Papaconstantinou 1984) (Table 3.5). The Cape gurnard is no exception with males found to mature at 299 mm TL and females at 343 mm TL. These lengths corresponded to ages of 3.6 years and 3.7 years respectively (see Chapter 5). Hecht (1977) reported 50% maturity at 305 mm TL (3yrs) for females and 340 mm TL (4yrs) for males. Although ages at maturity are similar, the length at maturity for females (343mm TL) was considerably higher for this study compared to Hecht's (305mm TL), whereas that for males (299 mm TL) was considerably lower (340 mm TL). Such changes may indicate that targeting is selective, or they may be the result of greater fishing pressure that has reduced biomass and thus released density-dependant pressures such as food and space for growth, and relieved intraspecicfic competition. More food means more surplus energy to put into faster growth and into reproduction. Yunokawa (1961) reported 50% maturity at approximately 200mm and 100% maturity at 250mm, which corresponds with 2 years of age for *Chelidonichthys kumu* from the Yellow and East China Seas, however did not indicate a difference for males and females. These age values are slightly lower than for other triglids which tend to mature in their third or fourth year (Table 3.5).

The value of δ for females (1.49 $year^{-1}$) and males (1.48 $year^{-1}$) indicated that maturation rates in terms of length are similar for the sexes.

In conclusion, the results of this reproductive study show that *Chelidonichthys capensis* is an r-selected, generalist species with an extended reproductive season and correspondingly high reproductive rate, small size at first breeding and a sex ratio of almost unity. A comparison with the study of Hecht (1977), 20 years ago showed spawning seasonality to be the same whilst the most obvious difference was that of the difference in size at maturity for females.

Chapter 4 - Feeding Biology

4.1 Introduction

Feeding and the search for food are important factors that influence the distribution, migration and growth of fishes (Caragitsou & Papaconstantinou 1990). Scientists study the feeding behaviour and diet of fishes for a variety of reasons. For example, the development of fishing gear and baits, gaining an understanding of how food may be limiting in a population, and affect inter- and intra-specific competition, for aquaculture purposes, where a sound knowledge of the nutritional requirements of a potential culture species is of utmost importance, and to gain an understanding of certain of the dynamics of a population, such as an ecological role, or production and abundance (Windell & Bowen 1978; Royce 1984). Trophic dynamics and food webs as well as understanding broad ecological processes are vital in the holistic approach required for multispecies modelling. The main objectives of gut content analysis are determining what constitutes the diet of a fish, what quantities the fish consumes, and how the feeding behaviour is affected by environmental factors, such as temperature, season, habitat, and prey size (Windell 1968). These data can be used to determine community structure, trophic levels, resource partitioning, and theoretically for predicting the impact of a change in the abundance of a particular species on the other members in the food chain.

Nikolsky (1963) categorised fish on the basis of what they ate and the number of different food types consumed, and arrived at the following useful, although subjective, divisions:

1) i) herbivorous and detritophagic - feeding on plant matter and decaying matter respectively
   ii) carnivorous - feeding on invertebrates
   iii) predators - feeding on fish
2) i) euryphagic - feeding on a variety of foods
   ii) stenophagic - feeding on a few different foods
   iii) monophagic - feeding on a single food type

Based on this classification, and on results of feeding studies world-wide, triglid species can be described as euryphagic, predatory and carnivorous. A wide variety of dietary items have been reported for a number of gurnard species around the world, for example *Prionotus carolinus* (Marshall 1946), *Eutrigla gurnardus* (Moreno-Amich 1994), and *Lepidotrigla cavillone* (Caragitsou & Papaconstantinou 1990) (see Table 3.1 for further examples). Dominant prey items in most cases were either decapod crustaceans or teleosts, with mysids dominant for some species such as *Prionotus evolans strigatus* in southern New England waters (Marshall 1946). A summary of various dietary studies performed on triglids around the world, including examples of dominant prey items, is provided in Table 3.1.

This study investigated the feeding biology of *C. capensis* on the Agulhas Bank in South Africa to determine species composition and seasonal changes in dietary composition.

Table 4.1 Summary of feeding studies on triglid species around the world (dominance based on percentage frequency of occurrence).

Species	Dominant group	Dominant species	Area	Author and Year
Chelidonichthys capensis	Stomatopods	*Pterygosquilla armata capensis*	West Coast, South Africa	Meyer & Smale 1991
	Teleost	*Paracallionymus costatus*		
	Teleost	*Cynoglossus zanzibarensis*	South Coast, South Africa	Meyer & Smale 1991
	Decapods	*Mursia cristimanus*		
		Goneplax angulata		
	Teleosts	*Caelorinchus simorhynchus*	Namibian shelf waters	Trunov & Malevanyy 1974
	Decapods	Portunidae		
	Teleosts	(not given)	Benguela System, Namibia	Bianchi et al 1993
	Teleosts	*Merluccius capensis*	Namibia	Macpherson & Mas Riera 1987
		Cynoglossus capensis		
	Decapods	*Mursia cristimanus*		
		Goneplax rhomboides		
	Teleosts	*Merluccius capensis*	Benguela System, West Coast, South Africa	Konchina 1989
		Sufflogobius bibarbatus		
		Cynoglossus capensis		
	Decapods	*Pasiphea semispinosa*		
	Decapods	*Mursia cristimanus*	East Coast, South Africa	Hecht 1976b
	Crustaceans	*Macropthalmus boscii*		
Chelidonichthys queketti	Mysids	Redeye mysid	West Coast, South Africa	Meyer & Smale 1991
		Lophogaster challengeri		
	Decapods	*Mursia cristimanus*	South Coast, South Africa	Meyer & Smale 1991
	Mysids	Red-eye mysid		
Eutrigla gurnardus	Mysids	*Lophogaster*	Catalan coast, Mediterranean	Moreno-Amich 1994
	Teleosts	*Callionymus maculatus*		
	Decapods	*Goneplax rhomboides*		
Lepidotrigla cavillone	Mysids	*Lophigaster typicus*	Greek Seas	Caragitsou & Papaconstantinou 1990
		Paramysis helleri		
	Decapods	(various)		
Prionotus carolinus	Decapods	(various)	Woods Hole, Massachusetts	Marshall 1946
	Copedpods	(unidentified)		
Prionotus evolans strigatus	Amphipods	*Gammarus locusta*	Menemsha Bight, New England	Marshall 1946
	Mysids	*Mysis americanus*		
Trigla lyra	Decpods	Portunidae	Namibian shelf waters	Trunov & Malevanyy 1974
	Stomatopods	Stomatopoda		

4.2 Methods

Stomachs were dissected from monthly samples covering as wide a size range as possible. A fullness index (FI) between 0 and 10 (with 0 being empty and 10 being 100% full) was assigned to each stomach examined, and used to deduce seasonal variation in feeding intensity. All samples were collected during day-time trawls thus diurnal feeding patterns could not be established. Significant differences in monthly fullness indices were tested for using one way analysis of variance and Tukeys' multiple range analysis at the 95% confidence interval. Stomach contents were removed and identified to the lowest possible taxonomic group (Barnard 1940; Day 1969; Kensley 1972; Branch *et al.* 1994). Each group was weighed, the number of individuals counted, and a visual estimate made of their volume. Items that could not be identified immediately were labelled and stored in 10% formalin for later examination. Storage of stomachs in a preservative was essential to prevent further action of digestive enzymes that could render the item unrecognisable (Laevastu 1965).

A number of gut content analysis methods are available, none of which can be used alone due to bias created by number, mass or weight (Hynes 1950; Hyslop 1980). For this reason, four methods of gut content analysis were used to determine the diet and to illustrate any seasonal changes in dietary composition. Frequency of occurrence, number, weight and volume of food items were taken into account, thus eliminating the possibility of over-estimating the importance of small food items, or under-estimating the importance of large food items in the diet (Hynes 1950; Hyslop 1980). In addition, an index of relative importance (IRI) was calculated for each food group that combined the percentages of frequency of occurrence (%F), number (%N) and volume (%V) in the following equation (Hobson 1974):

$$IRI = (\%N + \%V) \times \%F$$

The four methods of gut content analysis used in this study are described in detail below.

i) frequency of occurrence: the number of stomachs containing each taxonomic group were noted and calculated as a percentage (%F) of the total number of stomachs examined.

ii) contribution by number: the number of individuals in each species group was counted and calculated as a percentage (%N) of the total of all the items in all species groups in all the stomachs examined.

iii) contribution by volume: the volume of each food category was visually estimated and multiplied by the fullness index for that stomach thus taking into account the contribution made by each category to the fullness of the stomach. The values obtained for each food category was then summed and expressed as a percentage (%V) of the total of the values for each food category.

iv) wet weight: each taxonomic group was individually weighed for each stomach. The values were then expressed as percentages (%W) of the initial total weight of the stomach contents.

The results of all four methods were expressed for all stomachs examined to show dominant prey items, as well as on a monthly basis to illustrate any seasonal differences in diet.

4.3 Results

Of the 1416 stomachs examined 82 (5.8%) were everted. These stomachs were excluded from further analysis. Figure 4.1 illustrates seasonal variation in stomach fullness for the Cape gurnard. A general trend appeared in that peaks in the number of stomachs that were more than half full corresponded to troughs in the number of empty stomachs. Stomachs were most full during August and October 1995, and July, September and December 1996. In September 1996, over 60% of the stomachs examined were more than half full. The percentage of empty stomachs was highest in September and November 1995, and March, July and October 1996. In May 1996 and January 1997 none of the stomachs examined were empty.

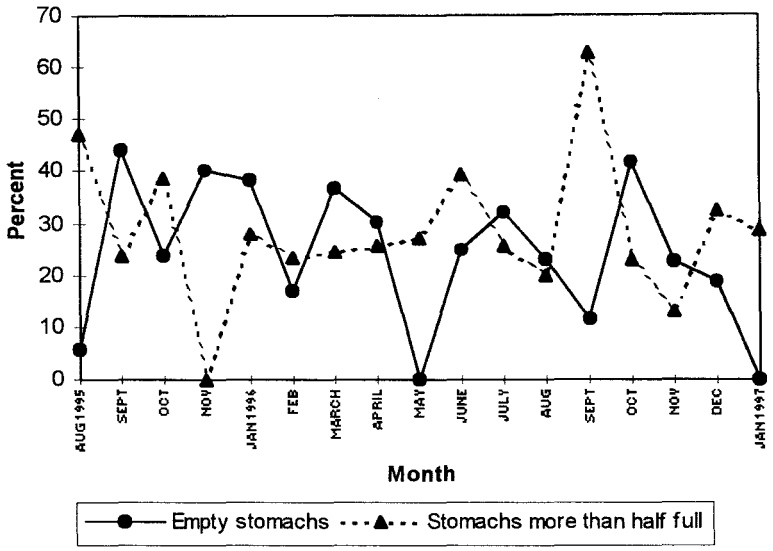

Figure 4.1 Seasonal variation in stomach fullness for *Chelidonichthys capensis* sampled during commercial and research cruises on the Agulhas Bank from August 1995 to January 1997.

Tukey's multiple range analysis, at the 95% confidence interval, showed there to be significant differences in mean monthly fullness indices (FI) ($F_{(16,\ 1317)}=4.471$, $p<0.05$). August 1995 FI values were significantly higher than those of September and November 1995, and January and October 1996, the value for whilst those of September 1996 were significantly higher than all other months except August and September 1995, March and December 1996, and January 1997. Values for November 1995 were significantly lower than those for August and October 1995, and June and September 1996. However it is noted that the sample size for November 1995 was low ($n=17$) in comparison to other months, introducing a greater of uncertainty when interpreting the results.

Table 4.2 Results of a multiple comparison of mean monthly fullness indices using Tukey's multiple range analysis at the 95% confidence interval for *Chelidoncihthys capensis* sampled on the Agulhas Bank from August 1995 to January 1997 (months with bars (|) in common columns do not differ significantly from each other; * indicates the month that is significantly different from other unbarred months in that column).

Month		Fullness Index								n
August	1995	4.56	|			*	|	|	|	97
September		2.24	|	|			|	|	|	34
October		3.68		|	|		|	|		429
November		0.60		|			|	|		17
January	1996	2.98	|	|			|	|		|	145
February		2.55	|	|	|		|		|	|	29
March		2.50	|	|	|		|	|			40
April		3.06	|	*	|		|	|	|	|	175
May		3.60	|	|	|		|	|	|	|	30
June		3.73	|	|	|		|	|			98
July		3.08	|	|	|		|	|			59
August		3.09	|	|	|			|	|	|	34
September		5.81	|		|					*	34
October		2.30	|	|			|	|			45
November		2.47	|	|	|		|	|			26
December		3.76	|	|	|		|	|	|	|	33
January	1997	3.67	|	|	|		|	|	|	|	9

A total of 34 different species were positively identified in the diet of *C. capensis*. More species were identified from the diet estimated from research samples (28) compared to the diet estimated from commercial samples (19). However species composition did not differ significantly ($F_{(4,\ 1317)} = 0.872$ $p < 0.05$) between the two diets. The most dominant prey items were the two brachyuran species *Goneplax angulata* and *Mursia cristimanus,* with relative importance indices (IRI) of 1026 and 439 respectively (Table 4.3). *G. angulata* (IRI=2185) was more important than *M.cristimanus* (IRI=661) in the diet estimated from commercial samples whilst the opposite was true for research samples where *M. cristimanus* (IRI=222) dominated over *G. angulata* (IRI=183). A third brachyuran species, *Hymenosoma obiculare,* played a significant part in the diet of fish from research samples but did not feature prominently in commercial fish samples' diets. The second most important dietary group for *C. capensis* was the teleosts, with twice as many species found in the diet of research fish compared to commercial fish, the ladder dragonet, *Paracallionymus costatus* and the redspotted tonguefish, *Cynoglossus zanzibarensis,* being preferred prey items in both groups. A similar trend as seen for the brachyuran species was seen with these two teleost species. *Cynoglossus zanzibarensis* (IRI=110) was more important than *Paracallionymus costatus* (IRI=61) in the diets of fish from research samples

whilst the opposite was true in commercial samples (*Cynoglossus zanzibarensis* = 100; *Paracallionymus costatus*=241). Unidentified caridea, penaeida and teleosts also played relatively important roles in the diet of the two groups.

Table 4.3 Stomach content analysis of *Chelidonichthys capensis* sampled during research and commercial cruises on the Agulhas Bank between August 1995 and January 1997 (%F = percentage frequency of occurrence, % N = percentage number, % W = percentage wet weight, % V = percentage volume).

Species	% FOO	% N	% W	% V	Total IRI	Research IRI	Commercial IRI
POLYCHAETA							
Polychaete worm	0.22	0.12	0.04	0.07	0.04	0.09	0.02
CRUSTACEA							
Unidentified crustaceans	4.39	2.93	3.44	4.85	34.12	116.83	3.48
Macrura							
Unidentified macrurans	3.02	10.46	0.09	0.29	32.44	127.84	0.75
Pandalinda brevirostris	0.58	0.65	1.01	0.78	0.82	4.21	-
Unidentified caridea	1.70	1.35	0.44	0.37	3.09	5.29	1.74
Unidentified penaeidae	3.09	4.60	0.70	0.52	15.80	9.81	17.73
Stomatopoda							
Pterygosquilla armata capensis	4.74	2.76	6.25	4.83	36.01	2.13	91.75
Anomura							
Upogebia capensis ?	0.07	0.02	0.04	0.03	0.00	0.02	-
Paguristes gamianus	0.07	0.02	0.00	0.00	0.00	0.01	-
Mysidacae							
Gastrosaccus sp.?	0.29	0.14	0.00	0.00	0.04	0.21	-
Purple-eyed mysid?	0.29	0.14	0.03	0.12	0.08	-	0.25
Mesopodopsis sp.	1.01	1.88	0.05	0.07	1.95	7.51	0.09
Amphipoda							
Hyperiidae							
Parathemisto sp.	0.65	5.00	0.00	0.00	3.24	-	10.67
Hyperia sp.	0.07	0.19	0.01	0.10	0.02	-	0.07
Ampeliscidae							
Ampelisca sp.	0.07	0.05	0.00	0.00	0.00	0.02	-
Brachyura							
Goneplax angulata	18.55	25.91	28.74	29.39	**1025.82**	183.47	**2185.29**
Mursia cristimanus	16.10	9.64	16.34	17.60	**438.63**	**221.89**	661.10
Ovalipes punctatus	1.22	0.79	0.54	1.08	2.29	2.23	2.16
Hymenosoma obiculare	3.95	5.96	0.45	1.34	28.86	115.50	1.05
Nautilocorystes ocellata	0.43	0.10	0.32	0.48	0.25	0.14	0.08
Megalopa larvae	0.14	0.05	0.00	0.00	0.01	0.03	-
Isopoda							
Idoteidae							
Synidotea hirtipes	0.43	0.26	0.02	0.02	0.12	0.62	-
TELEOSTS							
Unidentified teleosts	10.64	6.56	7.59	8.87	164.25	287.98	89.32
Serranidae?	0.07	0.02	0.00	0.00	0.00	0.01	-
Gobiidae	1.00	0.56	0.16	0.88	1.45	3.71	0.20
Caffrogobius agulhensis	0.07	0.07	0.11	0.17	0.02	0.09	-
Tetrarogidae/Aploactinidae?	0.07	0.07	0.10	0.12	0.01	0.07	-
Unidentifed pleuronectiformes	2.95	1.37	3.11	2.24	10.63	20.26	5.16
Cynoglossus zanzibarensis	7.91	4.01	16.21	9.33	105.50	**110.01**	**100.17**
Engraulis japonicus	0.07	0.02	0.04	0.23	0.02	0.10	-
Trachurus trachurus	0.36	0.17	0.78	0.48	0.23	0.67	0.03
Gonorhyncus gonorhyncus	0.07	0.02	0.04	0.02	0.00	-	0.01
Bregmaceros atlanticus	0.07	0.04	0.01	0.01	0.01	0.02	-
Callionymidae	0.22	0.07	0.07	0.07	0.03	0.03	-

Table 4.3 contd

Paracallionymus costatus	8.12	9.98	7.64	8.06	**146.52**	**60.74**	-
Chelidonichthys capensis	0.14	0.05	0.25	0.25	0.04	0.22	-
Chelidonichthys queketti	0.22	0.07	0.59	0.59	0.14	0.75	-
Merluccius capensis	0.22	0.10	0.73	2.35	0.53	1.75	0.03
Champsidon capensis	0.07	0.02	0.04	0.02	0.00	0.01	-
Syngnathus acus	0.43	0.17	0.45	0.31	0.21	0.26	0.17
Hemiramphidae?	0.07	0.02	0.01	0.01	0.00	-	0.01
MOLLUSCA							
Unidentified molluscs	0.29	0.07	0.10	0.13	0.06	0.19	0.01
Bivalvia							
Pelecypoda	0.36	0.12	0.08	0.04	0.06	0.04	0.07
Cephalopoda							
Sepia australis	2.16	1.68	2.08	2.01	7.96	8.04	7.73
Sepia sp.	0.86	0.79	0.29	0.47	1.09	3.00	0.23
Octopus vulgaris	0.07	0.07	0.10	0.06	0.01	0.05	-
Loligo vulgaris reynaudii	0.07	0.02	0.01	0.01	0.00	0.01	-
Gastropoda							
Natica sp.	0.07	0.02	0.00	0.00	0.00	-	0.01
Nassarius vinctus	0.22	0.07	0.04	0.03	0.02	-	0.07
shells	0.43	0.17	0.15	0.22	0.17	0.45	0.04
BRYOZOA							
Bryozoan colony	0.14	0.05	0.02	0.01	0.01	-	0.03
Unidentified matter	2.16	0.34	0.68	1.12	3.15	1.52	6.26
Stone	0.29	0.12	0.08	0.07	0.05	-	0.18

Figure 4.2 illustrates some of the dominant species observed in the diet of *C. capensis* as well as some of the more unusual items found.

Figure 4.2 Dominant and unusual prey items observed in the diet of *Chelidonichthys capensis* sampled from the East Coast of South Africa between August 1995 and January 1997 (top row from left: *Goneplax angulata, Mursia cristimanus*; middle row from left: *Paracallionymus costatus, Cynoglossus zanzibarensis;* bottom row from left: *Pterygosquilla armata capensis, Syngnathus acus*).

Monthly comparisons of dominant prey items for *C. capensis* are provided in Table 4.4. Either one or both of the two dominant brachyuran species appeared in each month, in most cases also being the dominant species. The preferred prey items for January 1996, the single west coast sample, were the mantis shrimp, *Pterygiosquilla armata capensis,* the amphipod, *Parathemisto* sp. and unidentified teleosts. October and November 1995, and March and May 1996, were also months not dominated by brachyurans, but by teleosts. Macrurans played a particularly important role in September 1995 and August 1996. The ladder dragonet, *Paracallionymus costatus,* was absent from the diet in the latter months of the year (August to January) but present from February to July. In March and May 1996 this species was dominant. Another teleost species, *Cynoglossus zanzibarensis,* as well as unidentified teleosts were present almost throughout the sampling period.

Table 4.4 Results of monthly comparison of dominant items (IRI>50) in the diet of *Chelidonichthys capensis* sampled during research and commercial cruises on the Agulhas Bank from August 1995 to January 1997 (figures are Indices of Relative Importance; * denotes research samples; ** denotes west coast sample).

Species	Aug 1995	Sep	*Oct	Nov	**Jan 1996	Feb	Mar	*Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan 1997
Goneplax angulata	7905	1658	113	-	-	3864	1904	207		3267	615	16773	13782	942	2200	79	-
Mursia cristimanus	140	-	54	470	-	951	-	842	1878	1006	1192	29120	200	4925	494	1699	5775
Ovalipes punctatus	-	139	-	-	-	-	-	-	-	-	-	709	-	-	-	-	-
Hymenosoma obiculare	-	-	131	-	-	-	-	123	-	-	-	-	-	-	-	-	-
Unidentified crustaceans	-	260	279	-	-	51	-	-	-	-	-	-	-	-	-	-	-
Macrurans UNID	-	744	-	-	-	-	-	101	-	-	-	328	-	-	-	-	-
Unidentified caridea	-	73	-	-	-	-	-	-	-	-	-	109	-	-	-	-	-
Unidentified penaeidae	334	566	-	-	-	-	-	-	-	-	-	215	-	-	-	-	459
Pterygiosquilla armata capensis	-	-	-	-	2562	-	-	-	479	-	-	-	-	-	-	80	-
Parathemisto sp.	-	-	-	-	360	-	-	-	-	-	-	-	-	-	-	-	-
Paracallionymus costatus	-	-	80	-	-	566	2838	-	5527	1460	85	-	-	-	-	-	-
Sygnathus acus	-	-	-	-	-	-	-	-	-	-	-	536	-	-	-	-	-
Unidentified teleosts	-	139	496	1424	57	112	-	76	-	-	144	15447	50	323	1139	241	3515
Cynoglossus zanzibarensis	193	208	75	-	-	279	182	255	261	-	589	638	-	-	-	3259	-
Unidentifed pleuronectiformes	71	-	57	-	-	-	-	-	-	-	-	88	-	-	-	-	-
Unidentified molluscs	-	-	-	49	-	-	-	-	-	-	-	-	-	-	-	-	-
Sepia australis	-	-	-	193	-	-	-	-	-	-	198	-	-	-	-	-	-
Sepia sp.	-	-	-	125	-	-	-	-	-	-	-	250	-	-	-	-	-
Unidentified matter	-	-	-	-	-	-	104	-	-	-	-	-	-	-	-	-	-

4.4 Discussion

Fishes have evolved organs with which to seek out their prey (Nikolsky 1963) and some authors consider the detachment and enlargement of the last three fin rays on the pectoral fin of gurnards to be such organs (Hecht 1976b; Heemstra 1986). These "feelers" are suggested to be used to feel out prey in soft sediments and results from this study indicate that *C. capensis* do indeed prey upon benthic species. Dominant prey items noted for *C. capensis* on the South African east coast in this study were similar to those observed in other studies (Hecht 1976b; Meyer & Smale1991) and included the two brachyuran species *G. angulata* and *M. cristimanus*, and the teleosts, *Paracallionymus costatus* and *Cynoglossus zanzibarensis*. Very few beaks or otoliths to aid identification were found in the guts of either research samples or commercial samples. Although the diets of fish from research samples appeared more speciose compared to those from commercial samples, it must be noted that research samples were worked up immediately after capture, allowing gut contents little time to digest. By comparison, commercial samples were sometimes a number of weeks old and may have been defrosted on one or more occasions before being worked up, meaning that commercial gut contents were in a more advanced state of digestion that rendered them more difficult to identify. Walmsley (1996) reports a similar scenario for the two bycatch skate species, *Raja wallacei* and *R. pullopunctata*, she investigated on the Agulhas Bank, in that diets of fish from research samples tended to be more speciose compared to commercial ones. In addition, dominant prey items for these two skate species were similar to those of *C. capensis* as determined from the present study.

The diet of *Chelidonichthys capensis* has been previously described by a number of authors (Trunov & Malevanyy 1974; Hecht 1976b; Macpherson & Mas Riera 1987; Meyer & Smale 1991). Larger *C. capensis* samples (301-593mm TL) examined from the South African south coast preyed selectively upon the mysid, *Lophigaster challengeri,* the brachyurans *Mursia cristimanus* and *Goneplax angulata,* as well as the two teleost species *Cynoglossus zanzibarensis* and *Paracallionymus costatus,* whilst juveniles (134-300mmTL) fed on cariids, *Processa austroafricana*, and *Hymenosoma obiculare,* a brachyuran (Meyer & Smale 1991). In the same study, but looking at west coast samples, the diet of juveniles

and adults were similar and consisted mainly of the ladder dragonet, *Paracallionymus costatus,* and mantis shrimp, *Ptergyosquilla armata capensis*, only the relative proportions differing with size, adults consuming almost four times as many mantis shrimps as juveniles. Hecht (1976b) reports crustaceans to have been dominant, particularly the brachyuran species *Mursia cristimanus* and *Macropthalumus boscii*, in the diet of *C. capensis* studied on the east coast of South Africa. Konchina (1989), for the same species but on the South African west coast, noted fish and crustaceans to be dominant. Smaller fish (300mm TL) preyed preferably on the shrimp, *Pasiphaea semispinosa*, and pelagic goby, *Sufflogobius bibarbatus*, whilst the diet of larger individuals (>500mm TL) consisted of fish species such as the shallow-water hake, *Merluccius capensis,* and the redspotted tonguefish, *Cynoglossus capensis*. By contrast, and in an earlier study, Trunov & Malevanyy (1974) found that the banded hollowsnout, *Caelorinchus simorhynchus (=Coelorinchus fasciatus),* and portunid crabs occurred most often in the stomachs of *C. capensis* in Namibian waters. Macpherson & Mas Riera (1987) also studied the diet of *C. capensis* off Namibia and dominant prey items in this case were more similar to those of Konchina (1989). Smaller individuals (300 - 390mm TL) preferred the pelagic goby, *S. bibarbatus,* and the decapod, *Pasiphaea semispinosa,* whilst larger individuals (>400mm TL) preyed upon shallow-water, redspotted tonguefish and the crustaceans *M. cristimanus* and *Pterygiosquilla armata capensis*. A variation in the composition of the diet according to size was also shown for one of the Mediterranean gurnards, *E. gurnardus,* (Moreno-Amich 1994). Larger fish preyed upon decapods and teleosts whilst smaller individuals preferred mysids.

The diets of fishes from the single west coast sample were dominated by the mantis shrimp, *Pterygiosquilla armata capensis*, as well as the amphipod, *Parathemisto sp.* and unidentified teleosts, items similar to those noted in other studies in the same area for the same species (Trunov & Malevanny 1974; Macpherson & Mas Riera 1987; Konchina 1989; Meyer & Smale 1991). Teleost species identified by Macpherson & Mas Riera (1987) in the diet of *C. capensis* also collected in Januray/February from the west coast included small shallow-water hakes, *Merlucius capensis*, the pelagic goby, *Sufflogobius bibarbatus,* and the redspotted tonguefish, *Cynoglossus capensis*. These authors also noted that the proportion of fish in the diet increased as predator size

increased. Konchina 1989) observed similar teleost species as well as the shrimp *Pasiphaea semispinosa*. The study by Meyer & Smale (1991) indicated the mantis shrimp *Pterygiosquilla armata capensis* to be dominant. The only single observed difference in the diets of west and east coast samples was the presence of the mantis shrimp *Pterygiosquilla armata capensis* in the stomachs of the former.

An early study by Davis (1949) indicated that several prey species found in the diet of *C. capensis* are also dominant prey items for several commercially and otherwise important species on the west coast. For example, the kingklip, *Genypterus capensis*, fed mainly on the callionymid, *Paracallionymus costatus*, and included the mantis shrimp, *Pterygiosquilla armata capensis*, in its diet. The large-scaled rattail, *Coelorhyncus fasicatus,* included *Pterygiosquilla armata capensis, M. cristimanus* and *Paracallionymus costatus* in its diet as did the smooth rattail, *Lucigadus ori (=Lionurus nigromaculatus)*, and the jacopever, *Helicolenus dactylopterus*. A more recent study on predation patterns of demersal teleosts on the east and west coasts (Meyer & Smale 1991) noted similar dominant prey items for other bycatch species. The lesser gurnard, *Chelidonichthys queketti*, preferably included the brachyuran *M. cristimanus,* in its diet as did the smooth horsefish, *Congiopodus torvus,* and H. *dactylopterus*. In the diet of six species of skate (*Raja* sp.), also important bycatch species, *Paracallionymus costatus, G. angulata, Cynoglossus zanzibarensis,* and *M. cristimanus* were dominant prey items (Smale & Cowley 1992).

Results from a feeding study by Booth (pers. comm.) on *C. queketti* from the Agulhas Bank indicate a certain amount of overlap with *C. capensis* in terms of prey items. Small brachyurans and teleosts were the dominant dietary items of *C. queketti*. This suggests a certain amount of niche overlap and perhaps competition between these two triglid species, and that a change in abundance of either due to overfishing could significantly affect the other.

Two relatively dominant prey items appear to be very similar in the diets of *C. capensis* from both the west and east coasts: *Goneplax angulata* and *Cynoglossus zanzibarensis* on the east coast, and *G. rhomboides* and *C. capensis* on the west coast. Thus it can be

said that although euryphagic, the Cape gurnard does have preferred prey items. In addition, results from this and other studies indicate that the Cape gurnard has a very similar diet to that of the Mediterranean gurnard, *Eutrigla gurnardus,* that also preyed upon a dragonet species, *Callionymus maculatus,* and a decapod species belonging to the genus *Goneplax, G. rhomboides* (Moreno-Amich 1994).

Diurnal feeding data were not available in this study but Konchina (1989) reported a variation in feeding intensity over a 24 hour period for *C. capensis* studied on the South African west coast, with intensity being greatest in the afternoon (1400-1700) and early morning (0500-0700). The same author noted that, although there were periods of peak feeding intensity, no stomachs were found with a fullness index greater than 60%. The largest mean monthly fullness index from this study was 58% during September 1996, also suggesting that *C. capensis* feed with average intensity throughout the year. Moreno-Amich (1994) observed that grey gurnard, *Eutrigla gurnardus*, in the north-western Mediterranean, fed more intensely at midday compared to the morning, and that feeding intensity was lower in winter.

Although not statistically tested due to low numbers, seasonal variations in diet for *C. capensis* were noted, for example teleosts dominated in the summer and autumn months of the year and brachyurans in the winter and spring months. Seasonal variation in the diets of triglid species has been noted by a number of authors. For example Caragitsou & Papaconstantinou (1990) noted a significant variation in the species of mysid, the dominant prey item throughout the year, preyed upon by the large-scale gurnard, *Lepidotrigla cavillone.* Marshall (1946) observed that the proportion of amphipods in the diet of *Prionotus carolinus* in Montauk, Long Island almost doubled from May to September whilst the number of mysids and cumacids decreased considerably. Dietary seasonal variation has been noted for *C. capensis* on the West Coast of South Africa by Macpherson & Mas Riera (1987).

As prey items, Trunov & Malevanyy (1974) describe the role of gurnards as "not very great". In support of this, Hecht (1976b) reports the only occasional predators of the Cape gurnard to be Jackass penguins, *Sphenscus demersus*, and the ragged tooth shark,

Carcharias taurus. Nepgen (1982) reported finding a single *C. capensis* in each of the guts of a yellowtail, *Seriola lalandi,* and a snoek, *Thyrsites atun*. On the odd occasion observations were made during the period of this study of juvenile lesser and *C. capensis* in the stomach of *C. capensis*.

In conclusion, the Cape gurnard is an opportunistic feeder preying preferentially on the benthic crustaceans *Goneplax angulata* and *Mursia cristimanus*, the dragonet, *Paracallionymus costatus* and the threespotted tonguefish, *Cynoglossus zanzibarensis*.

5. Growth, Age and Mortality

5.1 Introduction

Age and growth studies often provide the fundamental basis for management, as they are the foundation on which many management models are based (Ricker 1975). Information on the age structure of a fish population together with a knowledge of length/weight relationships provide details such as stock composition, life span, age at maturity, age at recruitment, mortality and production, parameters all essential in determining sustainable quotas for a fishery (Ricker 1975).

The difficulties in obtaining accurate age estimates have been described by numerous authors, e.g. Pannella (1973), Le Cren (1974), Simkiss (1974), Weatherly & Rogers (1978), Suzuki & Kimura (1990), and Secor *et al* (1991), and will only be briefly reviewed here. Various hard tissues of fishes, such as scales, fin rays, spines, operculi, vertebrae and otoliths have been found to contain rings showing various growth stages of a fish's life (Laevastu 1965; Weatherly & Rogers 1978; Suzuki & Kimura 1990). Suzuki and Kimura (1990) offer a few guidelines for choosing hard tissues to be used in an ageing study. The age marks present on the tissues should be easily distinguishable, form periodically and simultaneously in a population, and should correlate with the length of the fish. There should be as few false rings as possible, and collection and preparation of the tissue should be simple and quick. Scales are the easiest to collect and prepare for age estimation but are not accurate as they can be repaired, resorbed and replaced. In addition they are not accurate with growth in older fish and may display false check marks as a result of injury, a reduction in condition, or cessation of feeding during spawning (Weatherly & Rogers 1978; Royce 1984). Other hard tissues, such as rays, spines, vertebrae, operculi and otoliths are more difficult to collect, samples must usually be killed before tissue can be removed, and all require some form of preparation. Of these tissues, otoliths can be the easiest to prepare as, once removed and cleaned, they can be stored dry in paper bags and in some cases read whole. Fish can also be aged by analysis of length frequency

data, known as the Petersen method (Laevastu 1965; Tesch 1968), and by tagging studies (Royce 1984). The Petersen method is useful particularly for temperate zones where spawning is distinctly seasonal and is based on the assumption that length frequencies generally have modes representing single cohorts of recruitment events (Hilborn & Walters 1992). Species for which this method is applied must be fast growing and it is generally only reliable for younger age groups where there is little overlap between size classes (Weatherly & Rogers 1978). However caution must be exercised when using this method as it is difficult to obtain representative size frequency sampling over any range of fish lengths and localised sampling problems can lead to false size modes or mask real ones that may be present (Hilborn & Walters 1992). Tagging studies are generally only useful if an extended study period is available during which adequate numbers of tag returns can be made (Beamish & McFarlane 1983).

The use of otoliths for age determination of fishes is based on fluctuations in the growth rate of the fish being reflected in the composition of its otoliths. There are three types of otoliths found in most teleosts, namely the sagitta, lapillus and astericus (Gauldie & Nelson 1990). The largest of these, the sagittae, are more commonly used for age studies due to the size and relative ease of extraction. Otoliths are composed of calcium carbonate crystals that radiate outwards on an organic protein matrix (otolin), in three dimensions, from a nucleus (Williams & Bedford 1974; Gauldie & Nelson 1990). Differential deposition rates of these two components are visible as zones with different optical densities. When viewed with reflected light, the zones reflecting light (calcium carbonate) appear as opaque or white coloured rings whereas the zones absorbing light (otolin) appear as translucent hyaline or dark rings. Under transmitted light the opposite is the case: the opaque zones appear as dark bands whereas the hyaline zones are white (Pannella 1973; Williams & Bedford 1974). The calcium carbonate, which forms the opaque zone, is laid down during the rapid growth periods of the fish's life; the hyaline zones (otolin) are laid down during the slow growth periods, either during winter or when the fish is spawning (McEachran & Davis 1970; Williams & Bedford 1974). There is a large amount of disparity in the nomenclature for growth rings formed by pairs of opaque and hyaline zones. For example, Tesch (1968) refers to annuli, annual rings, year marks or check marks, whilst Campana &

Neilson (1985) prefer the term growth increment, and Buxton & Clarke (1986), discontinuity. In tropical areas, determination of age from hard tissues is particularly challenging as rings may not necessarily be annual (Tesch 1968; Pannella 1973). Thus the use of these check marks as age indicators must first be validated. If it can be shown that growth marks are formed at regular intervals then there will be a valid basis for age determination (Staples 1971; Payne 1977; Beamish & McFarlane 1983). A number of validation methods exist. For example, tag and release studies in conjunction with the use of hard tissue markers such as oxytetracyclene hydrochloride (Weatherly & Rogers 1978; Campana & Neilson 1982). This method is not suitable for short term studies as a large number of fish must be tagged, in order to increase the likelihood of recaptures, and be at large for a number of years before any valuable data can be obtained (Beamish & McFarlane 1983). A second method of age estimate validation is marginal zone analysis where monthly percentages of hyaline and opaque margins are plotted to give a curve. Based on the assumption that one hyaline and one opaque zone constitute an annual ring, one should find a single peak over a year for the number of hyaline margins and one peak per year for the number of opaque margins (Liew 1973; Payne 1977). Other methods include year class analysis, monitoring the growth of captured fish in a tank, and obviously similar results from any two methods of ageing (Weatherly & Rogers 1978).

A single previous growth and age study has been conducted on *C. capensis* in South Africa (Hecht 1976b). Maximum ages and asymptotic lengths recorded were 11 years and 586mm TL, and 12 years and 714mm TL, for males and females respectively. Samples were aged by viewing whole otoliths immersed in xylene, and annuli were validated by marginal zone analysis. It is realised that this study on the *C. capensis* in South Africa was done some time ago and technological advances now allow for more accurate age and growth data to be obtained, which was one of the aims of this study. More recently, Booth (In press) investigated the age and growth of the lesser gurnard, *Chelidonichthys queketti*, a similar sympatric, endemic South African gurnard, and found it to be a long-lived, fast-growing species, reaching ages in excess of 7 years.

Different methods have been used to estimate age for triglid species the world over, a review of which is summarised Table 5.1.

Table 5.1 Summary of various ageing methods for triglid species. Where values for L_∞, t_0 and K are not shown, no estimates for these parameters were given by the respective authors.

Species	Method	Validation method	L_∞	t_0	K	Author and Year
Aspitrigla cuculus	sectioned otoliths	none given	371(m); 417(f)	-	0.52(m); 0.46(f)	Baron (1985)
Aspitrigla cuculus	whole otoliths	none given	204(m); 276(f)	-	0.51(m); 0.22(f)	Papaconstantinou (1983b)
Chelidonichthys capensis	whole otoliths	marginal zone analysis	586(m), 713.5(f)	-0.19(m); -0.41(f)	0.186(m); 0.169(f)	Hecht (1976b)
Chelidonichthys kumu	burnt whole otoliths	marginal growth index	520	-0.291	0.406	Staples (1972)
Chelidonichthys kumu	fin rays, otoliths	marginal growth index	-	-	-	Staples (1971)
Chelidonichthys kumu	sectioned vertebrae	marginal zone analysis	548.3	-	-	Yunokawa (1969)
Chelidonichthys queketti	burnt sectioned otoliths	marginal zone analysis	297(m); 328(f)	-0.24(m); -0.59(f)	0.59(m); 0.38(f)	Booth (In press)
Eutrigla gurnardus	sectioned otoliths	none given	344(m); 380(f)	-	0.77(m); 0.86(f)	Baron (1985)
Eutrigla gurnardus	burnt whole otoliths	Petersen histograms, marginal growth index	264(m)	-	0.22(m)	Papaconstantinou(1982)
Prionotus evolans strigatus	otoliths, scales	length frequency analysis				Marshall 1946
Prionotus carolinus	otoliths, scales	length frequency analysis				Marshall 1946
Prionotus evolans	burnt sectioned otoliths	marginal zone analysis	-	-	-	McEachran & Davis (1970)
Trigla lucerna	sectioned ototliths	none given	484(m); 484(f)	-	0.46(m); 0.33(f)	Baron (1985)
Trigla lucerna	burnt whole otoliths	none given	-	-	-	Papaconstantinou (1984)
Trigla lyra	burnt whole otoliths	Petersen method	740.9	-0.811	0.11	Papaconstantinou (1981)
Trigloporus lastoviza	whole otoliths	marginal zone analysis	356	-1.12	0.133	Papaconstantinou (1986)
Trigloporus lastovista	sectioned ototliths	none given	369(m); 395 (f)	-	0.65(m); 0.58(f)	Baron (1985)

5.2 Methods

5.2.1 Growth and Age

Regular length/weight measures were obtained from commercial landings in addition to data from research cruises. If possible, a minimum of 30 fish per month were collected from Port Elizabeth and from Mossel Bay. The samples were weighed (to the nearest 1g) and measured (TL, to the nearest mm), and these data were used to determine length-weight relationships. The slopes of the natural-log linearised length-weight relationship for males and females were compared using analysis of covariance. Tukeys' multiple range test was employed to test for differences between pairs of slopes.

Yunokawa (1961) reported the preferable use of vertebrae for ageing *Chelidonichthys kumu* due to their regular, easily distinguishable growth marks. By contrast, scales have proved unsuccessful for ageing triglids. Staples (1971) rejected the use of scales as age indicators for *C. kumu* as the scales were small and regular circuli patterns were not evident. Similarly, Hecht (1977) investigated the use of scales for ageing *Chelidonichthys capensis* but found this method to be unsatisfactory. For these reasons, the use of scales was not investigated.

A pilot study was performed on a small number of otoliths to determine which method of preparation would give the clearest results for reading. Two pairs of sagittal otoliths were removed, burnt and mounted in resin; two further pairs were left unburnt. Sagittal otoliths often exhibit asymmetric growth, with stacking occurring on the sulcal side of the otolith. In this case a transverse section would more accurately show all the age marks (Brothers 1987). In order to ascertain whether this was the case for *Chelidonichthys capensis*, one of each pair of otoliths was cut longitudinally and the other transversely. The section giving the clearest results, the transverse, burnt section, was thereafter used for the remaining otolith samples (Figure 5.1)

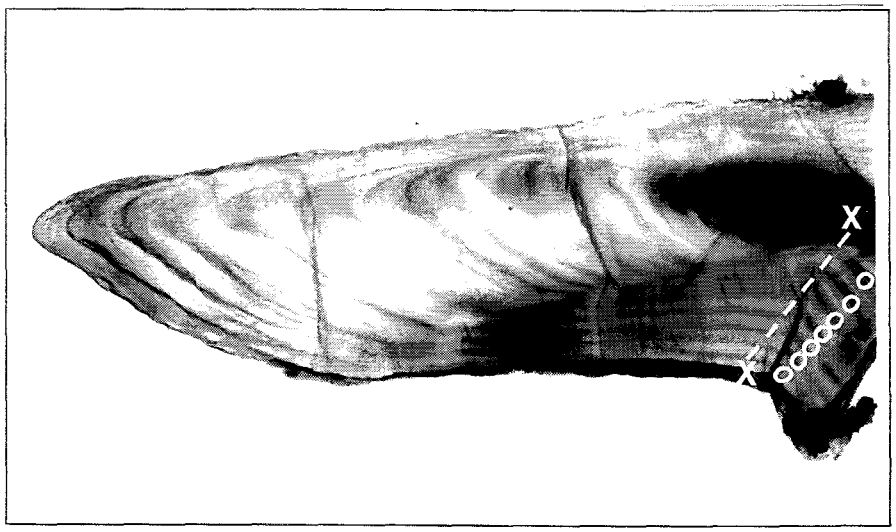

Figure 5.1 Photograph of a transverse, sagittal otolith section of a 7-year old *Chelidonichthys capensis* viewed under transmitted light. The line X---X shows the area where age was interpreted.

Sagittal otoliths were obtained monthly from as wide a size class distribution as possible, and cleaned and stored dry in paper seed envelopes. After collection, the left sagittae were lightly burnt over a methanol flame to enhance growth checks. During burning, the hyaline zones remain white whereas the opaque zones become brown (Papaconstantinou 1981). The extent of burning was critical and care was taken not to char the otoliths, especially the smaller ones that burnt very rapidly. The otoliths were mounted in clear casting resin and sectioned with a double-bladed, diamond edged saw, through the nucleus, to a thickness between 0.2-0.5mm. They were then mounted on microscope slides with DPX mountant and the number of rings counted using transmitted light (Campana & Neilson 1985). By trial and error it was established that low, transmitted light gave the clearest pattern of dark (opaque) rings. Fishes are usually spawned during seasons of fast growth when conditions are most favourable, therefore an opaque zone is laid down first (this is the nucleus), followed by an hyaline zone and is described as a 0 year old fish. A fish with a nucleus and 1 hyaline and 1 opaque zone is in its second growing season and is a 1 year old fish (or 1+) (Tesch 1968). This method of numerical designation for age was used in this study. Lower magnification for the smaller otoliths facilitated check distinction. In many cases, especially in larger otoliths, it was important to follow visible rings around the section to determine how many checks were present as some checks split into two or three rings, or joined up to form a single ring, depending on the exact angle at which the

otolith was sectioned. The pattern of checks was generally clearest along the lateral radius of the otolith and as far as possible this area was used for all readings (Figure 5.2).

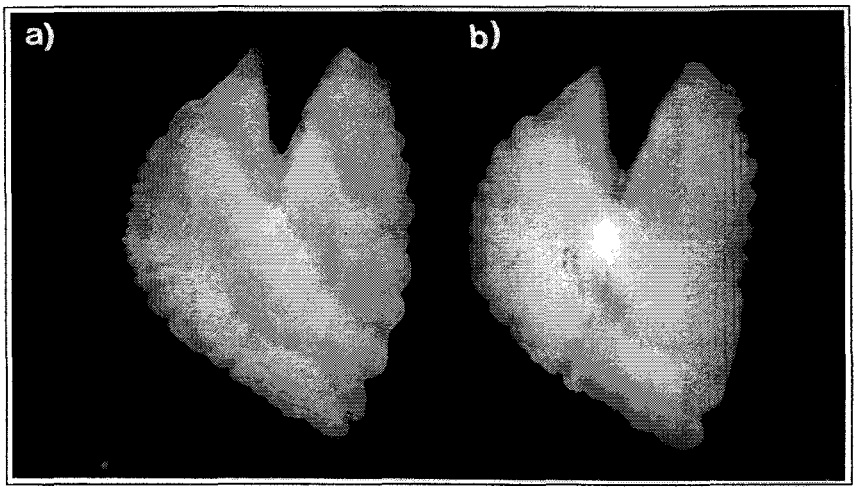

Figure 5.2 Photographs of the lateral (a) and medial (b) views of the sagittal otoliths of *Chelidonichthys capensis* sampled on the Agulhas Bank.

Otoliths were interpreted on three occasions at one week intervals. If two out of the three values agreed, this estimate was taken as the age of the fish. If the values did not agree and did not differ by more than two years, the average was used, otherwise the otolith was rejected.

During otolith interpretation, the appearance of the margins of the otolith sections were noted. The number of opaque and hyaline margins were expressed as monthly percentages in order to validate the timing of growth check formation. Although much historical data are available for the *C. capensis*, these data do not distinguish between male and female length frequencies. For this reason the Petersen method was not deemed suitable for age determination in *C. capensis* as males and females did differ significantly in length (Section 3.3).

Growth curves were fitted, using least squares, to the length-at-age data using the 3 parameter von Bertalanffy growth model,

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

where L_t is the length at time t, L_∞ is the predicted asymptotic length, K, the Brody growth coefficient, is the rate at which the length, L, approaches the asymptotic length, L_∞, t is age,

and t_0 shifts the growth curve along the age axis to allow for apparent nonzero length at age zero (Tomlinson & Abramson 1961; Ricker 1975; Hilborn & Walters 1992). Growth was modelled for males, females and pooled data. The von Bertalanffy growth model was chosen as its parameters are commonly used in population dynamics modelling (Ricker 1975; Pauly 1980), and it is the growth model used by many other authors to describe the growth of triglid species (see Table 5.1). The best fit was obtained by minimising the squared differences between the observed and fitted data using the absolute-error model (Punt & Butterworth 1993). Von Bertalanffy parameter estimates were determined using Newton's non-linear minimisation procedure (Zar 1996). The least squares method of estimation is ideal for data where ages are equally spaced but sample sizes not equal (Tomlinson & Abramson 1961). Differences between growth models fitted to male and female data sets were tested for using a likelihood ratio test (Draper & Smith 1966).

5.2.2 Age at Recruitment and Mortality Estimates

Length frequency data were transformed to age frequency distributions using an age length key (Butterworth *et al.* 1989). The number of fish in each age group in each 2cm size class was counted and the values for each size class summed. The data was then normalised by dividing the number in each size class in each age group by the total number for that size class. The normalised data was then multiplied by the observed length frequency for each size class and summed for each age group to give age frequency. Percentage age frequencies and percentage cumulative totals were calculated, and the age frequencies were natural logged. The natural logged values were used to plot catch curves and age at recruitment was estimated by fitting a logistic ogive, using non-linear minimisation of the residual sum of squares, to the percentage cumulative age frequency data. The logistic is described by the equation:

$$PR_{(L)} = \frac{1}{1+e^{-(L-L50)/\delta}}$$

where $PR_{(L)}$ is partial recruitment and can be defined as the proportion of fish at size L that is vulnerable to the fishing gear. Size classes that are not fished have a PR value of 0 whereas those with high fishing mortalities are considered fully recruited and have a PR value of 1 (Sinclair 1993). L_{50} is the estimated length at 50% recruitment and δ is the width of the ogive. Age-at-recruitment was taken as the age at which 50% of the population was

recruited to the fishery (Punt & Japp 1995). The likelihood ratio test was used to test for differences in the ages-of-recruitment between females and males.

First approximations of total annual mortality (Z) were obtained from the generated catch curves (Butterworth *et al* 1989). The negative of the slope of the linear regression line, fitted to points greater than the age at full recruitment, provided an estimate of Z (King 1995). Analysis of covariance was used to test for differences in the slopes. Natural mortality, M, was calculated from the equation:

$$\log M = -0.0066 - 0.279 \log L_\infty + 0.6543 \log K + 0.4634 \log T \text{ (Pauly 1980)}$$

where T is the mean annual seawater temperature (^{0}C) of the environment in which the species lives, and L_∞ and K are the von Bertalanffy growth parameters. The mean annual seawater temperature was taken as 12^{0}C (Schumann & Beekman 1984). It is noted that Pauly's empirical formula (1980) for estimating natural mortality, M, falls into the category of qualified guesses as inherent in it are the assumptions that small fish have high mortalities, fast growing species have high mortalities and higher ambient water temperatures. In addition processes influencing M, such as reproductive physiology, predation and schooling behaviour, are regarded as "random noise about the regression line" which may lead to biased estimates for species in which these processes do play an important role, for example strongly schooling pelagic fishes such as the Clupeidae (Pauly 1983). Although Pauly's equation has been shown to provide realistic mortality estimates for long-lived species (Buxton 1987), a second method, that of Rikhter & Efanov (1977) was also used to estimate M:

$$M = \frac{1.521}{t_m^{0.72}} - 0.155 yr^{-1}$$

where $t_m^{0.72}$ is the age at which 50% of the population is mature.

Fishing mortality (F) was obtained by substitution (F=Z-M).

5.3 Results

5.3.1 Length Weight Relationship

The results of the length weight relationships are presented in Figure 5.3. The value of b in most cases was approximately 3. There was no significant difference between the slopes of the regression models for weight as a function of length for males and females ($F_{(2,1334df)} = 2.892$; $p > 0.05$).

5.3.2 Otolith Reading

Of the 383 otoliths read, 31 (8%) were rejected as unreadable.

5.3.3 Validation of annuli

Marginal zone analysis illustrated that a single hyaline zone and a single opaque zone is deposited annually (Fig 5.10a). Hyaline zone formation occurred from September to March (Fig 5.10b) and opaque zone deposition from March to August.

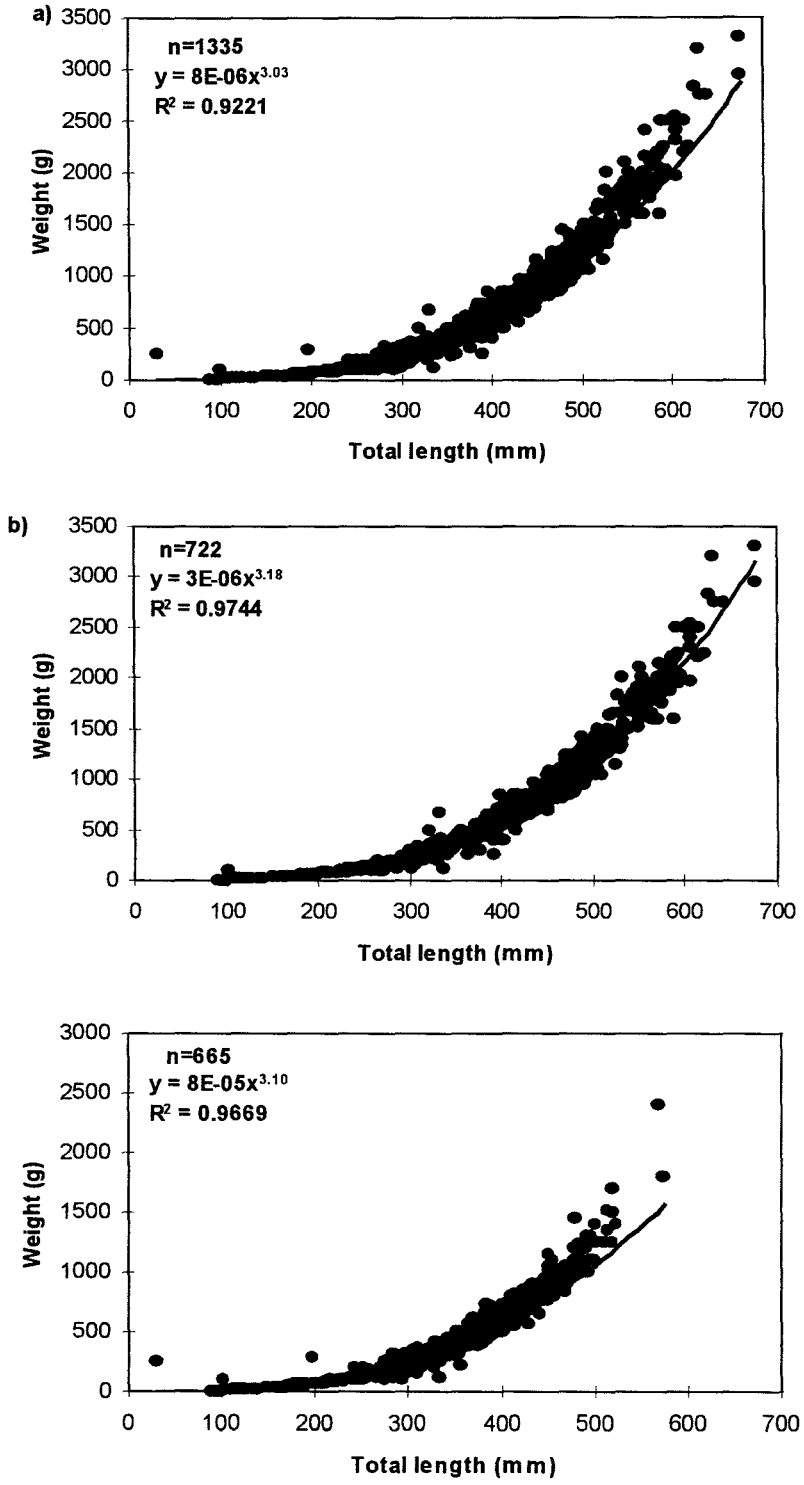

Figure 5.3 Length weight relationship for *Chelidonichthys capensis* sampled on the Agulhas Bank from August 1995 to January 1997. a) all samples; b) females; c) males.

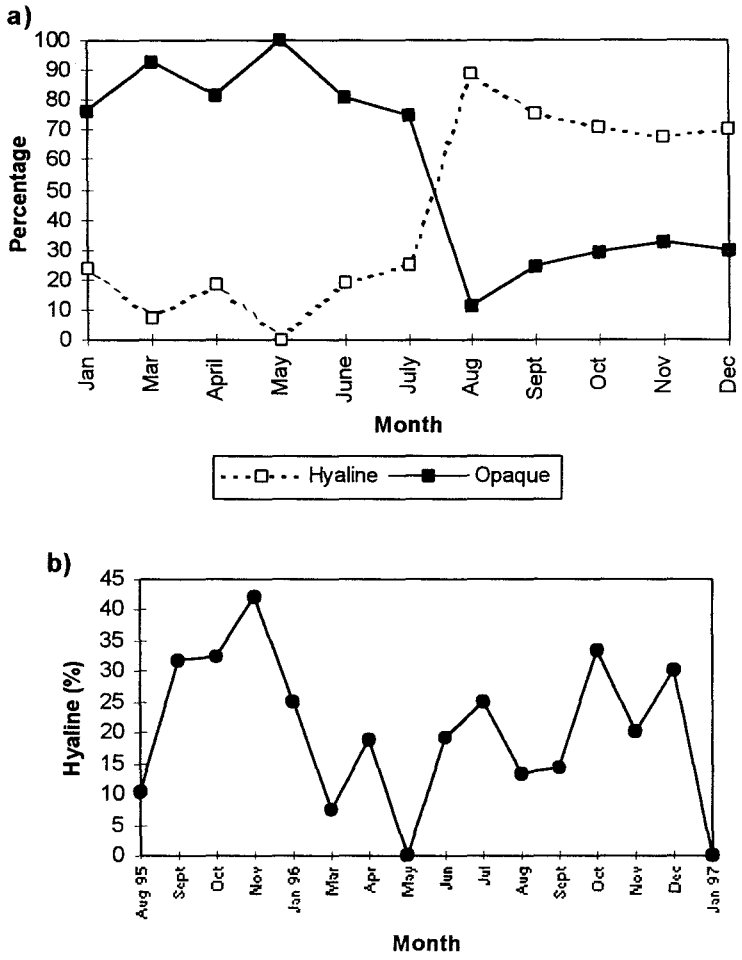

Figure 5.4 Percentage of *Chelidonichthys capensis* otolith samples sampled monthly on the Agulhas Bank from August 1995 to January 1997 a) with monthly cumulative percentage of hyaline and opaque margins illustrating annual nature of growth rings, and b) with hyaline margins to show months during which hyaline zones formed.

5.3.4 Age determination

Values for the parameters in the von Bertalanffy growth equation are presented in Table 5.2 and were calculated from combined data, and for male and female data separately. In order to compare overall growth performance it is necessary to compare the parameters K and L_∞. Since these parameters are statistically dependant, one cannot simply deduce any meaning by looking at either one alone. Due to their interaction, a further index is required to compare overall growth performance. One such parameter is known as phi prime (ϕ') (Pauly & Munro 1984) and is calculated from the following equation:

$$\phi' = 2\ln L_\infty + \ln K$$

The higher the value of ϕ', the larger the maximum size attained and the faster the growth rate.

Table 5.2 Growth parameters of the von Bertalanffy growth equation as determined by non-linear minimisation of the residual sum of squares for *Chelidonichthys capensis*, including the parameter ϕ', sampled on the Agulhas Bank from August 1995 to January 1997.

Group	L_∞	K	t_0	ϕ'	n	Age range
All	894.23	0.079	-2.043	6.45	383	1-16
Females	803.38	0.104	-1.619	6.51	239	1-16
Males	754.94	0.084	-2.537	6.17	144	1-12

Significant differences were found between the growth models for males and females ($F_{(3,\ 376df)}=38.58$; $p<0.05$) using a likelihood ratio test. Growth curves corresponding to the growth equations for each sex are shown in Figure 5.5.

The number of data points in the extreme upper and lower age groups were low (<5) which may have led to the unrealistically large L_∞ obtained. Exclusion of these points however led to larger L_∞ so it was decided to include these points when calculating the von Bertalanffy growth parameters. A normalised age-length key and the mean observed length-at-age, mean calculated length-at-age and standard deviations are presented in Tables 5.4a-c. Observed lengths-at-age compared favourably to those obtained by Hecht (1977) and differed on average by not more than 12 mm for females and 16 mm for males.

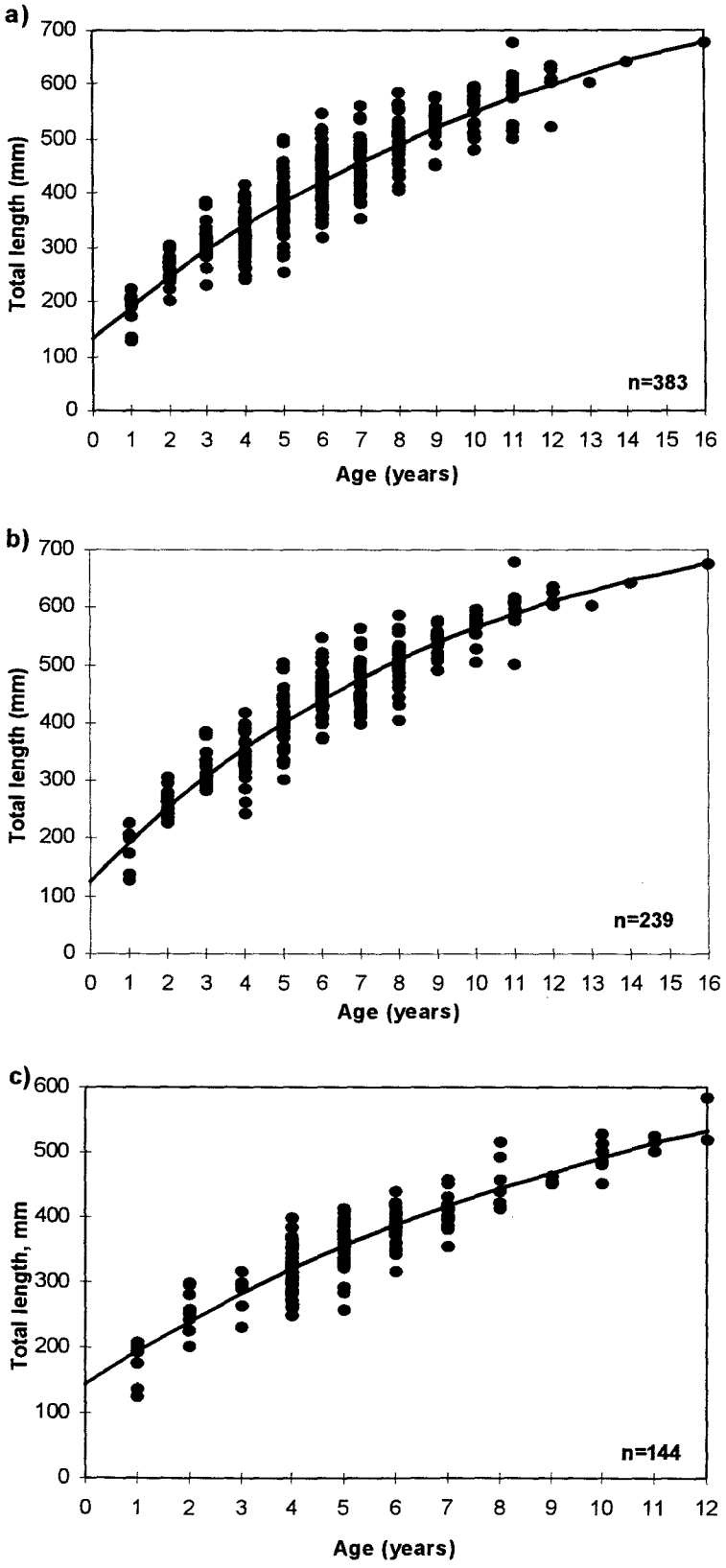

Figure 5.5 Growth curve fitted using the von Bertalanffy growth model for *Chelidonichthys capensis* sampled on the Agulhas Bank from August 1995 to January 1997. a) all samples; b) females; c) males.

Table 5.3a Normalised age length key for *Chelidonichthys capensis* sampled on the Agulhas Bank August 1995 to January 1997.

Age	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Length, mm																
90	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
110	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
130	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
150	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
170	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
190	6	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
210	9	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0
230	0	7	2	3	0	0	0	0	0	0	0	0	0	0	0	0
250	0	12	2	2	2	0	0	0	0	0	0	0	0	0	0	0
270	0	6	6	10	2	0	0	0	0	0	0	0	0	0	0	0
290	0	6	14	7	3	0	0	0	0	0	0	0	0	0	0	0
310	0	0	8	24	8	3	0	0	0	0	0	0	0	0	0	0
330	0	0	3	12	12	3	0	0	0	0	0	0	0	0	0	0
350	0	0	0	15	21	6	2	0	0	0	0	0	0	0	0	0
370	0	0	3	3	21	16	3	0	0	0	0	0	0	0	0	0
390	0	0	0	6	20	18	6	1	0	0	0	0	0	0	0	0
410	0	0	0	3	12	23	20	6	0	0	0	0	0	0	0	0
430	0	0	0	0	20	20	27	10	0	0	0	0	0	0	0	0
450	0	0	0	0	8	29	25	8	13	4	0	0	0	0	0	0
470	0	0	0	0	0	21	26	8	0	5	0	0	0	0	0	0
490	0	0	0	0	4	2	13	19	4	4	4	0	0	0	0	0
510	0	0	0	0	0	5	0	14	5	10	5	2	0	0	0	0
530	0	0	0	0	0	1	4	3	13	0	0	0	0	0	0	0
550	0	0	0	0	0	0	2	7	9	7	0	0	0	0	0	0
570	0	0	0	0	0	0	0	1	4	6	4	0	0	0	0	0
590	0	0	0	0	0	0	0	0	0	5	8	3	2	0	0	0
610	0	0	0	0	0	0	0	0	0	0	6	6	0	0	0	0
630	0	0	0	0	0	0	0	0	0	0	0	3	0	3	0	0
650	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
670	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Age frequency	31	41	38	86	134	147	128	77	48	40	27	14	2	3	0	0
% age frequency	4	5	5	11	16	18	16	9	6	5	3	2	0	0	0	0
Cumulative totals	4	9	13	24	40	59	74	84	90	95	98	100	100	100	100	100
ln age frequency	3	4	4	4	5	5	5	4	4	4	3	3	0	1	-	-

Table 5.3b Length range, mean observed length-at-age, standard deviations, and mean calculated length-at-age for *Chelidonichthys capensis* on the Agulhas Bank from August 1995 to January 1997.

Age	n	Length range, mm	Mean observed length, mm	Standard deviation	Mean calculated length, mm
0	0	-	-	-	133
1	9	125-223	183	33.02	191
2	18	200-304	261	28.75	245
3	22	230-384	306	34.08	294
4	46	240-416	329	41.94	340
5	67	255-501	380	46.29	382
6	62	310-545	423	47.82	421
7	48	353-560	455	45.15	457
8	32	403-583	495	44.34	490
9	24	450-576	529	35.25	521
10	19	451-595	541	43.66	549
11	14	500-676	578	50.68	575
12	6	519-633	595	41.31	599
13	1	-	600	-	622
14	1	-	640	-	643
15	0	-	-	-	662
16	1	-	675	-	679

Table 5.3c Length range, mean observed length-at-age, standard deviations, and mean calculated length-at-age for female and male *Chelidonichthys capensis* sampled on the Agulhas Bank from August 1995 to January 1997.

Females						Males					
Age	n	Length range, mm	Mean observed *length, mm	Standard deviation	Mean calculated length, mm	Age	n	Length range, mm	Mean observed length, mm	Standard deviation	Mean calculated length, mm
0	0	-	-	-	124.90	0	0	-	-	-	145.19
1	6	125-223	176.33	39.81	192.14	1	7	125-206	175	32.89	194.42
2	14	223-304	260.93	22.78	252.72	2	11	200-298	255.91	30.03	239.67
3	15	281-384	316.73	31.76	307.29	3	8	230-316	284	26.53	281.28
4	20	240-416	339.4	45.65	356.46	4	27	246-397	318.85	38.91	319.52
5	35	300-501	401.89	43.96	400.75	5	32	255-412	356.09	36.22	354.68
6	35	370-545	451.51	39.57	440.65	6	27	315-438	384.89	26.75	386.99
7	36	409-560	471.14	37.29	476.60	7	12	353-455	408.5	28.99	416.70
8	26	403-583	504	40.81	508.99	8	6	413-515	456	40.18	444.01
9	21	490-576	539.9	21.73	538.16	9	3	450-461	454.67	5.69	469.11
10	13	503-595	563	29.39	564.45	10	6	451-526	492.33	26.24	492.19
11	11	500-676	595.27	41.4	588.13	11	3	500-524	513	12.12	513.41
12	4	602-633	617.25	14.24	609.46	12	2	519-582	550.5	44.55	532.91
13	1	-	600	-	628.68						
14	1	-	640	-	645.99						
15	0	-	-	-	661.59						
16	1	-	675	-	675.64						

5.3.5 Age at recruitment and mortality estimations

Age frequency distributions derived from the normalised catch length frequency data (Table 5.3a), the estimated age-at-recruitment and catch curves are presented in Figure 5.6.

First approximations of age-at-recruitment for males and females were between 4.9 and 5.2 years and are presented in Table 5.4.

Table 5.4 First approximations of age at recruitment, t_r, for *Chelidonichthys capensis* sampled during research and commercial cruises on the Agulhas Bank from August 1995 to January 1997.

Group	t_r	δ	n
All	5.7	1.274	1427
Females	5.2	1.462	744
Males	4.9	1.076	683

The age-at-recruitment for females (5.2 years) was significantly higher than for males (4.9 years) ($F_{(2,52\ df)} = 19.31$; $p>0.05$). The value of δ indicates the steepness of the ogive with small values representing knife-edged gear selectivity.

First approximations of total mortality, Z, fishing mortality, F, and natural mortality, M, are given in Table 5.5. Estimations for M and thus Z were higher for females than for males whilst F was lower. The lower F value for females was unexpected since females are larger are should be selectively fished. This result may have been due to sampling error.

Table 5.5 First approximations of total mortality, Z, fishing mortality, F, and natural mortality, M, for *Chelidonichthys capensis* sampled on the Agulhas Bank from August 1995 to January 1997.

Group	Z	log M (Pauly)	M (Pauly)	M (Rikhter & Efanov)	M (Average)	F ($Z-M_{AV}$)
All	0.56	-1.07	0.09	0.41	0.25	0.31
Females	0.54	-0.96	0.11	0.45	0.28	0.26
Males	0.53	-1.01	0.10	0.35	0.22	0.31

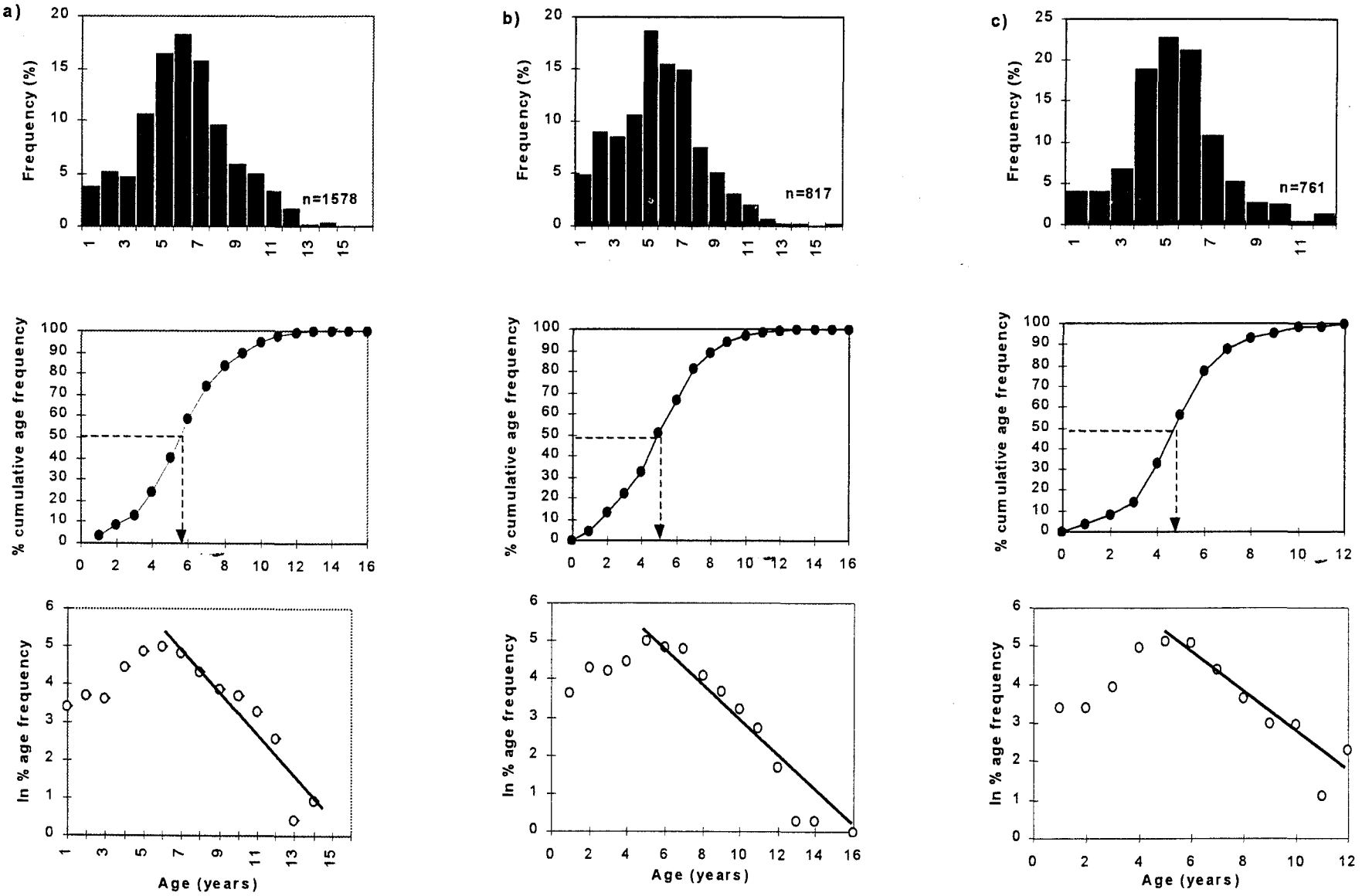

Figure 5.6 Age frequency distributions, age-at-recruitment and catch curves for *Chelidonichthys capensis* sampled on the Agulhas Bank from August 1995 to January 1997. a) all samples; b) females; c) males.

5.4 Discussion

The essential biological features of any fishery are the fish population dynamics. Analysis of these dynamics involves making predictions about birth, death, growth and movement of the fish in a population. This chapter has touched on three of these processes, namely birth, death and growth.

In fishes the relationship between length and weight can be represented by the equation of the form:

$$w=al^b$$

where w is weight and l is length (Ricker 1968). The value of b almost always lies between 2 and 4. The value b=3 indicates isometric growth whereby the fish is growing without changing its shape or specific density; values of b other than 3 indicate allometric growth, that is, as the fish grows its specific density changes (Ricker 1968; Royce 1984). This study indicated isometric growth (b=3.0271) for C. *capensis*. Analysis of covariance revealed no significant difference in the length/weight relationships for males and females. Since male and female growth in length and mass is thus equivalent in proportions, data can be pooled for use in stock assessment models. Hecht (1977) reported a value of 3.0151 for b in the length/weight equation, a value not dissimilar to that obtained in this study (3.0271). Chalmers (1976) studied weight conversion factors of several South African trawl species and reported the following length/weight relationship for whole weight gurnard calculated from data available from 1946-1974:

$$W=0.03470\ L^{2.67778}$$

The b value in this case is lower than that reported in previous studies on *C. capensis*. However the data from which this figure was derived was simply entitled "gurnard spp", and more than likely included the smaller gurnard, *Chelidonichthys queketti*.

Length ranges obtained for *C. capensis* in this study were similar to those for the yellow gurnard, *Trigla lucerna*, in the Thermaikos Gulf, Greece. Papconstantinou (1984) reports 100-767 mm FL for females and 100-340 mm FL for males.

Data collected from this study indicated that a single growth ring is deposited annually for *C. capensis* with opaque zone deposition occurring from March to August. Hecht (1977) reported the use of the opaque zones of otoliths to indicate age in years for *C. capensis*

sampled along the eastern Cape coast and also validated the annual nature of the rings. He reported hyaline zone formation from July to January and opaque zone formation from February to June. Marginal increment analysis of data collected by Yunokawa (1961) from *C. kumu* from the Yellow and East China Seas suggested two rings were laid down annually, one each in March and September. This is unusual for gurnards as many other triglid species only deposit one ring annually (McEachran & Davis 1970; Hecht 1977; Papaconstantinou 1981; 1982; Booth In press). Yunokawa (1961) also reported a spawning peak in March and it may be that the second ring counted was a spawning check mark.

Stacking of rings in the larger otoliths did present a problem in consistently counting the number of rings accurately. Stacking is a result of an increase in the thickness of the otolith rather than in its width or length, and is particularly noticeable in larger fish (Blacker 1974; Buxton & Clarke 1991), which brings about a necessity therefore to section otoliths. In addition, extended spawning periods (see Chapter 3) lead to diffuse growth patterns. If the entire population does not spawn simultaneously, checks are not formed at the same time which can lead to indistinct hyaline/opaque peaks. Care also had to be taken in determining the positions of the first few annuli. They were usually more difficult to identify due to the relatively rapid otolith growth in the early years of the fish as well as incomplete burning in older otoliths to protect the margins from charring.

The von Bertalanffy parameter estimates derived for *C. capensis* showed that this species is relatively long-lived and fast growing. The oldest fish noted was a female of 16 years sampled from research trawls. Generally large values for the Brody growth coefficient, K, indicate a fast growth rate and low values, a slow growth rate. Female *C. capensis* therefore had a faster growth rate (K=0.104) compared to the males (K=0.084). A similar result was reported in Hecht's (1976b) study. However, as the parameter K is dependant on the maximum asymptotic length, it cannot be interpreted independently when comparing growth rates between populations, stocks or species (Pauly & Munro 1984). The growth performance index ϕ' can be used for such comparisons and in this study indicated statistically superior growth performance for females (ϕ'=6.51) compared to males (ϕ'=6.17). This is in contrast to *C. queketti*, another local gurnard species, where the males grow faster than the females (Booth in

press). A fast growth rate and longevity are a common characteristic amongst triglid species (McEachran & Davis 1970; Elder 1976; Hecht 1977; Papaconstantinou 1981; 1982;1983; 1984; Booth, In press). When all the available age data were pooled, an unrealistically large L_∞ was the result (894.23 mm TL). This illustrates one of the difficulties of fitting the von Bertalanffy growth model where there are very few large and small fish. Small fish are often under-sampled by the fishing gear, and if the population is heavily exploited then even the largest samples may be well below the observed maximum length for the species. Values of L_∞ therefore, which relate to the extreme upper limits of the growth curve, represent extrapolations beyond the range of the data sampled. The same is true for t_0 values at the other end of the scale, which in this study were estimated as -2.54 and -1.62 for males and females respectively. Commercial data obtained by Hecht (1977) indicated more realistic values of L_∞, 702 mm TL for all fishes combined, and 714 and 586 mm TL for females and males respectively. The values of t_0, age at zero length, in this study were closer to zero, ranging between -0.086 and -0.413.

Results from first estimations of age-at-recruitment indicate that fishes are being recruited to the commercial fishery in their fifth year of growth and are fully recruited by the tenth year. Results from the reproduction study indicated that females matured in their third year and males in their fourth. Females and males are therefore being allowed a chance to mature and spawn before being caught, a point in favour for the management of this species.

The fishing mortality estimate (0.36 $year^{-1}$) for pooled data was higher than the natural mortality estimate (0.25 $year^{-1}$) indicating some fishing pressure on *C. capensis* on the Agulhas Bank. The total (0.61 $year^{-1}$) and natural mortality estimates for pooled data in this study were lower than the values obtained by Booth (in press) (0.73 $year^{-1}$ and 0.38 $year^{-1}$ respectively) for *C. queketti*. Fishing mortality however was almost the same, 0.36 $year^{-1}$ compared to 0.35 $year^{-1}$.

Following is the description of a preliminary yield-per-recruit model using the growth parameters and mortality estimates derived in this chapter.

5.5 Yield per Recruit

The aim of most age and growth studies is to estimate the potential yield of a fish stock at different levels of exploitation by making use of age, growth and mortality estimates (Ricker 1975). The yield per recruit model, an abbreviated form of the dynamic pool model of Beverton & Holt (1957), is a management tool allowing the optimum combination of age at recruitment and fishing mortality that produces the greatest yield, to be estimated (Pitcher & Hart 1982). It is now accepted that predictions of a maximum sustainable yield (MSY) are of little use for management as they fail to take into account interspecific interactions (Hilborn & Walters 1992). Instead, a marginal yield as defined by Gulland (1968) is used. The basic assumptions of the yield-per-recruit model are that recruitment is knife-edged, and that recruitment as well as the instantaneous rates of growth and mortality are constant from year to year (Beverton & Holt 1957).

The growth and mortality parameters used to estimate a first yield-per-recruit model are shown in Table 5.6. The model used is that described by Butterworth *et al* (1989) and is given by the relationship:

$$\text{YPR (F)} = \sum_{a=0}^{\max} w_{a+1/2} S_a \tilde{F} N_a [1 - e^{-(M+S_a F)}] / (M + S_a F)$$

where $\tilde{N}_a$, the relative proportion of fish at age a is defined as

$$\tilde{N}_a = \begin{cases} 1 & \text{if } a = 0 \\ \tilde{N}_{a-1} e^{-(M+S_{a-1}F)} & \text{if } 1 \leq a < \max \\ \tilde{N}_{\max-1} e^{-(M+S_{\max-1}F)} / (1 - e^{-(M+S_{\max-1}F)}) & \text{if } a = \max \end{cases}$$

and where w is the mass of the fish at age a, S_a is selectivity at age a, F is the instantaneous rate of fishing mortality on fully recruited age classes and M is the rate of natural mortality.

A dynamic pool model such as that given above is used to estimate the yield from each age class in the stock. The individual yields from each age class are then summed to give a total yield. The following steps were used to calculate the yield per age class:

i) Length at age and weight at age for 0.1 age groups were calculated using the von Bertalanffy growth equation and the length weight relationship estimated in Chapter 3.

ii) The selectivity pattern of the fishing gear for each age class was calculated from the following equation:

$$S_{(a)} = \frac{1}{1+\exp^{-(a-a50)/\delta}}$$

where $S_{(a)}$ is the selectivity of the gear on a fish of age a, a_{50} is the age-at-50%-selectivity and δ is the parameter that determines the width of the age-specific selectivity function.

iii) The percentage maturity for each age class was calculated from the following equation:

$$P_{(L)} = \frac{1}{1+\exp^{-(L-L50)/\delta}}$$

where $P_{(L)}$ is the proportion of mature fish at size L, L_{50} is the length at which 50% of the sample was found to be mature, and δ is the width of the ogive.

iv) Biomass-per-recruit was calculated by multiplying the proportion of fish in each age class by mass.

v) Yield-per-recruit was calculated for each age class using the above YPR equation and summation over all age classes gave a total yield.

Yield-per-recruit models were estimated for both the estimated and observed L∞'s and the results are presented in Table 5.7 and Figure 5.7. The effect of natural mortality on yield-per-recruit estimates was investigated using the calculated M (0.25 $year^{-1}$) value as well as one higher (0.28 $year^{-1}$) and one lower value (0.18 $year^{-1}$).

Table 5.6 Von Bertalanffy growth model parameters used to estimate a first yield-per-recruit model for *Chelidonichthys capensis* on the Agulhas Bank.

Parameter	Estimate
L_∞, maximum length	676 mm TL (observed); 894.23 mm TL (calculated)
K, Brody growth coefficient	0.079
t_0	-2.04 years
t_r, age at 50% recruitment	5.7 years
δ_{tr}	1.27 $year^{-1}$
t_m, age at 50% maturity	3.9 years
δ_{tm}	2.74 $year^{-1}$

Table 5.7 Response of various target reference points and respective estimates of yield estimated for *Chelidonichthys capensis* on the Agulhas Bank (F_{MAX}, $F_{0.1}$, F_{SB40} and F_{SB50} are the fully-selected fishing mortalities at which YPR_{MAX}, $YPR_{0.1}$, YPR_{SB40} and YPR_{SB50} occur. YPR_{MAX} is the maximum sustainable yield, $YPR_{0.1}$ is the yield at which the slope of the yield vs F curve is 10% of that at the origin, SBR_{SB40} is the yield at which the spawning biomass is 40% of that of the pristine level, and SBR_{SB50} is the yield at which the spawning biomass is half that of the pristine level).

M	F_{MAX}	$F_{0.1}$	F_{SB40}	F_{SB50}	YPR_{MAX}	$YPR_{0.1}$	SBR_{SB40}	SBR_{SB50}
0.18	0.29	0.18	0.25	0.18	183.04	171.58	1123.63	1394.55
0.25	0.40	0.22	0.34	0.23	105.52	97.36	575.45	725.66
0.28	0.48	0.24	0.39	0.26	85.49	77.99	445.73	560.17

Decreasing the fishing mortality value from F_{SB40} to F_{SB50} did not result in a proportional decrease in yield i.e. a large decrease in F only resulted in a small decrease in YPR. Figure 5.7 shows that increasing natural mortality results in increased yield-pre-recruit. The yield-per-recruit curves were asymptotic resulting in F_{MAX} and YPR_{MAX} values of 0.40 and 106 respectively at M=0.25. The model showed that a decrease in the value of natural mortality, M, resulted in lower yields, and that the yield at the estimated current F of 0.36 year^{-1} is between the marginal (90) and sustainable yields (106). The estimated F value (0.36 year^{-1}) was significantly higher than $F_{0.1}$ (0.22 year^{-1}) suggesting that the stock may be experiencing heavy fishing pressure.

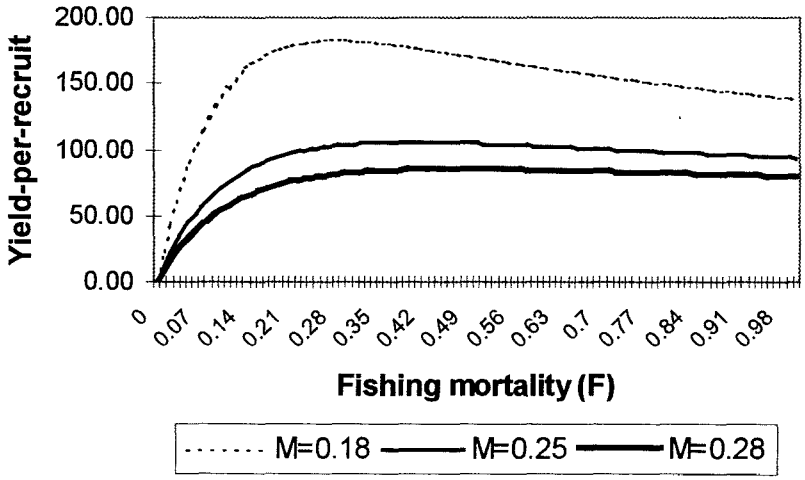

Figure 5.7 Yield-per-recruit as a function of fishing mortality (F) for *Chelidonichthys capensis* on the Agulhas Bank calculated when $L\infty$ = 894 mm TL, at three levels of natural mortality (M).

Figure 5.8 shows that keeping age-at-recruitment constant (5.7 years) and increasing fishing mortality from zero to 0.22 year^{-1} results in a substantial decline in the expected biomass-per-recruit. At the higher F value the biomass of fish surviving past age-at-

recruitment decreases more sharply compared to an unfished population. However keeping age-at-recruitment constant and varying fishing mortality resulted in practically identical curves.

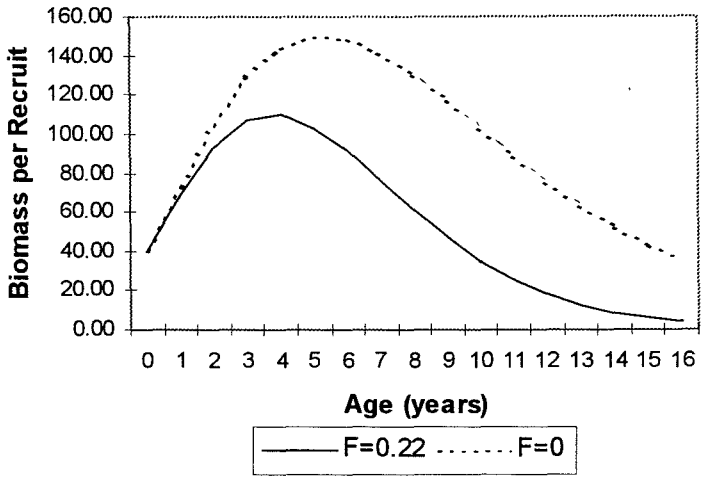

Figure 5.8 Expected biomass-per-recruit as a function of age for *Chelidonichthys capensis* on the Agulhas Bank for a fished and unfished population at t_r = 5.7 years and M = 0.25.

The maximum yield was attained at a very high F relative to the level of fishing mortality required to attain 90% of the maximum. Yields did not differ significantly at decreasing ages-at-recruitment. The model predicted that a maximum yield could be sustained over a wide range of age-at-recruitment as well as a range of fishing pressures.

Significant from this study then is the implication that yields could be kept constant despite large variations in the number and size of fishing vessels targeting *C. capensis*, or any change in fishing gear in terms of mesh size reduction. However results such as these must be treated with caution when one considers that recruitment may not necessarily be knife-edged, particularly for species such as *C. capensis* with extended spawning seasons. In addition, recruitment, growth and mortality rates will not be constant from year to year due to variable environmental conditions that directly affect these fish stock parameters.

Chapter 6 - General discussion with some considerations for the management of bycatch in the South African demersal trawl fishery.

Management with a sound scientific basis allows for the more efficient utilisation of a fishery. For example, appropriate management strategies, such as optimum catch sizes, bag limits, and restricted seasons and areas over spawning periods, can be determined from research data. A range of fishery management objectives exist and include criteria such as maximising biological production, maximising net economic return from a fishing industry, improving the socio-economic situation of the fishing community as a whole, conservation, administrative feasibility, and the ever increasingly important political acceptability (Gulland 1971; Beddington & Rettig 1983). Bycatch considerations have recently become critical constraints in the sustainable management of marine fisheries worldwide and it is now recognised that this aspect of fisheries requires the priority attention of fishery managers. Most of the world's fisheries have a substantial bycatch component that adds to the complex nature of producing a viable management plan. A great deal of concern has been expressed, not only by fisheries managers, but also by conservation and environmental groups, that bycatch and discards are having significant biological impacts on, and altering the structure of, marine ecosystems, as well as having significant economic effects on the fishing industry (Alverson *et al* 1994). Bycatch resulting from demersal trawling can have a number of indirect effects on species assembalges by influencing benthic habitat structure (Hutchings 1990). In addition, impacts on bycatch organisms result in follow-on impacts on organisms with which they have ecological interactions, such as predation and competition (Kennelly 1995). In order for management objectives to be achieved, data on the exploitation levels, reproductive strategy, feeding, and age and growth of bycatch species, such as that provided from this project, are required.

Length frequency analysis showed that male and female *C. capensis* differed significantly in size thus it would be difficult to justify basing management regulations, particularly size regulations, on results from pooled data. However proposing a different set of size regulations for different sexes of the same species is unrealistic so it is suggested that any size limit imposed should be above or equal to that of the larger sex, in this case the females. The sex ratio from

commercial data indicated a slight preponderance of males whilst that from research data showed females to be dominant in landed catches. Exploitation has been shown to affect community structure (Gulland 1987) and in this case may indicate that females have already experienced heavy fishing pressure on commercial trawling grounds thus their numbers are in the minority. The difference in the sex ratios between commercial and research data needs to be further investigated to discern the exact cause of the dissimilarity, before any form of management plan is considered.

The results of the reproductive study indicate year round spawning with significant peaks in reproductive activity during August and February. These peaks, as well as other less significant peaks, corresponded to those in the percentage of empty stomachs, suggesting that feeding intensity decreases during the spawning period. Due to an extended spawning period and no spawning aggregations, closed seasons would not be an effective management option for conserving *C. capensis*. There was little evidence from historical landing data of inshore/offshore seasonal migration that may be related to spawning thus restricted seasons or areas would be of little use. However Hecht (1976b) reported high mean monthly landings from October to March along the South African East Coast from 1967 to 1975, that then declined to a minimum in September. In addition, Van den Heever (1995) also suggested seasonal catches for *C. capensis* along the West Coast. This aspect clearly warrants a more detailed investigation to accurately determine seasonal movements that might relate to spawning periodicity for the Cape gurnard.

Both male and female *C. capensis* had fast growth rates, having attained close to 50% of their maximum size before sexual maturation. This is similar to other gurnard species (McEachran & Davis 1970; Elder 1976; Hecht 1976b; Papaconstantinou 1982, 1983, 1984) but slightly lower than for *C. queketti* that had attained more than 60% of its maximum size before sexual maturation (Booth 1997). The overall growth rates of females, as indicated by ϕ', showed that they grew faster than males. However the value of δ from the logistic ogive equation, describing maturation rate, showed that male sexual maturity proceeded more rapidly than female sexual maturity, although the onset was later. First

approximations of size at 50% maturity were estimated at 348mm TL and 350mm TL for males and females respectively, corresponding to ages of 4.6 years and 3.6 years. The value for female size at sexual maturity calculated in this study was only 2 mm less than that of Hecht (1976b), however that for males was very much lower, differing by 22mm. Such a decrease in size at sexual maturity may be as a result of overexploitation (Garrod & Horwood 1984; Gulland 1987). Productivity generally increases in exploited populations because of a decrease in competitive interactions between the individuals and, in an effort to take advantage of the corresponding increase in resources such as food, individuals begin to mature earlier (Ware 1984). The decreased growth rate after sexual maturation possibly results from a decrease in energy spent on somatic cell production and a concommittant increase in reproductive output.

Ages at 50% recruitment were estimated at 4.9 years and 5.2 years for males and females respectively. This suggests that both sexes are recruited into the South African commercial trawl fishery after reaching sexual maturity, a point in favour of simplifying management should this species become targeted, as it would allow a proportion of the spawner biomass to effectively be protected from current types of fishing gear. Booth (In press), in a similar study on the lesser gurnard, *C. queketti*, on the Agulhas Bank, also reported recruitment into the fishery before sexual maturation. This is in contrast to Hecht (1976b) who showed length frequency distributions of *C. capensis* to have modal peaks scattered between 249mm TL and 649mm TL. These results suggested recruitment between 289mm TL and 309mm TL, lengths corresponding to ages of 2 to 3 years, therefore bringing Hecht to the conclusion that *C. capensis* are recruited to the trawl fishery before sexual maturity. Hecht's study showed that his samples approached sexual maturity at 310mm TL, that more than 50% of the population were mature at 330mm TL, and 100% maturity was estimated at 370mm TL. However Hecht pooled his data for males and females which may have led to the difference in the estimation of age at sexual maturity.

Results from the feeding study show *C. capensis* to be an opportunistic feeder but preying preferentially on the crustaceans, *Goneplax angulata* and *Mursia cristimanus*, and the teleosts, *Cynoglossus zanzibarensis* and *Paracallionymus costatus*. Although stomachs of fish from

research catches contained a greater diversity of items compared to those from commercial landings, dominant items in both cases were the same, showing an active seeking out of prey items independent of other available prey items and habitat. The decreased variety of items in commercial samples may indicate that certain prey species are absent from commercial trawling grounds due to the deleterious nature of the trawling procedure that has destroyed habitats of potential species. More likely though is the fact that commercial trawlers choose to trawl well known, flat grounds where the chance of snaring a net on reef is low. By contrast, research trawling grounds are randomly selected by a computer and include reef areas that provide a wider variety of habitat type compared to muddy flats, thus offering a wider choice of prey.

This study study showed *C. capensis* to be a relatively fast-growing, long-lived species, in keeping with most triglid species the world over, with a maximum age of 16 years being attained by females. Fast-growing, long-lived species are ideal for *sustainable utilisation* as they mature relatively quickly, reproduce before becoming vulnerable to the fishery, and their extended life span means that reproductive potential is high for a relatively long period of time. Rapid growth, early onset of sexual maturity and an extended spawing period are all life-history traits ensuring high reproductive output per individual and maximum spawning for the Cape gurnard, as well as allowing this species to utilise extended areas of the Agulhas Bank.

Results from this study indicate a significant amount of niche overlap between the Cape gurnard and the smaller lesser gurnard, *Chelidonichthys queketti,* on the Agulhas Bank. The lesser gurnard can be found within a similar depth range (50-150m), is also an epibenthic predator feeding predominantly on small brachyurans and teleosts, and has an extended spawning period with peaks in spring and late summer (Booth 1997). Meyer & Smale (1991) report little sign of resource partitioning between the sympatric triglid species *C. capensis* and *Trigloporus africanus* on the Agulhas Bank, and Booth's (1997) results, in addition to those presented from this study, serve to strengthen this case.

Mortality estimates for *C. capensis* were similar to those found by Booth (in press) for the lesser gurnard. The first fishing mortality estimate (0.36 $year^{-1}$) was high compared to the

natural mortality estimate (0.25 $year^{-1}$) suggesting some fishing pressure on this species on the Agulhas Bank. Booth (in press) found similar results for the lesser gurnard. If the results of similar studies on other bycatch species indicate comparable levels of fishing pressure (see Booth in press), then this would provide suitable reason for urgently addressing the bycatch issue in the South African trawl fisheries.

Of the total mortality acting on a fish population, fishery managers can attempt to regulate fishing pressure by limiting the number and size of fishing vessels, or age-at-recruitment, by setting fishing mesh size regulations. The preliminary yield-per-recruit model predicted that a maximum yield could be sustained over a wide range of ages-at-recruitment as well as a range of fishing pressures. Such t_r and F values suggest simplified management and point in favour of a flexible management plan.

A number of management options do exist for the corrected sustainable utilisation of bycatch species. For example, developing new markets for bycatch species, multispecies fisheries management, closure of certain areas ("bycatch hotspots") to trawling, and the development and implementation of more selective fishing gears and practices (Alverson *et al* 1994; Kennelly 1995). For example, the cod trawl separator panel for reducing Pacific halibut bycatch in Alaskan fisheries (Stone & Bublitz 1995), enhancing the Fukushima flounder fishery in Japan with hatchery reared fish (Chopin *et al* 1995), use of turtle exclusion devices in the Gulf and south Atlantic shrimp fishery (Harrington & Vendetti 1995), and introduction of individual transferable quotas (ITQ's) in the eastern Bering Sea King and Tanner crab fisheries (Thomson 1995).

A first step in bycatch management would be identifying certain similarities between bycatch species, such as extended spawning seasons or attaining sexual maturity before recruitment, that would allow "pooled" management of the South African bycatch. However multispecies management has many associated problems (Annala *et al*, 1991) therefore in addition, efforts could be made to alter gear designs to reduce the amount of bycatch taken. Effective fisheries management requires that the gear used be selective towards the adult fish whilst allowing the juveniles to escape (Armstrong *et al,* 1990). Traditionally, the selectivity of towed gear, such as

the trawl nets used in the South African demersal fishery, has been determined by the minimum mesh size of the netting (MacLennan 1992). The use of square mesh netting at the codend showed better size selectivity than diamond mesh, the catch of smaller fish being reduced because the former shows less tendency to close-up once the netting has come along the direction of tow (Anonymous 1995a). There is growing interest in improving selective fishing technology in many countries around the world in an attempt to decrease the quantity of bycatch in their commercial fishing industries. By placing deflector grids, or bycatch reduction devices as they are colloquially known, between the body of the trawl net and the codend, the amount of finfish bycatch has been greatly reduced in the many of the world's crustacean fisheries, e.g. Australia's northern prawn fishery (Brewer *et* al 1995), the Norwegian shrimp fishery (Isaksen *et al.* 1992) and the South Atlantic shrimp fishery (Rulifson *et al.* 1992; Riedel & De Alteris 1995). This method has also been shown to be effective for reducing juvenile fish catches in fish trawling fisheries (Stewart 1991; Broadhurst & Kennelly 1995). In addition to being a conservation orientated approach, the reduction of trawl bycatch reduces the sorting time required to pick out the target species and improves the quality of the catch (Wray 1991; Larsen 1995). A literature survey revealed a single study of this nature done in South Africa. Botha & Payne (1980) compared the efficiency of beam and otter trawls at catching demersal fish. Although costly, efforts to continue such research in South Africa would pay in the long run as it would mean that present bycatch species would be available for harvesting which would help prevent current target species from being fished to economic extinction. Hall (1996) suggests the bycatch problem be made the responsibility of the fishing industry, pointing out that other industries set aside funds specifically for research and development to produce and keep up with technological advances. In the same way, the South African fishing industry should set aside funds for developing bycatch reduction gear and for marketing bycatch products. Education programs would be necessary to help fishers understand the ecological impacts of overfishing, and that management options, such as marine reserves, are in their best interest, despite the short term negative effects that they may have.

Future work is needed to assess all available data, most of which is captured in the Sea Fisheries Research Insititue database, for the Cape gurnard and other bycatch species to

determine more accurate biomass estimates. The current SANCOR bycatch program recognises primary and secondary bycatch species based on their economic value. The former include such edible species as buttersnoek, *Lepidopus caudatus,* St Joseph shark, *Callorhinchus capensis*, east coast sole, *Austroglossus pectoralis,* and John Dory, *Zeus capensis,* whilst the latter includes species that could be used for fish meal like lesser gurnard, *C. queketti*. Although necessary to concentrate on species that could provide alternate food sources for humans, the importance of the secondary bycatch species should not be overlooked. Some biological data, albeit slightly dated, does exist for both primary and secondary bycatch species that could currently contribute towards at least a preliminary bycatch management strategy. In addition, behaviour studies need to be initiated that would provide data useful in developing bycatch reduction devices. High biomass estimates on the west coast suggest a potential sustainable resource however the data from this study is limited in that, due to time and financial constraints, it could only be gathered from the Agulhas Bank area. Further data collection concentrating on the west coast of South Africa would thus undoubtedly be a necessity.

Whether the Cape gurnard becomes a targeted species or not, the bycatch situation in South Africa needs to continue to be urgently addressed. If current exploitation levels of target species continue to rise then the future of South African fisheries may well depend on the immediate, correct management of the current bycatch that could well become the target of tomorrow.

The aims then of this project, assessing the utilisation, studying the biology and considering the potential for sustainable utilisation of *Chelidonichthys capensis*, have been achieved. Although this study on the biology of *C. capensis* does not highlight any single factor that would render this species particularly vulnerable to utilisation, that is, it is not particularly slow-growing nor does it prey exclusively on a single species, further work is needed in certain areas before an appropriate management strategy can be chosen for the Cape gurnard.

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