BIOLOGY AND DEMOGRAPHY OF THE SPOTTED GRUNTER

POMADASYS COMMERSONNII (HAEMULIDAE)

IN SOUTH AFRICAN WATERS

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By

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Abstract

The spotted grunter, *Pomadasys commersonnii* (Haemulidae), is an Indian Ocean coastal species, extending from India to False Bay but is absent from the central Indian Ocean islands. Its taste and texture has made it one of the most important linefish species and is caught by recreational and subsistence fisherman along the entire east coast of South Africa. Because of its inshore distribution, reduced catch rates and estuarine dependence the species was de-commercialised in 1992. Since then it has been investigated as a candidate species for mariculture.

All previous work on the biology of the species was undertaken on fish collected in KwaZulu-Natal in the mid 1970's. All other information has been incidental and formed part of other ecological studies. All management plans for this species have been based on these data. To develop a more comprehensive management plan that incorporates the entire population of spotted grunter, it was deemed necessary to reassess the biology (including feeding biology, age and growth and reproductive biology) as well as the demography of the population throughout its distributional range in South African waters.

Analysis of the diet of spotted grunter, collected in estuaries, indicates that crustaceans form the bulk of the prey selected. Amphipods, mysids and estuarine brachyura predominate the diet of fish < 300 mm TL. At 200 mm TL fish start to prey on anomurans, which are extracted from their burrows using the 'blowing' feeding mechanism. Anomurans, in particular *Upogebia africana* and *Callianassa krausii*, become the preferred prey of fish larger than 300 mm TL. The high degree of diet flexibility that spotted grunter exhibit means that the composition and abundance of the macrobenthos of a particular environment will dictate the diet of the species.

Otolith growth zones were found to be deposited annually with the opaque zones being deposited during the austral summer (November – February). The optical definition of annual otolith growth rings differed significantly between geographic regions (namely: Western Cape, South Eastern Cape and KwaZulu-Natal). Growth (sex combined) of fish in the Western Cape were best described by the specialised 3 parameter Von Bertalanffy with a relative error structure in the form:

$$L_t = 753\left(1 - e^{-0.154(t+1.615)}\right)$$

while growth in the South Eastern Cape was best described by using the Schnute model with an absolute error structure in the form:

$$L_t = 177^{0.416} + \left(676.2^{-1.266} - 169.2^{-1266}\right)\left[\frac{1 - e^{-0.416(t-t_1)}}{1 - e^{-0.416(t_2-t_1)}}\right]^{\frac{1}{1.266}}$$

whereas growth was best described in KwaZulu-Natal using the specialised 3 parameter Von Bertalanffy with a relative error structure in the form:

$$L_t = 839\left(1 - e^{-0.17(t+0.349)}\right)$$

In the South Eastern Cape, length at 50% maturity was found to be 305 mm TL for males. Since females with ripe & running or spent gonads were not found in the South Eastern Cape and since histological evidence suggests that females in the South Eastern Cape have spawned, it appears that spawning does not occur in the South Eastern Cape. These results suggest that adults are resident in the estuaries of the Western and South Eastern Cape and undertake the spring/summer, northward spawning migration to KwaZulu-Natal.

After joining the resident spawner stock in KwaZulu-Natal and spawning in the offshore environment of KwaZulu-Natal, adults soon return to the southern regions of their distributional range. Juveniles recruit into KwaZulu-Natal estuaries at a length of 25 – 35 mm TL. A proportion of the eggs and larvae are transported southwards along the periphery of the western boundary Agulhas Current where juveniles (25 - 30 mm TL) recruit into the estuaries as far south as the Swartvlei estuary in the Western Cape. There is evidence to suggest that the fish, which occur in the Western Cape estuaries, have migrated there once they have attained sexual maturity further east.

TABLE OF CONTENTS

Chapter 5 – Demography

References

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CHAPTER 1 – INTRODUCTION

The spotted grunter (*Pomadasys commersonnii* Lacepede 1801) belongs to the family Haemulidae (Smith & McKay 1991). The common name spotted grunter is derived from the rows of distinct small, dark spots which cover the flanks and dorsal surface (Figure 1.1) and the rasping grunt made by the pharyngeal teeth rubbing together when the animal is removed from the water (Smith & McKay 1991). The dark spots extend onto the dorsal fins but do not extend onto the head. There is a well-defined dark blotch on the operculum (van der Elst 1988). Adults are silver, with a mother-of-pearl sheen on their upper flanks and 3 anal spines, whereas juveniles have a purple sheen and no spots (Smith and McKay 1991, Branch *et al.* 1994).

Figure 1.1. An adult *Pomadasys commersonnii* (< 600 mm TL). Note the rows of distinct small, dark spots which cover the flanks and dorsal surface as well as the defined dark blotch on the operculum

The natural distribution of the species is unclear. Blaber (1981) and van der Elst (1988) describe it as an Indo-Pacific species, inhabiting waters of temperate and tropical coasts, while Day *et al.* (1981), Smith & Mckay (1991) and Branch *et al.* (1994) describe it as an Indian ocean coastal species, extending from India to False Bay in South Africa but absent from central Indian Ocean islands such as the Seychelles.

Spotted grunter are particularly common in KwaZulu-Natal and the Transkei (van der Westhuizen & Marais 1977, Blaber 1981, Day *et al.* 1981), where adults are frequently found off sandy beaches or in tidal estuaries (Wallace *et al.* 1984). The species becomes less abundant towards the south presumably because of the transition to a more temperate environment (Day *et al.* 1981).

Spotted grunter are an important linefish species caught along the entire east coast of South Africa. Since 1992, spotted grunter have been de-commercialised and categorized as a recreational species. This is primarily because of its inshore distribution and estuarine dependence, hence its greater vulnerability to exploitation relative to other, purely marine species (Fennessy 1999). Its fine taste and texture makes it one of the most sought after fish by rod-and-line anglers (van der Elst 1988). The taste, texture and the high price per kilogram have resulted in it being investigated as a candidate species for mariculture in South Africa (Deacon & Hecht 1995).

Studies on oxygen consumption, salinty requirements, optimal diet, feeding frequency, optimal rearing temperature, optimal rearing photoperiod and their effects on growth of spotted grunter have been undertaken by Du Preez *et al.* (1986), Bussiahn (1992), Bacela (1998), Deacon & Hecht (1996), Deacon (1997), and Irish (1997). All studies were conducted on wild specimens caught in the South Eastern Cape, whereas sporadic and incomplete studies on the biology of the species have primarily been conducted on specimens from KwaZulu-Natal (Wallace 1975 a & b, Wallace & van der Elst 1975).

Spotted grunter are euryhaline and can tolerate salinities ranging from 0 to 90 ‰ (Wallace 1975a, Day *et al.* 1981) and can survive in low salinities for prolonged periods (Blaber & Cyrus 1981). However, mass mortalities have been recorded in the Kosi and St Lucia systems when salinities declined below 4‰ coinciding with water temperatures below 13°C (Blaber & Whitfield 1976). Similarly a mass mortality was observed in the temporarily closed Seekoei Estuary in the South Eastern Cape when salinities increased above 90‰ (Whitfield 1998 a). The thermal preference of juveniles was found to be between 24^0C and 25^0C (Deacon & Hecht 1995).

Although little is known about the feeding biology of juveniles, adults are described as opportunistic macrobenthivores and the composition of its diet is described as being dictated by the composition and abundance of the macrobenthos of the particular estuary in which it is found (Blaber 1983). According to Blaber (1983) and Wooldridge & Bailey (1982), juvenile spotted grunter in KwaZulu-Natal estuaries feed mainly on pelagic copepods and mysids as well as macrobenthic crustaceans.

Adults, on the other hand have been shown to feed mostly on anomurans such as the mudprawn *Upogebia africana* and the sandprawn *Callianassa kraussi* (van der Westhuizen & Marais 1977, Whitfield 1980 a, Hecht & van der Lingden 1992). Mouth gape limitation has been identified as responsible for the ontogenetic shift in prey selection (Blaber 1983). Field sampling and laboratory experiments have shown that the feeding behaviour of the spotted grunter is not affected by turbidity (Cyrus & Blaber 1987, Hecht & van der Lingden 1992).

The only area where spotted grunter have been documented to spawn is along the KwaZulu-Natal coastline (Wallace 1975 b, Wallace & van der Elst 1975, Harris & Cyrus 1997, Harris & Cyrus 1999). Following spawning in the marine environment (June to December), it is assumed that the larvae develop and stay at sea (Wallace & van der Elst *op cit.*, Whitfield 1998 b). On average, juveniles recruit into KwaZulu-Natal estuaries between 25 – 30 mm TL where they greatly exceed the number of adults (Wallace 1975 b). Partially spawned fish have been found to penetrate short distances into KwaZulu-Natal estuaries and on rare occasions ripe-running specimens seem to stray into this environment from adjacent spawning areas (Wallace 1975 b). Most adults that enter estuaries do so in a post-spawning condition. It is these, recently spawned fish, that compromise the bulk of the fish entering the KwaZulu-Natal estuaries during the season that has come to be known as the 'grunter run' (Wallace 1975 b). Depending on estuarine mouth condition, large numbers of spotted grunter are present in KwaZulu-Natal estuaries from about July to January, with a peak in abundance in November (Wallace 1975 a). According to Wallace (1975 a) these fish enter the KwaZulu-Natal estuaries to feed and recover after spawning.

A similar, albeit on a smaller scale, movement of grunter into estuaries occurs in the Western and South Eastern Cape estuaries from September to January/February (Marais & Baird 1980 a, Marais 1981, Marais 1983 a, Marais 1983 b, Plumstead *et al.* 1985, Plumstead *et al.* 1989 a). Since no detailed biological studies have been undertaken on spotted grunter in the South Eastern or Western Cape it has generally been accepted that all spotted grunter entering the estuaries during the 'grunter run' do so in a post-spawning condition (Day *et al.* 1981, Whitfield 1998 b) thus suggesting that the species spawns throughout its distributional range.

Although spawning has only actually been documented to occur off the KwaZulu-Natal coastline, juveniles enter all permanently open and temporally open / closed estuaries along the eastern seaboard of south Africa, but are virtually absent from estuaries south of the Swartvlei system (Whitfield 1989). Juveniles first enter the estuarine environment at 25-30 mm TL, where they grow at a rate of 1.2 to 1.5 cm per month in summer but more slowly in winter and at the end of the first year may reach 160 to 200 mm TL (Wallace 1975a). According to Day *et al.* (1981) and Wallace & Schleyer (1979) juveniles remain in the estuaries for at least the first year of life, after which they return to the sea where they reach sexual maturity at approximately 2-3 years of age at ± 400 mm TL (Wallace, 1975 b). From this original published data (Wallace 1975 b), the 400 mm TL minimum angling size limit was implemented.

Growth of spotted grunter has only been studied in northern KwaZulu-Natal (Wallace & Schleyer (1979). However, given the wide distributional range of the species, and the fact that growth varies temporally and spatially and that the methods used by

Wallace & Schleyer (1979) are dated implies that Wallace & Schleyer (*op cit.*) growth curve cannot be incorporated into age structured or yield per recruit models. In order to assess the status of the stock, a study of the age and growth of the species throughout its distributional range was therefore required.

Once fish have left the estuarine nursery grounds, the biology and movements of the subadults and adults are not well understood. A tagging report by Bullen & Mann (2000) indicated that tagged spotted grunter are largely resident in and around the same estuaries where they were originally tagged. Occasional adult fish were found to move great distances and these fish were termed nomadic (Bullen & Mann 2000).

The migration of spotted grunter into KwaZulu-Natal estuaries during the 'grunter run' has been identified to be closely associated with the reproductive cycle (Wallace 1975 b). The inshore prawn trawlers operating on the Tugela banks of KwaZulu-Natal catch significant quantities of adult grunter (Fennessy 1999). Given that adult grunter are not caught by inshore trawlers further southwards (Wallace *et al.* 1984, Peter Simms, Marine and Coastal Management (Mossel Bay) and Eyetu Fishing Pty Ltd, pers. comm) would suggest that the adult fish in the KwaZulu-Natal constitute the bulk of the spawning population of the region.

Wallace (1975 b) suggested the possibility of a longshore spawning migration but no evidence was presented to support the contention. Information on a longshore or inshore/offshore movement of fishes is critical to defining the boundaries of a unit stock (Cushing 1981) and to the understanding of the life history strategy, biology and dynamics of a species (Harden-Jones 1968, McKeowen 1984).

Despite the importance of the spotted grunter in the recreational and subsistence linefisheries in South Africa, there is no specific management plan for this species. The objectives of this project were to study the biology and demography of the species in the Western and South Eastern Cape and to consider the findings in the light of previous studies undertaken in KwaZulu-Natal and elsewhere so as to obtain a more composite picture of the biology and life history style of the spotted grunter. This thesis serves as a contribution toward the development of a management plan for this species.

This thesis consists of independent chapters on feeding biology, age and growth, reproduction and demography. The degree of repetition in some of the chapters was therefore unavoidable.

CHAPTER 2 – FEEDING BIOLOGY

Introduction

It is well established that estuaries form important feeding grounds for juvenile and adult fish that enter them. The availability of food largely determines the diet of these fish (Whitfield & Blaber 1978, Whitfield 1980 a, Smale & Kok 1983, Whitfield 1998 a, Coetzee & Pool 1991) and their distribution within the estuary (Whitfield 1980 b). In order for fish to efficiently utilise the estuarine environment, they must have the ability to change diet according to the availability of prey species (Whitfield 1998 a). Whitfield (1980 a) argued that diet flexibility of fishes in many Southern African estuaries is important because of the inherent instability of these systems and that this ability promotes stability in the fish population (Whitfield 1984). Blaber (1984) regards this opportunistic and flexible feeding behaviour in fish as a pre-requisite to living in estuaries.

The feeding biology of only two Indo-pacific *Pomadasys* species have previously been studied. These are the piggy, *P. olivaceum* (Buxton *et al.* 1984, Lasiak 1986), and the spotted grunter, *P. commersonnii* (van der Westhuizen & Marais 1977, Whitfield 1980 a, Marais 1984, Schleyer & Wallace 1986, Hecht & van der Lingen 1992, Daniel 1994). However, the previous studies on the feeding biology of spotted grunter have all been undertaken on fish > 70 mm TL. On examining the suite of papers on the feeding biology of spotted grunter it becomes clear that the diet of fish

>70 mm TL consists mainly of crustaceans, although the species of crustaceans may differ depending on where and when the fish was caught. Spotted grunter caught in the Swartkops, Sundays and Kariega estuaries were found to feed primarily on the mud prawn, *Upogebia africana* (van der Westhuizen & Marais 1977, Marais 1984, Hecht & van der Lingen 1992). Larger spotted grunter (127 – 600 mm TL) caught in the Great Fish River mostly consumed *Upogebia africana,* although mysids and amphipods contributed almost equally to the diet (Hecht & van der Lingen 1992). The consensus of these authors is that the prey selection of spotted grunter is highly flexible and that the composition and abundance of the macro benthos dictate the diet of the fish in each particular system.

In estuaries, adult spotted grunter forage on the bottom of the estuaries where prey is extracted from burrows using a gill chamber pump action. The functioning of the pump action is similar to that of a bellows, where a jet of water is forced into the burrow system and the prey is blown out (Day *et al.* 1981, van der Elst 1988, Whitfield 1988). The prey is then captured and consumed. When feeding in shallow water the caudal fin may often be seen waving above the water surface (Smith & Mc Kay 1991). The pump action is so powerful that hooked fishes have been known to blow the bait, especially blood worms, with such force that it is often shot far up the line (Smith & Mc Kay *op cit.* and personal observation).

Whitfield (1980 a) found that 65.5% of the total calorific intake of the spotted grunter (33 – 169 mm TL) in the Mhlanga estuary (KwaZulu-Natal) was provided by the anomuran *Callianassa krausii.* In the only feeding study undertaken on spotted grunter in the marine environment, Schleyer and Wallace (1986) found that the fish (337 – 857 mm TL) in the KwaZulu-Natal surf zone feed principally on the sand mussel, *Tivela polita* and swimming prawn *Macropetasma africanus.*

The feeding biology of smaller grunter <70 mm TL is not as clearly understood. Although van der Westhuizen & Marais (1977) found no difference in diet composition between different size classes of spotted grunter in the South Eastern Cape estuaries, Blaber (1983) found differences in the diet of fish less and greater than 70 mm TL in KwaZulu-Natal estuaries. Blaber (*op cit.*) attributed this to the increased ability of bigger fish to remove larger prey items from the substratum, whereas fish <70mm TL selected individual zooplankton and small macrobenthos. Larger fish are thus unlikely to feed on zooplankton and are apparently only capable of extracting prey organisms such as pencil bait *Solen cylindraceus* (Mollusca) and sand prawn, *Callianassa krausii* (Anomura) from the substratum in KwaZulu-Natal estuaries. Since very little is known of the feeding biology of smaller spotted grunter in the South Eastern Cape, one of the objectives of this study was to describe the diet selection of fish <70 mm TL in the Great Fish River estuary and identify the differences, if any between these fish, fish between 70 and 300 mm TL and mature fish > 300 mm TL.

Although sampling in all previous studies on the feeding biology of the species was conducted on a quarterly basis, the data were lumped and ignored possible seasonal differences in prey selection. It was for this reason that seasonal differences in diet selection of spotted grunter was also investigated.

In order to contribute towards a better fundamental understanding of the life history of this important angling species, data obtained from this and all previous studies on the diet preference of the species are finally presented in a composite form so as to illustrate the dietary flexibility of the species.

Materials and Methods

Sampling was conducted in the Great Fish River estuary. Gill nets were set monthly from June 1999 to August 2000 as close to the full moon spring tide as weather permitted. Nets were set parallel to the bank overnight for a 12-hour period. The nets were deployed in the lower and middle reaches of the estuary. The presence of subsistence fishermen meant that the nets could not be left unattended, even for a short while. Shallow water (<1m) did not allow for sampling in the upper reaches of the estuary. The mesh size and dimensions of the nets used are presented in Table 2.1.

Table 2.1. Dimensions of the gill nets used for sampling *P. commersonnii* in the Great Fish River estuary from June 1999 to August 2000.

Stretched mesh size	Net depth	Net Length	Total net area
44mm	2.5 m	30 m	$75m^2$
60mm	3 m	30 m	$90m^2$
75mm	3 m	2 x 30 m	$180m^2$
100mm	2.5 m	30 m	$75m^2$
120mm	2.5 m	30 m	$75m^2$
144mm	2 m	29 m	$58m^2$

Once the gill nets had been lifted in the morning, fish were removed and transported back to the laboratory within 2 hours. On all but two occasions, fish were worked up fresh on the day of capture. In November 1999 and January 2000 when large catches were made the fish that could not be worked up on the same day as capture were frozen to -20^0C and then thawed and processed within three days of capture.

Juvenile spotted grunter were captured in February and March 2000 by means of a seine net (30m x 2m x 4mm bar mesh), in the lower and middle reaches of the estuary.

All fish were measured for total and standard length (nearest mm) and weighed (whole and gutted) to the nearest gram. The stomach of each fish was removed and the contents preserved in 10% formalin for later analysis. The stomach contents of each fish were later examined and analysed in a petri dish under a dissecting microscope. Stomach contents were then identified to species level where possible. The percent number (%N), percent mass (%M), percent frequency of occurrence (%FO), and the index of relative importance (IRI), were used in the analysis of the diet of the species. Berg (1979) and Hyslop (1980), who critically assessed the advantages and disadvantages of the different methods and the importance of using at least one index that includes the number and one index that includes the bulk or mass of the respective prey organism. The IRI {IRI = % FO x (%N + % M) } was calculated according to the method of Pinkas *et al.* (1971). In order to facilitate comparison between studies and to obtain a robust estimate of relative importance of the prey, Cortes (1997) suggests that IRI values should be standardised by representing them as %IRI for all taxonomic levels considered. This meant that if IRI's determined by van der Westhuizen & Marais (1977), Marais (1984), Schleyer & Wallace (1986) and Hecht & van der Lingen (1992) were transformed into %IRI's, they could be compared to each other and to the IRI's obtained in this study.

To investigate size and seasonal related differences in the diets of spotted grunter, the indices of relative importance for fish <70 mm TL, 70 to 300 mm TL and adults ≥ 300 mm TL were compared with the use of Spearman Rank correlation. Since the number of fish that were captured with stomach contents was low, quarterly comparisons could not be made and the data therefore were lumped into two periods, *viz* September to February and March to August, roughly corresponding to summer and winter.

To determine the selection of prey size relative to fish size, length measurements (to the nearest 0.01 mm) of the most common prey item, *Callianassa krausii*, were taken.

Data obtained from this and all previous studies on the diet preference of the species are presented in a composite form so as to illustrate the dietary flexibility of the species.

Results and discussion

Very few (89) of the 609 specimens examined contained food in their stomachs; 20 fish < 70 mm, 37 fish 70 to 300 mm TL and 32 fish ≥ 300 mm TL. It is assumed that the low numbers (15%) are due to fish regurgitating their stomach contents after periods of stress, which could occur during capture in gill nets (Marais 1984). Because of the low sample numbers conclusions reached should be regarded as tentative.

Table 2.2 indicates that the small fish (<70 mm TL) are not as diverse in their diet selection as fish in the larger size classes. 100% of the prey consumed consisted of crustaceans and only four species were preyed upon. The amphipod, *Grandidierella lignorum* was the most important prey item in the diet of fish <70 mm TL. Two estuarine crabs, *Hymenosoma orbiculare* and *Cleistostoma edwardsii* were of second and third importance, respectively. The smaller of the two crabs, *Cleistostoma edwardsii*, was preyed upon more often than *Hymenosoma orbiculare* but the latter, as a result of its larger size, resulted in both species being of high importance to the diet of fish <70mm TL. The anomuran, *Upogebia africana* was the least common of the prey items. It must be noted that only fragments of thoracic segments were ever found in the stomachs of fish of this size and it is therefore assumed that these segments were largely scavenged.

The diet of the middle size group (70 – 300 mm TL) was also dominated by *Grandidierella lignorum.* The estuarine sand prawn (*Callianassa krausii)* was the second most important prey item (Table 2.2).

Table 2.2. Composite diet of spotted grunter <70 mm TL, >70 – 300 mm TL and 300 mm TL + collected in 1999 and 2000 from the Great Fish River estuary. Fish <70 mm TL were collected in February an March 2000.

Fish Size	< 70 mm TL (n= 20)				70 - 300 mm TL (n= 32)				300 mm TL + (n= 37)			
	%FO	%N	% M	%IRI	% FO	% N	% M	%I R I	% FO	% N	% M	%I R
Crustacea	**100**	**100**	**100**	**100**	**93.62**	**99.50**	**99.88**	**98.99**	**92.85**	**99.83**	**98.81**	**98.99**
Unidentified									*6.35*	*0.041*	*2.26*	*>1*
Brachyura					*23.4*	*0.17*	*24.77*	*4.5*	9.52	0.192	1.72	>1
Hymenosoma orbiculare	11.1	0.22	96.89	25.1	6.38	0.09	15.19	2.4	4.76	0.102	1.13	>1
Cleistostoma edwardsii	55.5	13.1	2.03	19.6	4.25	0.06	5.1	>1	3.17	0.05	0.5	>1
Thaumastoplax spiralis					12.77	0.22	4.48	1.5	1.59	0.04	0.05	>1
Anomura					*36.16*	*0.45*	*58.87*	*33*	*63.49*	*2.3*	*93.8*	*91.9*
Upogebia africana					12.76	0.13	7.16	>1	23.81	0.31	12.15	6.9
Callianassa krausii					23.4	0.32	51.71	30.6	39.68	1.99	81.65	77.9
Mysidacea					*6.37*	*0.26*	*0.026*	*>1*	*7.14*	*1.3*	*0.079*	*<1*
Mesopopsis slabberi					4.25	0.24	0.02	>1	2.38	0.01	0.009	>1
Rhopalopthalamus terranatalis	22.2	3.28	0.68	2	2.12	0.02	0.006	>1	4.76	1.29	0.07	<1
Isopoda												
Eurydice longicornis					4.25	0.04	10.75	1.1				
Amphipoda												
Grandidierella lignorum	44.8	50.8	0.4	53.3	23.4	98.38	5.44	61.2	6.35	96	0.99	14.4
Macura												
Palaemon pacificus									1.59	0.01	0.009	>1
Penaeus sp									1.59	0.01	0.09	>1
Mollusca					**2.12**	**0.02**	**0.02**	**<1**	**3.17**	**0.13**	**.031**	**<1**
Plecepoda												
Solen capensis					2.12	0.02	0.02	>1	3.17	0.13	0.31	<1
Annelida												
Polychaeta									**1.59**	**0.01**	**0.67**	**<1**
Lumbiensis spp									1.59	0.01	0.67	<1
Telostei									**1.59**	**0.01**	**0.10**	**>1**
Piscies					**2.12**	**0.02**	**0.07**	**>1**				
Soleidae					2.12	0.02	0.07	>1				

In the largest size group (≥ 300 mm TL), *Callianassa krausii* was found to be the most important prey item and *Grandidierella lignorum* the second most important item (Table 2.2). Figure 2.1 indicates that spotted grunter do not feed on sand prawn until they reach 200 mm TL. At about 200 mm TL they start to feed on the smallest sand prawns (20 mm – 50 mm from tip of rostrum to end of telson). Fish larger than 300 mm TL were non-selective and fed on the full size range of sand prawn (Figure 2.1). It therefore seems that the fish between 70 and 300 mm TL fall into a size range where prey selection shifts from *Grandidierella lignorum* to *Callianassa krausii.*

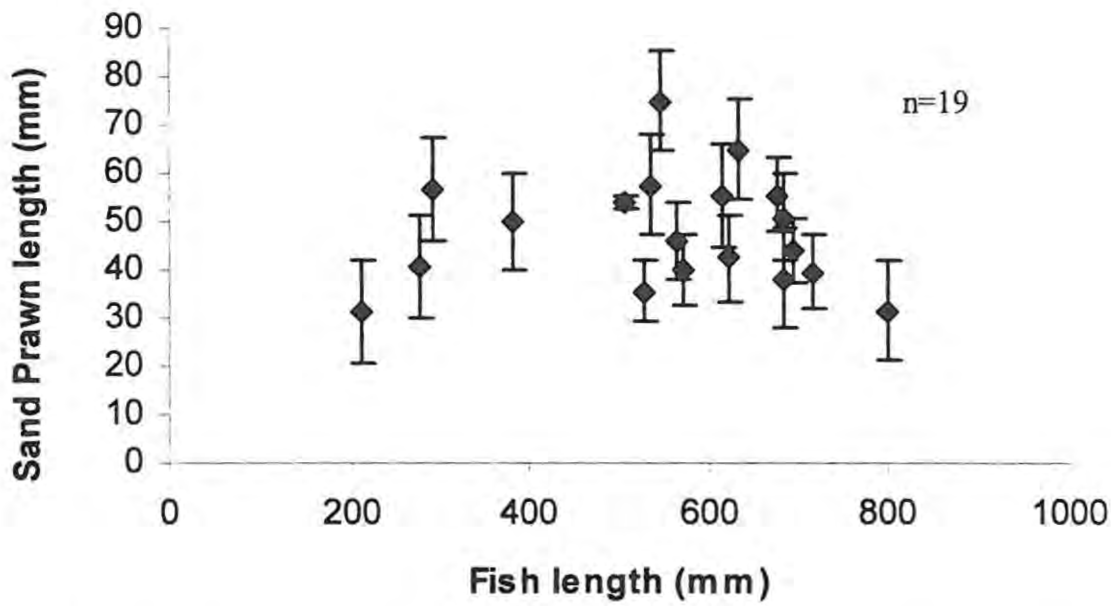

Figure 2.1. Mean size of *Callianassa krausii* (from the tip of rostrum to the end of telson) found in stomachs of *P. commersonnii* as a function of fish length. Fish were collected in the Great Fish River estuary in 1999 and 2000. n = number of stomachs containing *Callianassa krausi*

However, the larger fish (≥300 mm TL) still depend on *Grandidierella lignorum* as an important part of their diet in fact this amphipod is the second most important prey item in the diet of fish of this size (Table 2.2).

To summarise the data so far; amphipods form the bulk of the diet of fish < 70 mm TL. Fish between 70 – 300 mm TL prey on both amphipods and sand prawn (*C. krausii*) but only start to feed on sand prawn once they reach a size greater than 200 mm TL. At a size ≥ 300 mm TL, *Callianassa krausii* becomes the major prey item of the fish.

Jobling (1995) suggests that the reasons for ontogenetic changes in prey selection are twofold. Firstly, a small fish would be unable to capture, subdue and swallow a large prey item and secondly, a larger animal would have to expend too much time and energy searching for the large numbers of small prey that would be needed to meet its energetic requirements. Jobling's hypothesis provides the basis upon which the apparent ontogenetic shift in diet of spotted grunter can be explained. Initially, juveniles consume *G. lignorum,* which reach a maximum size of 4mm (Branch *et al.*1994). When the fish reach a size of 200 mm TL they start to feed on smaller *Callianassa krausii*, which ultimately becomes the dominant prey item of fish larger than 300 mm TL. *Callianassa krausii* can burrow as deep as 1,5 m into the sediment (Forbes 1973). The gill chamber pump action of the smaller fish may not be powerful enough to force the prey out (Blaber 1983). Secondly, if smaller fish were to obtain them, mouth gape limitation would make the larger anomurans unlikely prey items. The energy required for larger fish to actively search for and consume large numbers of amphipods outweighs the benefits, whereupon they switch to and select larger prey.

Grandidierella lignorum, which is the most common prey item of fish between 70 – 300 mm TL (Figure 2.2 a), is a euryhaline benthic amphipod capable of surviving in freshwater (Boltt 1969) and salinities of up to 45‰ (Blaber *et al.* 1983). However, the abundance of *G. lignorum* is negatively correlated with salinity (Coetzee 1983, Read & Whitfield 1989) and due to the continuous freshwater input into the Great Fish River estuary, the species is abundant throughout the year (Read & Whitfield *op* *cit.*). Similarly, relative abundance of *C. krausii* have been shown to remain stable throughout the year in South Eastern Cape estuaries (Forbes 1977). The two prey items that contribute over 90% to the diet of fish between 70 and 300 mm TL and fish larger than 300 mm TL (Figure 2.2 a and Figure 2.2 b) are therefore present in abundance throughout the year. It is probably for this reason that there was no difference in the summer and winter diets of these fish.

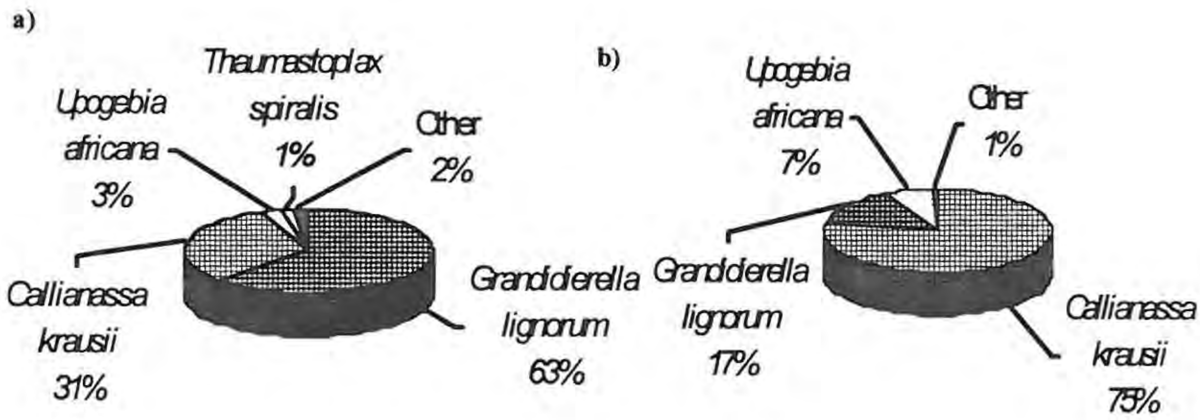

Figure 2.2 a) Most abundant prey items in the stomachs of *P. commersonnii* (70 – 300 mm TL) n = 33. b) Most abundant prey items in the stomachs of *P. commersonnii* (≥ 300 mm TL) n = 37. All fish were collected in the Great Fish River estuary from 1999 to 2000.

Although spotted grunter feed on a wide variety of prey items (14 species), they only target a few crustacean species, which are abundant all year round.

When examining Table 2.3 it becomes apparent that spotted grunter feed almost exclusively on crustaceans in the South Eastern Cape. In the Gamtoos, Swartkops, Sundays, Kariega and in both studies on the Great Fish River, anomurans were identified as the primary food items. In particular, the mud prawn *Upogebia africana*, was the single most important prey item in the diet of spotted grunter in the

Swartkops, Sundays, Gamtoos and Kariega estuary and the 1992 study on the Great Fish River estuary (Figure 2.3). However, the importance of *Upogebia africana* in the diet of spotted grunter has been shown to vary according to the size of the standing stock of sand prawn, *C. krausii* (Wooldridge & Bailey 1982). Wooldridge & Bailey (1982) and Daniel (1994) argue that its for this reason that *C. krausii* was encountered more often in the diet of spotted grunter in this estuary than in the Sundays. Daniel (1994) argues that in general, the lower utilisation of *Callianassa krausii* when compared to *Upogebia africana* is due to the fact that *Callianassa krausii* is not as abundant as *Upogebia africana* and it is not readily available to the fish because of its deep burrows (Whitfield 1988), which can be up to 1,5 m deep (Forbes 1977). *U. africana* has a habit of frequenting the surface of its burrow (Whitfield *op cit.*). The 'blowing' feeding mechanism of spotted grunter (van der Elst 1988), therefore makes this anomuran particularly susceptible to predation.

Table 2.3. Composite diet of *P. commersonnii* from six South African estuaries. Data for the Krom, Gamtoos, Swartkops and Sundays estuaries were obtained from Marais (1984). Data for the Kariega and the Great Fish River estuary1992 were obtained from Hecht and van der Lingen (1992). Diet composition is represented by a standardized, Percent Index of Relative Importance (%IRI). n = number of specimens examined.

Estuaries		Great Fish 99/00	Great Fish 1992	Krom	Gamtoos	Swartkops	Sundays	Kariegs
n		69	57	9	7	60	23	21
% stomachs with food		11	42	21.4	7	22	23	70
Size range (mm)		70-780	127-600	250-545	335-492	120-573	137-525	135-446
Prey items								
Crustacea		**99**	**99.01**	**34.1**	**100**	**98.8**	**55**	**99.7**
Brachyura				*9.1*		*4.9*		
	Unidentified	<1	<1	6.6	<1	1.9		
	Sesarma catenata					3		
	Hymenosoma orbiculare	<1	<1	2.5				<1
	Cleistostoma edwardsii	<1	<1			<1		
	Thaumastoplax spiralis	<1				<1		
Anomura				*25*	*99.2*	*63*	*55*	
	Unidentified					<1		
	Upogebia africana	6	55	18.4	98	68	53	98
	Callianassa krausii	72		6.4	1.2	26	2	
	Diogenes sp.					<1		
Mysidacea								
	Mesopopsis slabberi	<1	28					
	Rhopalopthalamus erranatalis	<1	<1					
Isopoda						<1		
	Eurydice longicornis	<1						<1
Amphipoda						<1		
	Grandidierella lignorum	19	13					<1
Macura								
	Palaemon pacificus	<1						<1
	Penaeus sp.	<1						
Mollusca		**<1**	**<1**	**62**		**<1**	**<1**	**<1**
Plecepoda								
	Solen capensis		<1			<1		<1
	Solen corneus	<1		62			<1	
Gastropoda								<1
Annelida		**<1**					**<1**	
Polychaeta								
	Lumbiensis sp.	<1					<1	
Plant		**<1**		**2.3**		**<1**		
	Zostera capensis					<1		
	Spartina capensis					<1		
	Acasia cyclops			2.3		<1		
Teleostei		**<1**				**<1**	**<1**	**<1**
	Gobidae	<1				<1		<1
	Soleidae						<1	

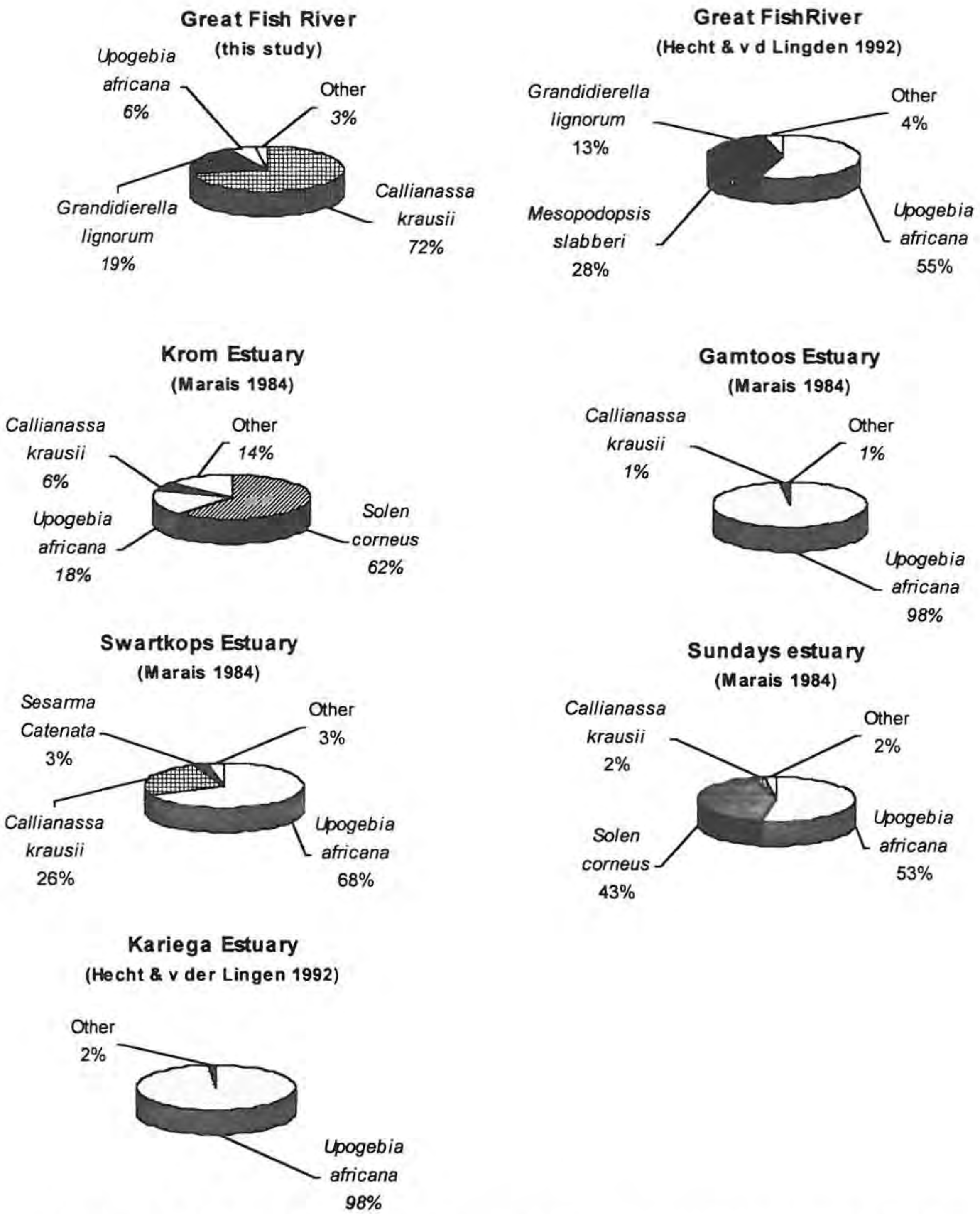

Figure 2.3. The most important prey items of *P. commersonnii* from seven South Eastern Cape estuaries. Percent values were calculated from data presented in Table 2.3.

In this study, *Callianassa krausii* contributed more to the diet of spotted grunter than *U. africana*. In the other study on the dietary preference of spotted grunter in the Great Fish River estuary, Hecht & van der Lingen (1992) did not find any *Callianassa krausii* in the stomachs of spotted grunter (Table 2.3, Figure 2.3). Similarly, in a feeding study in the Sundays estuary, Marais (1984) found that pencil bail (razor clam), *Solen corneus* contributed 43% to the diet of the fish (Figure 2.3). In a subsequent study in the Sundays River estuary (Daniel 1994), where the same methods as Marais (*op cit.*) were used, *Solen* species were found to be absent from the diet. It is possible that these differences could have been caused by changes to the habitat of the respective systems, however there is no information with which to test this hypothesis. Even though reasons for these discrepancies are not clear at this time, these findings suggest that the diet of spotted grunter is highly flexible.

Solen corneus was the most abundant prey item (Figure 2.3) of spotted grunter in the Krom estuary (Wallace 1984) and some were recorded in stomachs from fish in the Swartkops, and Great Fish River estuaries (Table 2.3). *Solen* species are known to burrow deeply into firm clean sand in estuaries and lagoons (Branch *et al.* 1994) and are inaccessible to most estuarine species. However the 'blowing' feeding mechanism of spotted grunter (van der Elst 1988) allows the fish to successfully hunt for these species when they are present. Daniel (1994) suggests that this mechanism can be seen as an adaptation to estuarine feeding, since the 'blowing' mechanism allows spotted grunter the flexibility to capture prey species that would under normal circumstances not be utilised to any great extent by other species except white steenbras (*Lithognathus lithognanthus*).

Conclusion

Blaber (1983) noted that the relative gut length, gross morphology of the gut and the daily feeding pattern of spotted grunter conform to the benthic carnivore pattern. Analysis of the diet of spotted grunter from this and other studies indicate that the species feeds on a wide variety of organisms and therefore its description as a benthic carnivore is fitting. The diet of fish < 70 mm TL in the Great Fish River estuary is dominated by crustaceans and smaller amphipods and estuarine brachyura form the bulk of their diet. However, they are fairly opportunistic and are capable of scavenging segments off larger anomurans. Similarly, amphipods also dominate the diet of spotted grunter between 70 and 300 mm TL. However from about 200 mm TL the fish start to feed on *Callianassa krausii* which later become the primary prey of fish larger than 300 mm TL. The year round abundance of the main prey items of fish > 70 mm TL is the best explanation for the year round similarity in the diet of *P. commersonnii.* Crustaceans are also the primary prey items of *P. commersonnii* in other estuaries in the South Eastern Cape. The two anomurans, *Callianassa. krausii* and *Upogebia africana,* as well as the pelecypod are exploited using the 'blowing' mechanism of feeding. It is this mechanism that allows spotted grunter the flexibility to exploit benthic species that are not usually available to other estuarine fish. Diet flexibility therefore allows the composition and abundance of the macrobenthos of a particular system to dictate the diet of the species in that system (Blaber 1983).

The importance of diet flexibility will be examined in Chapter 5 with respect to the life history and demographics of the species.

CHAPTER 3 – AGE AND GROWTH

Introduction

The ability to determine the age of fish is an important tool in fishery biology (Bagenal 1974). Age data in conjunction with length and weight measurements are essential to understand important life history parameters such as longevity, growth rate, age at maturity and mortality and the dynamics of fish migrations (Coetzee & Baird 1981, Matheson *et al.* 1986, Griffiths & Hecht 1995, Booth & Buxton 1997). Much of this information is necessary for population assessments and the determination of optimal yields and hence is vital to fisheries management (Ricker 1975, Gulland 1983, Powers 1983, Summerfelt 1987, Buxton 1993, Maartens *et al.* 1999).

Wallace & Schleyer (1979) conducted the only previous study on age and growth of the spotted grunter. The specimens used in their analysis were all collected from northern KwaZulu-Natal. By today's standards, the conclusions drawn are based on limited size classes and dated methods (Booth & Buxton 1997) such as using mean length-at-age to calculate the Von Bertalanffy growth parameters (Schnute 1981). It is also well documented that growth of a species varies both spatially and temporally. For these reasons it was deemed necessary to undertake a completely new study of age and growth of *P. commersonnii* incorporating specimens from the entire distributional range.

Age in fishes is most frequently determined by interpreting and counting the growth zones that occur in various hard tissues such as otoliths, scales, dorsal fin spines, vertebrae and operculae (Weatherly & Gill 1987). Cyclical variation in the somatic growth of fish is affected by internal factors such as spawning and stress, and external factors such as temperature, food availability and photoperiod, and is known as growth plasticity (Weatherly 1990). It is this plasticity that affects the formation of calcified tissues which is registered as growth zones in the hard parts of fish (Radtke *et al.* 1990). Growth zones are generally laid down on an annual basis and represent alternate periods of fast and slow growth. Adjacent translucent and opaque zones, which represent a year's growth, are collectively referred to as an annual growth zone or annulus (Griffiths 1988). Validation of these zones as annuli can be undertaken by plotting the optical appearance of the marginal zone against time (Pulfrich & Griffiths 1988, Schwartz 1990, Griffiths 1996, Gordoa & Moli 1997). Wallace & Schleyer (1979) in their study on *P. commersonnii* found that when viewed under transmitted light, one translucent zone was formed each year, usually between January and March.

Once the age at specific lengths has been determined, growth models can be applied to the data. The parameters obtained from growth models allow comparisons with other species or between the sexes of the same species (Isarev 1976, Japp 1989, Cowley 1990), locality (Payne 1977, Japp 1989), over different time periods (Ricker 1971, Weatherly 1987) or between discrete stocks of the same species (Griffiths 1996). Wallace and Schleyer (1979), in the only study on age and growth of spotted grunter found that the Von Bertalanffy growth equation best fitted the length-at-age data of the fish from northern KwaZulu-Natal. Since this early assessment no such study has been undertaken in any other region where the species is found.

P. commersonnii is widely distributed throughout the western Indian Ocean (Smith & Mc Kay 1991) and occurs in tropical, subtropical and temperate environments. The KwaZulu-Natal coastline and the northern third of the South Eastern Cape are considered to be subtropical, whereas the south western two thirds of the South Eastern Cape and the north-eastern part of the Western Cape are classified as warm-temperate (Branch *et al.* 1994). There is a marked decline in the average summer and winter sea temperatures from subtropical Durban (24-19 °C) southwards to Port Elizabeth (22-16 °C) and Table Bay (18-13 °C) (Whitfield 1998 a). Consequently, lower temperatures are also found in estuaries as one moves in a south-westerly direction along the coast (Day *et al.* 1981). Somatic growth of *P. commersonnii* has been shown to be highly temperature dependant (Deacon & Hecht 1996, Bacela 1998). The Sedgewick/ORI/WWF tagging program has identified that spotted grunter individuals generally remain resident within an 18 km home range (Bullen & Mann 2000). Differences in growth of a species that occurs in different thermal environments are well documented (see review by Edwards 1984). It is therefore hypothesised that growth of spotted grunter would be determined by the environmental conditions of the specific area in which they were captured.

Evidence presented in Chapter 5 suggests that spotted grunter in South African waters may consist of a single stock. To assess the status of the entire stock throughout its distributional range, using per recruit modeling, requires estimation of the growth parameters $L\infty$ and k. However, given that the fish south of KwaZulu-Natal are primarily estuarine dependant, this may prove to be difficult. More than 70 % of the estuaries along the South African east coast are small, temporally open/closed estuaries (Whitfield 2000) in which growth of the fish may be significantly different due to differential food availability in comparison to open estuaries. This hypothesis needs to be tested before a single growth curve can be constructed. Under the circumstances of the project, this was not possible. Instead, it was decided to describe the growth of the species from three distinct 'thermal' regions (Figure 3.1). Whitfield (1998 a) divided the South African coastline into three thermal zones namely: subtropical (from the border of South Africa with Mozambique to the Mbashe estuary), warm-temperate (from Mbashe to Cape Point) and cool-temperate (from Cape Point to Walvis Bay). These three thermal regions roughly correspond to recognised geographical regions of South Africa. KwaZulu-Natal corresponds to the subtropical region, the Eastern and South Eastern Cape together correspond to the warm-temperate region and the Western Cape corresponds roughly to the cool-temperate region (Figure 3.1). The three geographical regions and their associated thermal conditions were adopted for the purposes of this study.

Materials and Methods

In order to understand the biology of the species throughout its distributional range, a collaborative sampling effort was undertaken between Marine and Coastal Management (MCM) in Cape Town, Rhodes University (Grahamstown) and the Oceanographic Research Institute (ORI) in Durban. Information, material and data in the Western Cape were collected by researchers from MCM and from KwaZulu-Natal by ORI. The author collected all the material for the South Eastern Cape.

Sampling and data collection within the different geographical areas (Figure 3.1) was as follows:

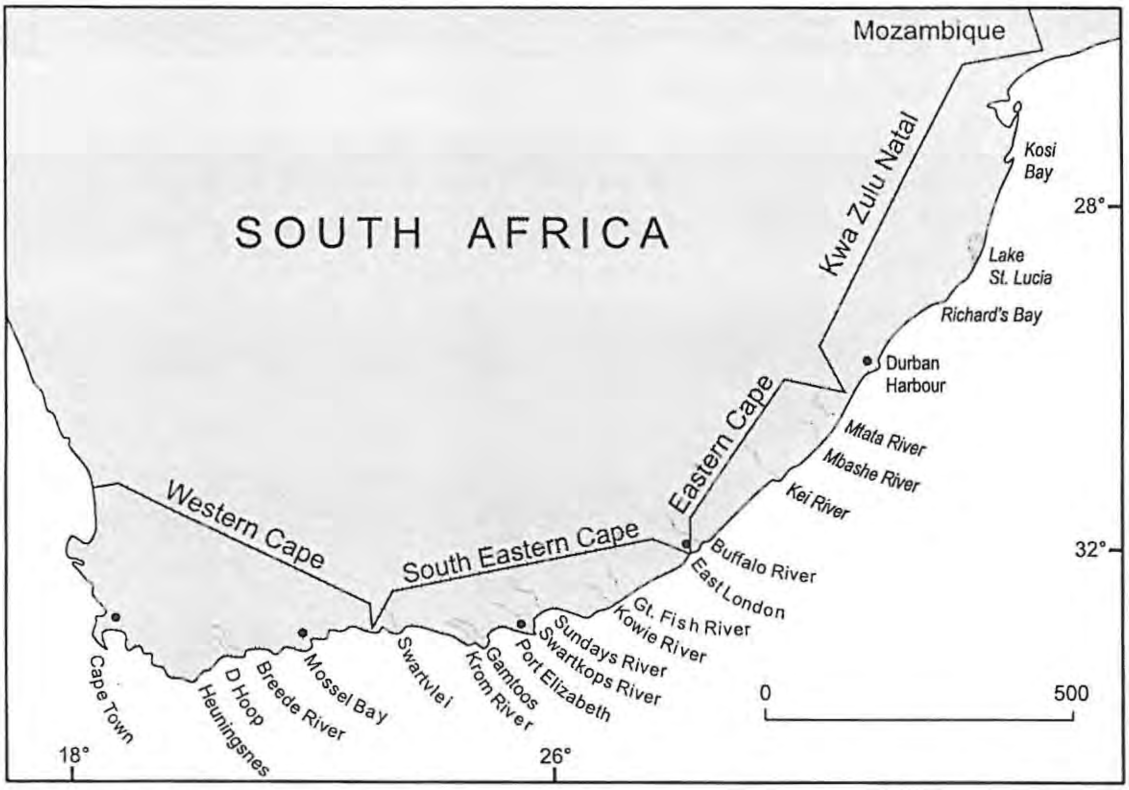

Figure 3.1. Map of the South African coastline illustrating the different geographical regions in which sampling took place.

South Eastern Cape.

Sampling in the South Eastern Cape was conducted primarily in the Great Fish River. Gill nets were set monthly from June 1999 to August 2000 as close to the full moon spring tide as weather permitted. Nets were set parallel to the bank overnight for a 12-hour period. The nets were deployed in the lower and middle reaches of the estuary. The presence of subsistence fishermen meant that the nets could not be left unattended, even for a short while. Shallow water (<1m) did not allow for sampling in the upper reaches of the estuary. The fleet of gill nets used and their mesh sizes are presented in Table 2.1.

Once the nets had been lifted in the morning, fish were removed and transported back to the laboratory within 2 hours. On all but two occasions, fish were worked up fresh on the same day as capture. In November 1999 and January 2000 fish that could not be worked up on the same day as capture, were frozen at -20^0C. These specimens were then thawed and processed within three days of capture.

The time and size at recruitment of juvenile fish into the South Eastern Cape estuaries has previously been studied by Beckley (1984 a), Whitfield *et al.* (1994), Ter Morshuizen *et al.* (1996 b) and Patterson & Whitfield (1996). Monthly recruitment sampling was therefore not undertaken. In February and March 2000, juvenile spotted grunter were collected for analysis by means of a seine net (30m x 2m x 4mm bar mesh), in the lower and middle reaches of the Great Fish River estuary.

Each fish was measured for total length (TL) and fork length (FL) (nearest mm) and whole and gutted weight was also recorded for each fish (nearest gram). The saggital otoliths of each fish were removed and stored dry in cross referenced brown paper envelopes and were then used for age and growth analysis.

Western Cape.

Spotted grunter were collected by Marine and Coastal Management (MCM) field researchers, from both the Breede and Heuningnes estuaries, between August 1998 and February 2000. Sampling in these estuaries was conducted on a quarterly basis using gill nets, seine nets, and rod and line. Dimensions of the gill and seine nets used in the sampling of these two estuaries are presented in Table 3.1

Table 3.1. Dimensions of the gill nets used for sampling of *P. commersonnii* in the Heuningnes and Breede estuaries from August 1998 to February 2000.

Stretched mesh size	Net depth	Net Length	Total net area
44mm	3 m	60 m	$180m^2$
50mm	3 m	60 m	$180m^2$
60mm	3 m	60 m	$180m^2$
75mm	3 m	60 m	$180m^2$
100mm	3 m	60 m	$180m^2$
120mm	3 m	60 m	$180m^2$
144mm	3 m	60 m	$180m^2$

The otoliths as well as the respective total length and weights of fish, collected in the Breede and Heuningsnes River estuaries were made available to the author by Dr Steve Lamberth of MCM. Saggital otoliths were removed from the specimens by MCM staff and stored in a similar fashion as described above. Otoliths were prepared and sectioned by the author.

KwaZulu-Natal.

Saggital otoliths from spotted grunter captured in estuaries, the marine inshore environment and from offshore trawls from KwaZulu-Natal were collected by Dr Sean Fennessy as part of ongoing research at ORI. Specimens captured in estuaries were captured by rod and line, seine net or gill nets. Marine inshore specimens were obtained by means of rod and line and specimens captured offshore were collected from prawn trawlers operating on the Tugela Banks. Saggital otoliths were sectioned by technical staff at ORI and were made available to the author for analysis. Fish length (FL and TL) was measured to the nearest millimeter.

The length/weight relationship, in the form of $W = aL^b$, was calculated monthly for fish collected in the South Eastern Cape and the Western Cape. Data obtained from Sean Fennessy (ORI, Durban) on fish collected in KwaZulu-Natal did not reflect individual fish weights. This region was therefore excluded from length/weight calculations. The value of the exponent (b) can be used as an indicator of condition (Ricker 1975). The length/weight relationship is a power function and the curves can be compared in terms of their slopes (b) (Hecht & van der Lingen 1992).

A logarithmic transformation of the equation $W = aL^b$ gives:

Log $W = \log a + b \log L$

The slopes were tested for differences using analysis of covariance (ANCOVA).

The minimum legal size limits for South African line fish are expressed in terms of total length. However, length measurements obtained in certain research operations are often recorded in fork length. It was therefore decided to calculate, by least squares regression, the fork length/total length relationship so that lengths-at-age could be expressed in terms of total length. The only length measurement taken for the fish collected by Steve Lamberth (MCM, Cape Town) was total length. Fish length measurements from KwaZulu-Natal and the South Eastern Cape were used in determining the total length/fork length relationship.

Otolith preparation and reading

Sagittal otoliths of fish collected in the Great Fish River estuary were extracted by cutting away a portion of bone from the prootic-exoccipital region. They were then lifted from the scull, cleaned and stored dry in cross-referenced envelopes. The left otolith from each pair of stored otoliths from fish collected in the Western and South Eastern Cape were embedded in a clear casting resin rod and sectioned (0.5 mm) using a double-bladed, diamond edged otolith saw. Care was taken to ensure that sections were cut through the nucleus. Each section was mounted on a glass slide with DPX mounting medium. All otoliths were viewed against a black background under reflected light using a dissection microscope. Otoliths were initially read once to gain familiarity with ring patterns. They were then read a further three times, at least a week apart and without any reference to size, locality or time of collection, to record the number of opaque and translucent zones. Otolith readings were only accepted if at least two out of the three readings coincided.

Validation of annulus periodicity was achieved by noting the optical appearance of the otolith margin and expressing it as a percentage of the monthly sample.

Estimation of otolith reading precision

Spawning, stress and external factors such as temperature, food availability and photoperiod influence zone formation in otoliths (Weatherly 1990). Patterns of otolith zone formation may therefore be a reflection of the internal and external environment that the fish was exposed to during its lifetime (Gauldie & Nelson 1990). The ultra-structure of otoliths may therefore differ between regions of which the environmental conditions are not similar (Edmonds *et al.* 1999). Griffiths (1996) noted that the zones of sectioned *Argyrosomus inodorus* otoliths became progressively less distinct from the South Western Cape to the South Eastern Cape. The optical distinction or clarity of the growth zones directly affects the accuracy of the reading of the otolith (Griffiths 1995). It would therefore be expected that reading otoliths with greater optical clarity would equate to a greater precision of the age estimates.

Campana *et al.* (1995) noted that some measure of precision is a valuable means of assessing the relative ease of determining the age of a particular structure, of assessing the reproducibility of an individual's age determinations, and for comparing the skill level of one reader with that of others. The Index of Average Percent Error (IAPE), originally developed by Beamish & Fournier (1981), can therefore be used to test the consistency of readings between age readers. Quantification of the differences in the optical clarity of otoliths can therefore be achieved. Assuming the skill of one reader is the same as that of another, the level of precision achieved on reading the age of the same structure can be an indicator of the "readability" of the structure.

The author and an independent and experienced reader (Professor T. Hecht) examined and read the same randomly selected otoliths from the three different geographical regions. Representative samples of otoliths were randomly selected from size classes that incorporated the entire size range of fish from that region. Otoliths of fish collected in KwaZulu-Natal were comprised of 50 from the St Lucia Estuary (originally collected by John Wallace of ORI in 1975) and 50 from Durban and surrounding areas (Collected by Sean Fennessy of ORI). Results obtained in Chapter

5 meant that it was necessary to identify optical clarity of South Eastern Cape otoliths during the 'grunter run' as well as during the rest of the year. Fifty otoliths from fish collected during the 'grunter run' and 50 otoliths from fish collected during the rest of the year were therefore selected for the South Eastern Cape. Twenty five otoliths from the Western Cape region (collected by Steve Lamberth, MCM, Cape Town) were examined. Each set of otoliths was read twice by each reader.

Precision of readings was tested using the Index of Average Percent Error (Beamish & Fourier 1981) as follows:

If n fish are aged and R is the number of times each is aged then X_{ij} is the ith age determination of the jth fish and X_j is the average age calculated for the jth fish as

$$X_j = \frac{1}{R}\sum_{i=1}^{R} X_{ij} \tag{1}$$

and the average error in ageing the jth fish, as a fraction of the average of the age estimates (APE), as

$$APE = \frac{1}{R}\sum_{i=1}^{R}\left[\frac{|X_{ij} - X_j|}{X_j}\right] \times 100 \tag{2}$$

The Index of Average Percent Error is calculated as

$$IAPE = \frac{1}{N}\sum_{j=1}^{N}\left[\frac{1}{R}\sum_{i=1}^{R}\frac{|X_{ij} - X_j|}{X_j}\right]\times 100 \qquad (3)$$

As the percent error is minimised, greater precision is achieved (Beamish and Fourier 1981).

The coefficient of variation (CV), as suggested by Chang (1982), can be incorporated into the IAPE in order to statistically test the reproducibility of ageing between readers. This can be achieved by replacing the average absolute deviation from the arithmetic mean in Equation (3) with the standard deviation. The percent error contributed by each observation to the average age-class may be estimated by an index of precision (Q) which is the CV divided by √R and the percent error in each age determination made for each observation can be obtained by multiplying the index of precision (Q_j) by the average age for the *j*th fish (Maartens *et al.* 1999).

Growth calculations

Student t-tests on the mean length-at-age ($p < 0.05$) and a *F* test on all data points showed no significant differences between males and females from any of the three regions. The data for the sexes were therefore combined for the purpose of growth calculations and for the construction of an age length key. Calculations were performed on Microsoft Excel spreadsheets designed by Dr T. Booth (Department of Ichthyology and Fisheries Science, Rhodes University).

Length-at-age was modelled using the Schnute and the three-parameter specialised Von Bertalanffy growth model (Schnute, 1981). The Schnute growth model is defined as

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

where L is the length of a fish at age t, t_1 is the age of the youngest fish in the sample and t_2 is the age of the oldest fish, L_1 is the mean length of the fish at age t_1, L_2 is the mean length of the fish at t_2, a and b are relative growth rates. The Von Bertalanffy growth model is described by the Schnute model with b = 1. This model reduces to the familiar form of

$$L_t = L\infty\left(1 - e^{-k\left(t-t_0\right)}\right)$$ Where,

L_∞ is the maximum theoretical length, K the Brody curvature parameter and t_0 the age-at-zero length and

$$t_0 = \begin{cases} t_1 + t_2 - \dfrac{1}{a}\ln\left[\dfrac{e^{at_2}L_2^{\ b} - e^{at_1}L_1^{\ b}}{L_2^{\ b} - L_1^{\ b}}\right] & \text{if } a \neq 0, b \neq 0 \\ t_1 + t_2 - \dfrac{t_2L_2^{\ b} - t_1L_1^{\ b}}{L_2^{\ b} - L_1^{\ b}} & \text{if } a = 0, b \neq 0 \end{cases}$$

then:

$$L\infty = \begin{cases} \dfrac{a^{at_2} L_2^{\ b} - e^{at_1} L_1^{\ b}}{e^{at_2} - e^{at_2}} & \text{if a} \neq 0\text{, b} \neq 0 \\ \exp\left[\dfrac{et_2 \ln L_2 - e^{at_1} \ln L_2}{e^{at_2} - e^{at_1}}\right] & \text{if a} \neq 0\text{, b} = 0 \end{cases}$$

and:

$$K = \begin{cases} a & \text{if a} \neq 0 \\ \dfrac{L_2 - L_1}{t_2 - t_1} & \text{if a} = 0 \end{cases}$$

The parameters for each model were estimated using a non-linear, downhill search to minimise the sum of the squared absolute and relative residuals (Booth & Buxton 1997). An absolute error structure assumes normal residuals (E_t) where,

$$\hat{L}_t = L_t + E_t \qquad E_t \sim N(0, \sigma^2)$$

where L is the model predicted length-at-age *t* the relative error structure assumes that error increases with age such that

$$\hat{L}_t = L_t e^{E^t} \qquad E_t \sim N(0, \sigma^2)$$

The quantity to be minimised for the absolute error structure of the model was

$$SS = \sum \left(L_t - \hat{L} \right)^2$$

and for the relative error structure of the model

$$SS = \sum \ln \left(\frac{L_t}{\hat{L}} \right)^2 \qquad \sum \left[t \ln \left(\frac{L_t}{\hat{L}_t} \right) \right]^2$$

For each model and error structure, a non-parametric one-sample run test was applied to test for randomness of the residuals and a Bartletts's test used to test for their homoscedasicity (Booth & Buxton 1997). The most statistically suitable model was chosen if the residuals were both random and homoscedastic. Variance estimates were calculated using (conditioned) parametric bootstrap sampling with 1000 bootstrap resamples. Standard errors and confidence intervals were constructed from the sorted bootstrap data using the percentile method.

An F test was used to identify differences between derived growth patterns of fish between the Western Cape, South Eastern Cape and KwaZulu-Natal. The F test was also used to identify differences in the growth curves of males and females between each of the three regions sampled. The F test (Zar 1996) is as follows

$$F_{obs}\left((m-1)p, \sum_{i=1}^{m} n_i - mp\right) = \frac{\left[SS_{Total} - \sum_{i=1}^{m} \quad\right] / (m-1)p}{\sum_{i=1}^{m} SS_i / \left(\sum_{i=1}^{m} - mp\right)}$$

where m is the number of models to be compared, p is the number of parameters for the common model, SS_i is the sum of squares of model i, n_i is the number of data points of model i and SS_{total} is the sum of squares of data from all models pooled. The growth models were considered statistically different if $F_{obs} > F_{crit}$ with the specified degrees of freedom.

Results

No significant difference was found between the total length/fork length data of male and female grunter from the South Eastern Cape (F test = 2.26 $p > 0.05$) or KwaZulu-Natal (F test = 3.54 $p > 0.05$) (Table 3.2). As a result, the combined data set of the total length/fork length relationship from each region was used to test for differences between regions. There was no significant difference in the total length/fork length relationship between the two regions (F test = 0.52, $p > 0.05$). The total length/fork length relationship for *P. commersonnii*, can therefore be described by the equation:

TL = 1.074 FL + 2.9263 (Table 3.2) (Figure 3.1)

Table 3.2. Total length/fork length relationships for *P. commersonnii* sampled in KwaZulu-Natal and the South Eastern Cape.

Region	Relationship	n	r^2
KwaZulu-Natal			
	Total length males (mm) = 1.074 fork length (mm) + 2.93	56	0.999
	Total length females (mm) = 1.055 fork length (mm) + 3.01	58	0.999
South Eastern Cape			
	Total length males (mm) = 1.066 fork length (mm) + 2.88	243	0.998
	Total length females (mm) = 1.07 fork length (mm) + 2.62	236	0.999
All regions			
	Total length (mm) = 1.074 fork length (mm) + 2.926	593	0.998

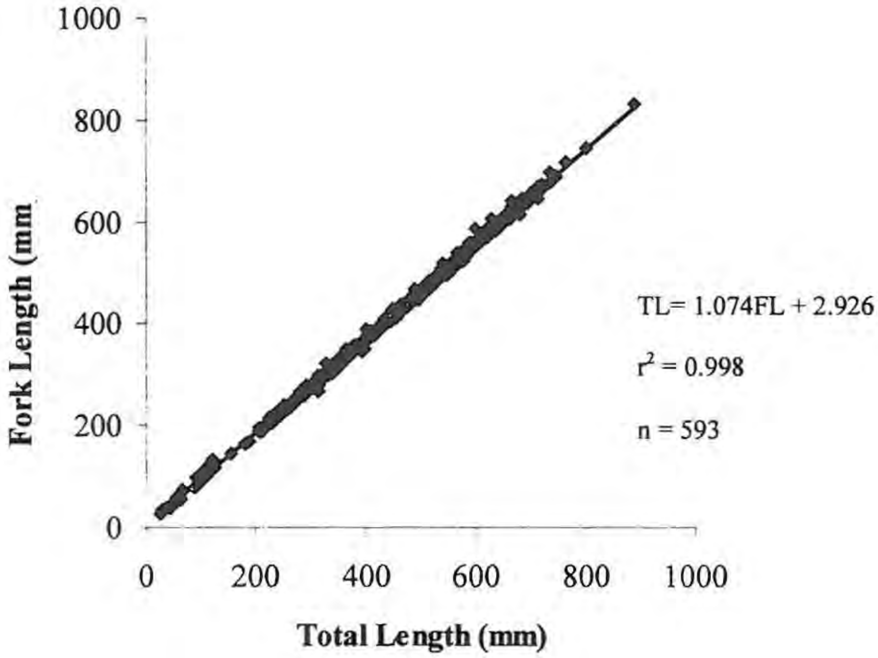

Figure 3.1. Relationship between total length and fork length for *P. commersonnii* from the Western Cape and South Eastern Cape.

No significant difference (*F* test = 0.72, $p > 0.05$) was found between the total length/weight data of male and female grunter from the South Eastern Cape (*F* test = 0.92 $p > 0.05$) or the Western Cape (*F* test = 0.84, $p > 0.05$). As a result, the combined data set of the length weight relationship from each region was used to test for differences between regions. There was no significant difference in the length weight relationship between the two regions (*F* test = 0.62, $p > 0.05$). The length/weight relationship for *P. commersonnii*, shown in Figure 3. 2 can therefore be described by the equation: $W_{(g)} = 2 \times 10^{-5} TL_{(mm)}^{2.891}$.

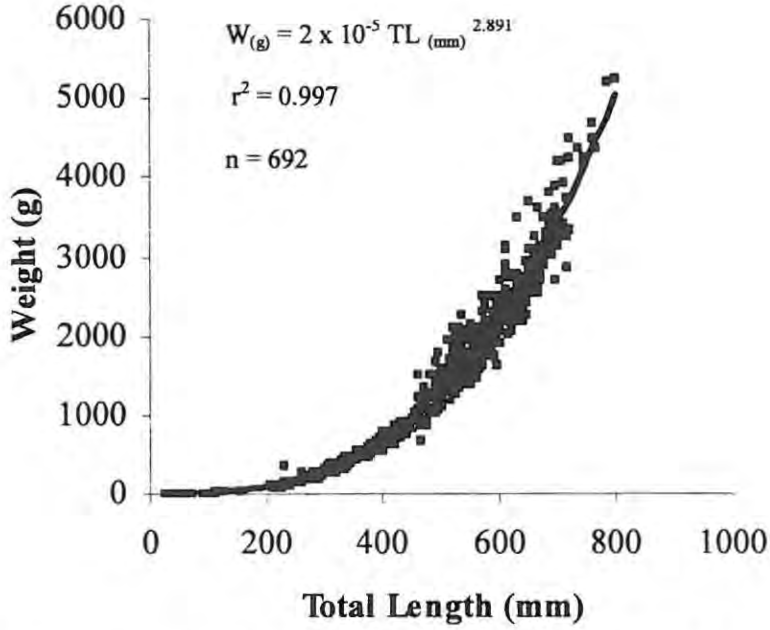

Figure 3.2. Relationship between total length and weight of *P. commersonnii* (n=692).

Since there were no significant differences between the fork length/total length relationship between KwaZulu-Natal and South Eastern Cape, the fork length/weight relationship for spotted grunter can be described by the equation:

$W_{(g)} = 3 \times 10^{-5} FL_{(mm)}^{2.885}$ $\qquad$ $n = 522$, $r^2 = 0.9918$

The value of *b* (2,8912), is less than the isometric growth exponent (3), indicating that this species displays allometric growth (Ricker 1975).

The otoliths of *P. commersonnii,* when examined under reflected light exhibited wide translucent and narrow opaque zones (Figure 3.3). Analysis of monthly percent frequency of opaque and translucent otolith margins from the Western Cape and the South Eastern Cape showed that one translucent and one opaque zone were deposited per year and therefore comprised an annulus. In the South Eastern Cape the opaque zone was deposited in January. In the Western Cape, the opaque zone was deposited primarily in January and February with 30 – 35 % of the population in the area depositing the opaque zone as late as March and April (Figures 3.4 and 3.5, respectively). Due to the unclear nature of the outer margin of the otoliths from KwaZulu-Natal the frequency and temporal nature of zone deposition could not be determined. However, Wallace and Schleyer (1979) showed that *P. commersonnii,* in KwaZulu-Natal, lay down one opaque and one translucent band annually and that the opaque band was formed between November, December and January.

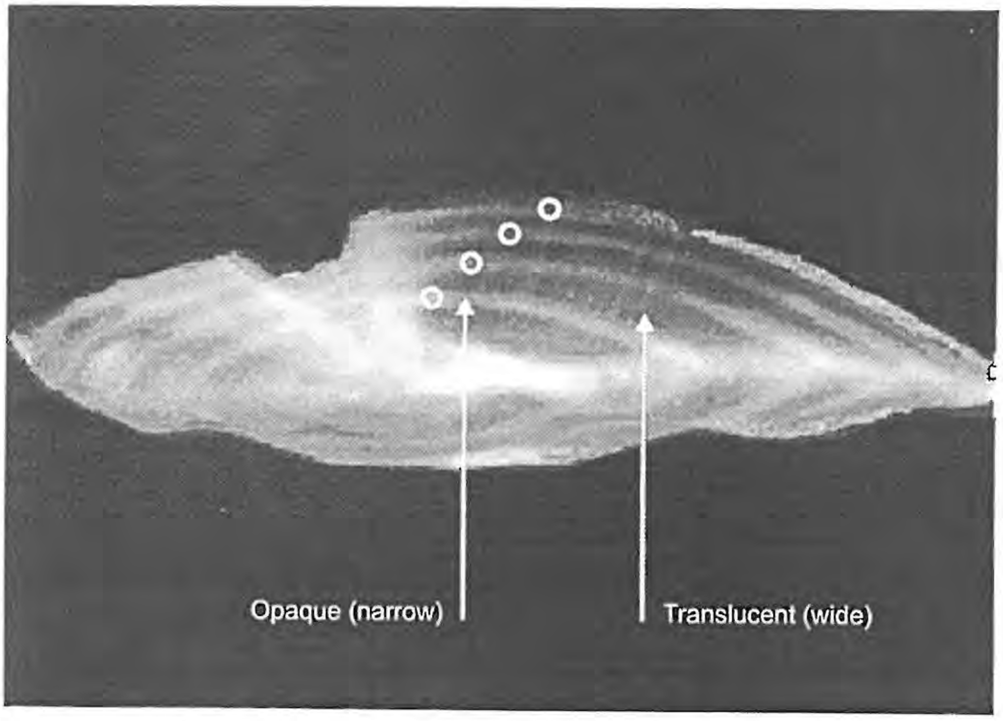

Figure 3.3. A sectioned otolith from a four year old spotted grunter, viewed under reflected light. Note the wide translucent and narrow opaque zones (circles).

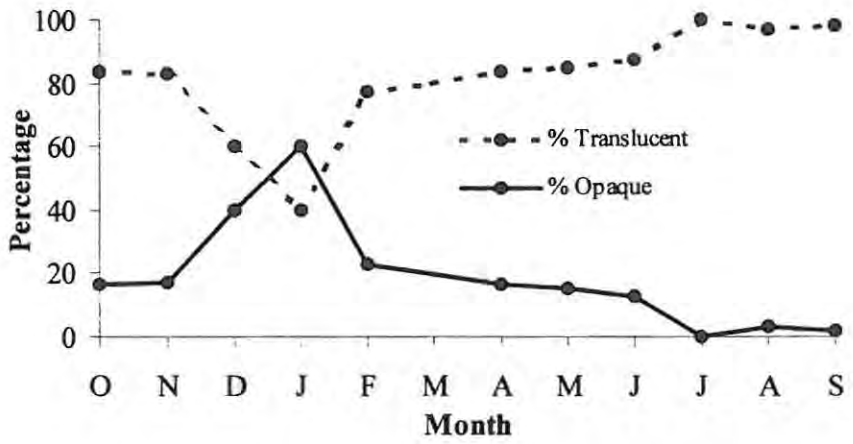

Figure 3.4. The mean monthly percent frequency of opaque and translucent otolith margins from fish sampled in South Eastern Cape estuaries in 1999 and 2000 (n = 513).

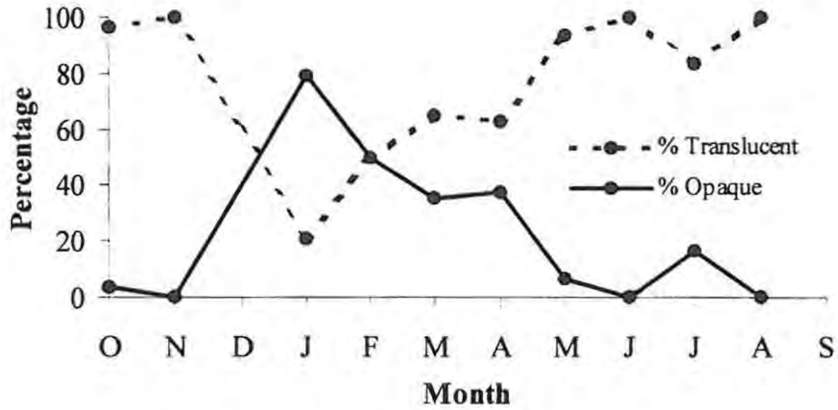

Figure 3.5. The monthly percent frequency of opaque and translucent otolith margins from fish sampled in Western Cape estuaries from 1998 to 2000 (n = 146).

Table 3.3 summarises the number of otoliths read from each of the three regions and those that were rejected.

Table 3.3. Number of otoliths used for age estimation per region.

Region	Total number used	Number Rejected	Percent Rejection
KwaZulu-Natal	202	16	8%
South Eastern Cape	431	26	6%
Western Cape	144	3	2%

Table 3.4 summarises the results of the index of reading precision of otoliths from each of the localities along the South African coastline. By arranging the data from north to south (KwaZulu-Natal to Western Cape) a clear trend can be seen. The distinct translucent and opaque zones in the otoliths from the Western Cape (Q = 2.225, CV = 4.45, Table 3.4) allowed them to be read with greater precision than those from the South Eastern Cape (Q = 4.33, CV = 8.67) and KwaZulu-Natal (St Lucia Q = 6.69, CV = 13.39; Durban Q = 8.91, CV = 17.83). Otoliths collected between February and August in the South Eastern Cape could be read with greater precision than those collected during the 'grunter run' (September to January/February).

Table 3.4. Comparison of the age estimates of *P. commersonnii* otoliths by two readers.

Region	Index of Average Percent Error (IAPE %)	Coefficient of Variation (CV%)	Index of Precision (Q)
St Lucia	10.20	13.39	6.69
Durban	13.62	17.83	8.91
South Eastern Cape (February to August)	6.51	8.67	4.33
South Eastern Cape (September to January/February)	5.08	6.34	3.17
South Eastern Cape (combined)	5.52	7.06	3.53
Western Cape	3.35	4.45	2.23

The age/length keys for *P. commersonnii* in the Western Cape, South Eastern Cape and KwaZulu-Natal are presented in Tables 3.5, 3.6 and 3.7 respectively. Observed lengths varied greatly within age-groups of fish from the Western Cape and South Eastern Cape (Table 3.5, 3.7). Length-at-age of fish from KwaZulu-Natal was less variable than either of the two other regions (Table 3.7).

Table 3.5. Age/length key for *P. commersonnii* sampled from Western Cape estuaries (1998-2000).

Total Length (mm)	Age (Years) 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
100-149																
150-199																
200-249																
250-299																
300-349																
350-399				1	1											2
400-449				1	1	4										6
450-499				2	1	7	1	1								12
500-549					4	16	3	6	5	1						35
550-599					1	12	5	9	10	2	1		1			41
600-649						1	5	4	3	1		3	2			19
650-699							2	2	10		3	3				20
700-749											2		2		2	6
750-799											1	1				2
800-849																
Total				4	8	40	16	22	28	4	7	7	5	0	2	143

Table 3.6. Age/length key for *P. commersonnii* sampled from South Eastern Cape estuaries (1999 – 2000).

Total Length (mm)	Age (Years) 1	2	3	4	5	6	7	8	9	10	11	12	13	14	Total
100-149	1														1
150-199	1														1
200-249	1	13	8	3	2										27
250-299		14	24	12	4										44
300-349			22	38	7	3	1								71
350-399			5	28	14	5	3	1		1					57
400-449				12	13	6	2	1		0					34
450-499				6	14	12	9	5	3	0	1				50
500-549				2	10	5	8	7	2	0	1				35
550-599				2	3	8	6	8	4	2	0				32
600-649				1	3	3	7	9	10	3	1	1			38
650-699				1	1		7	7	5	4	1		1	1	27
700-749							2	1	6	1	2				12
750-799								0		1					1
800-849								1							1
Total	3	17	59	101	72	42	45	40	31	12	6	1	1	1	431

Table 3.7. Age/length key for *P. commersonnii* sampled from KwaZulu-Natal (1998-2000).

Total Length (mm)	Age (Years) 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	Total
100-149	1	1																			2
150-199	1	6	1																		8
200-249		1	1																		2
250-299		1	9	9																	19
300-349			1	8	12	1															22
350-399				4	2	2															8
400-449				4	12	6															22
450-499				1	10	5		1	1												18
500-549					5	7	3	3	1				1								20
550-599					2	4	6	3	1		1				1						18
600-649					2	2	3	2	2	1	1										13
650-699						1	5	2	2	3	1				2	1					17
700-749						1		1	5	1	1	2	2				2			1	16
750-799								1		1	1	2	1	1	2	1					10
800-849																1		1			2
850-899														1				1	1		3
Total	2	9	12	26	45	29	17	13	12	6	5	4	4	2	5	3	2	2	1	1	200

The F test showed that there was no significant difference between the growth curves of male and female grunter from the Western Cape ($F = 0.29$, $p = 0.83$), South Eastern Cape ($F = 1.31$, $p = 0.27$) and from KwaZulu-Natal ($F = 0.1464$, $p = 0.93$). The most statistically suitable, sex combined growth model parameters and error structure of the models for each region are therefore summarised in Table 3.8.

The most statistically suitable model and associated error structure was chosen if the residuals were both homoscedastic and random. The Schnute growth model with an absolute error structure was the only model that successfully fitted the data obtained from the South Eastern Cape. The three parameter Von Bertalanffy, with a relative error structure, was the only model that successfully fitted the data from the Western Cape. Whilst length-at-age data from KwaZulu-Natal was adequately described using both growth models with an absolute error structure, that provided residual homoscedasticty and randomness, no significant difference was found between the two models using a likelihood ratio test (F=0.32, $p = 0.03$). Therefore, the Von Bertalanffy model was chosen, as it has fewer parameters making it statistically more robust (Booth & Buxton 1997).

Table 3.8. Parameters of the selected error structured growth models for *P. commersonnii* in the Western Cape, South Eastern Cape and KwaZulu-Natal that best fitted the data.

	Western Cape		**South Eastern Cape**		**KwaZulu-Natal**	
	Relative 3 parameter Von Bertalanffy		Absolute Schnute		Absolute 3 parameter Von Bertalanffy	
Parameter	Estimate	S E	Estimate	S E	Estimate	S E
L_∞	753	18.76	-		839.11	19.25
K	0.154	0.28	-		0.17	0.33
t_0	-1.615	2.65	-		-0.349	1.43
a	-		0.416	0.06	-	
b	-		-1.266	0.39	-	
L_1	-		177.4	5.67	-	
L_2	-		676.2	15.81	-	

The combined sex growth curves of spotted grunter from the Western Cape, South Eastern Cape and KwaZulu-Natal are presented in Figures 3.6, 3.7 and 3.8 respectively.

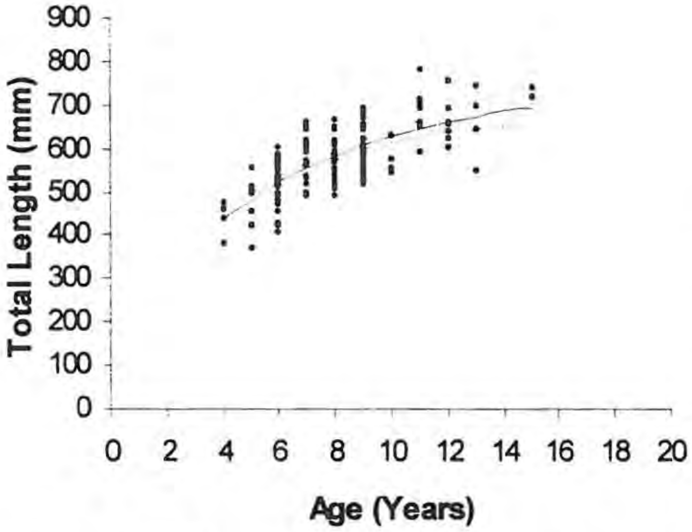

Figure 3.6. Observed and predicted lengths-at-age of *P. commersonnii* from the Western Cape between 1998 and 2000. The growth model that best fitted the data was the relative three parameter Von Bertalanffy model. 95% confidence intervals (dotted lines) are shown.

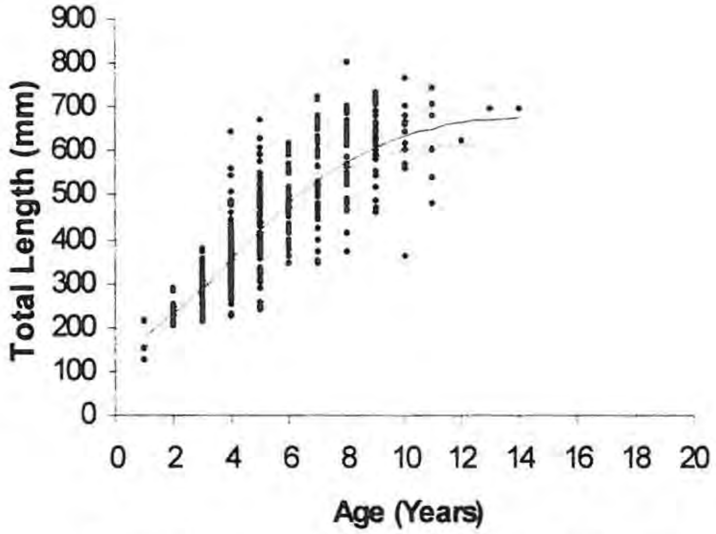

Figure 3.7. Observed and predicted lengths-at-age of *P. commersonnii* from the South Eastern Cape between 1999 and 2000. The growth model that best fitted the data was the Schnute model with an absolute error structure. 95% confidence intervals (dotted lines) are shown.

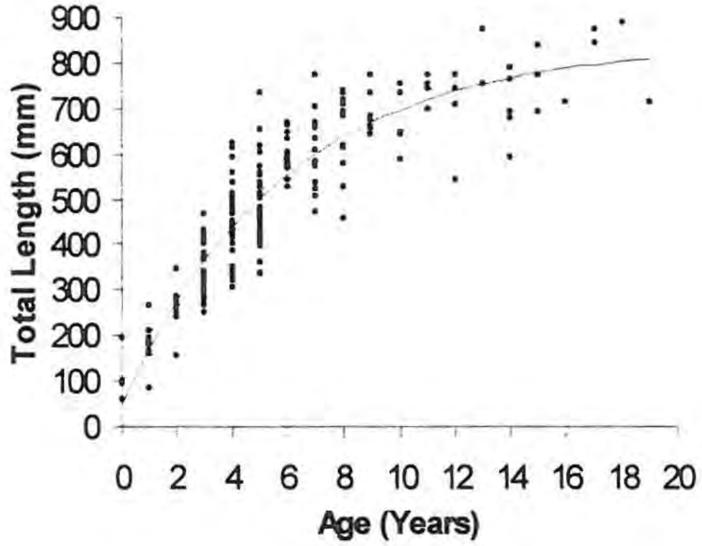

Figure 3.8. Observed and predicted lengths-at-age of *P. commersonnii* from KwaZulu-Natal between 1998 and 2000. The growth model that best fitted the data was the absolute three parameter Von Bertalanffy model. 95% confidence intervals (dotted lines) are shown.

Discussion

Wallace & Schleyer (1979) showed that the narrow opaque zone of the otolith is deposited from spring to mid summer (November – January) in KwaZulu-Natal and that the wider translucent layer is laid down in the winter months. This pattern of zone formation has been observed in many other South African marine fish species (Geldenhuys 1973, Hecht & Baird 1977, Coetzee & Baird 1981, Buxton & Clarke 1986, Buxton 1987, Booth & Buxton 1997). Opaque zone formation in KwaZulu-Natal therefore occurs after the spawning season (July to November) and was suggested by Wallace & Schleyer (1979) to occur as a consequence of a reduction in growth rate while the fish are recovering from the metabolic drain of spawning. It was also suggested that the deposition of the wide translucent zone in the winter months shows that there is no evidence of a winter slowdown in growth (Wallace & Schleyer 1979).

In KwaZulu-Natal, adult spotted grunter enter the estuaries in large numbers after spawning. This event is known as the 'grunter run'. It is suggested that this immigration into estuaries is to regain energy lost to the process of gonadal development and spawning (Wallace 1975a). The majority of the adults appear to remain in the estuaries until the early onset of gonadal development (March) after which they move out into the marine environment. The period of opaque zone formation (November to January) therefore corresponds to this post-spawning, estuarine feeding phase (Wallace 1975 b) in KwaZulu-Natal. Translucent zone formation therefore corresponds with the period of further gonadal development and spawning when spotted grunter are at sea.

Because otolith growth occurs as a result of the differential deposition of calcium carbonate and protein, the metabolism of either or both of these components is believed to be central to annulus formation (Casselman 1974, Simkiss 1974, Griffiths 1988, Buxton & Clarke 1989, Lang 1992). It therefore follows that any factor that affects protein or calcium metabolism may influence otolith growth. Campana & Neilson (1985) identified that external environmental factors including temperature, food availability, and photoperiod as well as internal factors such as spawning and stress (Weartherly 1990) determine the patterns of zone formation. Opaque zone formation in spotted grunter from the South Eastern and Western Cape, although similar to KwaZulu-Natal in that it occurred after the spawning season, was shown to occur between January and March/April. Evidence presented in Chapters 4 and 5, indicates that fish from the South Eastern and Western Cape are exposed to lower average temperatures. Spawning may therefore be delayed and as such may occur from December onwards. It follows then that due to the timing of the spawning period of fish from the South Eastern and Western Cape, opaque zone formation may occur later in these fish than in those fish from KwaZulu-Natal.

Not only did the seasonal timing of otolith zone formation differ between the three regions but fluctuations in internal and external environmental conditions resulted in patterns of zone deposition that influenced the readability of the otoliths in these regions.

Independent of season, the well defined pattern of zone formation in otoliths from the Western Cape meant that these otoliths were read more accurately than those from the South Eastern Cape or KwaZulu-Natal. However, in the South Eastern Cape, readability of otoliths prior to (February to August) and during the period of the grunter run (September to January/February) differed. Differences in the clarity of annuli between fish found in the Western Cape and the South Eastern Cape have also been observed in the otoliths of *Argyrosomus inodorus* (Griffiths 1996). *Argyrosomus inodorus* otoliths from the South Western Cape had very distinct and clear opaque and translucent zones. The zones became more diffuse when moving further east to the Southern Cape and then to the South Eastern Cape. When considering the pattern of readability of spotted grunter otoliths from north to south along the coastline and the evidence presented by Griffiths (*op cit.*), it is hypothesised that the greater zone clarity of otoliths during the grunter run in the South Eastern Cape, is a result of the influx of fish into the region that originate from regions further south. This hypothesis is further examined in Chapter 5.

It must be mentioned that even though a concerted effort was made to collect specimens from the older year classes in each of the regions, great difficulty was encountered in obtaining fish over 12 years of age. The majority of these older specimens were collected in the KwaZulu-Natal marine environment from trawl surveys. This implies that fish older than 12 years make very low contributions to the biomass of the spotted grunter population.

This chapter has focussed on the age and growth of the species separately in each of the three regions that it occurs. Evidence presented in Chapter 5, suggests that the species undertakes an annual spawning migration from the Western and South Eastern Cape to KwaZulu-Natal. This suggests that prior to and after the spawning season spotted grunter may be found *en route* to or from the spawning ground. Identifying key biological data necessary to accurately define the age and growth of the species in each particular geographical region is therefore hampered by the temporal, distributional overlap. However, as a result of the differences in the internal and external environmental conditions that fish were exposed to, age and growth of spotted grunter differed in each of the three regions examined. These differences will be further examined in Chapter 5, where they will be used in understanding the spatial and temporal demography of the species.

As mentioned earlier, because of the wide geographic range of the species plus the fact that it is largely restricted to estuaries south of KwaZulu-Natal (which may be either permanently open or temporally closed) there may be further considerable differences in growth throughout the region. Never the less the study has provided good insight into the growth of spotted grunter in the three major 'thermal' regions along the South African coast. To undertake an assessment of the current status of the stock, the data may either be combined after weighting the curves according to the relative abundance of spotted grunter in the respective regions or alternatively the stock may be assessed on a regional basis assuming that the growth parameters obtained from three regions are representative of the areas as a whole.

CHAPTER 4 - REPRODUCTION

Introduction

The success of any fish species is ultimately determined by the ability of its members to reproduce successfully in a fluctuating environment, thereby maintaining viable populations (Moyle & Cech 1982). As a result, fishes exhibit a diverse range of reproductive strategies involving elaborate behavioural, anatomical and physiological adaptations to maximise reproductive success (Balon 1975).

Although studies on reproduction contribute to the overall understanding of the biology of a species, such studies are also important for management. Relevant aspects for management include the determination of the age and size at sexual maturity, the breeding season, fecundity and the spawning area. These aspects are also important for understanding and explaining fish migration (McKeown 1984). Aspects such as gonadal development, age at maturity and sex differentiation have been investigated for another South African *Pomadasys* species, *P. olivaceum* (Joubert 1981). Aspects of the reproductive biology of *P. commersonni* in northern KwaZulu-Natal have been described by Wallace (1975 b).

P. commersonnii appears to be a dioecious gonochorist (Wallace 1975 b, Day *et al.* 1981, Whitfield 1988). It has been documented by Wallace (*op cit.*) that length at 50% maturity occurs at 300 mm (TL) in males and 360 mm (TL) in females. Wallace's (*op cit.*) study was undertaken in the area from Durban Bay to Inhaka Island (Mozambique), which included many of the northern KwaZulu-Natal estuaries, in particular the St. Lucia estuarine Lake system, Richards Bay and Durban Bay. Adults were found to spawn primarily from September to December. The high proportion of partially spawned and recently spent fish in October indicated that this month might equate to the peak of the spawning season with adults in a recently spent condition found as late as February. Wallace (*op cit.*) also suggested that, due to the occurrence of partially spawned fish in estuaries, spawning probably did not occur at any great distance from the estuary.

Since juveniles of the species have been documented to enter KwaZulu-Natal estuaries at about 25mm to 35mm (Wallace & van der Elst 1975, Whitfield 1980 b), the larval and early juvenile stages are assumed to occur only at sea. In a recent study by Harris & Cyrus (1999) pre-flexion and flexion larvae of *P. commersonnii* were collected in the marine dominated Durban Bay mouth as early as June. This observation further supports the suggestion by Wallace (1975 b) that spawning occurs in the KwaZulu-Natal marine environment.

Apart from the work of Wallace (1975 b) in KwaZulu-Natal, very little is known about the reproductive biology of *P. commersonnii* elsewhere in its distributional range. Since a 'grunter run' (see Chapter 1) also occurs in the Western and South Eastern Cape, albeit on a smaller scale, and in the absence of contradictory information it has been assumed that the reproductive seasonality of the species is homogeneous throughout its distributional range (Day *et al* .1981, Wallace & Schleyer 1979, Whitfield 1998 b).

Given the range of the species in South African waters and in the absence of published information on the reproductive biology of spotted grunter in the Western and South Eastern Cape, the objectives of this study were:

a) To determine whether the species reproduces in the Western and South Eastern Cape.
b) To determine whether there are any differences in the size at sexual maturity between regions.

These are basic criteria used in fisheries management (Booth & Buxton 1997) and also contribute to the general understanding of the reproductive strategy of a species (Balon 1975).

Materials and Methods

Fish collected from the Great Fish River were weighed to the nearest gram, the gonads were removed and weighed to the nearest 0.01 gram and assigned a macroscopic index of maturity (Table 5.1). Descriptions of gonadal development for each of the macroscopic stages were made. Macroscopic stages were further defined by histological examination of the gonads of 4 fish per gonadal stage per sex per month.

Tissue, selected for histological examination, was fixed in Bouins's Fixative for 2 weeks before being transferred to 60% propanol for storage. The tissue was then dehydrated through a series of increasing alcohol concentrations, cleared in xylene and impregnated with paraffin wax (Samoilys & Roelofs 2000). The wax impregnated gonad tissue was sectioned between 5 and 7μm using a rotary microtome. Sections were mounted onto glass slides and stained using standard Gill's haematoxylin (a protein stain) and eosin (a cytoplasmic stain) procedures. After drying, coverslips were placed over the slides using DPX mounting medium (Humason 1979). Light microscopy was used to examine the stained sections.

The criteria and terminology described by Booth & Buxton (1997), Hibiya (1982) and Samoilys & Roelofs (2000) for oocyte and spermatocyte development were used to describe gonad development in spotted grunter. Macroscopic, gonadal staging criteria were determined from these observations. Dr Justus Rutaisire (Department of Ichthyology and Fisheries Science, Rhodes University) assisted with the identification and interpretation of atresia and post-ovulatory follicles.

Macroscopic staging of spotted grunter gonads collected in the Heuningsnes and Breede River estuaries was carried out by MCM staff using a seven stage scale. The criteria used for the staging of gonads by MCM staff are presented in Table 4.1. Samples were not available for direct comparison and calibration with the 5 stage maturity scale used in this study. However, this did not impact on the interpretation of seasonal patterns. Due to the small sample size the results from the two Western Cape estuaries were lumped

Table 4.1. Macroscopic appearance of *Pomadasys commersonnii* gonads observed by MCM staff in the Western Cape from 1998 – 2000.

Stage	Macroscopic appearance
1)	Immature but visually identifiable, testis thin and threadlike, ovaries clear and rounded.
2)	Early development or recovery, testis flattened & whitish, ovary translucent, pale orange and rounded.
3)	Late development or recovery, testis more rounded, milt sometimes present in vas deferens, ovaries opaque, eggs small but visible.
4)	Ripe, testis white, milt present, ovaries turgid, eggs clearly visible.
5)	Pre spawning/ripe & running, testis turgid & white, milt may be extruded from cloaca freely under stress, eggs may be squeezed from cloaca or flow freely, hydrated eggs present, sometimes slight haemorrhaging.
6)	Partially spawned.
7)	Spent.

Since no males or females from the Western Cape and no females from the South Eastern Cape were found in the ripe and running or spent stages, determination of length-at-maturity of these fish was not possible. Length-at-maturity could however be determined for males in the South Eastern Cape by fitting a logistic ogive to the proportion of reproductively active fish in 50 mm TL size classes. For the purpose of this study, length-at-maturity is defined as the size at which 50% the fish are sexually mature (Garratt 1985, Smale 1988, Booth & Hecht 1997). The two-parameter logistic ogive is described by the equation;

$$P(l) = \frac{1}{1 + \exp^{-\left(\frac{l - l_{50}}{\delta}\right)}}$$

Where P(l) is the percentage of mature fish at length l, l_{50} the length-at-maturity and δ the width or steepness of the ogive (Booth & Hecht 1997). Model parameters were estimated by minimising the squared difference between the observed and predicted values.

The most common method for determining gonadal activity in fish is the use of the gonadosomatic index (GSI) (DeVlamming *et al.* 1982). This method requires representative monthly samples of mature fish of the population of fish over a period of at least one year. The gonads of each fish are weighed and a ratio of gonad weight to total body weight is determined. Prior to spawning, the gonad starts to mature, resulting in an increase of the index thus indicating the onset of the breeding season. Gonads can also be staged macroscopically on a monthly basis, which involves categorising the gonad into a stage of development based on visual criteria (West 1990). This method is often used in conjunction with the GSI method. However, the most accurate method of assessing gonadal activity is by way of monthly histological examination of the gonad tissue (Booth & Hecht1997).

Monthly GSI indices were generated for both males and females collected in the Great Fish River (South Eastern Cape) using the equation:

$$GSI = \frac{GonadMass}{EvisceratedMass}$$

Fish weight, provided by MCM from samples collected in the Western Cape, was whole weight. According to De Vlamming *et al.* (1982) the GSI values determined from whole weight would be largely inaccurate due to the temporal variation in weight of the viscera. However, in order to establish broad seasonal trends in gonadal activity in the Western Cape it was decided to determine monthly GSI indices using whole weight.

Given the absence of ripe & running and spent female fish in the South Eastern Cape it was decided to back-calculate the time of spawning from daily growth zones on the otoliths of newly recruited juveniles. In order to validate the daily growth zones, information on larval and juvenile growth was obtained from A.D. Connell (CSIR, Durban) who has reared juvenile spotted grunter from eggs collected in Durban Bay. The mean length of hatchery reared juvenile potted grunter after 38 days was 21.9 mm (TL), while the calculated mean length of wild caught fish after 38 days was found to be 37 mm (TL). However, Connell (pers. comm.) was of the opinion that his fish were stunted due to inadequate nutrition. Without access to further accurate information the analysis was undertaken on the assumption that the growth rings were deposited daily.

The recruits were captured in the Great Fish River estuary in February 2000 and ranged in length from 25 to 65 mm TL. The otoliths of 42 fish were mounted on a slide using Canada balsam, which becomes malleable when heated (Secor *et al.* 1992). Using small circular movements, the otolith was then ground by hand using various grades of wet water paper (from grade 150 to 800), until the core was almost visible. During grinding, the otolith was checked at regular intervals under a compound microscope to ensure that the core had not been ground through. The section was then polished using a 1 μm alumina paste and finally 0.3 μm paste. The slide was then heated to melt the Canada balsam allowing the removal of the section. The section was then glued to a clean slide using cyanoacrylate glue (superglue), which enabled the grinding and polishing of the other side. The other side was then ground until the core was located and then polished as described above. Of the 42 otoliths prepared in this manner 17 had increments that were readable from the core to the edge. Daily increments were counted three times at1000X magnification. The average of the count was then taken as the age of the fish in days. The hatching period could then be back-calculated in order to establish the breeding season.

Results

Histological evaluation of reproductive stages

The mature gonads of *P. commersonnii* are paired and lie in the upper posterior portion of the visceral cavity. Testes range from creamy white to beige, are elongate and slender, while ovaries are deep purple to dark red, heavier, rounder and bilobed and join posteriorly. The histological observations and the corresponding macroscopic criteria for each reproductive stage of development are presented in

Table 4.2

Developmental stages of the testes

1) Immature (Figure 4.1).

Histological examination revealed that immature testes were dominated by aggregations of spermatogonia. Spermatogonia, which are characterised by their large size, prominent cytoplasm and highly basophylic nuclear chromatin, were not situated in spermatogenic crypts and formed part of tightly packed pockets.

2) Resting (Figure 4.2).

Resting testes still showed pockets of highly visible spermatogonia. The testes were however categorised by primary spermatocytes (with smaller nuclei) in the spermatocrypts. A small amount of secondary spermatocytes were visible in the spermatocrypts.

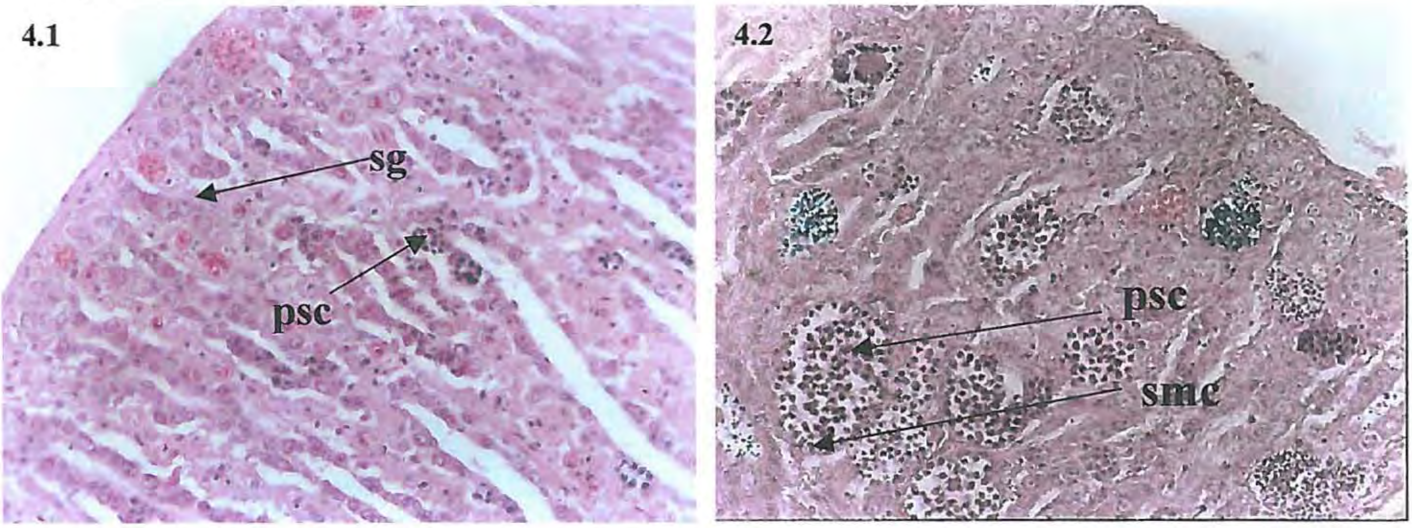

Figure 4.1) Immature testis: Spermatogonia (sg) predominate the lobules. Few primary spermatocytes (psc) are present. 4.2) Resting testis: Spermatogonia present, many primary spermatocytes in spermatocrypts (smc).

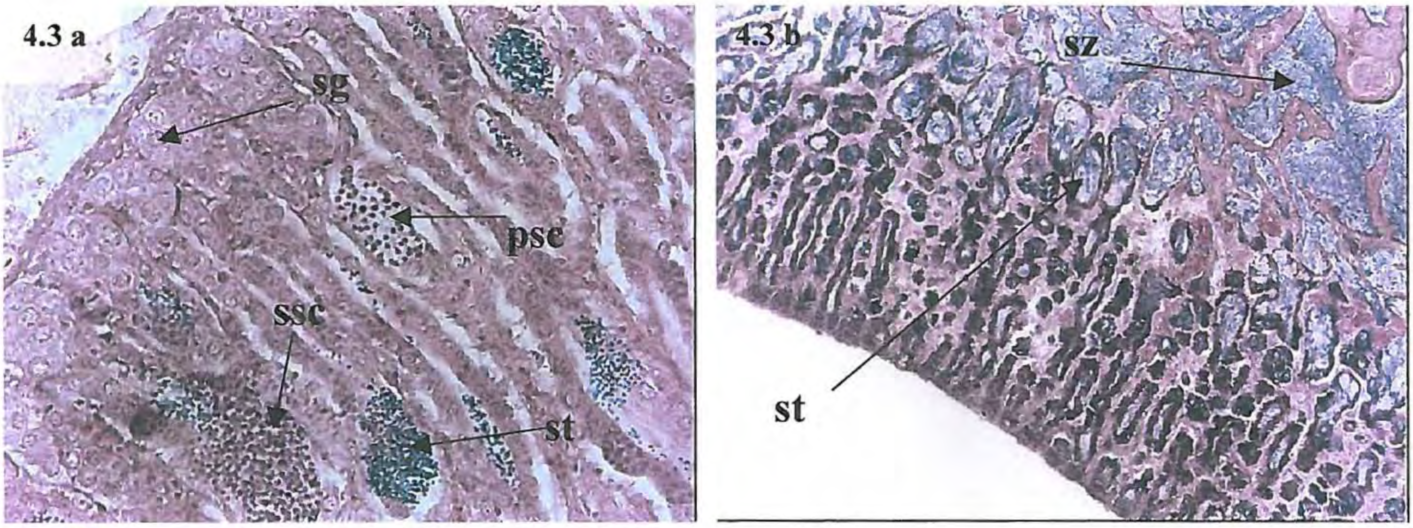

Figure 4.3 a) Early developing testis, primary and secondary (ssc) spermatocyts present, few spermatids (st) in spermatogenic crypts. 4.3 b) Developing testis, mature spermatozoa (sz) and spermatids in duct, all stages of spermatogenesis present.

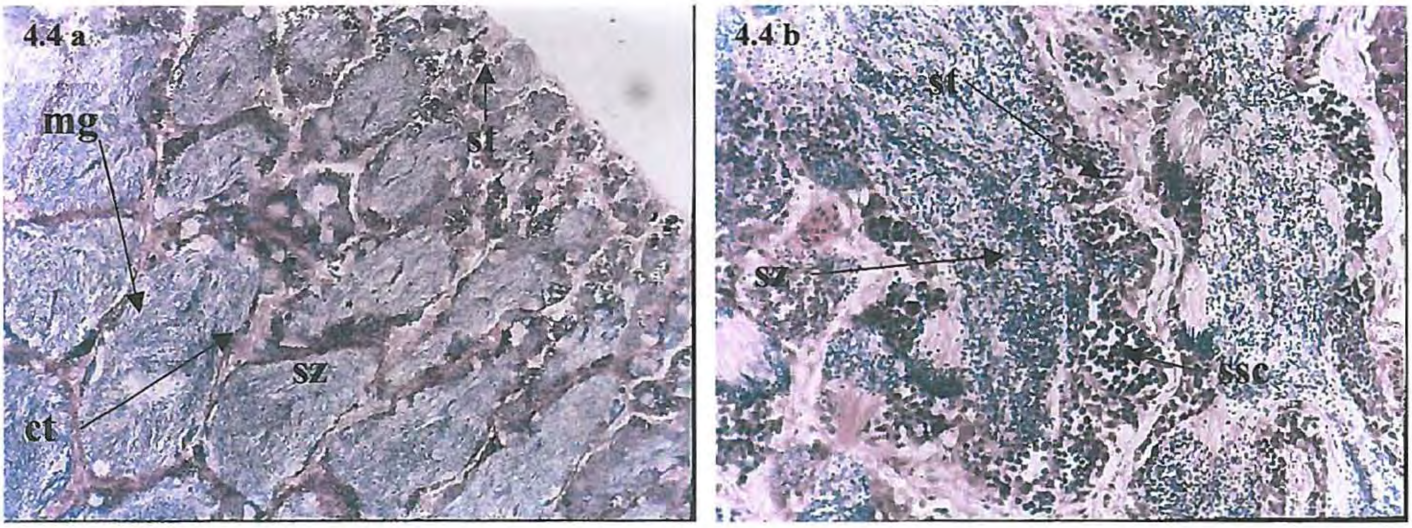

Figure 4.4 a) Ripe and running testis, mega-crypts (mg) held together with connective tissue (ct) filled with spermatozoa. 4.4 b) Ripe and running testis showing remanants of a ruptured spermatogenic crypt, secondary spermatocyts, spermatids and spermatozoa present.

3) Developing (Figure 4.3).

Developing testes showed all the developmental stages of spermatogenesis. Early developing males (Figure 4.3a) had a few secondary spermatocytes and spermatids present.

In developing testes, (Figure 4.3b) primary spermatocytes were not as prevalent in the spermatogenic crypts as were secondary spermatocytes. Secondary spermatocytes were displaced to the lumen of the tubule, with the centre of the crypt filled with spermatids. With the rupturing of the secondary spermatocyte cysts, spermatids were released into the tubule lumen to mature into spermatozoa. The sperm ducts were mostly filled with mature spermatozoa, with spermatids also present but to a lesser degree.

4) Ripe & running (Figure 4.4a and b).

The massive collection of mature spermatozoa in the central sperm duct (Figure 4.4a) distinguished ripe & running testes from developing testes. Spermatids were still present in spermatogenic crypts, however the majority of these crypts were found closer to the wall of the testis. Spermatids that were released from crypts were often released into adjoining crypts. This led to the formation of mega-crypts. However, these crypts had no primary or secondary spermatocytes in the outer edges and were only held together by connective tissue.

Once these mega-crypts had ruptured, (Figure 4.4 b) the size of the spermduct increased. Remnants of spermatogenic crypts were still visible in the lumen tubules and the enlarged spermduct.

5) Spent (Figure 4.5).

Only small crypts of primary spermatocytes were visible in the testis of spent males. The distinguishing factor was the few spermatozoa and spermatids that remained in the degenerated tubule lumens and sperm ducts.

Developmental stages of the ovary

1) Immature (Figure 4.6).

Oogonia were observed in close association with the ovigerous lamellae. They consisted of small cells with a single, large nucleus and basophilic cytoplasm. Oogonia, that had undergone first meiotic division, which were now pre-vitelogenic oocytes, were also present. They consisted of early perinucleolus stages. The ovary also had a thin capsule.

2) Resting (Figure 4.7).

This stage was histologically similar to the virgin stage in that there were many pre-vitelogenic oocytes. The presence of post ovulatory follicles (POF's), atretic, perinuclear oocytes., and thicker gonadal wall therefore distinguished this stage from virgin.

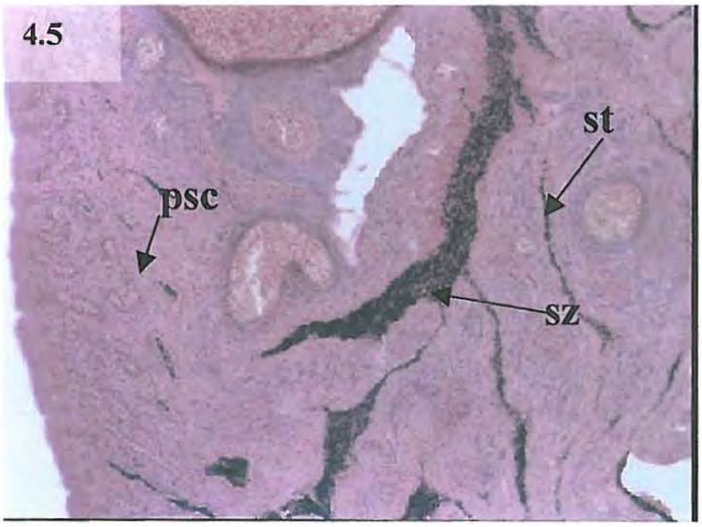

Figure 4.5) Spent testis, primary spermatocytes, spermatids and spermatozoa remaining in degenerated tubule lumens and sperm duct

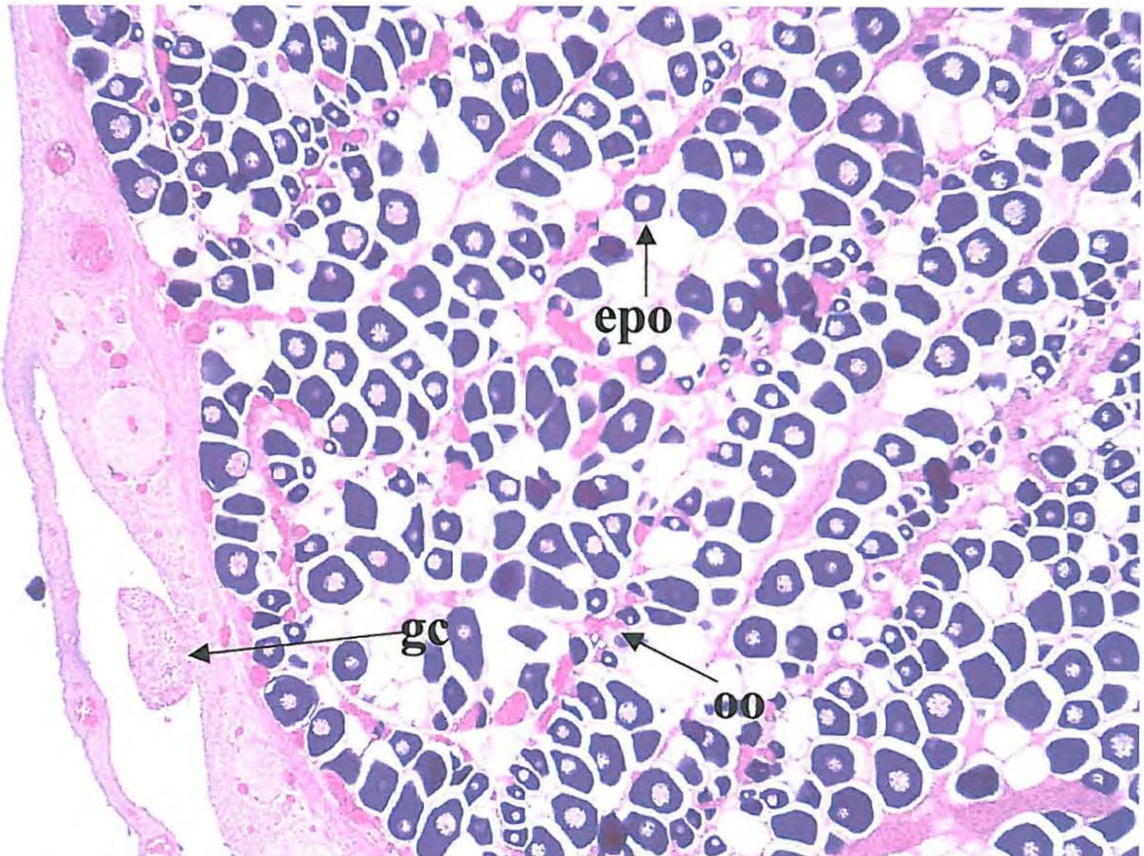

Figure 4.6). Immature female ovary with oogonia (oo), early perinuclear oocytes (epo), and a thin gonadal capsule (gc).

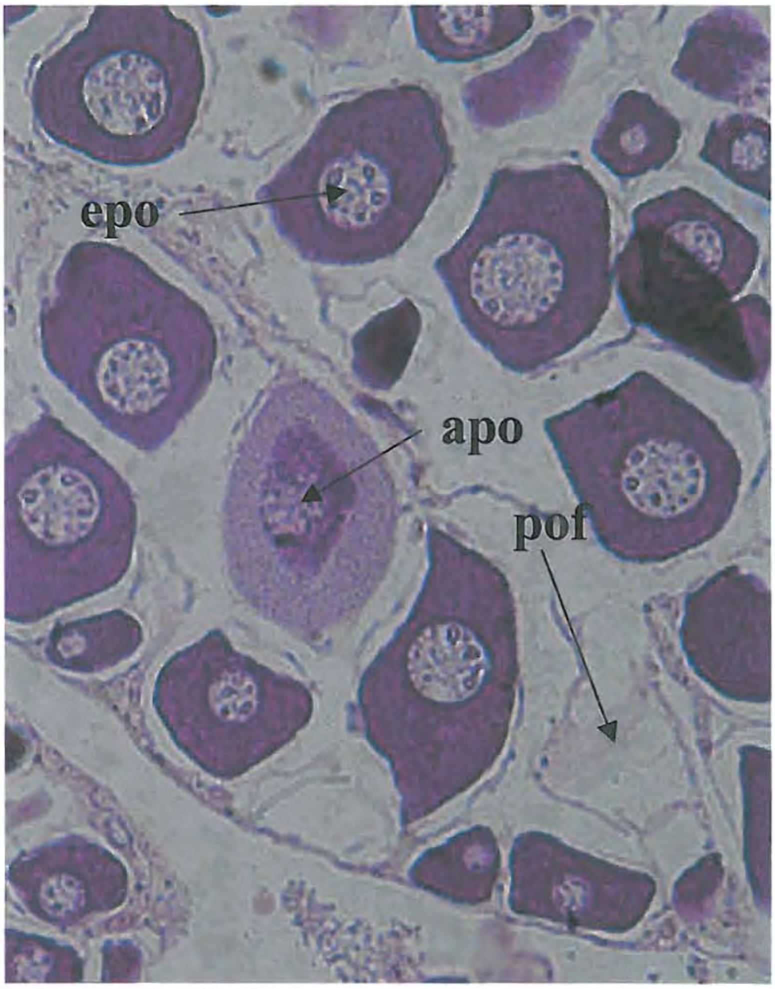

Figure 4.7). Resting female ovary. Early perinuclear oocytes (epo), post ovulatory folicles (pof) and atretic perinuclear oocytes (apo) present.

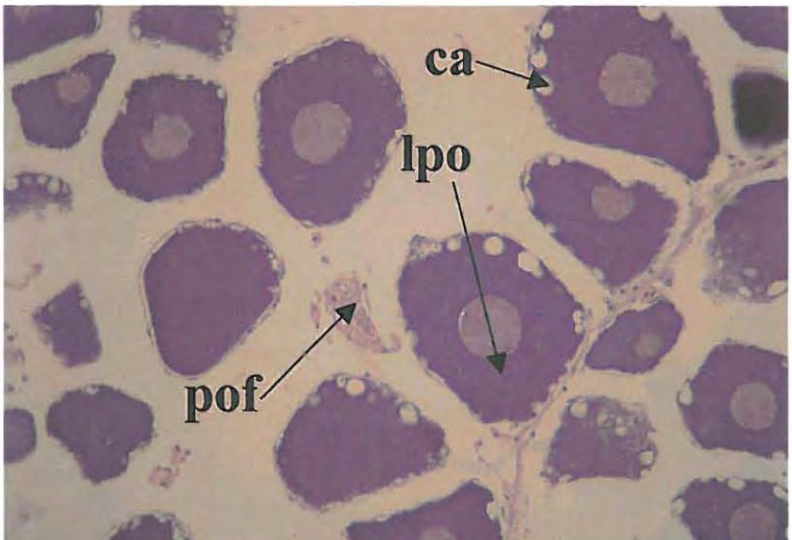

Figure 4.8). Developing female ovary, showing cortical alveoli (ca) in the late perinuclear oocytes (lpo). Pof's are still visible.

3) Developing (Figure 4.8).

The formation of the zona radiata, a non-cellular membrane formed between the folicular layer (zona granulosa and theca) and the developing oocyte, marked the end of the primary growth phase and was followed by the appearance of cortical alveoli in the cytoplasm. Developing ovaries are distinguished from resting ovaries by the presence of these cortical alveoli (West 1990) and as such, indicate the initiation of vitellogenesis (Samoilys & Roelofs 2000). Post ovulatory follicles were still present.

Ovaries with fully hydrated oocytes, indicative of a ripe & running condition (Samoilys & Roelofs, 2000) were not found. A full description of vitellogenesis was therefore not possible.

Table.4.2. Macroscopic appearance and equivalent histological characteristics of *P. commersonnii* gonads at various stages during gonadal recrudescence.

Stage	Macroscopic appearance	Histological appearance
Immature	Ovaries small and translucent and dorsoventrally flattened. Testes are pale, long and threadlike.	Ovaries dominated by oogonia with characteristic polygonal, early perinuclear oocytes present. Testes mostly with spermatogonia in loose pockets.
Resting	Ovaries increase in size and are pale red to orange at anterior end. Testes are triangular in cross section and beige in colour.	Ovaries similar to immature but gonadal wall is thicker. A few post ovulatory follicles and atretic perinucluear oocytes are present. Testes with primary, and to a lesser degree, secondary spermatocytes present.
Developing	Ovaries swell and are turgid with superficial blood vessels well developed. Colour deep purple and eggs not visible to the naked eye. Testes are triangular and beige to sandy brown in colour. If the testis is ruptured, sperm is extruded.	Ovaries have cortical alveoli in the perinuclear oocytes (late perinuclear oocytes) indicating the start of vitelogenesis. Post ovulatory follicles still present. Spermatogenic crypts of testes filled with spermatids and secondary spermatocytes. Sperm ducts contain fair amount of spermatozoa.
Ripe & running	Testes are large, turgid, wide and triangular in shape and firm to the touch. Sperm is extruded from the cloaca if pressure is applied to the abdomen. Ovaries in a ripe & running condition were not found.	Spermatogenic crypts ruptured, inundating the sperm ducts with mature spermatozoa. Spermatids in final stages of maturity in remaining crypts.
Spent	Testes thin and threadlike. No visible sign of dramatic haemorrhaging. Few blood vessels visible on anterior end of lobe. Spent ovaries were not found.	Few spermatozoa and spermatids remaining in the degenerated tubule lumens. Small crypts of primary spermatocytes are visible.

Length at sexual maturity

The logistic ogive model predicts that 50% sexual maturity in males occurred at 305 mm TL (3 years) and all males are mature at 450mm TL (5 years) (Figure 4.9).

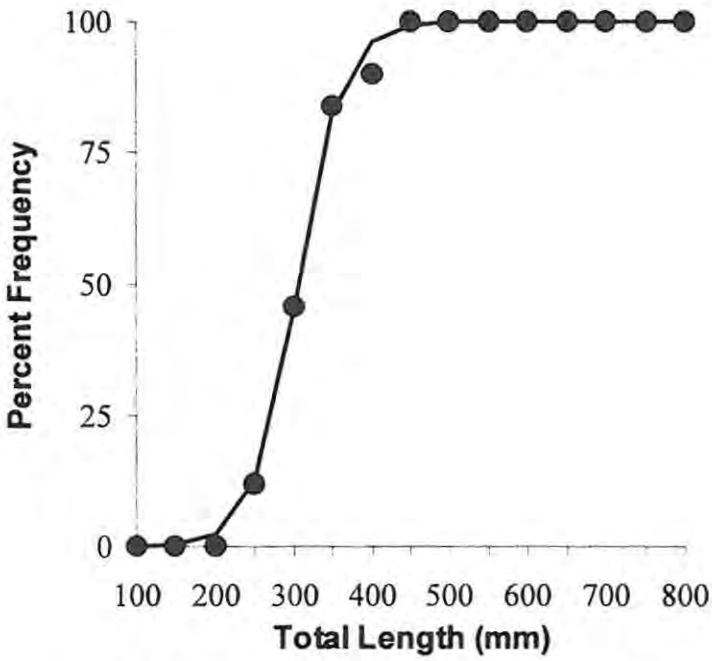

Figure 4.9. Percent frequency of mature male *P. commersonnii* in 50 mm TL length classes sampled in the Great Fish River estuary from 1999 to 2000. n = 217

The data showed that males entering the Great Fish River estuary between August and January had the highest GSI values recorded in the study (Figure 4.11 a). Only seven males in Stage 4 (ripe & running) were observed between October and January and spent males (n = 3) (stage 5) were only recorded in November and January (Figure 4.14). Despite the limited gonadal activity during this period, the majority of the males, as in the remainder of the year, were in a resting and/or developing stage (Figure 4.14, Figure 4.11 a).

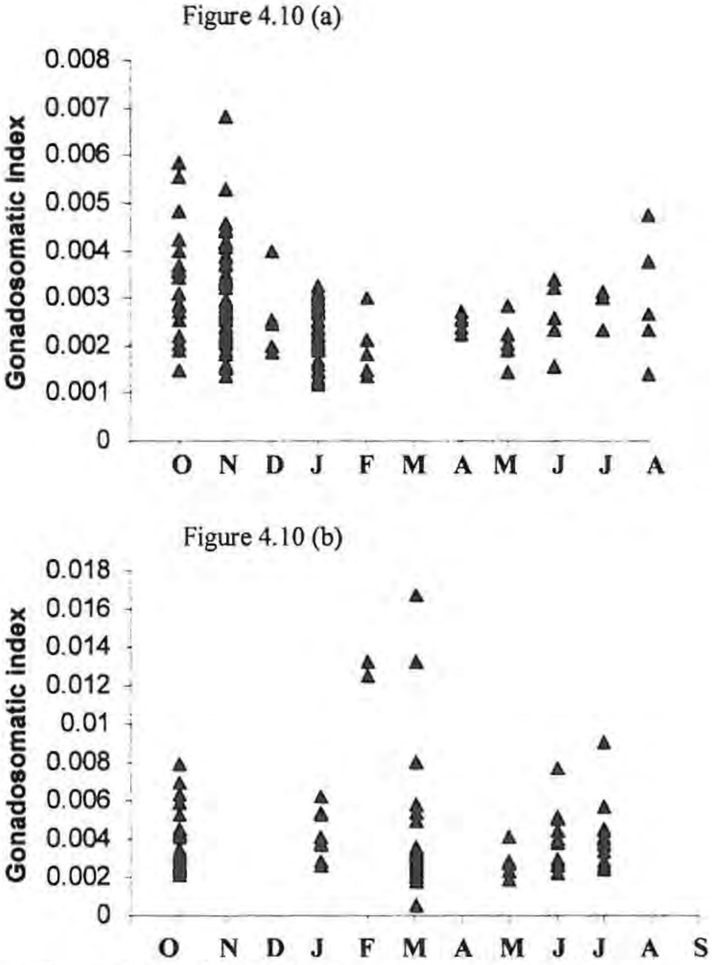

Figure 4.10 . Monthly gonadosomatic indices for female *P.connersonnii* sampled in a) the Great Fiah River (n = 178) from 1999 – 2000 and b) sampled in the Western Cape estuaries (n = 87) from 1998 – 2000.

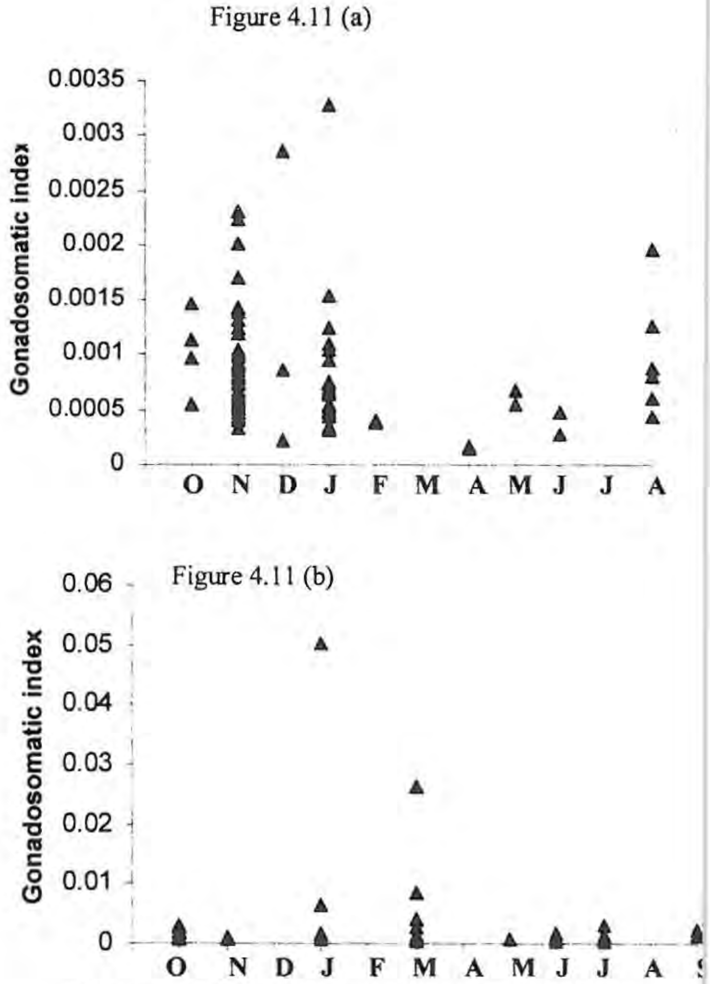

Figure 4. 11. Monthly gonadosomatic indices for male *P.connersonnii* sampled in a) the Great Fiah River (n = 168) from 1999 – 2000 and b) sampled in the Western Cape estuaries (n = 57) from 1998 – 2000.

This was corroborated by the histological data, with moat males being in the early stages of spermatogenesis. From these data we can conclude that male spotted grunter show some, though limited, gonadal activity during the period October to January in the South Eastern Cape.

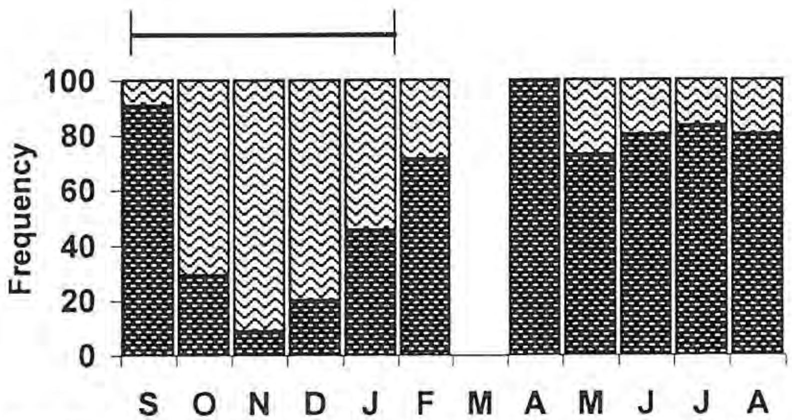

Figure 4.13. Monthly percentage of gonad stages for mature female *P. commersonnii* sampled in the Great Fish River from 1999 to 2000. n = 158. Solid line indicates the time of the 'grunter run'.

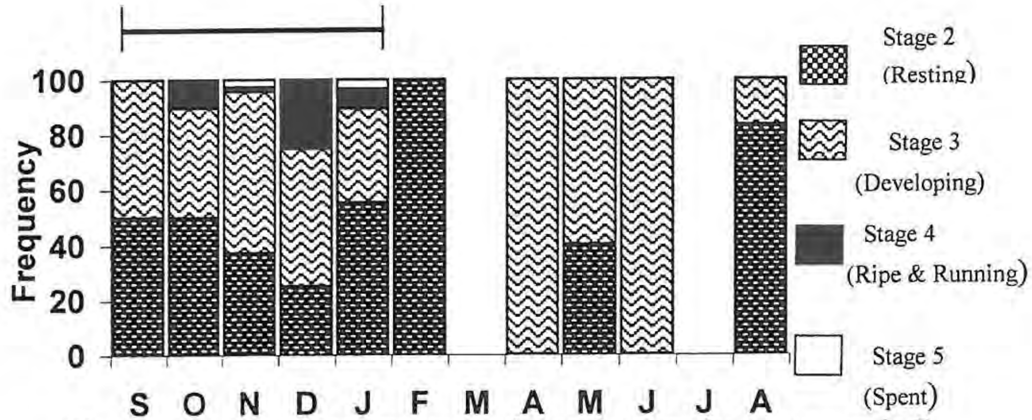

Figure 4.14. Monthly percentage of gonad stages for mature male *P. commersonnii* sampled in the Great Fish River from 1999 to 2000. n = 168. Solid line indicates the time of the 'grunter run'.

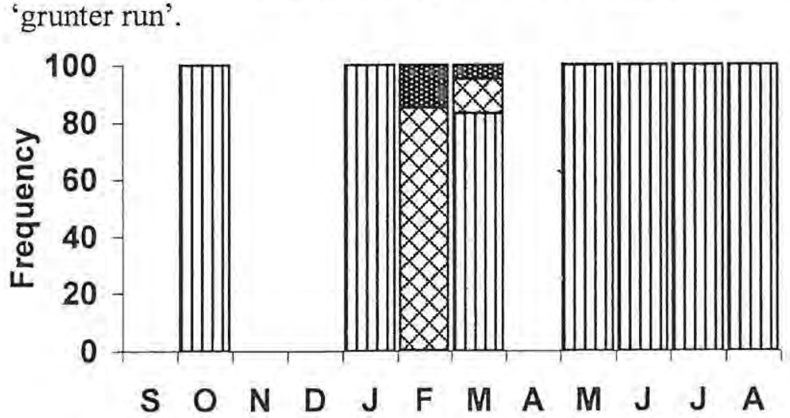

Figure 4.15. Monthly percentage of gonad stages for mature female *P. commersonnii* sampled in the Western Cape from 1998 to 2000. n = 97.

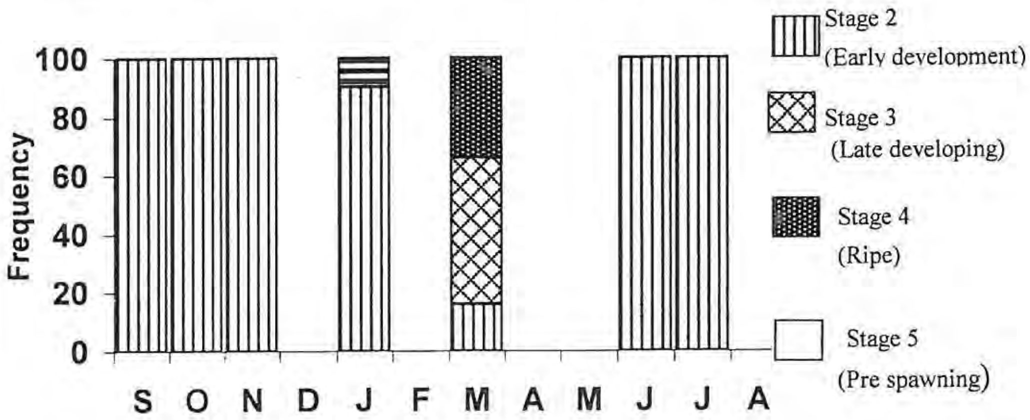

Figure 4.16. Monthly percentage of gonad stages for mature male *P. commersonnii* sampled in the Western Cape from 1998 to 2000. n = 22.

Although very tentative, GSI data shows that females and males in the Western Cape have greater values in the period January to March (Figure 4.10 b, 4.11 b). A limited number of late developing (n=7) and ripe (n=3) females were found in February and March (Figure 4.15). Similarly, two males were found to be in the more advanced ripe stage and 3 males were found to be in the late development stage in March. Males were primarily the early development stage from June to January in the Western Cape (Figure 4.16) and mature females were predominantly in the early development stage from March to January (Figure 4.15). Due to the low number of fish sampled throughout the year, a tentative assumption would be that males and females show very little gonadal activity in the Western Cape, though a slight increase in activity may occur during the period January to March. The absence of pre-spawning, spawning and spent females, and the fact that juveniles of the species are not found in the Western Cape indicates that spawning does not occur in the region. Since there is limited gonadal activity beyond the early development stage, it is suggested that spawning must occur elsewhere.

During the period January to September, mature females with resting ovaries dominated the catches of the South Eastern Cape, while those with developing ovaries were more prevalent in the spring and early summer months from October to December (Figure 4.13). Correspondingly GSI values peaked in October and November (Figure 4.12), but never exceeded a value of 0.007 (Females in stage 4 have recorded GSI values greater than 12.6, Sean Fennessy ORI unpublished data). Given that only two stages of female gonadal development were encountered, GSI values in the South Eastern Cape are only partially representative of the absolute range and cannot be used to define the spawning season in the South Eastern Cape.

Estimation of the spawning season

The back-calculated 'birth dates' of fish determined from daily increment analysis of sagittal otoliths are shown in Figure 4.16. Since all fish in the sample were captured on the same day (22/2/2000), growth in length (mm TL) from date of hatching could be determined (Figure 4.17). The time of hatching, based on the assumption that increments were daily, varied between 26 August and 22 January.

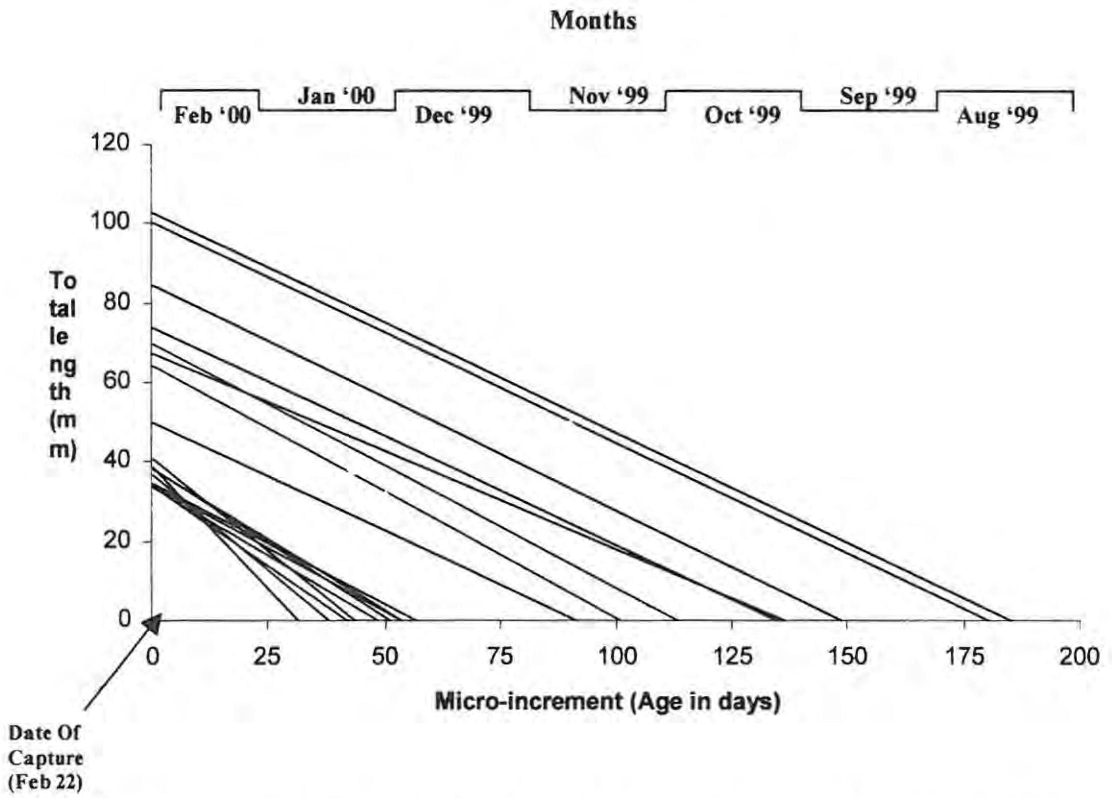

Figure 4.17. Back-calculated birth dates from daily growth rings of otoliths. Length-at-capture is correlated with the birth date of each specimen. All specimens (n = 17) were captured in the Great Fish River estuary on 22 February 2000.

Discussion

It has been documented by Wallace (1975 b) that length at 50% maturity occurs at 300 mm (TL) in males and 360 mm (TL) in females captured in KwaZulu-Natal. This study found that males, in the South Eastern Cape, obtained 50% maturity at a very similar length (305 mm TL). Since determination of the length at 50% maturity for females in the South Eastern Cape was not possible, Wallace's (1979 b) estimation of 50% maturity for females (360 mm TL) was therefore used for the interpretation of the life history of the species in the South Eastern Cape.

The evidence of post ovulatory follicles in the gonads of mature spotted grunter indicate that these mature females have previously spawned. During the time of the 'grunter run' in the South Eastern Cape and Western Cape (September to January/February), the gonads of the mature fish in the estuaries were either in stage 2 (resting) or stage 3 (developing). Gonadosomatic indices indicate an increase in male gonadal activity in the South Eastern Cape over the period August to January. The GSI of female fish in the South Eastern Cape peaked in October and November and dropped off from December to January. Given that the maximum GSI value recorded did not exceed 0.007, which corresponded to stages 2 and 3 (resting and developing) the data suggests that although spotted grunter show evidence of previous spawning, they do not spawn in the nearshore environment of the South Eastern Cape coast.

Wallace (1975 b) and Wallace & van der Elst (1975) observed that at the onset of gonadal development (Stage 2), fish in KwaZulu-Natal exit the estuaries and return to the sea to complete vitellogenesis, spermatogenesis and ultimately spawn. Adults in stage 4 are therefore not frequently encountered in the estuarine environment. Adults then return to the estuaries in a spent condition from the end of July.

By sampling purely in an estuarine environment and not in the marine environment may lead to the suggestion that important stages in the reproductive cycle of spotted grunter that occur in the marine environment of the Western and South Eastern Cape could have been overlooked. The GSI index and macroscopic staging data based on samples collected purely from an estuarine environment may therefore not provide sufficient evidence on whether spawning takes place in the region or not.
However, very few mature spotted grunter have ever been recorded offshore in the Western and South Eastern Cape. Small mesh trawling surveys of the South Eastern and Western Cape undertaken in 1984 by Wallace *et al.* ranged from a depth of 4,5m to 58m. Out of 111 265 fishes caught during this survey, only 7 were spotted grunter. Six of the specimens were caught in 12 meters of water and 1 at a depth of 28 meters. A trawl fishing company (Eyethu Fishing Pty Ltd.) operating east and west of Port Elizabeth in depths ranging from 50m to 180 m, report that catches of *P. commersonnii* are rare and only about 12 individuals have ever been recorded (Peter Simms, MCM, Mossel Bay, pers. comm.).

Unlike in KwaZulu-Natal, where large numbers of spotted grunter can be found offshore (Fennessy 1999), spotted grunter may therefore be restricted to the shallow inshore region and the estuarine environment of the Western and South Eastern Cape. The results obtained from sampling purely in the estuarine environment can therefore be considered to be representative of the majority of the population in the region. Spawning does therefore not occur in the Western and South Eastern Cape.

As mentioned previously, the only area where grunter have been documented to spawn is off the KwaZulu-Natal coastline (Wallace 1975 a, Wallace 1975 b, Wallace & van der Elst 1975, Connell 1996, Harris & Cyrus 1997, Harris & Cyrus 1999). Since the egg, larval and juvenile stages are assumed to occur at sea, juveniles of the species have been documented to recruit into the KwaZulu-Natal estuaries from September to February, at a length of 25mm to 35mm TL (Wallace & van der Elst 1975, Whitfield 1980). Whereas juveniles are rarely encountered in Western Cape estuaries south of the Swartvlei estuary (Whitfield 1988), juvenile *P. commersonnii* are known to enter South Eastern Cape estuaries at about 25 to 30 mm TL (Beckley 1984, Whitfield *et al.* 1994, Ter Morshuizen *et al.* 1996 a, Patterson & Whitfield 1996). Prior to recruitment, fish in the larval and juvenile stages of development tend to accumulate in the vicinity of estuary mouths (Boehlert & Mundy 1988, Whitfield 1989, Potter *et al.* 1990). In a recent study by Harris & Cyrus (1999), pre-flexion and flexion spotted grunter larvae were collected in the marine dominated Durban Bay mouth as early as June. In surveys of the ichthyoplankton assemblages of the marine inshore region in Algoa Bay (Beckley 1986), and off the Kowie and Great Fish River estuaries and South Eastern Cape nearshore environment (Whitfield *et al.* 1994), no spotted grunter larvae were found. It is therefore most likely that juveniles recruiting into the South Eastern Cape estuaries are spawned and pass through the larval stages of development elsewhere.

The daily growth zones of otoliths collected in the South Eastern Cape suggested that fish hatched from August to January. This corresponds to the estimated spawning period of adults in KwaZulu-Natal (Wallace 1975a, Wallace 1975 b, Wallace & van der Elst 1975). After spawning, adults return to KwaZulu-Natal estuaries in large numbers in a spent condition (stage 5) from about July onwards. It is assumed that adults enter the estuary to feed and regain condition after spawning (Wallace 1975 b). This time has become known as the 'grunter run'. Contrary to this, the gonads of the majority of adults caught in the Great Fish River estuary during the KwaZulu-Natal spawning season (August to January) are either in stage 2 or 3. From this it can be concluded that the juveniles found in the South Eastern Cape estuaries were not spawned in the region.

The information presented here on gonad development would suggest that the seasonal influx of adult spotted grunter into the South Eastern Cape estuaries is not directly linked to the reproductive cycle of the species. Given the absence of a clearly defined spawning season or event in the South Eastern Cape, the area may be used as a 'stop-over' *en route* to or from a spawning ground (McKeowen 1984). In the following chapter, an attempt is made to describe the seasonal occurrence of adult spotted grunter in the South Eastern and Western Cape.

CHAPTER 5 – DEMOGRAPHY AND GENERAL DISCUSSION

Introduction

This chapter seeks to provide an explanation of the life history of the spotted grunter. To achieve this aim, the information provided in the preceding chapters is viewed in relation to the demography of the spotted grunter along the eastern seaboard of South Africa.

Decisions on whether specific animal movements represent migrations or not have been highly controversial in past decades (see McKeowen 1984). Definitions of the migration phenomenon have, however, become broader in recent years, and at present encompass most animal movements. Dingle (1980, in McKeowen *op cit.*) describes migration as a specialised behaviour especially evolved for the displacement of an individual from one spatial unit to another. This definition was adopted for the purposes of the present study.

Migrations may generally be divided into three kinds: gametic, for reproductive purposes; climatic, to secure more suitable environmental conditions; and alimental, for the procurement of food (Nikolskii 1963, Harden-Jones 1968). As pointed out by van der Elst (1976), more than one type may be operative at any one time.

The identification and accurate description of any migratory pattern is of importance to the understanding of the life history of a species (McKeown 1984). Since migrations may cross many geographical and political boundaries, knowledge of the life history style of a species is essential for the successful management of that species (McKeown *op cit.*, Griffiths & Hecht 1995).

The most common method employed in the investigation of migratory patterns of South African marine species is by monitoring temporally and spatially related changes in the size composition and the associated reproductive condition of catches along the South African coast. This general approach has been used to study the movements of *Engraulis capensis* (Crawford 1981a), *Sardinops ocellatus* (Crawford 1981b, Armstrong *et al.* 1987), *Pomatomus saltatrix* (van der Elst 1976), *Atractoscion aequidens* (Griffiths & Hecht 1995), *Argyrosomus inodorus* and *Argyrosomus japonicus* (Griffiths 1995).

Detailed investigations into the biology of the above-mentioned species have facilitated the understanding of the life history of each species including their migratory patterns. Based on these patterns, spatial as well as temporal recommendations have been suggested for the management of each species.

Several authors have speculated on the possible migratory nature of spotted grunter (Lilliecrona 1966, Wallace 1975 b, Marais & Baird 1980 b). The absence of scientific evidence has meant that the spotted grunter is currently considered a non-migratory species. Management regulations pertaining to size and bag limits have therefore been enforced as a standard throughout the species' range and at present, there are no seasonal regulations in place.

The annual migration of spotted grunter ('grunter run') into the estuaries of KwaZulu-Natal and the inshore environment takes place between July and January. At this time of year fish enter the estuaries in abundance and literally thousands of recreational and subsistence fisherman descend on the estuaries, in particular the St Lucia estuarine system (Wallace & van der Elst 1975). Large shoals of spotted grunter move in and out of the St Lucia mouth and 'narrows' with the tides and into the lake where CPUE improves. Rock and surf angler catch data from KwaZulu-Natal show a similar pattern of abundance from late winter to early summer with large numbers still being caught in February (Wallace & van der Elst *op cit.*). By March, abundance in the estuaries and the inshore areas drops and relatively few specimens are encountered until August. This migration has been closely linked to the reproductive cycle of the spotted grunter by Wallace (1975 b), who suggested that after spawning in the offshore zone, large shoals of grunter migrate into inshore areas. In KwaZulu-Natal, spotted grunter therefore undertake a lateral (inshore/offshore) migration and it is argued that it may be alimental in design as a method to recover condition after spawning (Wallace *op cit.*).

A similar gregarious, albeit smaller 'grunter run' occurs in the South Eastern Cape from September to January/February. During this period, estuarine catches improve markedly (Marais & Baird 1980 a, Marais 1981, Marais 1983 a, b, Plumstead *et al.* 1985, Plumstead *et al.* 1989 a). In the absence of contradictory information, it has been assumed that, as in KwaZulu-Natal, fish in the South Eastern Cape migrate from the offshore to the inshore environment. It has been assumed that this migration is also motivated by alimental needs (Day *et al.* 1981, Wallace & Schleyer 1979, Whitfield 1998 a). However, in the light of the data and information presented in previous chapters, it appears that spotted grunter in the South Eastern Cape are largely confined to the estuarine and marine inshore environment, suggesting that the fish migrating into the inshore and estuaries during the 'grunter run' do not originate from an offshore stock. The fish migrating into the estuaries and inshore regions of the South Eastern Cape during the 'grunter run' must therefore originate from other inshore and estuarine areas along the coast, suggesting a longshore rather than an inshore/offshore migration. Since spawning does not take place in the Western or South Eastern Cape, migration into the estuaries of these respective areas is therefore not motivated by the immediate need for recovery after spawning. In the light of this evidence, it became necessary to re-examine the preconceived ideas concerning the movements of spotted grunter.

By examining the life history style of spotted grunter and in particular the temporal and spatially related changes in seasonal abundance and the sympatric changes in biology, this chapter aims to identify the specific types of migration that spotted grunter undertake, as well as offer explanations as to the motivation behind them.

Materials and Methods

Since the distributional range of the species extended beyond the practical (and financial) means of this study, certain data pertaining to spatial and temporal size composition could not be obtained personally by the author. Similarly, obtaining catch per unit effort (CPUE) data from areas other than the Great Fish River estuary were also not within the scope of this study. In order to obtain a better understanding of the life history of the species and to present a holistic view of the above mentioned subjects, it was therefore necessary to recalculate, collate and incorporate previous, published data as well as data obtained from Sean Fennessy (ORI, Durban) and Steve Lamberth (MCM, Cape Town). Acknowledgements are made where applicable.

In order to identify the timing of the 'grunter run' in the Great Fish River estuary, gill nets were set monthly from June 1999 to August 2000 as close to the full moon spring tide as weather permitted. Nets were set parallel to the bank overnight for a 12-hour period. The nets were deployed in the lower and middle reaches of the estuary. The presence of subsistence fishermen meant that the nets could not be left unattended, even for a short while. Shallow water (<1m) did not allow for sampling in the upper reaches of the estuary. The dimensions of the nets used are presented in Table 2.1. Measurements (to the nearest mm) were taken for total and standard length of each fish. CPUE was determined by calculating the number of fish caught per m^2 of gill net per month.

Chi-squared analysis was used to investigate the difference between the length frequency of fish present in the estuary during the 'grunter run' and fish present in the estuary during the rest of the year.

The length/weight relationship, in the form of $W = aL^b$, was calculated for fish collected in each season. Since differences in this value between fish in different months are presumed to be associated with nutritional condition (Ricker 1975), the value of the exponent (*b*) was used as an indicator of the condition. The length weight relationship is a power function and such curves can be compared in terms of their slopes (*b*) (Hecht & van der Lingden 1992). If the length/weight relationship is plotted for each season, the slopes can be statistically compared using analysis of covariance (ANCOVA) (Zar 1996).

Mean monthly condition factor was calculated for fish collected in each month. Condition factor for each fish collected was calculated according to the following equation:

$$\text{Condition factor} = (M / L^b) \times 100$$

where M is eviscerated mass in grams, L is Total Length in mm and b is the exponent obtained from the overall length weight relationship.

Angler catch cards obtained from Steve Lamberth (MCM- Cape Town) were used to determine monthly CPUE in the Heuningsnes River estuary from the Western Cape. The CPUE data was determined as: number fish caught / rod/ hour fished.

It was hoped that CPUE data would identify the timing of the 'grunter run' in the Western Cape.

Previously published estuarine CPUE data from the South Eastern Cape were available for the Krom (Marais 1983 a), the Gamtoos (Marais 1983 b), the Swartkops (Marais & Baird 1980 a), the Sundays (Marais 1981), the Kei (Plumstead *et al.* 1985) and the Mbashe (Plumstead *et al.* 1989 a). The location of these estuaries is shown in Figure 3.1. For each of these estuaries, data was recorded by the authors as:

Total mass of spotted grunter caught / m^2 / month.

To identify months when adults predominated the catch in each estuary it was necessary to determine the mean mass of fish collected in each estuary per month. Since total sexual maturity occurs at 650g (450 mm TL), months where the mean mass of fish caught is greater than 650g, can be considered as months where adults constitute the majority of the estuarine population. The total mass of spotted grunter caught/ m^2/month in each estuary was therefore divided by the total number of fish caught in that estuary per month. Data were standardised by presenting each month's mean mass of fish caught as a percent of the entire catch of the period of sampling. Anglers catch data were therefore excluded as effort could not be standardised. CPUE data obtained in this study were similarly converted to reflect mean mass of fish captured per month.

The Sedgewick/WWF tagging programme has been operational since 1984. Since 1984, 4798 spotted grunter have been tagged nation-wide. Tagging has been instrumental in understanding the migratory patterns of many marine fish species (see McKeowen 1984). Since the Sedgewicks/WWF tagging programme is ongoing, the author requested the Oceanographic Research Institute (Durban) to generate a summary report on information pertaining to all recaptured spotted grunter that were tagged between 1984 and 2000. The report was produced by Bullen & Mann (2000).

The size composition of spotted grunter catches from various regions along the South African coast was also investigated using length frequency analysis. Length frequency distributions of gill net catches and angler catches from the Breede and Heuningsnes estuaries were calculated from data provided by Steve Lamberth (MCM Cape Town). Length frequency distribution of spotted grunter collected in the Great Fish River estuary was calculated from data collected in this study. Length frequency data of gill net catches from the Kosi and St Lucia estuaries, as well as data from landed and random, ORI sanctioned trawls, from the Tugela banks were obtained from Sean Fennessy (ORI Durban).

Results

CPUE data showed an increase in abundance of spotted grunter in the Great Fish River estuary from September to January, which fits the angler's description of a 'grunter run'. The catches peaked in November and January but in December, less than 0.1 fish/m^{2}net were caught. Very few fish were present in the estuary during the remainder of the year from February to August (Figure 5.1). The period between February and August are therefore considered to fall outside the 'grunter run'.

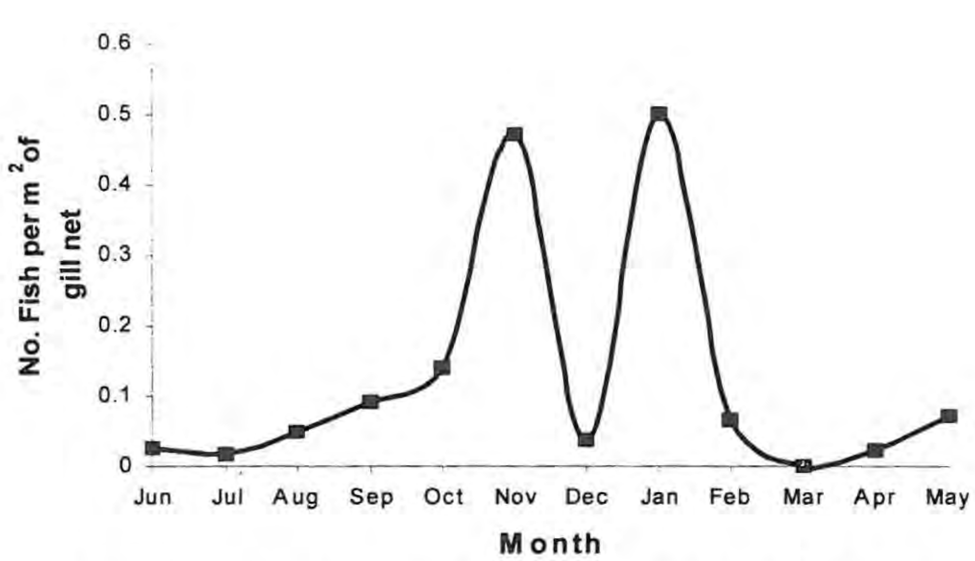

Figure 5.1. Monthly CPUE (number of fish caught per m^2 of gill net per month) of *P. commersonnii* in the Great Fish River estuary from July 1999 to June 2000.

Chi-squared analysis showed that there was a significant difference ($p = 0.0007$) in the proportion of adults and juveniles present during the 'grunter run' with a larger proportion of adults present during this period. However, the proportion of juveniles and adults did not differ significantly throughout the rest of the year. During the period February to August 52% and 48 % of the population consisted of juveniles and adults respectively. Sixty percent of the population present during the grunter run were sexually mature fish, greater than 650 g (400 mm TL, Chapter 3), compared to only 48 % during the rest of the year.

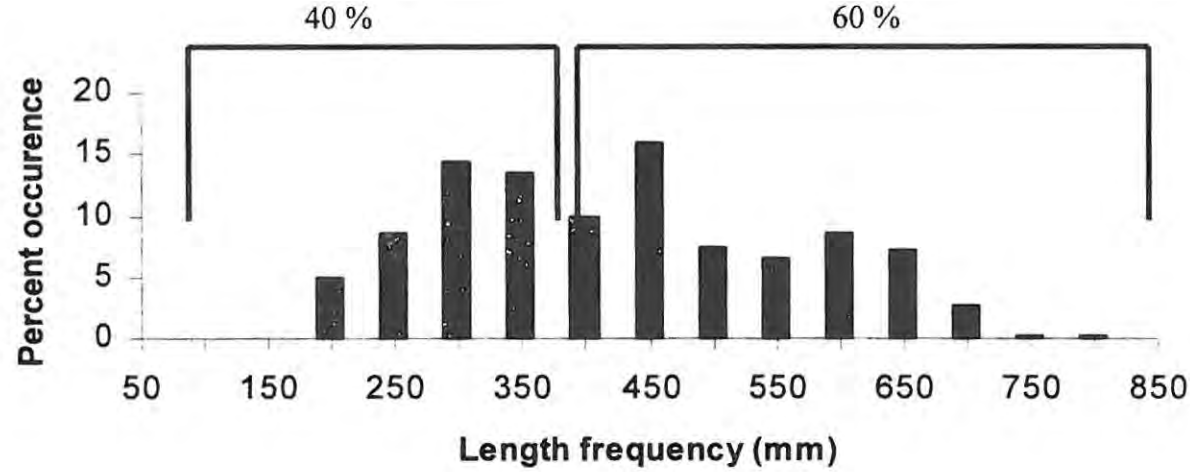

Figure 5.2. Length frequency of fish sampled the Great Fish River estuary from September 1999 to January 2000.

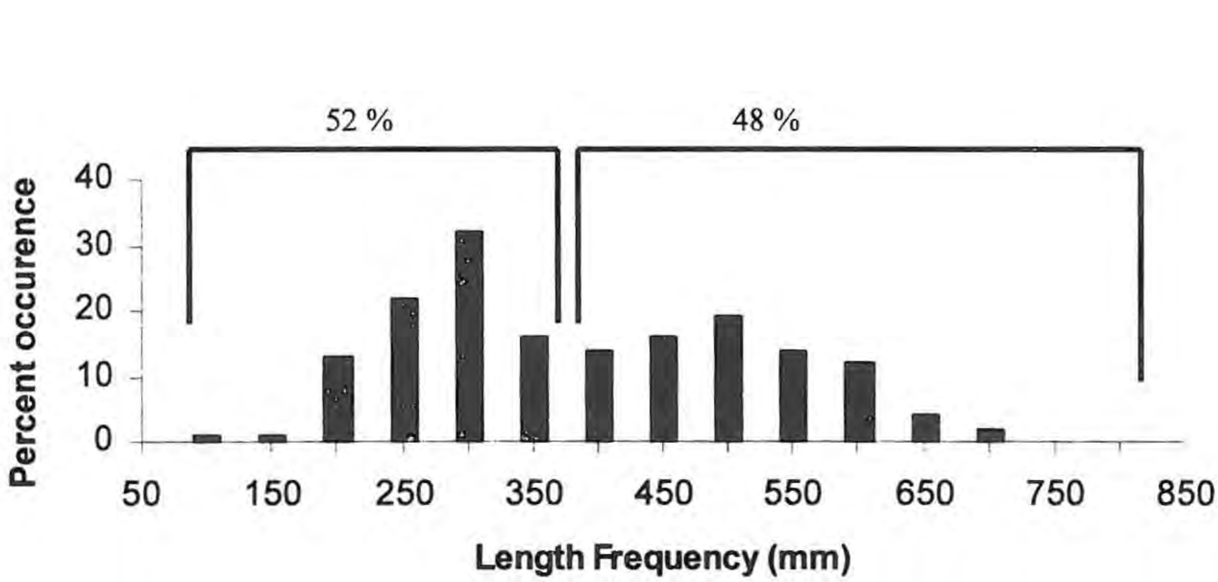

Figure 5.3. Percent length frequency of fish sampled the Great Fish River estuary from June to August 1999 and from February 2000 to August2000.

Analysis of the mean monthly condition factor of fish, although appearing to peak between February and April, showed that there was no significant difference throughout the year (Figure 5.4). This indicates that the condition of spotted grunter, at least in the Great Fish River, does not differ significantly throughout the year.

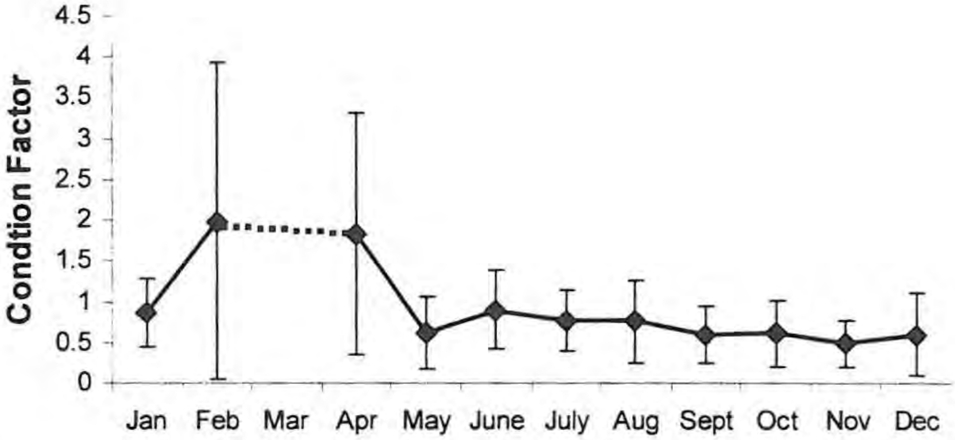

Figure 5.4. Mean monthly condition factors (± standard deviations) of fish sampled in the Great Fish River from 1999 – 2000. n = 532.

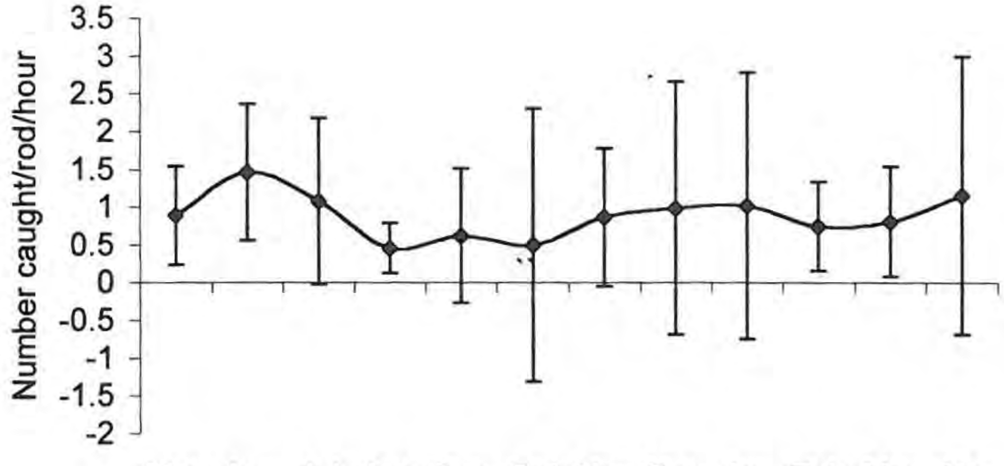

Figure 5.5. Mean monthly angler catch of spotted grunter / rod /hour in the Heuningsnes River estuary from 1995 to 1999. n = 756

Figure 5.5 indicates that mean monthly CPUE did not differ significantly in the Heuningsnes estuary and it was therefore not possible to identify a specific 'grunter run' in this estuary.

Figure 5.6 shows that adult fish (larger than 650g) are present in Eastern Cape estuaries at different times of the year. In the Krom and Gamtoos estuaries, peak abundance of adult fish occurred during the months August to March. However, these abundance peaks are bimodal (September to November and from January to April). In the Swartkops, Sundays and Great Fish River estuaries predominantly adult fish contributed to the year round catch. The Kei and Mbashe estuaries have a have a relatively shorter period of abundance with a distinguishable, single peak of abundance that stretches from September to January (Figure 5.6).

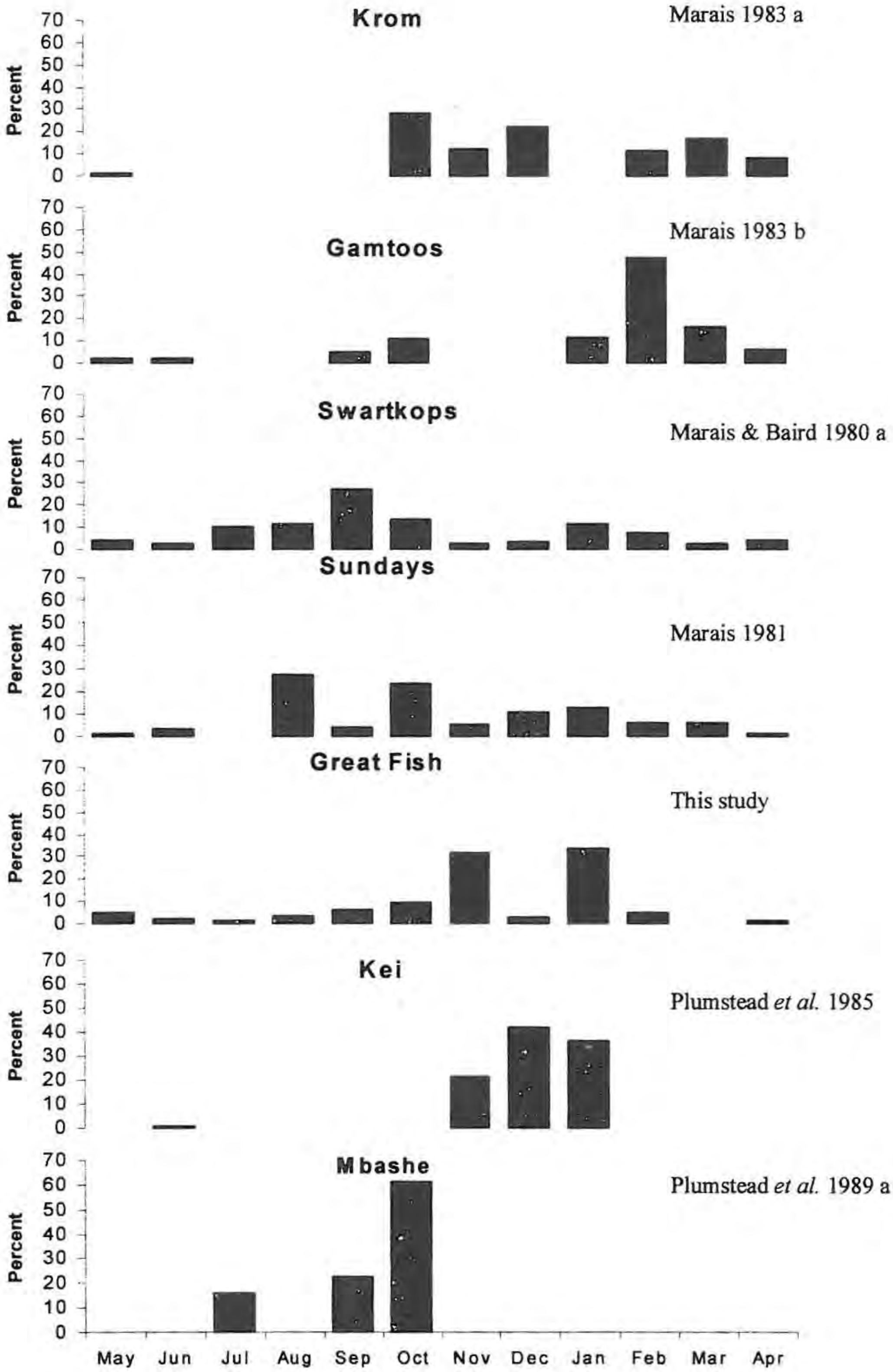

Figure 5.6.Mean catch per unit effort (numbers / m ^{2} / month) for all estuaries sampled with gill nets in the Eastern and South Eastern Cape. Estuaries are arranged from south (top) to north (bottom). When presented by authors, inter annual data was lumped. Months in which the mean mass of fish was less than 650 g were excluded.

A summary of all recaptures of grunter from the Sedgewick's/WWF tagging programme is presented in Table 5.1. The recapture rate of 3.2 % is considerably lower than the program average (Bullen & Mann 2000). Bullen & Mann (*op cit.*) suggest that grunter appear to be largely resident, displaying little or no movement even in those that have been at liberty for up to eight years. Bullen & Mann (*op cit.*) suggested that there is some evidence of nomadic behaviour in larger individuals. The average distance moved relative to the point of release was 18 km. Only 1 fish tagged in KwaZulu-Natal, 4 fish tagged in the South Eastern Cape and 2 tagged in the Western Cape moved distances greater than 100 km. A summary of the movements of these fish is presented in Table 5.2. The average distance that the remaining tagged fish moved is also presented in Table 5.1.

Table 5.1. Summary table of tagged, spotted grunter movement. Data was collected from 1/1/1984 to 30/6/2000.

	KwaZulu-Natal	South Eastern Cape	Western Cape	Totals and Averages
Total number tagged	2838	1574	469	4881
Number recaptured	102	32	17	151
% Recapture	3.5	2	3.6	3.15
Maximum days free	2860	1118	1821	2860
Maximum distance moved	235 km	823 km	563	823 km
Average distance moved	5.6 km	43 km	43 km	18 km
Average distance moved of fish not in Table 5.2	3.3 km	3.8 km	0 km	3.1 km

able 5.2. Tagging analysis of fish from KwaZulu-Natal, South Eastern Cape and Western Cape that moved ıore than 100 km from point of release.

ease :	Point of release	Length (mm TL)	Recapture Date	Point of recapture	Length (mm TL)	Days free	Growth (mm TL)	Distance Moved (Km)	Directior (North / South)
				KwaZulu-Natal					
1/10/07	Richards Bay	380	1992/03/19	Durban	400	164	20	235	South
				South Eastern Cape					
5/02/24	Gamtoos	380	1994/08/30	Durban offshore	N/A	1038	N/A	823	North
93/12/19	Great Fish	350	1999/09/10	Swartkops	360	308	10	155	South
39/12/24	Great Fish	270	1993/10/23	Port Elisabeth	335	912	65	150	South
89/08/23	Gonubie	520	1995/02/27	Kowie	N/A	79	N/A	131	South
				Western Cape					
90/06/03	Breede	530	1997/06/06	Swartkops	N/A	1272	N/A	563	North
94/12/10	Breede	335	2000/02/23	Swartvlei	N/A	34	N/A	182	North

Length frequency analysis showed that fish smaller than 400 mm (TL) only occurred in KwaZulu-Natal and South Eastern Cape estuaries (Figure 5.7). The majority of legal size fish (larger than 400 mm TL) that were caught by anglers in the Breede and Heuningsnes estuaries were larger than 600 mm (TL). Gill net sampling in the Breede and Heuningsnes estuaries only produced 2 fish smaller than 400 mm TL. 98% of fish captured in gill nets in the Western Cape were therefore larger than 400 mm TL.

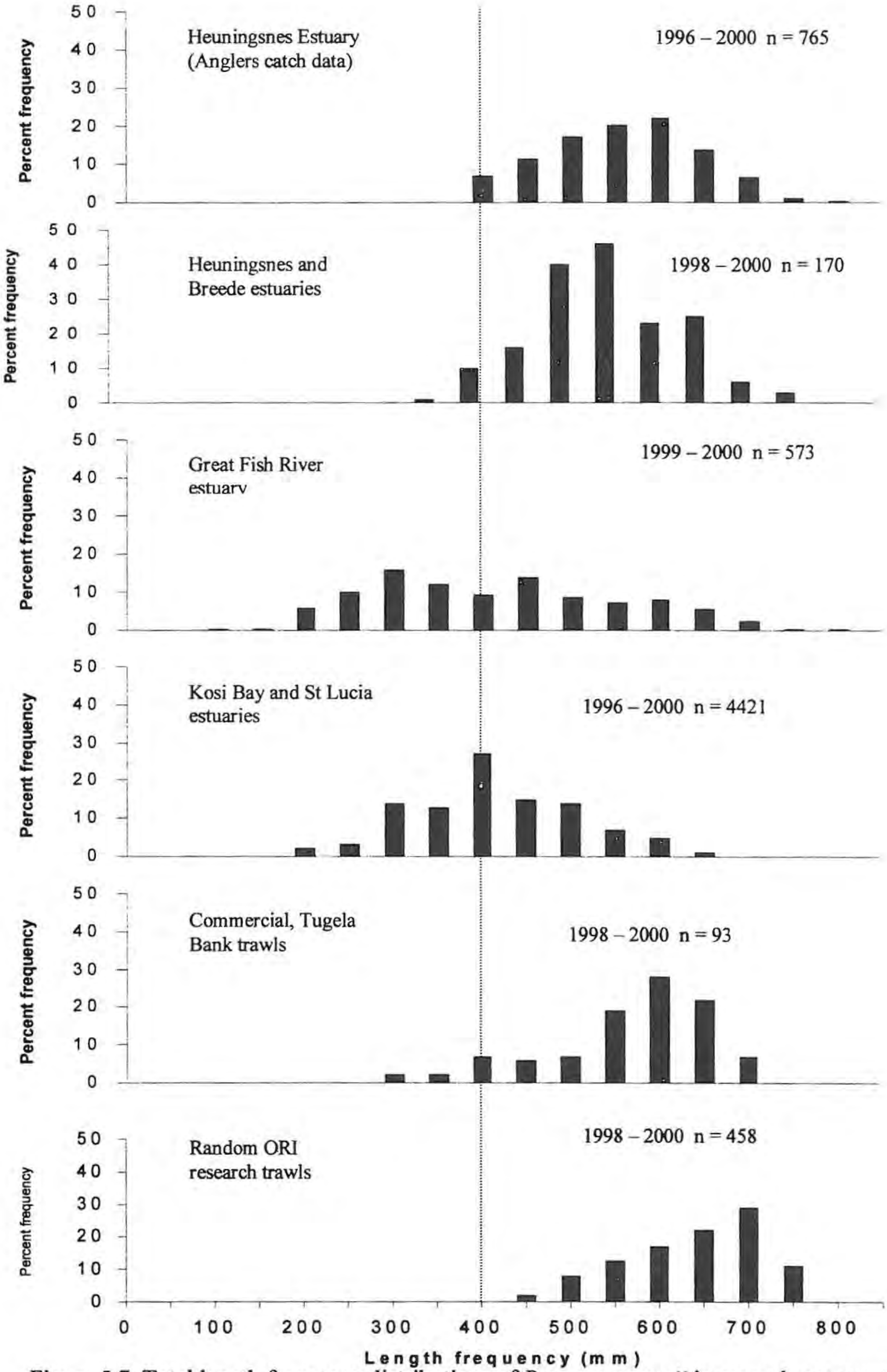

Figure 5.7. Total length frequency distributions of *P. commersonnii* in several east coast estuaries from the Heuningsnes in the south to Kosi Bay in the north and inshore trawl catches. Unless otherwise stated, data are obtained from gill net catches. Years and number of fish sampled are displayed on figure. Dotted line indicates minimum legal size.

Although seine-netting has been carried out in the Breede and Heuningsnes estuaries, only 1 spotted grunter (407 mm TL) has been collected since 1998 (Steve Lamberth Pers. com.). Gill net catches in the Great Fish River were similar to those from the St Lucia and Kosi Bay estuaries in that juveniles form a large portion of the population. Length classes from 200 mm TL to 650 mm TL are well represented in these estuaries with proportionally more juveniles being captured in the Great Fish River than in the St Lucia Estuary. Results obtained from Sean Fennessy (ORI Durban) show that the marine offshore stock on the Tugela Banks of KwaZulu-Natal consists mainly of spotted grunter larger than 600 mm TL (Figure 5.7). Very few juveniles were encountered in the trawls. It would therefore appear that the majority of the offshore stock is comprised of adults.

General discussion

The data presented in this study shows that the 'grunter run' occurs mainly between September to January. This confirms the general belief held by anglers that the spring and summer months are 'better' months for catching spotted grunter. Clearly however, there is substantial variation in intraseasonal patterns of abundance, which may lead to a misinterpretation of the migration patterns and by implication the life history of the species. For example, the Great Fish River estuary data shows high abundance in Novemebr and January but a marked absence of adult fish in December. Similarly, CPUE data obtained by Plumstead *et al.* 1985, Plumstead *et al.* 1989 a, Plumstead *et al.* 1989 b from specific months in 1981 differed by up to 400% from catches in the same month in 1982. Work undertaken by Wallace (1975 b) and Marais (1983 b) suggests that differences in interannual rainfall, flooding, estuary mouth conditions, periods of upwelling at sea as well as the behaviour of the species may explain variability in abundance. More specifically, Marais (1983 b), Ter Morshuizen *et al.* (1996 b) and Whitfield (1998 a) showed that flood conditions are negatively correlated with abundance of spotted grunter. The heavy rains in December 1999 could therefore be a probable cause of the low CPUE in that month. Several authors (Marais & Baird 1980 a, Marais 1981, Marais 1983 b, Plumstead *et al.* 1989 a) working in the Eastern and South Eastern Cape show that in some years, large numbers of grunter are still present in the estuaries as late as February. Rainfall in late January 1999 and February 2000 CPUE data may also not be a true reflection of the actual abundance of spotted grunter in the region for that month.

In identifying the timing of the 'grunter run' it is necessary to consider both CPUE data as well as environmental factors that affect the occurrence of spotted grunter in estuaries in the region. Since abundance peaked in November and January and the fact that the CPUE data recorded in December and February may not be an accurate representation of mean monthly abundance, the 'grunter run' may span the months from September to January/February in the South Eastern Cape.

Since spotted grunter are not found in any large numbers in the offshore environment of the South Eastern Cape or Western Cape (see Chapter 4), they must be confined largely to the estuaries of the respective regions. This implies that the seasonal migration of fish into the estuaries, from September to January/February, must occur along an inshore, longshore axis. According to McKeowen (1984), the key to understanding the motivation behind a migration is to identify the start and end point of the migration.

Evidence presented in Chapter 3 indicated that otolith zone clarity differed between the Western Cape, South Eastern Cape and KwaZulu-Natal. The opaque and translucent zones of otoliths from fish collected in the Western Cape were more distinct than otolith zones from the South Eastern Cape and KwaZulu-Natal, whereas the otolith zones from fish in the South Eastern Cape were more defined than otolith zones from KwaZulu-Natal. This meant that otoliths from the Western Cape could be read with a greater degree of accuracy than those from the South Eastern Cape and KwaZulu-Natal. Otoliths from KwaZulu-Natal were read with the least accuracy. Differences in the clarity of annuli between fish found in the Western Cape and the South Eastern Cape have also been observed in the otoliths of *Argyrosomus inodorus* by Griffiths (1996), who also found that zones became less clear when moving further east to the Southern Cape and to the South Eastern Cape.

In addition, evidence was presented in Chapter 3 that readability of otoliths from the South Eastern Cape also differed on a seasonal basis. The annuli of otoliths collected during the observed 'grunter run' (September to January) were more distinct than those collected during the rest of the year (February to August). It was thus hypothesised that the greater zone clarity of otoliths during the 'grunter run' in the South Eastern Cape, was a result of an influx of fish into that region that originate in the southern regions of its distribution range.

These findings would suggest that spotted grunter undertake a spring/summer migration and that fish originating from areas south of the South Eastern Cape pass through this region *en route* to and from northern areas (see Figure 5.8).

The movement of fish from one place to another during migration requires a specific amount of organic fuel for their metabolic requirements (McKeowen 1984). High energy-containing compounds required for migration (e.g. fat reserves) can either be stored prior to migration or can be acquired *en route* (McKeowen *op cit.,* Griffiths & Hecht 1995). In order to provide the bioenergetic requirements for migration, fish that feed *en route* must be capable of changing their diet and food gathering techniques (McKeowen *op cit.*). The evidence presented in Chapter 2 suggests that spotted grunter have the flexibility to change diet according to the abundance and composition of the macrobenthos of the environment that they inhabit. The estuaries of the South Eastern Cape can, therefore, be considered as 'feeding stopovers'

(McKeowen *op cit.*), while *en route* to and from the southern regions of their distributional range.

In Chapter 4, evidence was presented that spotted grunter do not spawn in the Western and South Eastern Cape. The presence of post ovulatory follicles in the gonads of female spotted grunter from the Great Fish River, indicate that these fish are not in delayed adolescence (Jonsson & Jonsson 1993) but have spawned previously. Stage 2 gonads were observed in August and stage 3 gonads (the most reproductively advanced stage to be observed in the South Eastern Cape) were encountered during the period September to December. Since female fish in a ripe and running or spent condition were not found in the South Eastern Cape, it would appear that the progression of gonadal development from stage 3 (developing) to stage 4 (ripe and running) does not occur in the South Eastern Cape. The only area where spotted grunter have been documented to spawn is off the KwaZulu-Natal coastline (Wallace 1975 a, Wallace 1975 b, Wallace & van der Elst 1975, Connell 1996, Harris & Cyrus 1997, Harris & Cyrus 1999). It is therefore suggested that fish moving into the South Eastern Cape during the period September to December are primarily *en route* to KwaZulu-Natal to spawn.

Several other South African marine species namely *Pomatomus saltatrix* (van der Elst 1976), *Atractoscion aequidens* (Griffiths & Hecht 1995) and *Argyrosomus japonicus* (Griffiths 1995) also undertake a spring/summer migration from the southern reaches of their distributional ranges to northerly regions. All of the above species migrate to the sub-tropical waters (Greenwood & Taunton-Clark 1992) of KwaZulu-Natal in order to spawn. All the evidence provided here similarly suggests that spotted grunter migrate along the South Eastern Cape nearshore environment, passing in and out of estuaries, *en route* to the warmer waters of KwaZulu-Natal in order to spawn in spring and summer.

Other species such as *Pomatomus saltatrix*, *Atractoscion aequidens* and *Argyrosomus japonicus* that undertake a migration to KwaZulu-Natal, return to the southern ranges of their distribution within a few weeks after spawning (van der Elst 1976, Griffiths & Hecht 1995, Griffiths 1995). The north and southward paths of their migratory routes may be very different. *Atractoscion aequidens* for example is suspected to migrate northwards, close inshore, while following its preferred prey. Once spawning in KwaZulu-Natal has occured the species is said to "ride" the south westward flowing Agulhas current to the southern ranges of its distributional (Griffiths & Hecht 1995). *Pomatomus saltatrix*, *Atractoscion aequidens* and *Argyrosomus japonicus,* upon arrival in their southern ranges, display typical post spawning physical characteristics (Tyler & Sumpter 1996) that include low condition factors and spent gonads with post ovulatory follicles.

Since spotted grunter in the Western and South Eastern Cape are principally confined to estuaries, the northward migratory route must be the same as the southward. The CPUE data obtained from the South Eastern Cape indicates an influx of larger fish into the area for a period of 5 or 6 months (September to January/February). In November, 91 % of the females were in stage 3 (developing). CPUE in January, peaked at 0.5 fish / m^2 net. However, 46% of females present in the estuary during this month were in a resting stage (stage 2). In February and March, 72 % and 100% of females were in stage 2 respectively. Spotted grunter in KwaZulu-Natal estuaries have been shown to revert to a resting stage of development within a few weeks after spawning (Wallace 1975 b). Since, the majority of fish at the start of the 'grunter run' (September to December) are in stage 3 and the majority of fish at the end of the 'grunter run' (January / February) are in stage 2, it is hypothesised that the population of fish present in the Great Fish River estuary during the 'grunter run' consists of an overlap of fish that may be *en route* to as well as those returning from the spawning grounds of KwaZulu-Natal.

Seasonal abundance data from the Krom and Gamtoos estuaries, displayed bimodal patterns in temporal abundance with larger catches of adults being recorded in the period September to November and then again from January to April (Figure 5.5). These two estuaries are geographically further away from the KwaZulu-Natal spawning grounds than the Great Fish River. Since the majority of fish would migrate from and through these estuaries in a northerly direction before spawning, they can be seen to be virtually absent from these southern estuaries during the spawning season. The second peak of abundance from January to April can therefore be interpreted as fish returning to these estuaries after spawning in KwaZulu-Natal. It appears that the abundance of larger individuals extends throughout the period August to February in the South Eastern Cape estuaries. Since the Great Fish River is essentially half way between the southern and northern ranges of the species' distribution, the data corroborates the suggestion that the South Eastern Cape simultaneously supports larger specimens that are *en route* to and from the spawning area. Due to the geographical location of the South Eastern Cape estuaries, this period of overlap would therefore be over a longer period of time than that for the northern estuaries. The Kei and Mbashe estuaries, which are geographically closer to the spawning grounds than the Great Fish River, have a relatively short, single peak of adult abundance that stretches from September to January (Figure 5.5). In these estuaries, populations in any one estuary would consist of specimens either *en route* to or from the spawning ground, however, the period of high abundance is shorter than that in the South Eastern Cape estuaries.

Wallace & Schleyer (1979), and this study showed that the opaque zone formation in the otoliths of specimens caught in KwaZulu-Natal corresponded with the post-spawning, estuarine feeding phase of the population (November to January). In the South Eastern Cape, opaque zone formation occurred primarily in January. This corresponds to the period when it is hypothesised that the spotted grunter return to the area after spawning. In the Western Cape, the opaque zone was deposited primarily in January and February with 30 – 35 % of the population in the area depositing the opaque zone as late as March and April. Assuming that the opaque band corresponds to the post-spawning feeding phase of the spotted grunter, the period February to April corresponds with the hypothesised period for the return of post-spawning adults to this area.

Contrary to other western boundary current migratory species in South Africa such as *Pomatomus saltatrix*, *Atractoscion aequidens* and *Argyrosomus japonicus,* where very few adults are present in KwaZulu-Natal out of the spawning season, that region appears to be host to a perennial, 'resident' population of juvenile and adult spotted grunter. It is not known however, whether the adult fish in KwaZulu-Natal migrate further north (into Mozambique) to spawn. Spotted grunter migrating from the Western and South Eastern Cape therefore join the resident KwaZulu-Natal population prior to spawning. Wallace (1975 b) noted that fish in a post spawning condition start entering the estuaries of KwaZulu-Natal from as early as July and Harris & Cyrus (1999) collected spotted grunter larvae in the Durban Bay Harbour from as early as June. Post spawning adults have also been observed in KwaZulu-Natal as late as January/February (Wallace 1975 b). Spawning therefore appears to occur over a protracted period from June to January. Since the onset of spawning has been correlated with water temperature in many fishes (see Conover 1992), the warmer waters of KwaZulu-Natal (Greenwood & Taunton-Clark 1992) are presumably more conducive to the earlier spawning of spotted grunter 'resident' to the region. Since spotted grunter from the South Eastern and Western Cape are exposed to the cooler waters of these regions, their gonads are in a resting or early stage of development (Chapter 4) during the winter and spring months (June to November). These fish migrate northwards during September to December and would therefore only be able to spawn in the latter part of the KwaZulu-Natal spawning season.

It is generally accepted that spawning is timed to maximise the probability of offspring survival (Cushing 1990, Wootton 1990, Conover 1992). By being exposed to lower temperatures, it is hypothesised that spotted grunter from the South Eastern and Western Cape spawn 'later' in the season than the 'resident' population of KwaZulu-Natal. This strategy protracts the spawning season, which may increase the probability that larvae find optimal conditions for growth and survival (Mc Keowen 1984, Conover 1992). Most of the South African east coast has a spring / summer rainfall pattern. This coincides with the spawning activity of spotted grunter, and may theoretically increase the nursery potential of the east coast by opening many small estuarine systems, which close during the winter. Read & Whitfield (1989) also observed that there is a higher biomass of mysids, *Grandidierella lignorum,* in closed estuaries during this period. Whitfield (1994) concluded that olfactory cues entering the marine environment from estuarine systems are probably the most important factors influencing the immigration of estuarine dependant species. The introduction of adequate fresh water during the spawning season may therefore be crucial to the early juvenile survival of spotted grunter.

As discussed in Chapter 4, spawning in KwaZulu-Natal occurs in deeper offshore waters and juveniles recruit into the estuaries at about 25mm to 35mm (Wallace & van der Elst 1975, Whitfield 1980 b). Similarly, spotted grunter juveniles also recruit into South Eastern Cape estuaries at about 25 to 30 mm TL (Beckley 1984, Whitfield *et al.* 1994, Ter Morshuizen *et al.* 1996 a, Patterson & Whitfield 1996 and this study), implying that eggs, larvae and early juveniles are transported rapidly southwards to the estuaries in the Cape.

The Agulhas Current has been implicated in the southward larval dispersal of several species that spawn in KwaZulu-Natal (van der Elst 1976, Heydorn *et al.* 1978, Joubert 1981, Smale 1984, Garratt 1988, van der Elst & Atkin 1991, Griffiths & Hecht 1995, Beckley & Connell 1996). Beckley & Connel (*op cit.*) provided greater detail and suggested that eggs spawned on the periphery of the current could be dispersed southwards in the south-westward shelf currents and the larvae/early juveniles could reach the Cape nursery areas in three to four weeks. The age of the 25 – 30 mm TL juveniles that recruited into the Great Fish River estuary has been estimated at between 25 to 35 days (Chapter 4). This close correlation between Beckley &

Connell's (*op cit.*) estimate of the transport time and the age of recruiting juveniles suggests that these juveniles originate from adults spawning in the periphery of the Agulhas current in KwaZulu-Natal and transported to the South Eastern Cape (see Figure 5.8). Of interest, is the observation that juveniles that recruit into KwaZulu-Natal estuaries are also 25 – 35 mm TL, suggesting that this may be the minimum size that juveniles must attain before recruiting into any South African estuary.

Wallace (1975 a) showed that spotted grunter juveniles remain in KwaZulu-Natal estuaries until they attain maturity (400 mm TL), after which they move into the nearshore and offshore environment. The absence of an offshore population in the South Eastern Cape (see Chapter 4) means that juveniles in this area also remain in estuaries at least until they attain sexual maturity. Although the tagging data does not provide evidence of any long shore movement, there is other evidence to suggest that a limited southward dispersal of adults does occur. Extensive gill and seine surveys in the Heuningsnes and Breede river estuaries have shown that only adults (370-780 mm+ TL) occur in Western Cape estuaries. (Data from MCM, Steve Lamberth, Cape Town). Similarly, beach seine and angler catch surveys in the Western Cape have also only shown the presence of adults (390-610 mm TL) in the surf zone (Bennett *et al.* 1994, Lamberth *et al.* 1995). Therefore, since juveniles are rarely found in estuaries south of the Swartvlei estuary, adults in the Breede and Heuningsnes estuaries as well as the inshore marine environment of the Western Cape and Southern Cape must have moved into these regions from areas further north (see Figure 5.8).

The tagging data (Bullen & Mann 2000) suggests that spotted grunter are resident to certain estuaries. Of the 151 recaptured fish, 144 were resident for up to 8 years and

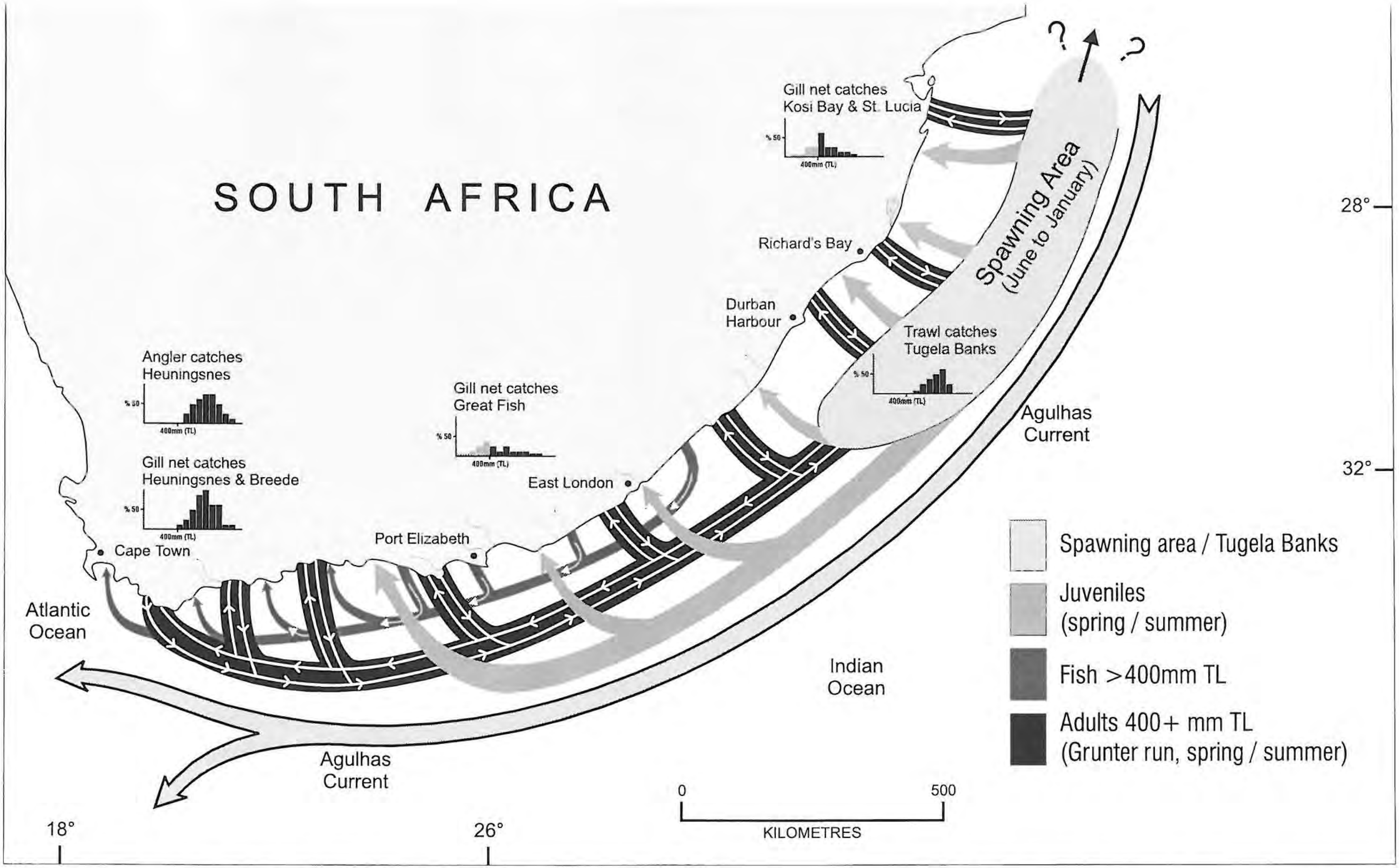

Figure 5.8. The theoretical life history cycle and migratory patterns of *Pomadasys commersonnii* along the South African eastern seaboard. For the sake of clarity, the lateral dynamics of the migratory patterns are not drawn to scale. For further geographic localities see Figure 3.1

remained within a 3.5 km radius of point of capture. Since only a few larger individuals have been recaptured up to 823 km from the point of release it was suggested by Bullen & Mann (2000) that these individuals are 'nomadic roamers'. On the basis of these data it has been suggested that spotted grunter do not undertake an annual migration. However, in light of the previous discussion Bullen & Mann's (2000) description of the species as being resident cannot be totally accurate. What the tagging data does show is that individuals that are not migrating to or from the spawning grounds, occupy a very limited home range (Mc Keowen 1984). Seven of the 151 recaptured fish moved distances greater than 100 km (Table 5.2). Although there was no evidence to suggest movement of fish to the Western Cape, one adult, originally tagged in the Gamtoos River estuary (South Eastern Cape), was recaptured 9 years later in the offshore region of Durban Harbour (KwaZulu-Natal) in August. Considering that only 32 fish, tagged in the South Eastern Cape, have ever been recaptured, the movements of 1 fish (3% of recaptures in the area) cannot be summarily dismissed as 'nomadic' behaviour and could at least provide some evidence for a migration to KwaZulu-Natal. Since the recapture rates are low, coupled with the fact that the actual numbers of recaptures are also small, this evidence should be regarded as highly speculative. However, it should not be entirely dismissed. Tagging data could therefore, if not considered in the light of other information and data, lead to incorrect conclusions on the life history of a species.

From the preceding results and discussions it appears that the South African spotted grunter population comprises a single stock. However, the stock appears to be divided into geographically related sub-populations that can be differentiated by their growth patterns and timing of the reproductive cycles. Due to its migratory nature, the species is well adapted to obtain food in most estuarine and marine environment. However, it is the inshore nature of the migratory pattern of the fish that makes this species particularly susceptible to exploitation. The abundance of spotted grunter in estuaries in the Western and South Eastern Cape at specific times of the year means that adults are susceptible to capture by recreational and subsistence fishermen both *en route* to and from the spawning ground. During the post-spawning 'grunter run', when fish in KwaZulu-Natal enter estuaries adjacent to spawning grounds in order to regain condition, the spawner stock is again vulnerable and is heavily targeted by fishermen. Juvenile spotted grunter, being estuarine dependant, are also vulnerable to subsistence and recreational fishing effort especially in areas where poor compliance and inadequate enforcement means that there is very little regard for minimum size limits (Daniel 1984, Hutchings & Lamberth 2002, Mann *et al.* 2002). The offshore adult population on the Tugela Banks of KwaZulu-Natal is also being exploited as a by-catch species of the prawn trawl industry. The complex life history of the species will therefore have to be taken into account in developing an effective management plan for the stock.

The overall objective, as described in the Linefish Management Protocol (Griffiths *et al.* 1999), for the management of any South African linefish species is "to manage the resource so as to ensure its equitable and optimum sustainable utilisation (Penney *et al.* 1997). Central to the development of a successful management plan for any species is the thorough assessment of the stock (where this is possible) that allows for the calculation of optimal fishing levels.

The three main assessment methods that have been recognised as being suitable for the assessment of most South African linefish stocks are per-recruit analyses, dynamic, age-structured production modeling and *ad hoc* tuned Virtual Population Analyses (VPA) (Griffiths *et al.* 1999). Species such as the Galjoen, White Steenbras and Elf, Geelbek and many other South African line fish species, by nature of their complex life-history styles and lack of a long time-series of accurate catch and effort data, are most successfully assessed by means of per-recruit models (Butterworth *et al.* 1989, Punt 1993, Appeldoorn 1996).

Per-recruit methods are flexible in that they can be tailored to accommodate complex life-history strategies (Buxton 1992, Punt *et al.* 1993) and fisheries that target different stages of the life-cycle (Griffiths 1997a) and would be the method of choice for developing a management plan for the spotted grunter. Data required for per-recruit analyses may be divided into two categories, those needed for 'per-recruit' curves and those necessary for the estimation of fishing mortality (*F*). Data include growth parameters, length/weight relationship, age at maturity and natural mortality. *F* may be estimated using a catch curve or tag-and-recovery methods (e.g. Butterworth *et al.* 1989, Gulland 1983, Hilborn and Walters 1992). The life history of the spotted grunter is such that obtaining data relating to the per-recruit curves may not be as simple as in other South African linefish species. Whereas *F* could be estimated for fish along the entire Eastern seaboard with the available data, growth curves and their associated parameters have been shown to differ throughout the distributional range of the species. The financial constraints of this study meant that the biology of fish from only one estuary in the South Eastern Cape could accurately be described. Data obtained from the Western Cape were similarly obtained only from two estuaries. As a result, the demographics of the species throughout the greater part of its southern distribution range is only represented by three geographically widely separated spot samples over a period of two years. Data collected in the former Transkei was collected several years ago and may not be representative of the current size composition of the population. Ideally, it is necessary (Booth 1997) to collect population size composition, length-at-age and length-at-maturity data throughout the distributional range (from Mozambique to False Bay) at several representative sites over a period of a single year.

Once the technical analyses have been performed, the target and threshold reference points (Caddy and Mahon 1995) can be determined for the stock. Using this information, management regulations can be implemented according to the status of the stock (Griffiths *et al* 1999).

Owing to the large number of species caught in the South African linefishery, it will take several years for all species to be assessed quantitatively. The Linefish Management Protocol (Griffiths *et al.* 1999) has therefore made provision for the use of other, less reliable, stock status indicators to develop management recommendations for a species such as the spotted grunter. Rigorous guidelines for the use of indicators are difficult to establish and in the absence of reliable assessments, guidelines have been set as a starting point for developing regulatory action (Grifffiths *et al.* 1999). Before an accurate assessment has been completed, these stock status indicators should be investigated and the resulting conditions could therefore identify, at least primarily, if the stock needs rebuilding.

The information presented here illustrates the complexity of the life history of the spotted grunter and clearly does not yet provide all the information that is required upon which a satisfactory stock assessment can be undertaken. Nevertheless, it contributes to the general body of knowledge for this species and has highlighted the need for further work. In particular, additional work on growth in closed estuaries throughout its distributional range as well as the degree and duration of residency in open as well as in temporally open/closed estuaries. The latter could be achieved through a dedicated tagging project with a greater degree of spatial resolution. Based on such information it might become necessary to estimate fishing mortality on a narrower spatial basis and to ultimately aggregate the results to estimate the overall current status of the stock.

Until such time as the necessary information is available upon which to undertake an assessment of the stock, it is suggested that the bag limit be reduced to 5 fish per day as a precautionary measure and that the size limit be retained at 400 mm TL and that the species remains de- commercialised. However, given the prevalence of spotted grunter in the catches of subsistence fishers it would be necessary to consider allowing them to sell their catch through an exemption, on condition that there is adequate control by the marine inspectorate. A similar permit exemption might have to be considered for the prawn trawlers in KwaZulu-Natal.

Conclusion and Summary

The information on the life history of spotted grunter provided in this study can be summarised as follows (also refer to Figure 5.8):

The juveniles of the sub-tropical population in KwaZulu-Natal are confined to estuaries. Upon attaining maturity, the adults move into the marine environment where large numbers can be found, year round, in the inshore region and on the Tugela Banks. After spawning in the marine environment, the adults return to the estuaries in a post spawning condition to feed and regain condition. The eggs hatch in the marine environment and pass through the larval stage before the juveniles recruit into the estuaries between 25 – 35 mm TL.

It is suggested that a portion of the eggs and larvae are transported southwards from the spawning area on the edge of the Agulhas Current. Larvae hatching in the peripheral regions of the current pass through the larval stages at sea and the early juveniles recruit into South Eastern Cape estuaries from the age of 25 days at 25 – 30 mm TL. Juveniles do not recruit into estuaries south of the Swartvlei estuary. Juveniles < 70 mm TL feed on Amphipoda and Brachyura. They remain in the South Eastern Cape estuaries and at about 200 mm TL start to feed on anomurans, which also become the dominant prey item of the adults. On attaining sexual maturity some fish (larger than 390 mm TL) leave the South Eastern Cape estuaries and move south into the estuaries of the Western Cape. Those fish that do not move to the Western Cape remain in the estuaries of the South Eastern Cape and undertake an annual reproductively motivated migration to the warmer waters of KwaZulu-Natal.

Similarly, adults that have moved to the Western Cape later join those of the South Eastern Cape and migrate to KwaZulu-Natal to spawn.

The migration to KwaZulu-Natal occurs during the spring/summer months (the 'grunter run') during which they become particularly vulnerable to angler effort. A high degree of diet flexibility allows spotted grunter to feed *en* route. Gonad recrudescence continues *en route* and the majority of spotted grunter are capable of spawning towards the end of the spawning season. After spawning in the marine environment in KwaZulu-Natal, fish that originated from the Western and South Eastern Cape return to their respective regions between January and March. After hatching in KwaZulu-Natal, juveniles pass through the larval stages in the marine environment and once more recruit into the estuaries of KwaZulu-Natal and the South Eastern Cape completing the cycle.

The information presented in this study has contributed to our understanding of the complex life history of the spotted grunter and has brought us a step closer to undertaking an assessment of the stock. Before an accurate assessment of the stock is concluded, upon which appropriate management plans can be formulated, it is suggested that the bag limit be reduced to 5 fish per day, as a precautionary measure and that the size limit remain unchanged. The species should also remain de-commercialised, except for subsistence fishers and possibly prawn trawlers in KwaZulu-Natal

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