AN ASSESSMENT OF THE SOUTH AFRICAN LONGLINE FISHERY WITH EMPHASIS ON STOCK INTEGRITY OF KINGKLIP, *Genypterus capensis* (PISCES: OPHIDIIDAE)

THESIS

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ABSTRACT

The South African demersal longline experiment is assessed with emphasis on the target species, kingklip *Genypterus capensis*. The hypothesis that kingklip on the South African coast comprise a unit stock is tested. Recommendations for the management of the fishery are made.

Longlining was found to be commercially viable. Techniques have been developed to target on either kingklip or the Cape hakes, *Merluccius capensis and M. paradoxus*. Longline fishermen exploit the kingklip spawner stock from August to November by taking advantage of prespawning aggregations on the South-East Coast. Effort switches to the West Coast in late summer and early winter where kingklip are less abundant and a larger proportion of hake is caught. Catch rates of kingklip on the South Coast have declined sharply and the resource there has been exploited at a rate greater than that required to retain 50% of the unexploited biomass. There is a 17,6% probability that the spawner biomass on the South Coast has already been depleted below its pristine level. On the West Coast the catch rates of kingklip are lower than on the South Coast and have not changed significantly, although within the 95% confidence limits there is a possibility that the resource there has also been depleted below 50% of its pristine level.

Genypterus capensis on the South African coast comprise a unit stock. Comparison of kingklip morphology using multivariate and discriminant function analysis and of otolith morphology using univariate statistics shows that there are no significant differences between the fish on the West and South Coasts. They are a slow growing species and were aged up to 25 years. Kingklip on the West Coast are smaller and have a lower L_∞ than those on the South Coast, but this is not a characteristic of discrete stocks. Kingklip on the South Coast mature earlier than those on the West Coast and aggregate to spawn on the South-East Coast in spring. There is no obvious spawning period on the West Coast. It is hypothesized that kingklip spawning on the South-East Coast is in response to favourable environmental conditions that enhances the survival of their eggs and larvae.

It is recommended that demersal longlining be established as a permanent kingklip-directed fishery but that effort should not be allowed to increase. The West and South Coasts should be managed separately. A TAC of 5 000t for kingklip should be introduced for 1989 of which 2 000t should be allocated to the West Coast and 3 000t to the South Coast. A closed season for kingklip from 1 August to 30 September on the South-East Coast is recommended. Hake-directed longlining should not be allowed as its effect on the hake spawner stocks are unknown and could be a potential threat to the stability of the demersal trawl fishery.

1. INTRODUCTION

The kingklip *Genypterus capensis* (Smith 1849), a member of the family Ophidiidae, is an eel-like demersal fish endemic to southern Africa, with a distribution extending from Walvis Bay on the west coast to east of Algoa Bay on the south coast (Smith 1965). It is an important food fish with a high market value in South Africa. Before 1983, the species was taken only as a by-catch in the bottom trawl fishery for the Cape hakes *Merluccius capensis* and *M. paradoxus*, rarely exceeding 3% of the annual catch (Chief Directorate Marine Development 1984).

In 1983, an experiment was initiated to test the viability of demersal longline fishing in South Africa. The first request was to longline for hake but once a restricted number of demersal longline permits had been issued, fishermen soon found that kingklip was more valuable and somewhat unexpectedly, very available. Soon the experiment became targetted wholly on kingklip. As a result, total kingklip catches increased from 3 131 tons in 1982 (all by trawl) to 11 267 tons in 1986 (Table 15), of which 8 634 tons (76%) was caught by the experimental longliners. Thus, within four years, exploitation of kingklip in South African waters had increased by over 300%. Obviously the effect this massive increase would have on the kingklip and other demersal fish resources was unknown. Consequently, a research programme to monitor the experiment and to assess the impact of the fishing technique on demersal fish resources (particularly kingklip and hake), was initiated.

This thesis outlines the South African demersal longline experiment from its inauguration in 1983 up to June 1988. The viability of longlining in South Africa was investigated and the hypothesis that the kingklip off the South African coast is a single unit stock was tested.

Origins of Longlining and its Development in South Africa

In this study the term "longlining" refers to the South African experimental demersal longline fishery and should not be confused with other forms of longlining, such as pelagic longlining for tuna.

Linefishing, with the exception of the primitive fish spear, is probably the oldest method of fishing (Holdsworth 1874). The longline system employed in South Africa has its roots in Spain and Portugal, though local modifications have been made. Cornide (1788), cited in Lleonart and Camarasa (1987), describes the introduction of primitive longlining in the 18th century to Galicia, north-west Spain, from Catalunna on the Spanish Mediterranean coast. Cornide also refers to the work of Despuig, who described longline fishing in the 16th Century in Tortosa, Spain. Further reference to longlining in the 18th Century is also found in the Spanish manuscripts of Joan Salvador I Riera (Lleonart and Camarasa 1987). Longlining subsequently spread from Spain to Portugal where it became well established. The target species of these Spanish and Portuguese longline fishermen was, and still is, the European hake *Merluccius merluccius* (Lourido 1978). This relatively simple form of fishing has developed into a remarkably sophisticated and highly successful method of exploiting demersal species. It is well established in the northern hemisphere as well as in waters off South America, Australia and New Zealand (Gulland 1970) but, until recently, it was largely unknown or neglected in South Africa.

In South Africa demersal fish are exploited by bottom trawlers on predominantly soft or muddy substrata. Large areas, especially deeper than 300 metres on the edge of the continental shelf, are very rocky or consist of hard corals (Scott 1950) and are not practical to exploit with bottom trawling gear. The idea that the Cape hakes could be exploited on these grounds with longlines was first mooted in 1982 and the necessary approval to experiment with longlining was granted in January 1983. However, all longline permits issued were strictly "experimental". This provision implied that the fishery was not a permanent one and that permits could be withdrawn should the fishery, for what ever reason, prove not to be viable.

The fishery grew rapidly and different techniques were developed for the variable and often extreme physical oceanographic conditions on the South African coast. For the purposes of this study, the South African coast is subdivided into "West" and "South" Coast regions (Fig. 1). The term "West Coast" refers to the area west of 20°E and south of the Orange River and includes ICSEAF (International Commission for the Southeast Atlantic Fisheries) Division 1.6. "South Coast" refers to the area east of 20°E from Cape Agulhas to Algoa Bay and includes the whole of ICSEAF Division 2.1 and part of 2.2. Reference is also made to the "South-East Coast" and to the "Intermediate Area". The South-East Coast describes the eastern portion of the "South Coast", more specifically the area to the east of the longitude of Mossel Bay towards the Great Fish River (Fig. 1). The Intermediate Area describes a portion of the South Coast from the western boundary of the South-East Coast area to 20°E and includes the southern-most portion of the Agulhas Bank labelled "?" in Figure 1.

Ten longline permits were issued in 1983, but at first only a few were activated. In 1984 the number of permits was reduced to seven and these seven vessels fished consistently throughout the experiment, targetting virtually entirely on kingklip. They formed the core of the longline fleet and were all between 30 and 50 metres long. No restrictions were imposed on the catching of kingklip, but all hake caught (considered a by-catch) was deducted from the hake quota already held by the permit holder. That hake allocation was part of the Total Allowable Catch (TAC) for hake of the South African demersal trawling fleet.

The success of these seven vessels led to a flood of applications for longline permits and in July 1985 six new permits were issued, this time to the owners of smaller vessels. As they had no hake quota, each of these new longline permit holders was accommodated by means of a hake "allowance" within the TAC for that species. Therefore, from July 1985, longline effort increased and thirteen permits remained in force for the duration of the experiment.

Kingklip Stock Integrity

The kingklip *Genypterus capensis* belongs to the family Ophidiidae, a cosmopolitan carnivorous family of mostly deep water fish (Smith 1965). The genus *Genypterus* is found in the southern hemisphere only around the coasts of southern Africa, South America and Australasia (Barnard 1927, Smith op.cit.).

Genypterus capensis is very similar to the New Zealand rockling *G. blacodes* and the two may in fact be synonymous (Barnard 1927). The same may be true of the South American cusk-eel *G. chilensis*. Leslie (Sea Fisheries Research Institute, pers. comm.), using starch-gel electrophoresis, found no biochemical difference between *G. capensis* and *G. blacodes* and also no difference between the different kingklip stocks around the southern African coast. Until comparative studies on the genus are completed, however, *Genypterus capensis* can be considered endemic to southern Africa.

The advent of longlining in South Africa and the exploitation of new kingklip grounds has placed renewed emphasis on the dynamics of the kingklip stock(s). In 1986, kingklip longline catches peaked at 8 634 tons, of which 6 324 tons (73%) were caught on the South Coast, where a discrete stock was believed to exist (Payne 1985).

Before 1983, research on kingklip was restricted to samples obtained from trawlers. Wrzesinski (1975) made a preliminary study of age and growth of kingklip caught from north of the Orange River around the tip of southern Africa and from the eastern Agulhas Bank. He concluded from length frequency data that kingklip were generally older and larger the farther south and east they were found on the southern African coast. He emphasized that the differences he found might have been the result of either sampling artifact associated with the depth distribution of the species or to real differences between the dynamics of local stocks.

Isarev (1976a, 1976b, 1976c) used morphometrics, meristics and otolith morphology in an attempt to identify different kingklip stocks. He concluded that two separate stocks existed on the West Coast and he called these the "Tropical" stock from Luderitz northwards, and the "sub-tropical" stock from Luderitz southwards to Cape Agulhas. He also found differences in gross and otolith morphology between the sub-tropical stock and the kingklip in ICSEAF Division 2,1 (South Coast). However, he stressed that his result was tentative because his sample size on the South Coast was small.

Payne (1977) working concurrently but independently of Isarev and Wrzesinski also identified separate kingklip stocks using otolith morphology, growth rates and meristics. His results were similar to those of Isarev and he also concluded that two separate stocks existed on the West Coast. These he called the "Walvis Stock" (north of 23°S), and the "Cape Stock" from 27° to 35°S. The two stocks were analogous to the tropical and sub-tropical stocks of Isarev. He also suggested that a third stock off the South-East Coast might exist. Subsequently Payne (1985) concluded that a separate kingklip stock did indeed exist on the South-East Coast. He also suggested that another stock may exist between the South-East stock and the Cape stock (referred to in this study as the "Intermediate stock") or that it might be an extension of the Cape stock (Fig. 1). Therefore three discrete kingklip stocks had been identified on the South African coast, with the possibility of a fourth.

Badenhorst (1988) reviewed the longline fishery up to June 1986 and, on the basis of longline catch statistics alone, tentatively suggested that the kingklip resource was continuous around the South African coast. He also suggested that there was greater continuity than previously thought, although there was not necessarily a pronounced interchange between the Cape stock and the kingklip in the Intermediate Area or between the latter and those of the South-East Coast.

The present study was therefore aimed at establishing the status and stock integrity of the kingklip off the South African coast. The intention was also to supply some of the basic scientific information essential in establishing a rational management policy for the longline fishery.

The term "stock" has been used vaguely and in many ways to delimit groups of fish from systematic to applied management units (Kutkuhn 1981). Identifying a "stock" requires a sound definition as well as an *a priori* reason to believe that separate stocks or sub-populations do in fact exist (Kutkuhn op. cit.). In terms of this study a stock is considered to be a management unit, i.e. its characteristics are such that their separate management is justified. This includes the "ideal stock" definition of Cushing (1968) which defines a stock as one which has a single spawning ground to which the adults return year after year and which is contained within one or more current systems maintaining it within the same geographical area. A broad set of characteristics were used to identify possible discrete kingklip stocks. These included aspects of the biology and population parameters of the species and the longline techniques used to exploit them. These results were also assessed placing emphasis on the differences between the two oceanographic regimes on the West and South Coasts.

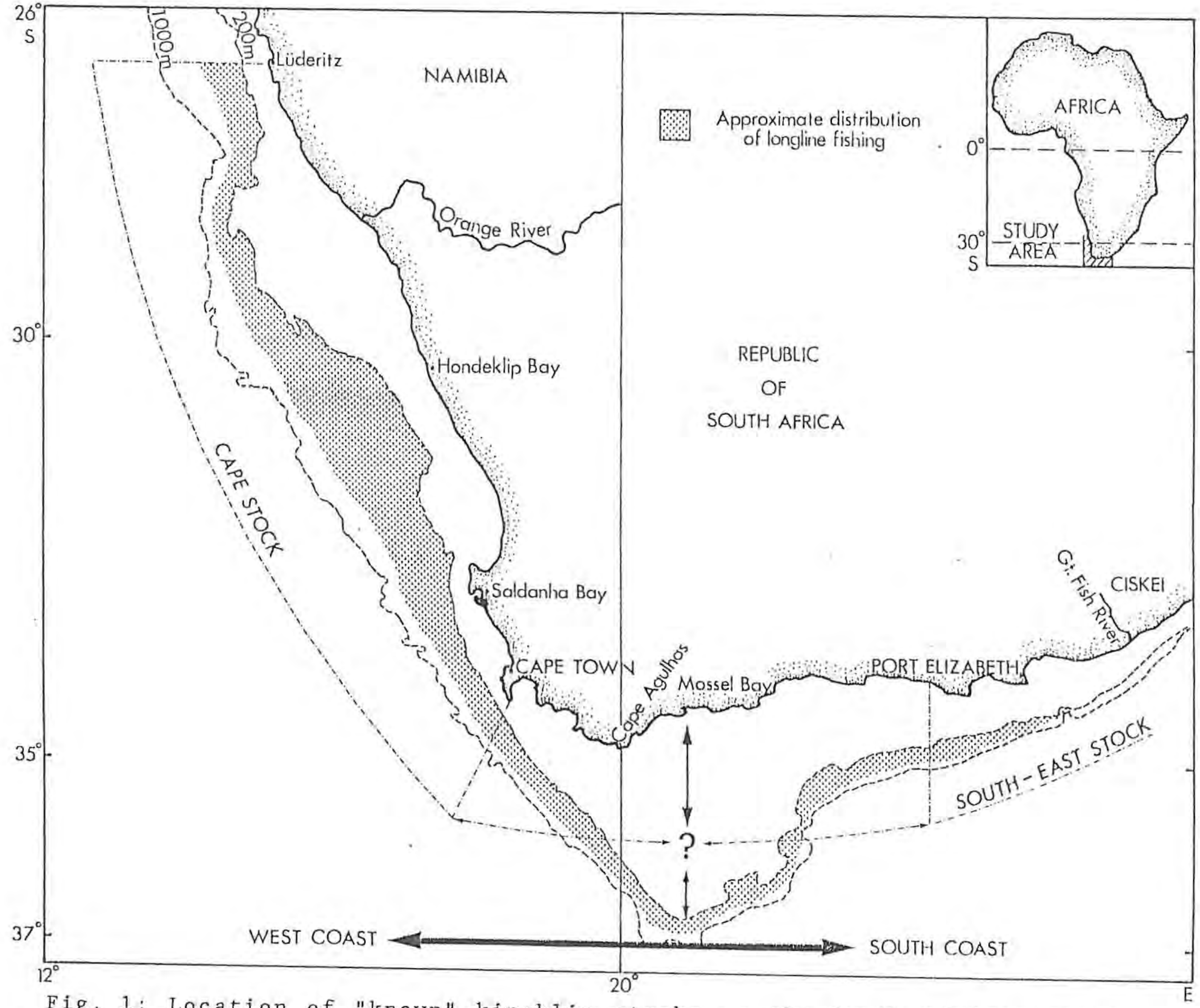

Fig. 1: Location of "known" kingklip stocks on the South African coast and the areas defined in this study. Note the approximate distribution of longline fishing between the 200m and 500m contours.

2. OCEANOGRAPHIC FEATURES OF THE SOUTH AND WEST COASTS

Introduction

As one of the aims of this thesis was to determine kingklip stock integrity and another was to analyse the status of the longline fishery on the South African coast, an overview of the oceanography, with particular emphasis on the distinction between the South and West Coasts, is presented. Reference is also made to the viewpoints of the longline fishermen and skippers.

Fish, in common with other living organisms, have evolved life history strategies that are closely linked to their environment (Cushing 1982). In the ocean, this environment is always dynamic. Many fisheries such as that for the South African anchovy base their exploitation strategies upon the migratory patterns of fish stocks which, in turn, are closely linked to the dynamics of the ocean.

Little is known of the behaviour of the kingklip stock(s). By assessing the oceanographic features of the South and West Coasts useful assumptions could be made that may assist in the identification of potential stocks of kingklip. Kingklip are a demersal species but their eggs and larvae are pelagic (Brownell 1979). Spawning, feeding behaviour and migratory patterns are likely to have evolved in response to environmental and oceanographic conditions. These possible responses will be considered further in this chapter.

The major difference between the West and South Coasts is the nature of the water bodies within the two areas. The South Coast east of 23°E and the south-eastern margin of the Agulhas Bank are bounded by the Agulhas, a deep, warm, western boundary current. In contrast, the West Coast is bounded by a shallow, cool eastern boundary current system , the Benguela (Fig. 2). These two systems are different in that the Benguela responds mainly to atmospheric forcing whereas the flow of the Agulhas Current is controlled by the dynamic forces in the ocean and the topography of the ocean floor. The marked physical differences between these two water bodies are accompanied by biological differences that could have implications for the fish resources of the regions.

Oceanic Boundaries of the West and South Coasts

The north-flowing Benguela joins with the South-East Trade Wind Drift to form the eastern boundary of the South Atlantic Gyre (Bang 1971). It is a cool sluggish movement of water separated from the West Wind Drift to the south by the Agulhas retroflection (Shannon 1985). The Benguela system is considered to extend seawards to the 1 000 metre contour, that is, beyond the known offshore limit of kingklip exploitation along the shelf edge (Fig. 2). A well developed oceanic thermal front often coincides with the shelf edge on the West Coast from Cape Point to Cape Frio, forming an effective seaward boundary. The area considered in this study is well within the dynamic northern boundary of the Benguela system (Cape Frio), which migrates seasonally between 15°S and 18°S (Shannon 1985). The boundary accepted as the southern margin of the Benguela is, however, critical to the present study.

The southernmost extent of the Benguela system was considered by Hart and Currie (1960) to be the southern limit of intense upwelling which occurs at about 34°S, or off the Cape Peninsula (Andrews and Hutchings 1980). In summer, large-scale upwelling can extend as far east as Cape Agulhas (35°S 20°E). Cape Agulhas is, therefore, considered to be a more appropriate boundary of the West Coast system by Harris and Van Foreest (1978) and Shannon (1985). The longitude of 20°E will be considered here to be the south-east limit of the Benguela system and therefore includes the western edge of the Agulhas Bank.

The Benguela's south-east boundary also forms the south-west boundary of the Agulhas and South Coast areas. Despite the general assumption of a division at 20°E, it is realized that this boundary is a dynamic feature dependent upon a combination of meteorological and oceanographic events (Shannon 1985).

The waters of the Agulhas Current originate mostly from the South Equatorial Current via the Mozambique and the East Madagascar Currents. In addition, a large quantity of water is recycled back into the Agulhas Current system from the south-east. The Agulhas Current is swift and deep (up to 6 knots - Boyd, Sea Fisheries Research Institute, pers. comm.), and although there are seasonal perturbations, modification by local atmospheric input is limited. Thus, the circulation behaviour of the Agulhas is in sharp contrast to the intricate system of upwelling on the West Coast (Bang 1971, Andrews and Hutchings 1980, Lutjeharms 1981). South of Durban, the Agulhas Current follows the shelf edge, relatively close to the coast between 26°S and 34°S, but there is believed to be a wind-induced counter-current very close inshore (Lutjeharms and Valentine 1981). South of 34°S, the Agulhas Current diverges from the coast and follows the continental shelf (Agulhas Bank) and retroflects at about 20°E (Fig. 2).

South and south-west of the Agulhas Bank, the Agulhas Current meets South Atlantic waters in an area of complicated dynamic interaction, retroflection and eddy formation, and there is a continual state of flux and change (Shannon 1985). The South Coast system, therefore, has no precise southern boundary.

Interactions Between the Agulhas and Benguela Systems

The Agulhas Current exerts considerable influence on the Benguela system. The surface waters of the Benguela are characteristically 15°C - 17°C in winter and about 18°C - 19°C during summer (Andrews and Hutchings 1980, Boyd and Agenbag 1985). Due to upwelling close inshore, water temperatures often fall as low as 10°C. In contrast, the Agulhas Current surface waters have a mean temperature greater than 21°C in winter and typically greater than 23°C in summer (Shannon 1970). In the area of mixing at about 20°E, temperatures are generally greater than 20°C in the summer and greater than 16°C in winter. The water in this area has properties of both the Benguela and Agulhas systems, and may be advected north-west in the summer upwelling season into the Benguela, forming eddies or plumes (Shannon 1985).

These plumes and eddies are generally less than 50 metres deep and usually located about 100 nautical miles or more from the coast. Subsurface and central water components of the Agulhas Current may also move around the Agulhas Bank and upwell along the West Coast, at least as far north as 30°S. The season of maximum probability of penetration of Agulhas water into the Atlantic is late summer and the minimum likelihood from late winter to early spring (Shannon 1985).

Shannon (1985) concluded that the waters of the Agulhas Current affects the Benguela system substantially and that it has a strong influence on the life history of the fish off the Cape Coast. Egg and larval surveys have shown that there is a westward and then a northward movement of Agulhas water around the Cape in an area west of 20°E during summer (October - March) and an intermittent movement inshore farther east (Shelton 1984). On the other hand, sustained westerly winds in the winter months suggest a net inshore eastward flow of surface water in the area between 18°E and 27°E, implying that South Atlantic tropical surface water may be seasonally important along much of the South Coast. Clearly the two systems are distinct but at times each exerts considerable influence on the other.

Seasonal Variations in the Agulhas and Benguela Systems

Other features also distinguish the West and South Coasts. Pearce and Gründlingh (1982) studied the seasonality of the Agulhas Current and concluded that there is little seasonal surface variation but that the total subsurface transport may vary seasonally. These subsurface shifts were related to the influence of the Northeast Monsoon (Lutjeharms 1976), which controls the flow patterns north of Madagascar. Lutjeharms (1976) concluded that it was likely that at or near the sea surface, the Agulhas Current is fed through the Mozambique Channel whereas at intermediate depths both the Mozambique and South Madagascar currents act as tributaries of the Agulhas. At still greater depths there is a more continuous flow through the Mozambique Channel.

Longline and trawl fisherman (pers. comm.) frequently report inconsistencies in the strength of the subsurface Agulhas Current, particularly on the South-East Coast. Some longline skippers speculate that subsurface currents are linked to either strong monsoons in the North Indian Ocean or to cyclones in the South Indian Ocean. Observations such as these assist in the interpretation of scientific data. The inconsistency in the subsurface drift of the Agulhas Current plays havoc with activities of longline fishermen, the current often increasing sharply overnight while the lines are set, resulting in frequent and costly loss of equipment. Also on the eastern Agulhas Bank the substrata is very rocky with much coral and is considered ideal for kingklip, yet longline fishermen are reluctant to set lines there. Shifts in the current cause fouling of the lines and considerable loss of equipment.

The "Good Hope Jet" Current

Currents off Cape Point are also reported to be extremely variable although not as strong as on the South-East Coast. Bang and Andrews (1974) report the existence of a shelf-edge jet (the Good Hope Jet) south-west of Cape Point which contrasts the sluggish flow of the Benguela system (Fig. 2). These authors suggest that the Agulhas water intrusions intensify the frontal gradient and, therefore, assist in the maintenance of the jet. The jet may also become a prominent shelf-edge feature farther south than Cape Point and may act as a narrow conduit into which shallow patches of Agulhas water are drawn into the Benguela system.

Much ichthyoplankton from the southern margin of the Benguela is carried northwards in this manner. Shelton and Hutchings (1979) demonstrated the importance of the "Good Hope Jet" for the northward transportation of anchovy eggs and larvae and Crawford (1980) suggested that other species may use the same system. Good catch rates of large spawning hake, mostly *M. capensis*, by longliners south-west of Cape Point suggest that this species may also utilize the jet to carry their eggs and larvae north. Furthermore, it is possible that kingklip which spawn east of 20°E on the edge of the shelf in response to favourable environmental conditions may also be responsible for much of the kingklip recruitment onto the West Coast. Ichthyoplankton spawned east of Cape Point may drift towards the jet in surface currents set in motion by the prevailing southeasterly winds in the spring and summer (Duncan and Nell 1969). Longline skippers note that kingklip catches on the South-East Coast increase after south-easterly winds and indications are that this is related to spawning activity. Other researchers also report good kingklip catches associated with spawning (Hecht 1976, Payne 1986) and Roberts (1987) suggests that *G.blacodes* have an apparent prespawning aggregation which is associated with good catches. Thus, kingklip eggs and larvae may be advected westwards across the Agulhas Bank from the continental shelf margins (where spawning is known to occur), and possibly eventually into the Good Hope Jet.

Longline skippers (pers. comm.) also note that, on the southern Agulhas Bank, kingklip go 'on the bite' after strong westerly gales, and this may be associated with aggregations related to either feeding or spawning. These gales result in strong surface counter currents eastwards to north-eastwards, which would effectively transport eggs and larvae onto the Agulhas Bank and prevent them from being carried into the Agulhas retroflection region (Fig. 2). Thus, there are mechanisms during summer and winter which could prevent the loss of reproductive products to the Agulhas return current.

Another factor that could possibly affect the transport of eggs and larvae on the South and West Coasts is the presence and intensity of thermoclines. On the Agulhas Bank, westerly gales result in mixing to 75 metres (Pugh 1982 cited in Shannon 1985), whereas in summer and autumn a much more intense thermocline develops at about 50 metres. A strong thermocline may effectively block eggs from reaching the surface. Therefore, the observed peak in kingklip spawning activity in late winter and spring, when the thermocline is weak, could possibly enable the eggs and larvae to utilize the surface current patterns discussed.

Bathymetry and Substratum

Noticeable bathymetric and sediment differences exist between the South and West Coasts. On the West Coast there is considerable variation in the bathymetry. Generally, the West Coast continental shelf is wider than the eastern part of the South Coast and the shelf edge gradient less steep. On the West Coast, the the continental shelf is at its narrowest off the Cape Peninsula and to the south-west (Dingle *et al.* 1987). It is at its widest (180 km) off the Orange River. Farther south, at about 31°S, is a shallow feature called Childs Bank. From between 31°S and 35°S the shelf break is irregular, the main feature being the Cape Canyon west of Cape Columbine (Fig. 2).

On the South Coast, east of Port Elizabeth, the shelf edge is very narrow. West of this point the continental shelf widens to form the eastern margin of the Agulhas Bank. The Agulhas Bank which is the southernmost margin of the African continental bathymetry, reaches its maximum southward extension between Mossel Bay and Cape Agulhas. In general, the main surface and subsurface flow of the Agulhas Current follow the edge of the continental shelf, diverging initially from the coast at Port Elizabeth and thereafter moving farther offshore at 23°S often forming dynamic waves (Lutjeharms 1981).

The area of initial divergence of the Agulhas Current south of Port Elizabeth has been shown to be an important kingklip spawning ground (Hecht 1976, Payne 1986). Further, this area is located close to the St Francis and Padrone canyons (Dingle *et al.*

1987). Sands in the Agulhas system have formed large underwater dunes (Dingle *et al.* op. cit.) that leave the shelf via canyon head complexes such as the St Francis and Padrone canyons. Dingle *et al.* (op. cit.) note that, on the West Coast, only three rivers contribute to the shelf sediment flux. In contrast, the larger number of rivers on the South Coast, combined with the strongly flowing Agulhas Current, leads to a greater sediment flux which may increase the productivity of the benthic fauna and may account for the increased abundance of the benthic feeding kingklip (Macpherson 1983).

It is also possible that the narrow shelf margin in this area provides a smaller niche space which may suggest high, but misleading levels of abundance. In this respect, it is noticeable that the area on the South-East Coast where kingklip are most abundant coincides with a relatively small patch of authigenic sediments (Dingle *et al.* 1987) and the St Francis feeder canyon. Dingle (*et al.* op. cit.) also describe the eastern Agulhas Bank as a fissured and unstable zone, perhaps providing a better habitat for the kingklip who are believed, as with other species in the genus, to live in holes and burrows (Herald 1953, Briggs and Caldwell 1955, Macpherson 1983). In contrast, on the West Coast, extending from the South Agulhas Bank to the Cape Canyon there is a broad band of authigenic sediments and a single narrow and fissured zone south-west of Cape Point. It is possible that the authigenic sands may be favoured kingklip feeding grounds and that the fissured zones are preferred for spawning. The West Coast grounds, with their broad band of authigenic sands (Fig. 2), may permit kingklip to feed over a wider area, which may account for a lower level of abundance. On the south-east side of the Agulhas Bank, Hecht (pers. comm.) noted that, movements of kingklip onto and off the trawl grounds, may be associated with favourable spawning and feeding periods. A similar situation may exist on the grounds off Cape Point.

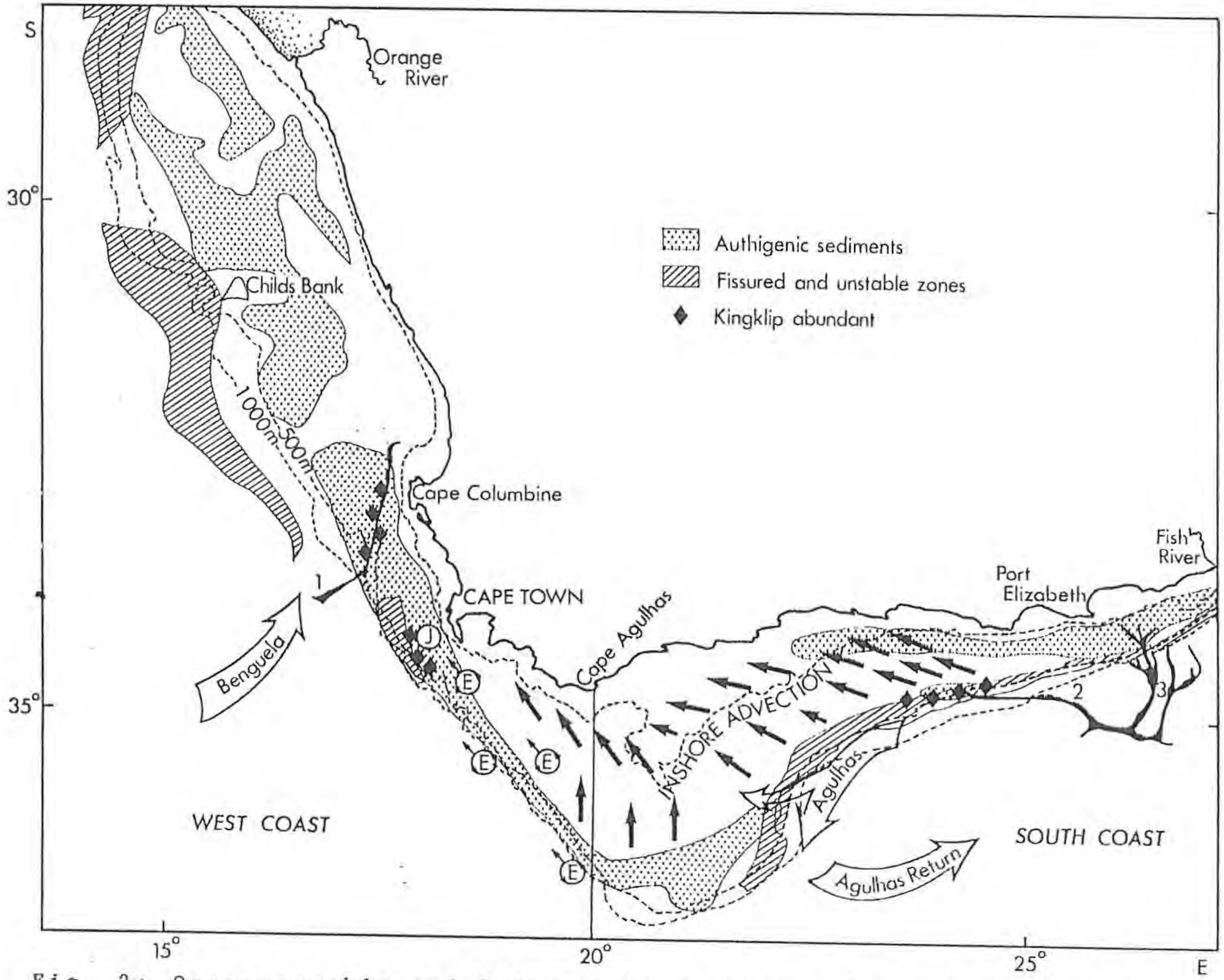

Fig. 2: Oceanographic and bathymetric features of the South and West Coasts of South Africa. Note: 1 = Cape Canyon; 2 = St Francis Canyon; 3 = Padrone Canyon; E = eddies of warm Agulhas water advecting into Benguela system and J = Good Hope Jet Stream

3. OVERVIEW OF SAMPLING STRATEGY, MATERIALS AND METHODS

Biological sampling of longline-caught kingklip commenced in February 1987 and continued through to May 1988. Details of specific techniques used are given in the appropriate sections of this thesis. In 1987 five cruises aboard commercial longline vessels were undertaken, each of approximately two weeks' duration. The objective of these cruises was to collect biological samples and to assess the longline fishing techniques.

Conditions on board the vessels were not always conducive to sampling. Consequently, samples often had to be frozen and processed later, in laboratories ashore. The following general procedure was followed when sampling the commercial catches on board.

Fresh specimens were obtained as the kingklip were hauled on board. Only those fish showing no signs of pathology, barotrauma or damage were selected for biological processing. A range of sizes of fish considered representative of the days' catch with approximately equal numbers of each sex, was selected for the biological samples.

The kingklip were first weighed on a standard dial balance to the nearest 100g then measured for total length. A note was made of any external parasites. Undamaged fish were selected for morphometric measurements (Chapters 5 and 6).

Each fish was dissected and the contents and state of fullness of the gut noted (although this information was recorded it was not used in the present study). The sex of each fish was noted and the maturity state estimated (Chapter 8, Table 11). Gonads were frozen immediately and accurately weighed ashore. Lastly, the otoliths were removed for ageing and morphometric measurements (Chapter 6).

As the fish were hauled on board they were randomly measured and the length frequency of the days catch obtained (Chapter 10). Land-based length-frequency measures were also undertaken. The day's catch was also monitored for sex ratio, and the percentage hook occupation was randomly assessed. It should be noted that, as the hauling of the line is a relatively slow process taking up most of the day, the catch could be continuously monitored and sampled.

Initially, the sampling strategy required that monthly samples be obtained from as many areas on the coast as possible. However this aim proved impossible because the areas and months sampled were restricted by the movements of the vessels. The longline vessels tended to fish particular areas according to season, fish abundance, weather and current conditions. Consequently larger numbers of samples were obtained in specific areas at specific times of the year rather than an even distribution in all areas throughout the year.

Biological samples were also obtained aboard the R.S. *Africana*. Where necessary, these samples were used to compliment the longline sampling programme. The areas sampled are shown in Figure 3 and the total monthly biological samples are listed in Table 1. Details of the sample sizes applicable to specific sections of the study are given in the appropriate Chapter.

Table 1. Summary of total monthly biological samples collected aboard longline vessels and the R.S. *Africana* (note that the area labelled "Agulhas" refers to the "Intermediate Area" referred to in the text and shown as (?) in Fig. 1.

		South coast			
Month	Total West	Agulhas	South-East	Total South	Total
January	Nil				
February	154	0	0	0	154
March	244	0	0	0	244
April	307	0	0	0	307
May	170	19	231	240	401
June	171	20	5	25	196
July	32	215	37	252	284
August	0	0	37	37	37
September	0	91	147	238	238
October	0	122	310	432	432
November	Nil				
December	Nil				
Totals	1078	467	767	1234	2312

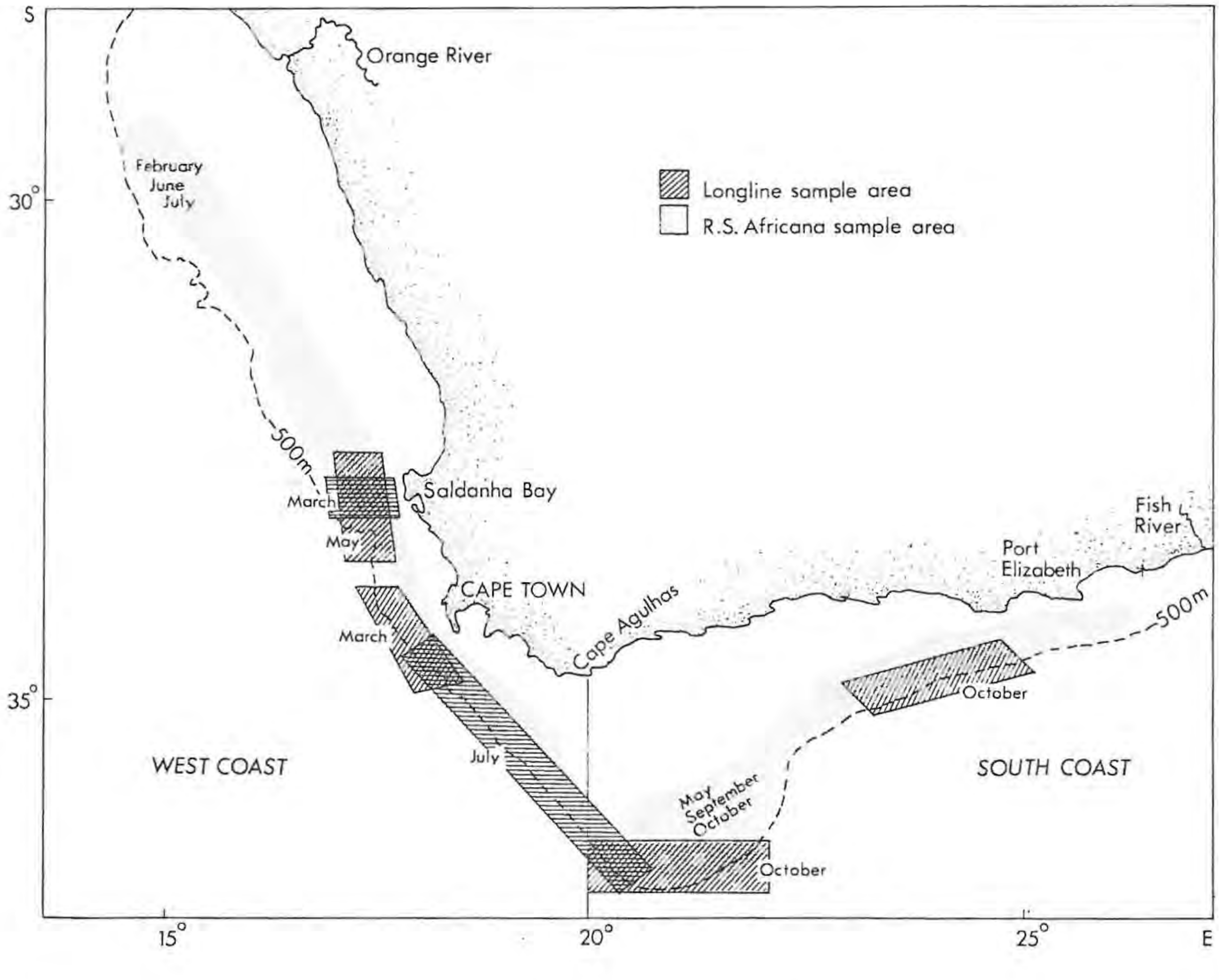

Fig. 3: Areas and months in which samples were obtained on board longline vessels and the R.S. *Africana*.

4. LONGLINE FISHING TECHNIQUES

Introduction

Within the last ten years, longlining worldwide has become highly mechanized and in most countries in which it is practised, has proved to be a commercially viable alternative to trawl fishing (Gustafsson 1988). Many different longline systems are used throughout the world. Each one has been designed for a specific set of conditions, such as local oceanography, boat size, available manpower and target species (Gustafsson op. cit.).

In much the same way that trawlers can adjust their gear to target for demersal, midwater or pelagic species, longlines can be adapted for specific fishing grounds, different depths and selected fish species. Perhaps the best documented bottom longline fishery is that for Pacific halibut, *Hippoglossus stenolepis* (Skud 1972). In that fishery, characteristics such as fish size and area fished are determined by the design of the gear, the material used in its construction and the conditions under which the fishing takes place (Mhyre 1969).

Most studies on longline selectivity are, however, only done to compare the methods effectiveness with that of trawling (Saetersdal 1963, Mhyre 1969, Hoag *et al*. 1984); otherwise, longline techniques are rarely documented. Individual fishermen or groups of longline fishermen are often competitive and are reluctant to release their trade secrets. In South Africa, however, uniform longline techniques have been developed by the experimental fleet. Here, there are variations in the design of the gear associated with the different areas fished and species targetted for. In this chapter, the South African longline system is described and the differences between the techniques used on the West and South Coasts are presented.

Description of Longline Techniques

All information on the techniques used by the longline fleet was obtained by direct observation aboard different vessels. Information was also obtained from fishing managers and shore skippers. Of particular value was the information gained from the Spanish and Portuguese crew who worked directly with and prepared the longlines. The local South African crews on board the longline vessels have since learnt the skills of the Portuguese and Spaniards and their level of proficiency is now such that the foreign crew are no longer required.

In South Africa a "double longline", consisting mostly of multifilament lines, has been developed. The double-line system is designed to cope primarily with the strong and unpredictable currents encountered on the South Coast and also with the rough substratum. The two-line system (Fig. 4) requires that both lines (the top and bottom line) are shot and hauled simultaneously. Should the bottom line (fish line) part it can still be recovered using the thicker, stronger top line, which is joined at intervals to the bottom line by a thinner line, the barandillo (Fig. 4). The two line system can be adjusted and two distinct variations have been developed. They are referred to in this study as: (a) The Demersal Bottom Line (DBL) - kingklip-directed and (b) The Demersal Midwater Line (DML) - hake-directed. These definitions are important and they are referred to in the text hereafter.

Longline vessels vary in overall length from 18 to 50 metres and are either converted tuna boats or old stern or side trawlers. Depending on the size of the vessel, the number of crew varies between 10 and 25. Vessels are either freezers or "wet fish" boats (fish retained on ice), and generally spend 30 or 15 days at sea respectively. The smaller vessels shoot between 6 000 and 7 000 hooks and the larger vessels between 9 000 and 14 000 hooks per day.

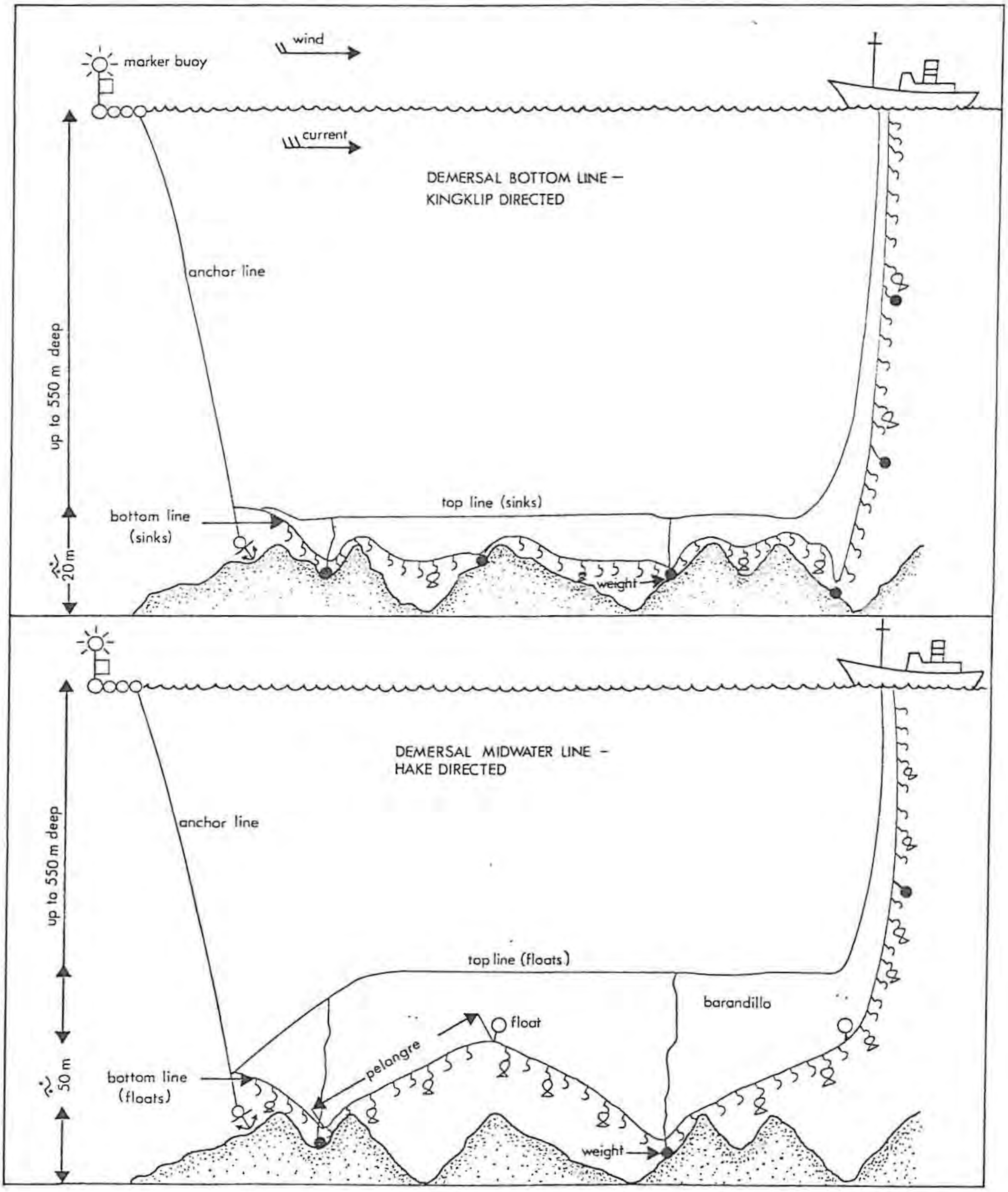

Fig. 4: The demersal longline as developed in South Africa. The two different techniques used are shown - DBL (top) and DML (bottom).

When directing catches at kingklip with the DBL, the lines are shot at night from about 20h30 to 22h00. Recovery of the line commences at sunrise and continues for most of the day (on average eight hours). Thus, the whole DBL is given a soak time of approximately eight hours at night, maximizing the effort for the benthic, nocturnal-feeding kingklip (Macpherson 1983).

In contrast, when directing effort at hake on the West Coast, the DML is shot later at night than the DBL, from about 22h30 to 24h00. Recovery commences from about 0900h thus giving the whole line a night-time soak of approximately six hours and a daylight soak of three hours. The gear is therefore left in the water during the day for a longer period, allowing time for the vertically migrating hake to return to the bottom, enhancing their exposure to the gear.

The longlines are anchored at both ends with a 27mm polypropylene line (Fig. 4), the length of which is at least two to three times the depth of water. The anchor lines are marked at each end with a 'dan' buoy and, depending on the current strength, a string of large plastic buoys as well as several smaller non-collapsible metal buoys. Longline skippers gauge the strength of the current by the number of buoys pulled below the sea surface. The unpredictability of the current on the South Coast (Chapter 2) frequently results in complete sets of longline gear being dragged below the surface and not recovered.

The top line (Fig. 4) of the DBL is a non-buoyant 14-16mm polyester line that theoreticaly lies on or close to the substratum. In contrast, the top line of the DML (Fig. 4) is a buoyant 14-16mm polyethylene line that theoretically floats above the bottom line and assists in raising the bottom line off the sea floor, thus decreasing the chances of it fouling.

The bottom line consists of units (pelangre*) approximately 50 metres long, to which are attached between 25 and 30 hooks (Fig. 5). The pelangre are strung together to form the bottom line. The pelangre on the DBL is normally a 6-7mm polyester multifilament line that sinks, effectively lying on the sea bed alongside the top line. In contrast, the pelangre of the DML is often a thinner polyethylene line, between 4 and 6mm diameter that is buoyant and lies above the sea floor. The top and bottom lines are joined at intervals of 150 - 220 metres by the barandillo (Fig. 4), normally a 7mm polypropylene line. The top line is recovered by means of a small warping drum and is stowed on the aft deck with the barandillos' attached.

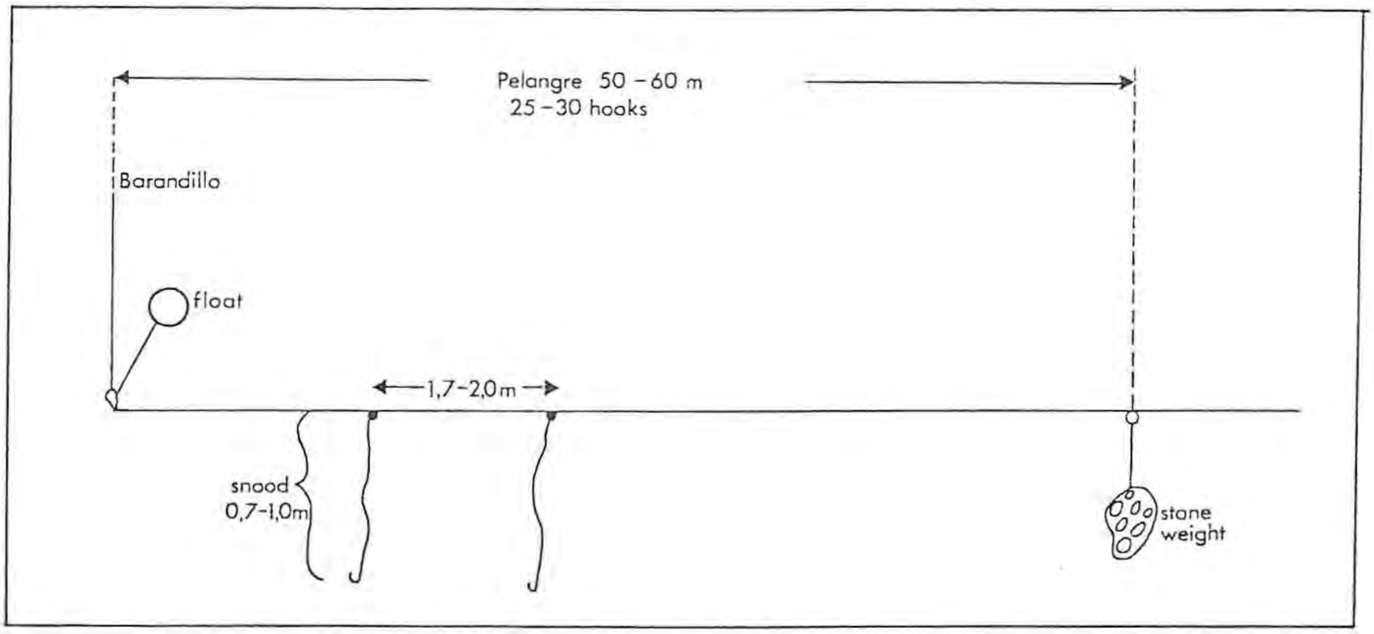

Fig. 5: The pelangre, the principle unit used in the constrúction of the demersal longline

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* The term 'pelangre' may lead to some confusion. It is derived from Spanish meaning 'fish line' and is often referred to by them as the 'bottom line'. To avoid confusion in the terminology used here 'bottom line' refers to the complete fish line and 'pelangre' is taken to mean the units of line to which are attached 25-30 hooks that are used to make up the 'bottom line' (Fig. 5).

The bottom line is recovered in units referred to as tubs. These units may consist of three or four pelangre depending on the size of the tub (receiving receptacle) into which the line is coiled and prepared for the next shoot. Each tub therefore has between 75 and 130 hooks. A line of 12 000 hooks will therefore require between 90 and 160 tubs. The bottom line is hauled with a hydraulicaly operated winch referred to as the "line hauler", which it reaches by first passing through a set of rollers. Any fish on the line are broken off at the rollers and fall on the deck.

Preparation of each tub is done manually and is a slow and labour-intensive process. Each pelangre is carefully repaired and the hooks replaced. Hook sizes vary but, in general, larger hooks (6/0) are used on the DBL when targetting for kingklip and the smaller hooks (4/0) are used on the DML when targetting on hake. 'J'-shaped hooks are used with either 'flat heads' or eyes for the attachment of a single length of monofilament nylon. The hook and line together is referred to as a gangion or a snood (Norwegian terminology).

Snood lengths vary between 700 and 1 000mm (Fig. 5). There is a tendency to use lighter monofilament line on the snoods attached to the DML for hake (0,8mm diameter) and slightly stronger monofilament on the kingklip-directed DBL (up to 1,6mm diameter). Each snood is attached to a swivel on the pelangre and is spaced between 1,7 and 2 metres apart. This hook spacing is standard throughout the fleet and is by tradition an arms length apart.

Each tub is prepared for shooting by neatly coiling the pelangre in the tub and hanging the hooks around the tubs perimeter. One hour before shooting, the hooks are baited with either pilchard *Sardinops oscellatus* or horse mackerel *Trachurus trachurus*, the latter being preferred because it lasts longer on the hook and does not fly off the hook as easily as does pilchard when the line is shot (baiting is done by hand although one vessel was equipped with an automatic baiting system). Sand is packed in the tub prior to shooting and baiting to prevent the weight of the bait from dragging the snood out of the tub. It also keeps the coil in place when shooting.

Shooting requires coordination and precision because it is done at speed (about 7 knots). While the top and bottom lines are running out, the barandillo is attached to the bottom line at intervals of approximately one tub. If the DBL system is being set, then weights are attached at the joins of the pelangre, that is every 25 - 30 metres. However, if the DML is being set, then small, robust, non-collapsible floats (approximately 200mm in diameter) are attached alternately with the stone weights (the weights used vary from about 1 to 3kg and consist of stones or bricks, often wrapped in old netting). This, in combination with the buoyant top and bottom lines, raises the lines off the sea bed in a series of catenaries (Fig. 4). Thus, the bottom line is raised above the substratum (estimated to approximate 50m) in a position in the water column where hake are presumed to be most abundant during the day.

Shooting (setting) of the line is normally done by steaming down wind or with the prevailing current, and recovery is in the opposite direction. Lines 20km long are common. Longliners frequently set lines on grounds close to one another, requiring careful coordination. The longlines are often set with turns and loops in order to remain on preferred grounds. Often, up to 10 boats shoot within a 20km^2 area (an average of 100 000 hooks per night) illustrating the intensity of longline exploitation in places.

The differences between the types of gear used on the West and South Coasts are summarized in Table 2.

Conclusions

South African longline fishermen have developed two distinct longline techniques. On the West Coast the demersal midwater line is used. This is a buoyant lighter line with floats and smaller hooks that is used to target on hake from about November to July. On the South Coast the demersal bottom line is used. This is a thicker, non-buoyant line with no floats and more weights and larger hooks than the DML and is used to target on kingklip in late winter and spring (August - November).

Clearly the type of gear used can, if conditions are favourable, be adjusted to target for a particular species. It should, however be kept in mind that it is impossible for the variations in longline gear reported here to be 100% specific. The proportion of any one species caught with a particular gear will undoubtedly be affected by such other factors as spawning aggregation, local and seasonal shift in abundance, localized depletion as a result of intense exploitation in a small area and oceanographic condition. Also, of course, the dictates of the local and overseas market play a key role.

Table 2. Summary of differences in longline gear and techniques used on the West and South Coasts.

	SOUTH COAST	WEST COAST
Method	DBL	DML
Target species	kingklip	hake
Season	spring/early summer	late summer to winter
Line shot	20h30 - 22h00	22h30 - 24h00
Recovered	from sunrise	from 0900
Floats	no	yes
Weights	yes	alternate with floats
Top line	non-buoyant polyester 14-16mm diameter	buoyant polyethylene 14-16mm diameter
Bottom line	non-buoyant polyester 6-7mm diameter lies on bottom	buoyant polyethylene 4-7mm diameter catenary effect
Hook spacing	1,7 - 2,0m	1,7 - 2,0m
Hook size	mostly 6/0	mostly 4/0

5. KINGKLIP MORPHOMETRICS

Introduction

Effective management of an important fish resource requires extensive knowledge of the biological characteristics of the exploited species and, in particular, the separation of the species into discrete spawning units or stocks (refer to Chapter 1 for stock defininitions used in this study). Morphometric features and anatomical structures have traditionally been used in taxonomy and fisheries science to identify fish species and different fish stocks, but these can be influenced by the environment (Ihssen *et al.* 1981, Bowering 1988). Nevertheless, they can be as valuable in indicating stock integrity as other more genetically related features (Casselman *et al.* 1981).

Isarev (1976a) used morphometric characters of kingklip to identify stocks on the West Coast. He made 13 measurements and grouped his fish samples into length intervals to test for differences between areas. Lay-Son (1984) made 20 body measurements to clarify the taxonomic status of *G. blacodes* and *G. reedi* and concluded that the two were synonymous. However, morphometric analysis revealed that differences on a subspecific level existed between the two species in different areas. The techniques used by these researchers attempted to contend with the problem of allometry (the change in proportion with size) by grouping fish into length classes and creating new variables that were ratios of the measured parameters with either the total length or the head length. This method can, however, be misleading because it is a fact of allometric growth that the ratios of the original variates change continuously and in a regular manner with size (Corruccini 1972). Further, the correlations and variance obtained between many of the variables with univariate statistics is ignored.

Analysis by means of multivariate techniques was considered more appropriate for kingklip morphometric data because a large number of variables was used and the effects of allometry would be reduced. Multivariate analysis of morphometric data using principle components and discriminant functions has been employed successfully to delineate fish stocks (Todd and Smith 1980, Casselman *et al.* 1981, Gon 1987, Gardner *et al.* 1988, O'Maoileidigh *et al.* 1988, Reddin *et al.* 1988). Therefore, in this study, Principle Component Analysis (PCA) and Discriminant Function Analysis (DFA) were used to test for the possible existence of discrete kingklip stocks on the South and West Coasts.

Materials and Methods

Kingklip were collected for morphometric measurements from commercial longline vessels. Only specimens that showed no signs of pathology, barotrauma or damage were used, each specimen being frozen straight with mouth closed and pectoral fins folded posteriorly. This procedure retained the shape of the fish for later measurement in the laboratory ashore. Morphometric measurements were also done aboard R.S. *Africana* using suitable specimens obtained from the research trawls.

Most of the 447 specimens used were mature (83%) and in the length range 500 - 1 000mm. However, to obtain a more complete size range, kingklip up to 1 250mm and down to 270mm were also measured. All samples were obtained in 1987, of which 242 were caught on the West Coast (males = 86, females = 156), and 205 (males = 122, females = 83) from the South Coast. The morphological measurements (to the nearest 5mm on a standard measuring board) made on each fish (Fig. 6) were as follows:

1. TL Total length - measured from the tip of the snout (premaxilla) to the end of the dorsal fin;
2. AA anterior to anus - measured from snout to anus;
3. AD anterior to dorsal - measured from snout to beginning of dorsal fin;
4. AP anterior to pectoral - measured from snout to base of pectoral fin.

All other measurements were made to the nearest 0,01mm with a vernier caliper and were as follows:

5. HL head length - measured from snout to end of opercular spine;

6. LP length of pectoral fin - measured from base of pectoral at beginning of fin rays to the tip of the pectoral fin;

7. ED eye diameter - measured vertically through the pupil from edge of the perimeter of the orbital;

8. ES eye to snout - measured obliquely from the inside of the orbital to the tip of the snout;

9. IO interorbital - measured horizontally between the orbits;

10. DH depth of the head - measured vertically, transecting the pupil and immediately forward of the barbel from the dorsal to the ventral margin of the head;

11. MS maxilla to snout - measured laterally from the posterior margin of the maxilla to the tip of the snout;

12. M width of maxilla - maximum width of the maxilla;

13. B length of barbel - maximum length of barbel measured from base of fleshy protruberance of barbel to the tip of barbel.

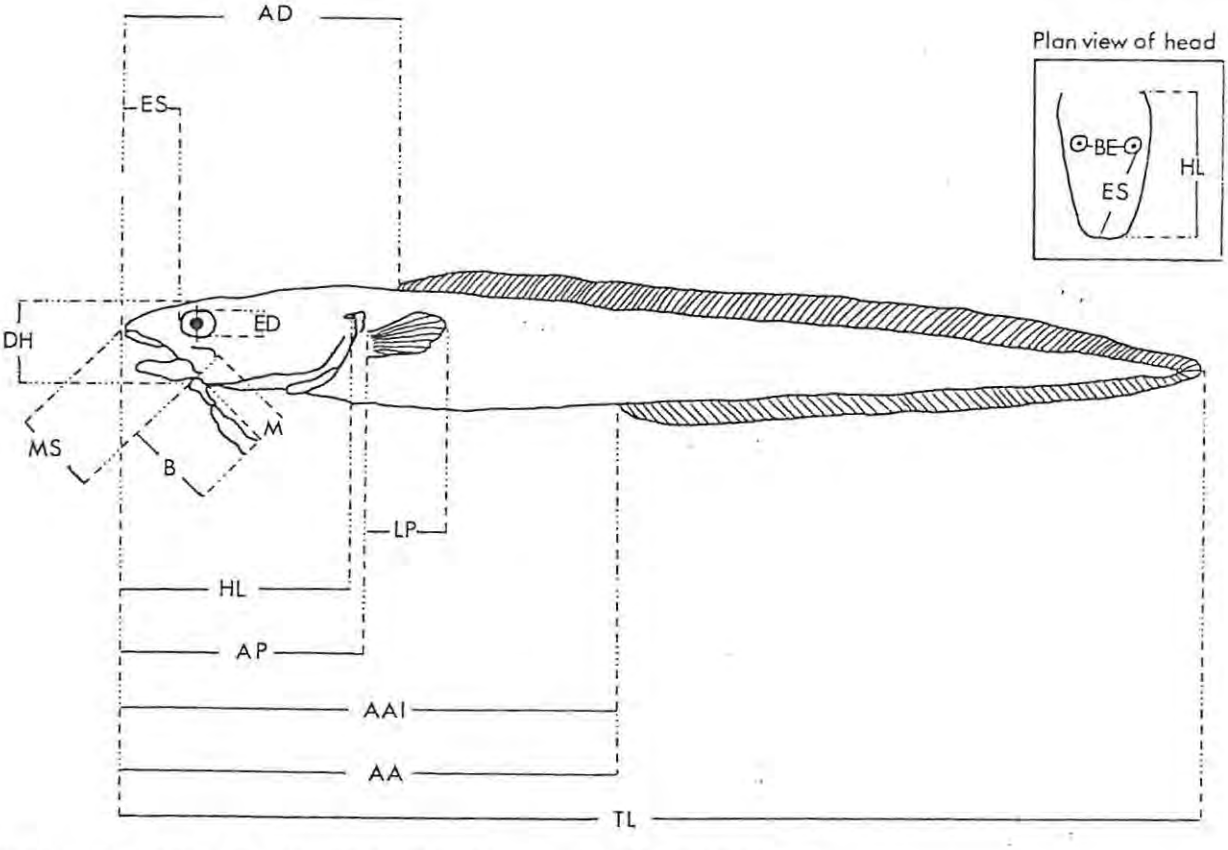

Fig. 6: Kingklip morphometric measurements

Statistical Analysis

All measurements were transformed into natural logs to reduce heteroscedasticity (Sharp *et al.* 1978) and to more closely approximate multivariate normality (Bowering 1988). All statistical processing was carried out with the SAS Statistical Processing package (1985). The following statistical procedure was followed:

1. The data were tested for multivariate normality (a prerequisite for PCA and DFA) using the following hypothesis:

H_o: All morphometric variables are multivariate normally distributed

2. Multivariate analysis was carried out to test if any of the variables (morphometric measurements) were significantly affected by either sex or area.

1. H_o: Sex does not affect any of the variables and

2. H_o: Area does not affect any of the variables

The variables AA, AD, AP, HL, LP and B were tested for significant correlation with total length (TL) and the variables ED, ES, IO, MS and M were tested for significant correlation with head length (HL).

3. The data were subjected to PCA. PCA does not assume differences among the samples but produces coordinates along the axis of greatest variation. The proportion of explained variation decreases with each principal component (Todd and Smith 1980) and is used to establish the significance of each variable. Thus, PCA transforms the original correlated set of variables into a new uncorrelated set of variates called principle components (Chatfield and Collins 1980). The relative importance of each variable can therefore be estimated and, if necessary, only a few variables need be used in further analysis.

4. The selected variables were subjected to DFA. DFA produces axes that maximize the graphical separation of the predefined groups (Chatfield and Collins 1980).

All morphometric measurements were entered on a single computer spread sheet along with all relevant information.

Results

The data (all morphometric variables used) were multivariate normally distributed ($P > 0,001$) and the correlation matrix showed that all variables were significantly correlated with either TL or HL. The lowest correlation was 0,86 between eye diameter and depth of the head and between eye diameter and barbel length. Nevertheless, all correlations were significant ($P > 0,001$).

Multivariate analysis to test if any of the morphometric variables are significantly different between males and females or between areas was tested at the 5% level of significance (Table 3). No significant differences were found between sexes except for the variables eye diameter and barbel length. There were significant differences between areas for all variables except for the variables eye diameter and barbel length. Consequently, the variables eye diameter and barbel length were not used in further analysis and the data were treated to a more detailed investigation for differences between areas using PCA and DFA assuming that there was no significant difference between the sexes.

The data were not dominated by any one variable as all variables had similar variances (Table 4). The first principle component described 96,7% of the total variance and the eigenvectors of the first principle component were approximately the same for each variable (Table 4). A plot of the first two principle components showed poor discrimination between the West and South Coasts, and to improve it, the data were analised using Discriminant Function Analysis.

Table 3. Results of multivariate analysis of kingklip morphometric data to test if either sex or area does not significantly affect any of the variables

Dependent Variable	SEX			AREA		
	F value	Prob>*F*	reject(R) accept(A)	*F* Value	Prob>*F*	reject(R) accept(A)
TL	7,99	0,005	A	0,26	0,61	R
AA	8,10	0,005	A	0,14	0,71	R
AD	7,20	0,008	A	0,01	0,94	R
AP	5,13	0,023	A	0,07	0,79	R
HL	7,53	0,006	A	0,30	0,58	R
P	7,10	0,008	A	0,68	0,41	R
ED	1,22	0,269	R	7,83	0,01	A
BE	6,86	0,009	A	0,14	0,71	R
ES	4,27	0,039	A	0,55	0,45	R
DH	5,02	0,026	A	0,01	0,99	R
MS	6,21	0,031	A	0,02	0,89	R
M	5,48	0,018	A	0,26	0,61	R
B	3,02	0,083	R	3,71	0,05	R

Table 4. Statistical results of principle component analysis of kingklip morphometric data

Character	Mean	Variance	EIGENVECTORS		
			PC1	PC2	PC3
TL	6,51	0,096	0,292	-0,155	-0,038
AA	5,72	0,125	0,290	-0,100	-0,060
AD	5,12	0,121	0,290	-0,130	-0,096
AP	5,02	0,121	0,290	-0,060	-0,110
HL	4,96	0,124	0,290	-0,120	-0,006
P	4,07	0,118	0,280	-0,190	0,900
BE	2,84	0,185	0,290	-0,291	-0,030
ES	3,50	0,150	0,290	-0,030	-0,040
DH	3,76	0,115	0,290	-0,030	-0,390
MS	4,18	0,127	0,290	-0,060	-0,060
M	3,15	0,140	0,290	0,130	-0,090
EIGENVALUES			11,60	0,090	0,090
VARIANCE (%)			96,7	0,7	0,7

Discriminant Function Analysis

DFA by area gave a significant level of separation between the West and South Coasts (Table 5). Of the West Coast sample, 71,5% were classified as such and 28,5% were classified "South Coast". Of the South Coast sample, there was better discrimination and 83,4% were classified correctly and 16,6% as "West Coast". Plots of the first three canonical variables in two dimensions (Fig. 7) and in three dimensions (Fig. 8) showed there was some separation between the two areas, but that there was a substantial overlap beween the areas. The distance between the means of the two areas was significant [Mahanalobis distance (D^2) = 1,1873; *F* = 10,77 ; *P* > mahanalobis distance = 0,0001].

Table 5. Results of discriminant function analysis on kingklip morphometric data with percentage of sample from each coast classified into alternative area (numbers in parenthesis)

Sample tested AREA	 N	% Classified as West Coast	% Classified as South Coast
WEST	242	71,5% (173)	28,5% (69)
SOUTH	205	16,6% (34)	83,4% (171)

Conclusions

With respect to the selected morphometric variables, there is no statistically significant difference between sexes except in the cases of eye diameter and barbel length. On the contrary, there were significant differences between areas in respect of all variables except for eye diameter and barbel length. It is

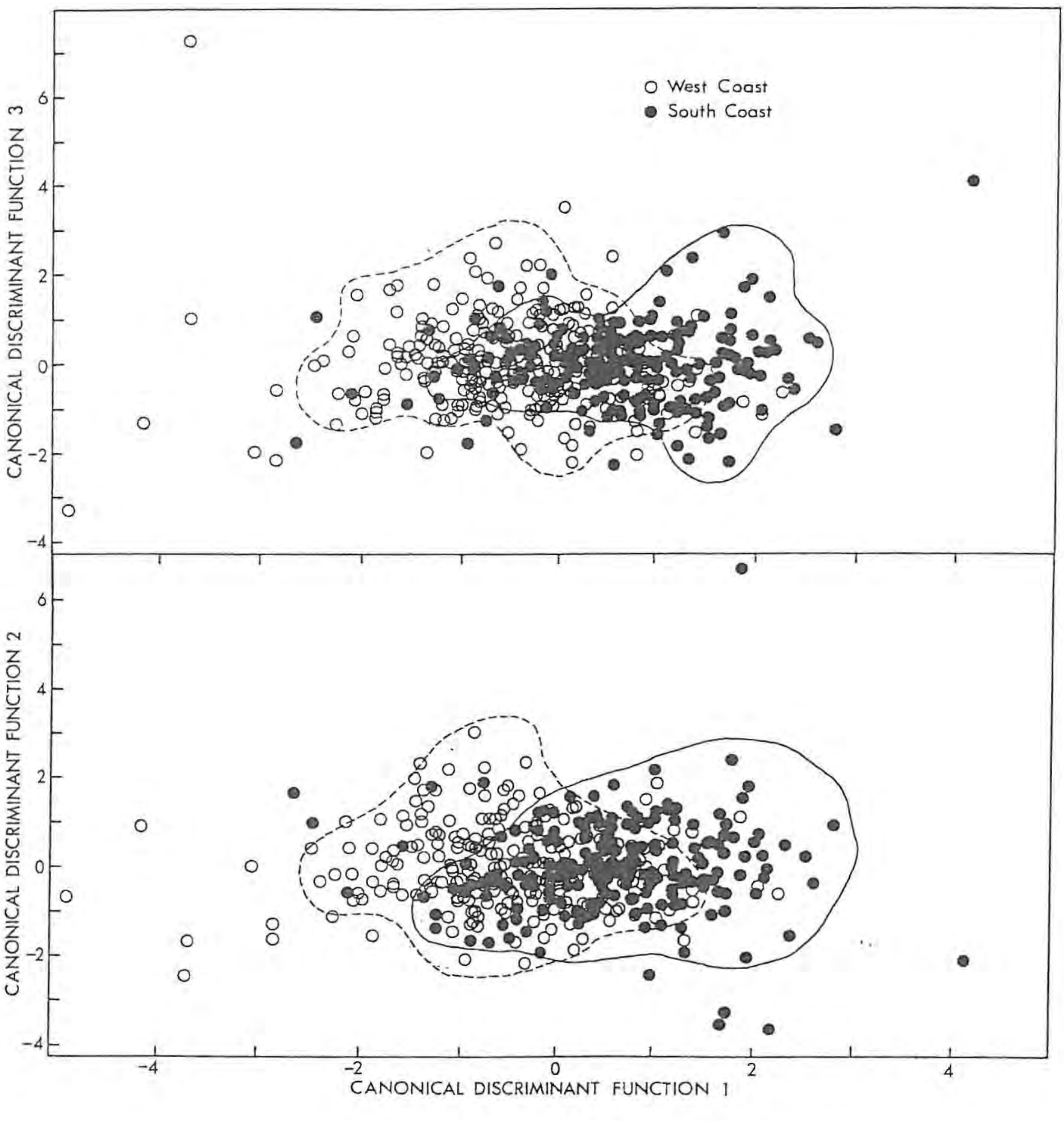

Fig. 7: Two dimensional presentation of Discriminant Function Analysis of morphometric variables used to test if differences exist between kingklip on the West and South Coasts. The first three canonical variables have been used. Canonical functions 1 & 2 are presented in the bottom figure and 1 & 3 are presented in the top figure.

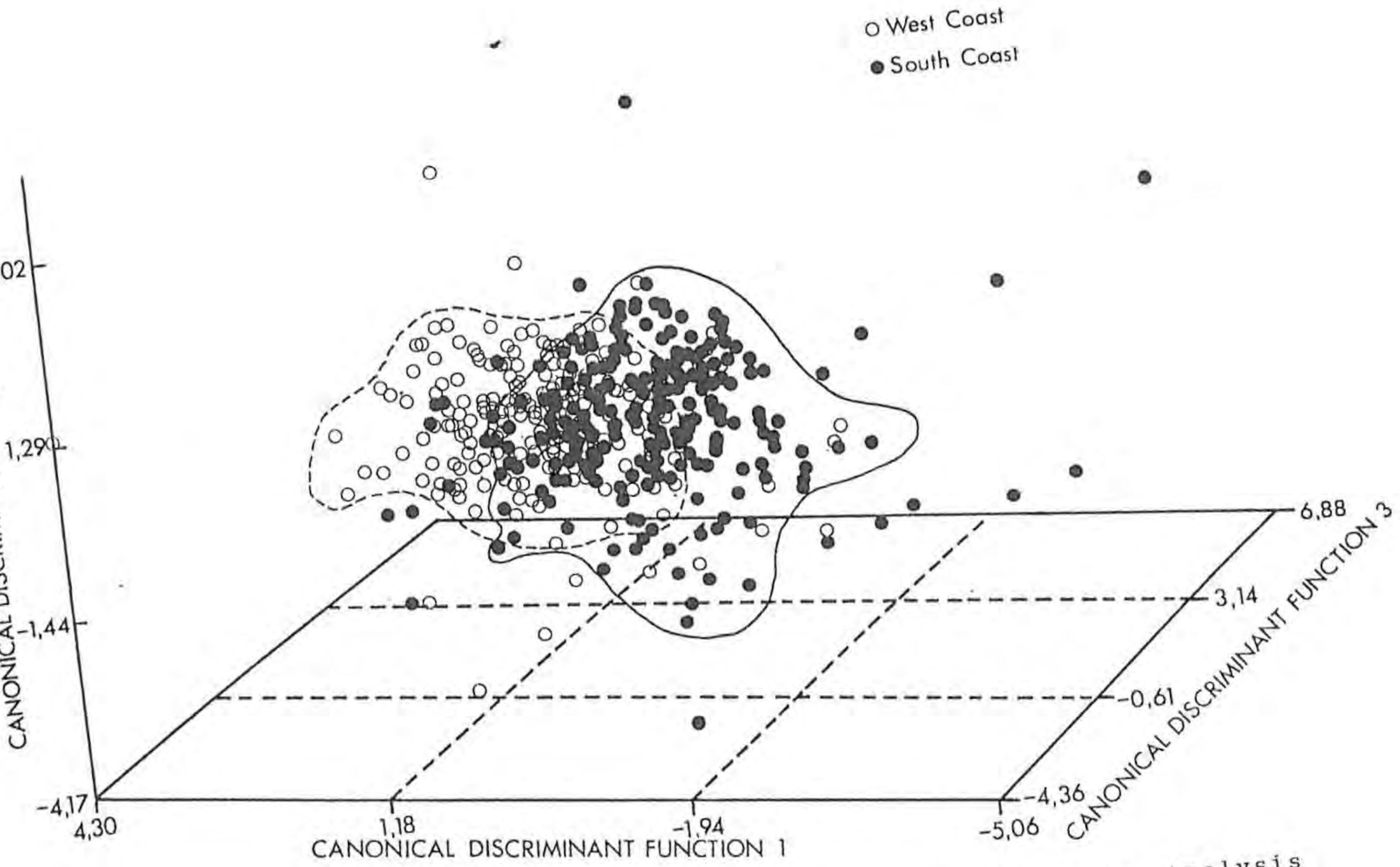

Fig. 8: Three dimensional presentation of Discriminant Function Analysis used to test for differences between kingklip on the West and South Coasts. Note: The South Coast samples predominate on the right-hand side of the figure and the West Coast on the left-hand side, but that there is a large overlap.

thought likely that difficulty in measuring the parameters barbel length and eye diameter resulted in large inconsistencies and consequently an unacceptably high variance. However, it is also possible, though less likely, that different preferences for habitat depth between males and females may account for the differences in eye diameter. Also the differences in barbel length between males and females may be due to different feeding habits.

Jolicoeur and Mosimann (1960), cited in O'Maoileidigh *et al.* (1988) demonstrated that a principle component having all coefficients of the same sign was indicative of size variation, whereas any component having both positive and negative coeficients was indicative of shape variation. Principle Component 1 accounted for 96,7% of all variation in the group of variables used and it could therefore be assumed that size variation occurs between the kingklip on the West and South Coasts and that variation in shape is unlikely.

Discriminant Function Analysis also shows that there is a difference between the kingklip on the West and South Coasts, but that there is considerable overlap between the two areas. This suggests that kingklip on the West Coast are not discrete from those on the South Coast, but that other factors may affect the body morphology of the kingklip. It is likely that the differing environments of the two coasts accounts for the change in the body morphology of the kingklip, and that this is more likely related to size than shape. Comparison of the gross morphology of kingklip therefore suggests that they are a single stock with small but insignificant differences in shape between those caught on the West and South Coasts.

6. KINGKLIP OTOLITH MORPHOLOGY

Introduction

Calcified structures, for instance scales, otoliths and certain bones, can provide valuable information for stock identification (Ihssen *et al.*1981). Otoliths for example, under detailed examination, have been found to contain characteristics that are stock-specific (Ihssen *et al.* 1981, Hecht 1987). They should however be dealt with separate to studies of gross morphology, because specific techniques requiring specialized analysis are used (Ihssen *et al.* op. cit.). The same structures can also be used for routine studies of age and growth and this is dealt with in the following chapter.

Messieh (1972) used the optical appearance of the nucleus, the relative sizes of the growth zones and winter rings of otoliths to identify different stocks of herring in the Gulf of St Lawrence. Casselman *et al.* (1981) used otolith shape to discriminate among whitefish stocks in Lake Huron and Rojo (1977) discriminated between different stocks of cod *Gadus morhua* L. on the basis of otolith length and weight. In South African waters, Botha (1971), used the shape and the length:height ratio of otoliths as a means of distinguishing between the species of Cape hake, *Merluccius capensis* and *M. paradoxus*.

Frolinka (1977) studied otolith shape and length of the *G. blacodes*, a species closely related to kingklip, and found no difference between the otoliths of the males and females. However, he did find that otoliths of that species could be grouped into three categories (smooth, flat and ostate) attributable to the size of the fish and to locality.

Otolith characteristics have also been used to identify kingklip stocks. Isarev (1976b) looked at differences in the length:height ratio and in the mass of kingklip otoliths in specimens collected off South Africa and South West Africa, but he could draw no positive conclusions with respect to kingklip stock integrity on the South Coast because of his small sample size. Nevertheless, he was able to identify two discrete stocks on the West Coast (referred to in Ch. 5) on the basis of otolith morphology. Payne (1977) came to the same conclusion from studying otolith morphology. He found that the relationship between otolith length and fish length was diphasic, and that in the early growth phase at least, the relationship between the South-East and Cape stocks was significantly different, but that in the second growth phase there was no significant difference. The South-East stock appeared to have an otolith length:height ratio intermediate between Payne's so named Walvis and Cape stocks. Neither Payne nor Isarev mentioned any differences between sexes.

Payne (1985) later concluded that there were significant differences in the otolith length:height ratio between the South-East and Cape stocks and theorized that there may be another stock intermediate between those two.

In this study, kingklip otolith morphology was used to test whether stocks on the West and South Coasts of South Africa were discrete. The relationships between total fish length and both otolith weight and length:height ratio was investigated. Further, the South Coast data were split into the South-East Coast and the Intermediate Area, as defined in Chapter 1 to test if differences in kingklip otolith morphology exist between the West Coast, South-East Coast and Intermediate Area.

Materials and Methods

Otoliths from 1 889 kingklip were used and of these, 1 672 could be used for otolith measurements. Otoliths showing any signs of irregularity were not used. The sample sizes for each area are given in Tables 6 and 7. Otoliths were first cleaned and dried and then the maximum length and height were measured with a vernier caliper to the nearest 0,01mm.

Initially, 100 pairs of otoliths were measured and the results tested for significant differences between left and right otoliths. There was no significant difference (*t*-test, $P < 0,001$) and thereafter only one otolith of the pair was measured. That same otolith was weighed on an electronic balance to the nearest milligramme.

Statistical Analysis

All relevant data, including total fish length, total fish weight, sex, area and month caught were captured on a single database. A students *t*-test was used to determine equality of the population correlation coefficients (Zar 1974) between areas and sex. Where slopes were not linear, the data were log-transformed for linearity and then tested. The slopes of the respective populations were first tested for equality. If the slopes were the same then the intercepts were tested for equality. In this way the following otolith characteristics were investigated :

1. the relationship between otolith weight and total fish length was determined and tested for difference between the sexes;

2. if there was a significant difference between the sexes, the data were separated and tested for difference between areas;

3. the relationship between otolith length:height ratio and total fish length was determined and tested for difference between the sexes;

4. if there was a significant difference between the sexes, the data were separated and tested for difference between areas.

Results

The relationship between otolith weight and fish length was exponential (Fig. 9a) and significantly different for males and females (Table 6). Males from approximately 590mm have heavier otoliths than females. The relationship for each sex is given by:

Males: $OW = 0{,}0200 \; . \; TL^{2,26}$ 1

Females: $OW = 0{,}0350 \; . \; TL^{2,08}$ 2

where OW = otolith weight (mg) and TL = fish length (cm).

Table 6. Statistics and tests for significance between sex and area for otolith weight to total fish length relationships of kingklip (*t*-test value : $t\alpha_{(2)\infty}=3{,}12$; Tested for significance at 98% level)

Populations compared	n	SLOPE *t*	SLOPE significant	INTERCEPT *t*	INTERCEPT significant
Males/Females All areas	1672	6,373	yes	52,99	yes
Males West to South	600	0,861	no	5,924	yes
Females West to South	1071	0,077	no	8,596	yes

If the sexes were considered separately, no significant difference in the otolith weight:fish length between the West and South Coasts could be found (Figs 9b & 9c). The curves for both coasts closely approximated each other and no distinction could be made between the South-East Coast and the Intermediate Area. The intercepts were, however, significantly different for males and females. The theoretical otolith weight at zero total length was in each case slightly greater on the South Coast than on the West Coast. The differences were small and the same exponential functions given above (equations 1 and 2) describe the relationships between otolith weights and total fish lengths for males and females.

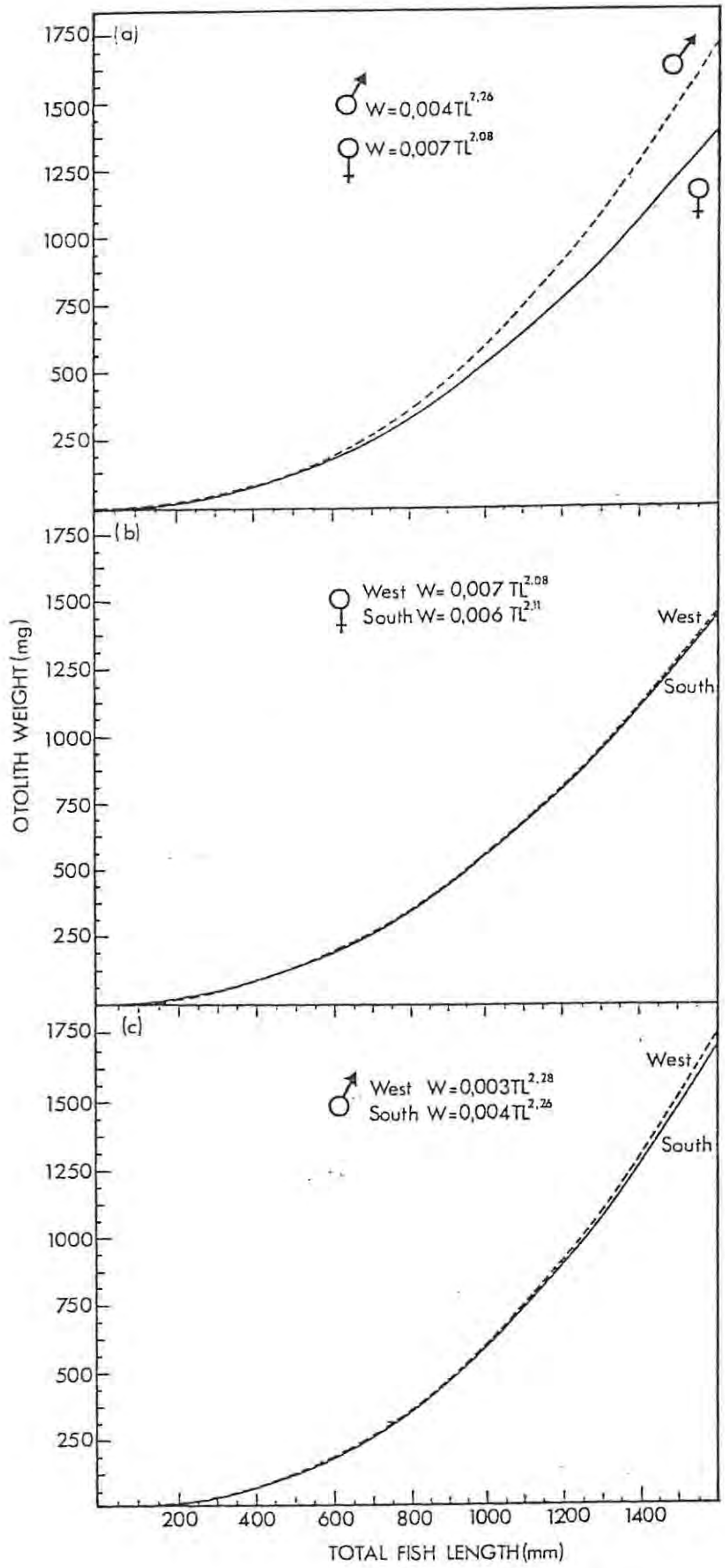

Fig. 9: Comparison of kingklip otolith weight:fish length relationship between sexes (a), females by area (b) and males by area (c).

The slopes of the relationship between otolith length:height ratio and fish length were similar for males and females (Fig.10a), but the intercepts were significantly different (Table 7) and are described by the following linear relationships:

Males : $L:H = 2,38 - 0,005\ TL$ 3

Females: $L:H = 2,43 - 0,005\ TL$ 4

where L:H = otolith length to height ratio and TL = fish length.

Table 7. Statistical data for length:height ratio to total fish length correlations (t-test value: $t_{\alpha(2)\infty} = 3,12$; Significance tested at 98% level).

Populations compared	n	SLOPE		INTERCEPT	
		t	significant	*t*	significant
Males/Females All areas	1672	0,924	no	23,68	yes
Males West to Inter.	324	0,370	no	8,052	yes
Males Inter. to South-East	389	2,915	no	40,33	yes
Females West to Inter.	874	1,102	no	20,11	yes
Females Inter. to South-East	518	0,241	no	1,592	no

Comparison of the slopes of the relationship between otolith length:height and fish length of males showed that there was no significant difference between either the West Coast and the Intermediate Area or the South-East Coast and the Intermediate Area (Fig. 10b and Table 7). However, the intercepts of both comparisons were significantly different.

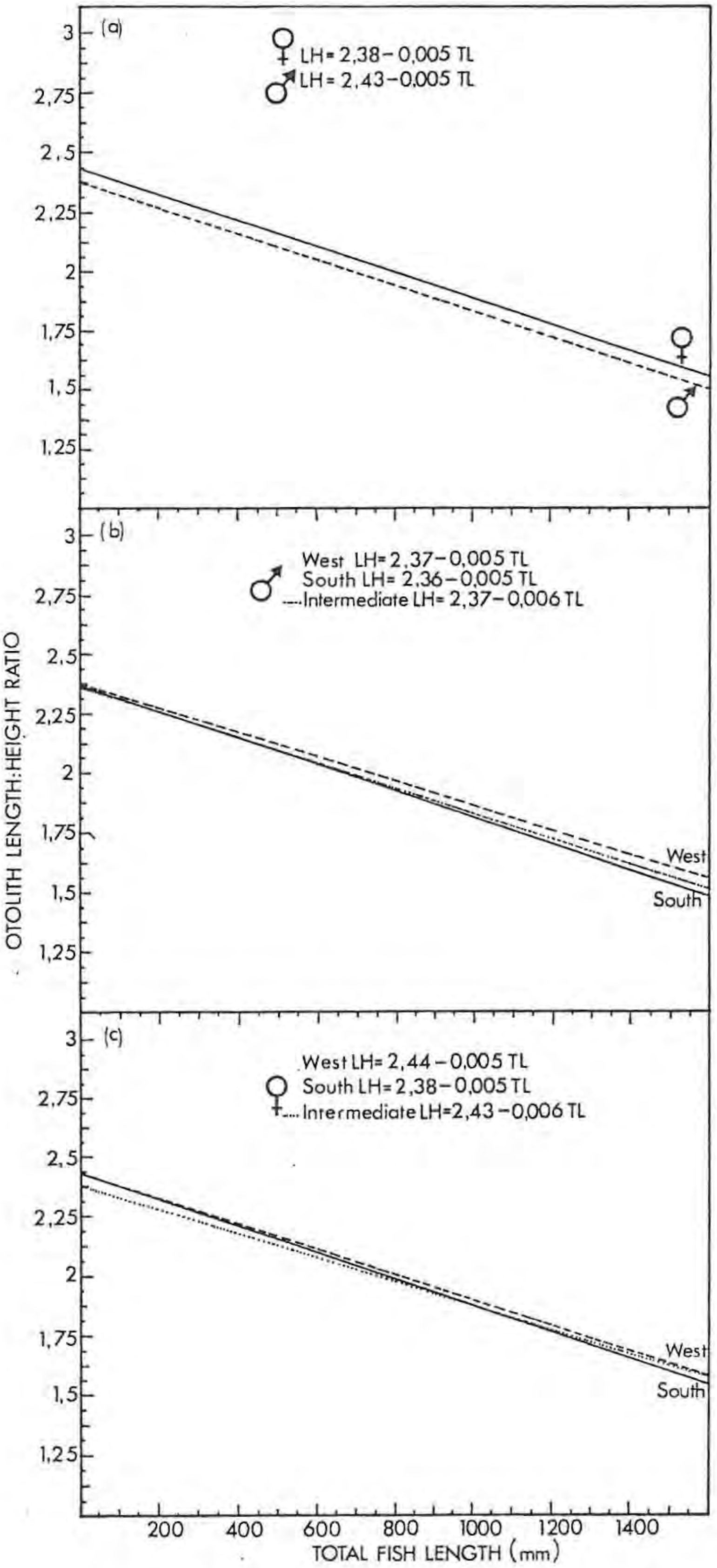

Fig. 10: Comparison of kingklip otolith length:otolith height ratio to fish length between sexes (a), for males by area (b) and females by area (c)

Similarly, for females (Fig. 10c), there was no significant difference between the slopes of the length:height ratios of the West Coast and Intermediate Area, but there was a significant difference between the intercepts. Between the Intermediate Area and the South-East Coast neither the slopes nor the intercepts were significantly different (Fig. 10c; Table 7).

Conclusions

The results of this investigation have shown that there is no significant difference in the otolith morphology of kingklip around the South African coast. There are, however, significant differences between male and female kingklip, a fact not previously recorded. Male kingklip > 590mm have heavier and shorter, wider otoliths than female kingklip.

The relationship between otolith length: height ratio and total fish length suggest that both sexes of kingklip on the South Coast have a lower otolith length:height ratio than for the same sex on the West Coast. However, this change is not abrupt and the shift from the West to the South Coast is probably a gradual one.

The diphasic pattern of otolith length:fish length relationships for kingklip (Payne 1977) is not discussed in this section but is considered in Chapter 7. However, a similar diphasic growth pattern occurs in the relationship between otolith weight and total length, the apparent change occurring at approximately 590mm (Fig.9). The results of the investigation of aspects of kingklip reproduction presented in Chapter 8 suggests that this length approximates the length at 50% maturity. Clearly the diphasic pattern in otolith growth is associated with the onset of maturation in kingklip. This pattern is however suppressed when the length:height ratio is regressed against fish length (Payne 1977). The results of the otolith length: height ratio to fish length analyses are similar to those of Payne (op. cit.), but a different interpretation may be given.

From the analysis carried out, it would appear that the Cape, South-East and Intermediate stocks are not discrete but are rather part of a single kingklip population, the otolith morphological characteristics of which show little variation around the South African coast. It is possible, however, that localized 'sub-populations' have evolved life history traits closely linked to their immediate environment. In this way, local kingklip populations are likely to exist (with variations in otolith shape for example) but are probably not mutually exclusive. Frolinka (1977) made a similar observation for the closely related *G. blacodes* in South American waters, suggesting that otolith morphology was specific to fish in particular environments. The results of the investigation into kingklip otolith morphology therefore support the findings on gross morphology presented in Chapter 5 that the kingklip caught off the South African coast are a unit stock.

7. AGE AND GROWTH OF KINGKLIP

Introduction

Population parameters are often used to identify characteristics of sympatric fish stocks, that is stocks that are not isolated by physical barriers (Ihssen *et al.* 1981). These parameters may, however, be sensitive to extrinsic factors and are often characteristic of the environment as well as the stock itself. Fish stocks may therefore respond to the environment in different ways, which may then be viewed as characteristic of the particular stock (Casselman *et al.* 1981). Thus, the growth of fish within a particular population or stock may be characteristic of its environment and may differ from a stock in a nearby but different environment. This does not necessarily mean, however, that the stocks are discrete because they might not be reproductively isolated (Ihssen *et al.* 1981).

Determining the age of fish is also essential if the population dynamics of the species or stock is to be understood. For example, knowledge of the correct age of a fish is a prerequisite to solving such life history problems as longevity, growth rate, age at maturity and mortality, all of which are prerequisites of modern dynamic pool models (Gulland 1983, Hughes 1986, Butterworth *et al.* 1988).

The age and growth of kingklip has previously been studied, although not always using consistent techniques. In all cases the Von Bertalanffy growth model was fitted. Wrzesinski (1975) determined kingklip age and growth around the entire South African coast and established that *Genypterus capensis* (sexes combined) was a long-living species with a slow growth rate (Table 10). Hecht (1976) determined kingklip growth in the vicinity of Algoa Bay on the South-East Coast for both sexes combined and came to a similar conclusion, but with a lower L_∞. Isarev (1976c) found differences in the growth rate between male and female kingklip in the tropical stock but little difference between the growth rate of sexes in the sub-tropical stock. Payne (1977) established that females grew slightly faster than males after five years in both the Walvis and Cape stocks and that the Cape stock grew to a significantly larger size than the Walvis stock. Payne (op. cit.) also found a diphasic pattern in the relationship between otolith length and total fish length and noted that this also differed between the stocks in the different areas. Payne (1985) also established that kingklip growth rate on the South-East Coast was significantly higher than on the West Coast.

Clearly age interpretation is subjective, varying between researchers and with the techniques employed. Kingklip age and growth on the South and West Coasts in this study was investigated using sectioned and whole otoliths and appropriate growth models were fitted to the data using robust statistical analysis. This information is used to help establish if discrete kingklip stocks exist on the South African coast. Morales (1982) and Morales-Nin (1987 unpub.) presented basic guidelines for the interpretation of kingklip otoliths in all ICSEAF areas and these, with some modifications, were used in this study.

Materials and Methods

During routine biological sampling, both sagittal otoliths were removed by clearing the gill arches and drumming muscles from the vertebrae and brain case then, by clipping the bone of the brain case with bone cutters and snapping the head back, the otoliths were exposed and could be removed with forceps. To clean them, they were stored for about one week in a 5% solution of KOH. Thereafter, they were dried and weighed and prepared for sectioning and reading as soon as possible. Kingklip otoliths are thick and large (Payne 1977) and difficult to read whole, particularly in older fish.

1. Sectioning techniques

Kingklip otoliths were prepared for sectioning using techniques developed by Bedford (1983). Moulds were made from 400mm long and 25mm diameter plastic tubing (cut in half longitudinally). The moulds were sealed at each end and given a thin inner coating of petroleum jelly to facilitate easy removal of the rods once the resin had set. A thin layer of black pigmented polyester resin was poured into the base of the mould. When this became tacky, the otoliths were placed lengthways and lateral side up in the resin, and allowed to settle so that the margins of the otoliths were just covered by the pigmented resin. A second layer of clear polyester resin was then poured over the otoliths and allowed to set for eight hours. Too rapid a setting process resulted in excessive heat and cracking of the otoliths. The use of black resin facilitated the interpretation of the margin and also ensured that the nucleus of the otolith could be clearly seen for sectioning.

Using the technique developed by Rauck (1976), transverse sections of approximately 0,5mm were cut through the nucleus of each otolith with a pair of circular diamond-tipped blades. Each section was then mounted on a glass slide with clear DPX mounting liquid and numbered.

2. Reading techniques

The terminology adopted at a recent South African linefish workshop (Hecht and Smale 1986) was used to describe all age related features when reading the otoliths. Both whole and sectioned otoliths were viewed with a binocular dissecting microscope. Whole otoliths were immersed in water in a black petri dish and viewed with reflected light. The opaque rings appeared white and the hyaline bands translucent. Sectioned otoliths were viewed with transmitted light. Under those conditions the opaque rings appeared dark and the hyaline rings clear. Initially, the ring counts and interpretation of the kingklip otoliths were compared with the techniques used by previous workers.

Both Hecht (Dept. Ichthyology and Fisheries Science, Rhodes University) and Payne (Sea Fisheries Research Institute, Cape

Town) were consulted. The guidelines of Morales-Nin (1987 unpub.) for kingklip annuli interpretation were also referred to. Otoliths were read in groups of ten, alternating between whole and sectioned otoliths. Thus, two readings were done initially, followed by the same procedure approximately two weeks later. If there was no agreement between the first two sets of readings then a third reading was made. If the third reading did not agree with either of the first readings, the otolith was rejected. A total of 1 889 otoliths were read of which 92% (1 735) were accepted (Table 8).

Table 8. Summary of otolith numbers read and accepted by area and sex.

Sex	Total West Coast accepted	Total South Coast accepted	Total accepted	Percent rejected
Male	228	399	627	7,5
Females	585	523	1 108	8,5
Total	813	922	1 735	8,2

Whole otoliths could be read easily for fish up to eight years of age. Thereafter, interpretation became more dependent on the sectioned otoliths. The technique of reading whole and sectioned otoliths was especially useful for interpreting annuli in the first five years of growth because, in the third and fourth years of growth, the annuli appeared as groups (multiple rings) of opaque bands which were more easily interpreted in the whole otolith. Thereafter, as the fish growth rate slowed down, the bands were more compact and easier to interpret in the sections. Multiple rings were more apparent on the dorsal and ventral margins of the transverse section, a finding confirmed by Morales-Nin (1987). A set of rings were only accepted as annuli if they were continuous in both the whole and sectioned otoliths. These were most easily counted from the nucleus to the margins on the medio-lateral plane of the section where the opaque rings were thinner and more pronounced.

The nature of the margin was recorded as either opaque or hyaline. The stacking effect of the opaque rings on the margins of the otoliths in the older fish made it difficult to distinguish between opaque and hyaline margins. Therefore only fish younger than 12 years old were used to determine the periodicity of ring formation.

3. Statistical analysis

The periodicity of ring formation was determined from the monthly percentage frequency of opaque and hyaline margins. The relationship between otolith length and total fish length was determined and the data were tested for differences between areas and sex. Where necessary, iteration techniques were used to determine the best fit to the data and the slopes tested for differences between them (Zar 1974 - *t*-test for comparison between linear relationships).

The relationship between total length and total fish weight was determined for kingklip from the West and South Coasts and also for the South Agulhas Bank. The data were made linear by log transformation where necessary; thereafter they were tested for differences between slopes and intercepts.

The use of the Von Bertalanffy growth model has been questioned (Knight 1968, Roff 1979, Pauly 1981) and when observed curves were fitted, mean lengths at age were mostly used. This method has been found to be statistically unsound and more sophisticated and robust techniques for fitting growth curves have been used in this study (Hughes 1986, Hughes and Punt 1987, Butterworth *et al.* 1988). The statistical and fitting procedures recommended by Hughes (1986) and Hughes and Punt (1987) for determining appropriate growth models were followed to describe the growth of kingklip on the West and South Coasts. First the Schnute (1981) four-parameter model was used to determine the best growth model for the data. Second, the data were tested for homoscedasticity and randomness of residuals, and the most appropriate error model (Hughes 1986) was determined. The appropriate growth curves were then calculated.

Results

1. Zone formation

The percentage opaque margins remained high for most of the year and declined to approximately 50% between August and October (Fig. 11), confirming the findings of Hecht (1976) and Payne (1977). It was therefore accepted that a single opaque and hyaline ring per year was formed. The ends of the opaque margin were counted as annuli and the approximate time of formation of the hyaline ring, 1 September, was taken as the kingklip birth date.

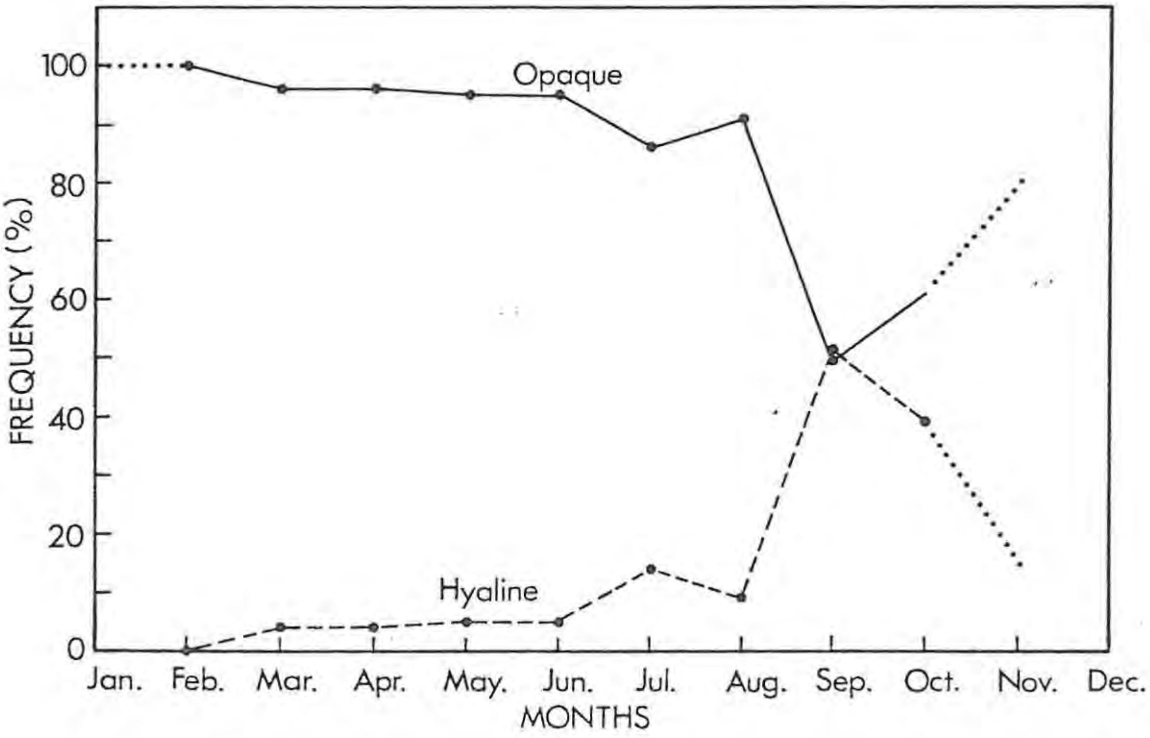

Fig. 11: Monthly percent hyaline and opaque otolith margins observed for kingklip on the West and South Coasts

2. Relationship between total fish length and otolith length

The relationship between total fish length and otolith length was diphasic and differed between sexes but not between areas (Fig. 12) (The split was obtained by iteration, that is by randomly varying the data on the upper and lower portions of the curve to obtain the most significant linear correlation).

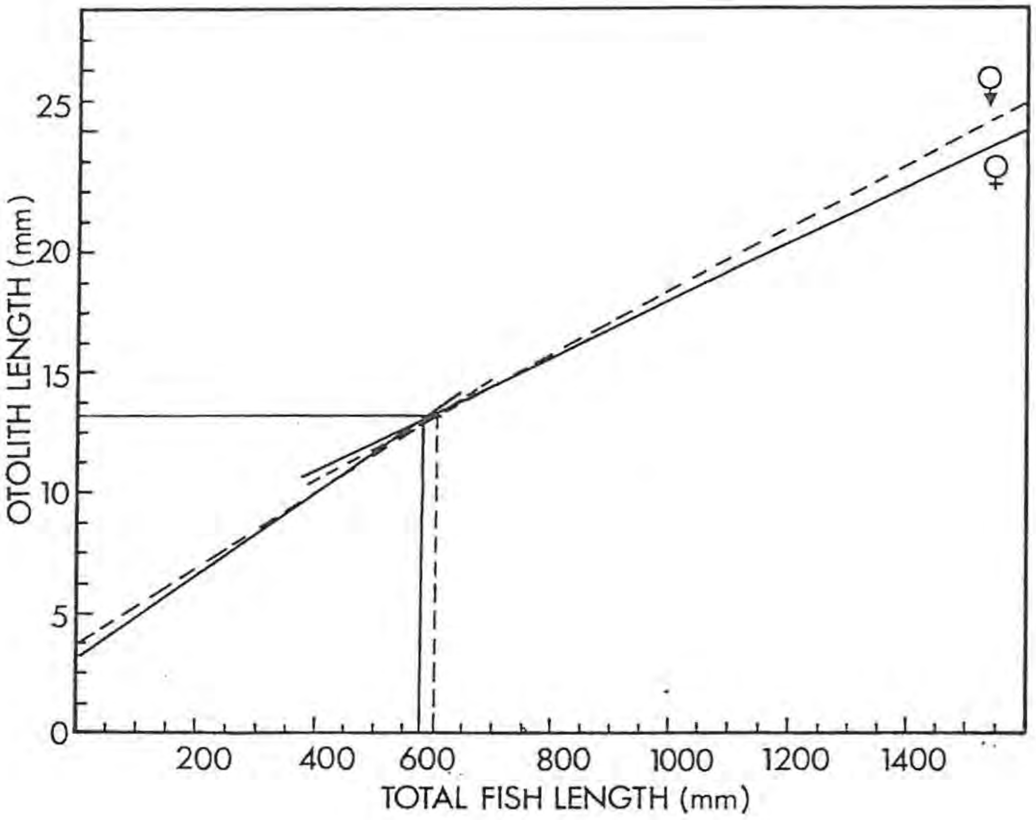

Fig. 12: Kingklip otolith length:fish length relationship for sexes combined

The relationships between the first and second growth phases are described by the following functions:

Males
Phase 1 : OL = 36,3 + 0,158TL (n = 248, $r^2 = 0,855$) 5
Phase 2 : OL = 52,5 + 0,131TL (n = 379, $r^2 = 0,860$) 6

Females

Phase 1 : OL = 29,7 + 0,173TL (n = 420, r^2 = 0,885) 7

Phase 2 : OL = 61,1 + 0,119TL (n = 688, r^2 = 0,811) 8

where : OL = Otolith length (mm), TL = Total fish length (mm) (statistical tests for the difference between the slopes of each phase for the males and females was significant $P > 0,001$). The shift in growth phases occurs at approximately 580mm and 600mm in males and females respectively.

3. Relationship between total fish length and weight

No significant difference was found in the length:weight relationship between male and female kingklip (Zar t-test for comparing slopes $t = 0,85$; $t_{(0,01)(2),1886}$; $P > 0,001$). There was a significant difference ($t = 5,69$; $t_{(0,01)(2)1886} = 2,57$; $P < 0,01$) in the length:weight relationship between kingklip on the West and South Coasts (Fig. 13).

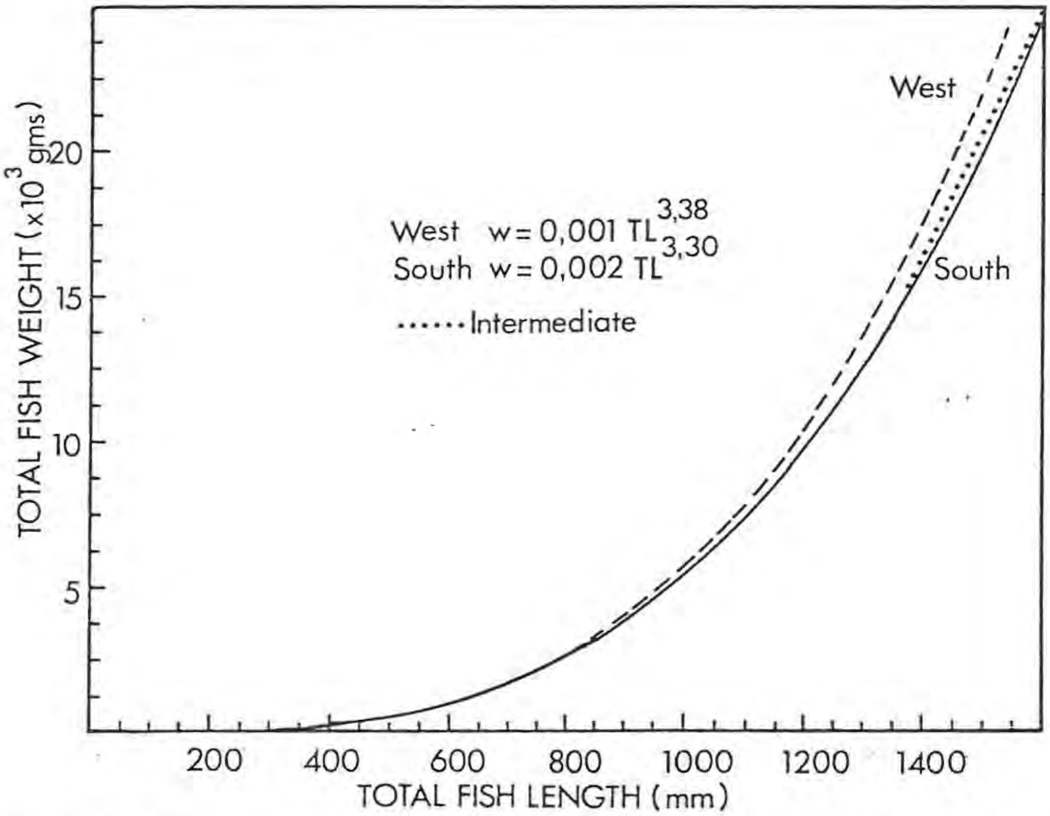

Fig. 13: Kingklip length:weight relationship (sexes combined) for the West and South Coasts. The upper limit of the curve for the Intermediate area showing its close approximation to the South Coast curve is also shown

The length:weight relationship for kingklip in the Intermediate Area was similar to and not significantly different from either the South Coast or the South-East Coast. The functions describing these relationships are given below:

West Coast: $W = 0{,}001TL^{3{,}38}$ 9

South Coast: $W = 0{,}002TL^{3{,}30}$ 10

Combined : $W = 0{,}001TL^{3{,}31}$ 11

where W = total fish weight and TL = fish length.

4. Age and growth of kingklip

Residuals of all the data sets were randomly distributed and the data were homoscedastic (i.e all age classes were adequately represented and had similar variances). Therefore, the absolute error model (Hughes 1986, Hughes and Punt 1987) could be used when testing for the most appropriate growth model. The three-parameter special Von Bertalanffy model (Pauly 1981) was found to be the most suitable to describe and compare kingklip growth with respect to sex and area. The form of this equation is :

$$L(t) = L_\infty \left(1 - e^{-K(t-t_o)}\right) \qquad 12$$

where L(t) is total length at age t, L_∞ is the theoretical maximum size the fish would reach if it were to grow indefinitely in the manner described by the Von Bertalanffy model, K is the intrinsic rate of decrease in growth and t_o a constant equal to the age at zero length.

The L_∞ for female kingklip was larger than that for the males. However, males on the South Coast (Fig. 14) reach a greater L_∞ than males on the West Coast (Fig. 15) although the early growth rate is not very different (Fig. 18).

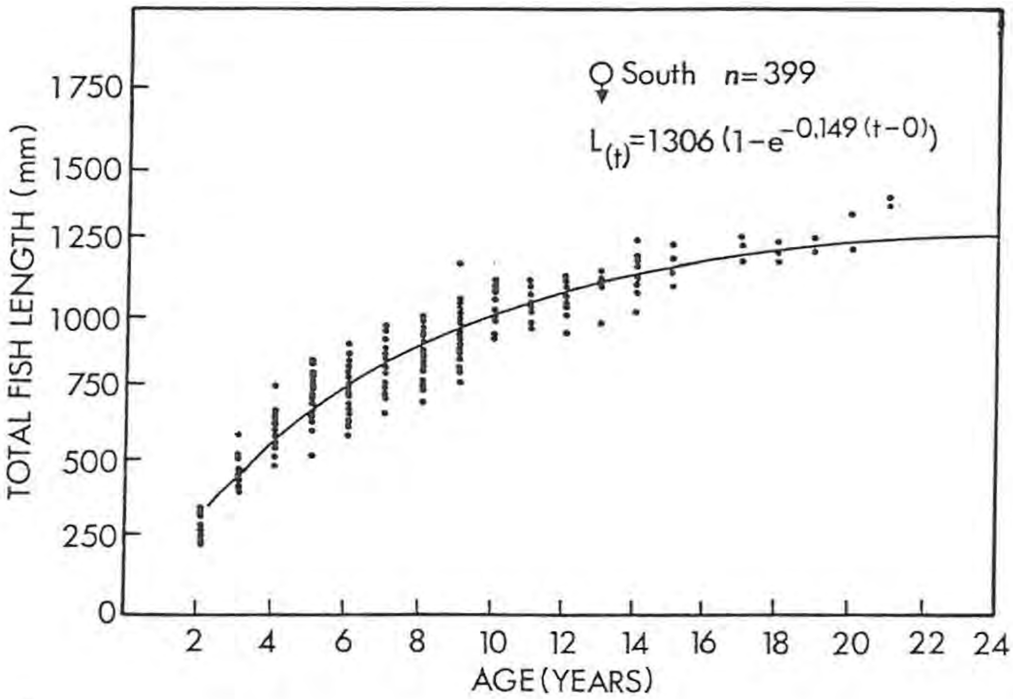

Fig. 14: Calculated Von Bertalanffy growth curve for kingklip (males) on the South Coast showing the distribution of observed lengths at age

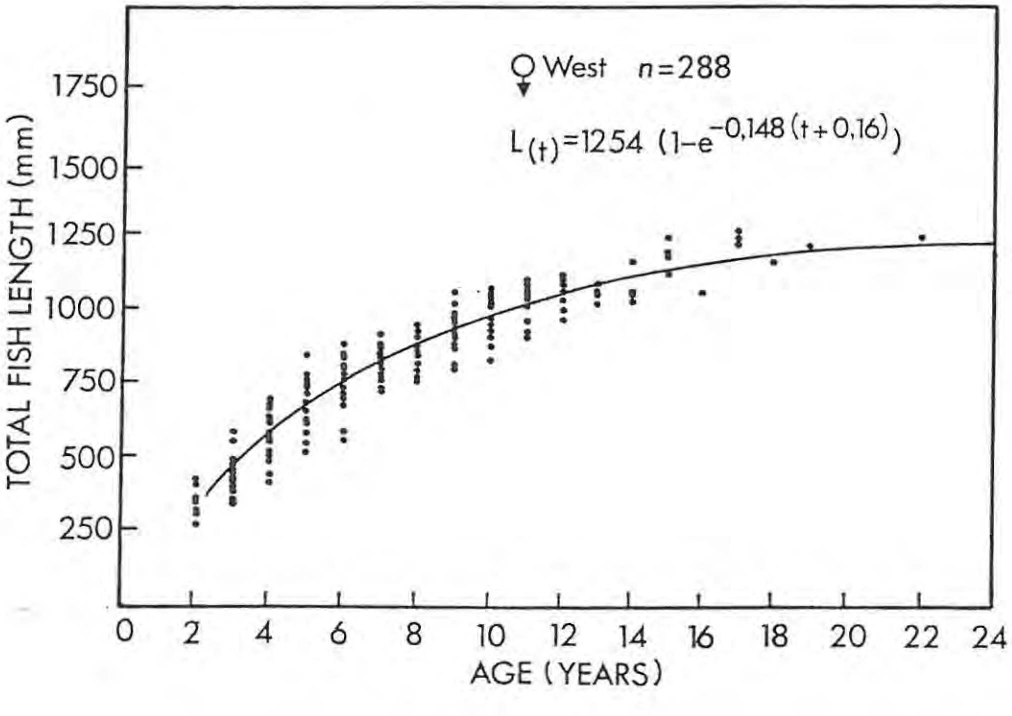

Fig. 15: Calculated Von Bertalanffy growth curve for kingklip (males) on the West Coast showing the distribution of observed lengths at age

Females on the South Coast (Fig. 16) also have a greater L_∞ than females on the West Coast (Fig. 17) and have a faster early growth rate (Fig. 18). The Von Bertalanffy growth curves are described by the following relationships:

Males

West Coast: $L(t) = 1254,4\ (1 - e^{-0,1477(t + 0,16)})$ 13

South Coast: $L(t) = 1305,7\ (1 - e^{-0,1487(t + 0,0)})$ 14

Females

West Coast: $L(t) = 1328,5\ (1 - e^{-0,1351(t + 0,48)})$ 15

South Coast: $L(t) = 1414,8\ (1 - e^{-0,1378(t - 0,44)})$ 16

Combined

West Coast: $L(t) = 1291,5\ (1 - e^{-0,1414(t + 0,32)})$ 17

South Coast: $L(t) = 1360,2\ (1 - e^{-0,1423(t - 0,22)})$ 18

L = fish length (mm) and t = period (years)

Growth in weight is described by the following Von Bertalanffy function:

$$\text{Weight} = W(t)_\infty\ (1 - e^{-k(t - t_o)})^b \quad \ldots\ldots\ldots\ldots\ldots \quad 19$$

and is the same as growth in length except $W(t)_\infty$ is the infinite weight predicted by the Von Bertalanffy equation and $b = 3$ for the Von Bertalanffy *special* growth model. These values are given in Table 9.

Conclusions

The results of the study on kingklip age and growth presented here suggest that females grow to a larger size than do males, confirming the findings of Payne (1977). Further, both male and female kingklip on the South Coast have a greater L_∞ than those

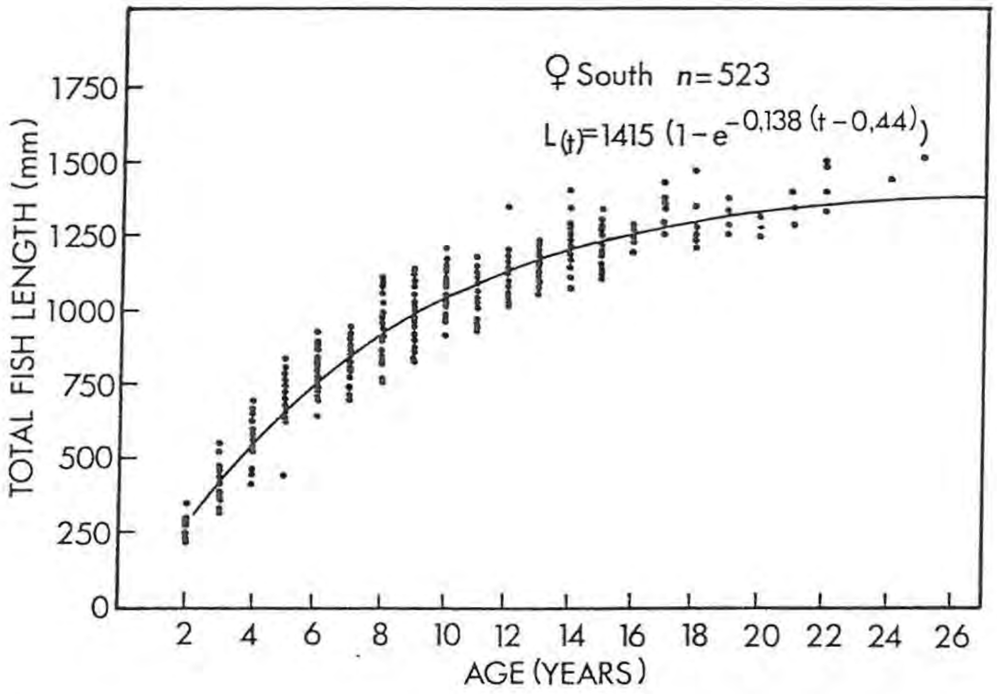

Fig. 16: Calculated Von Bertalanffy growth curve for kingklip (females) on the South Coast showing the distribution of observed lengths at age

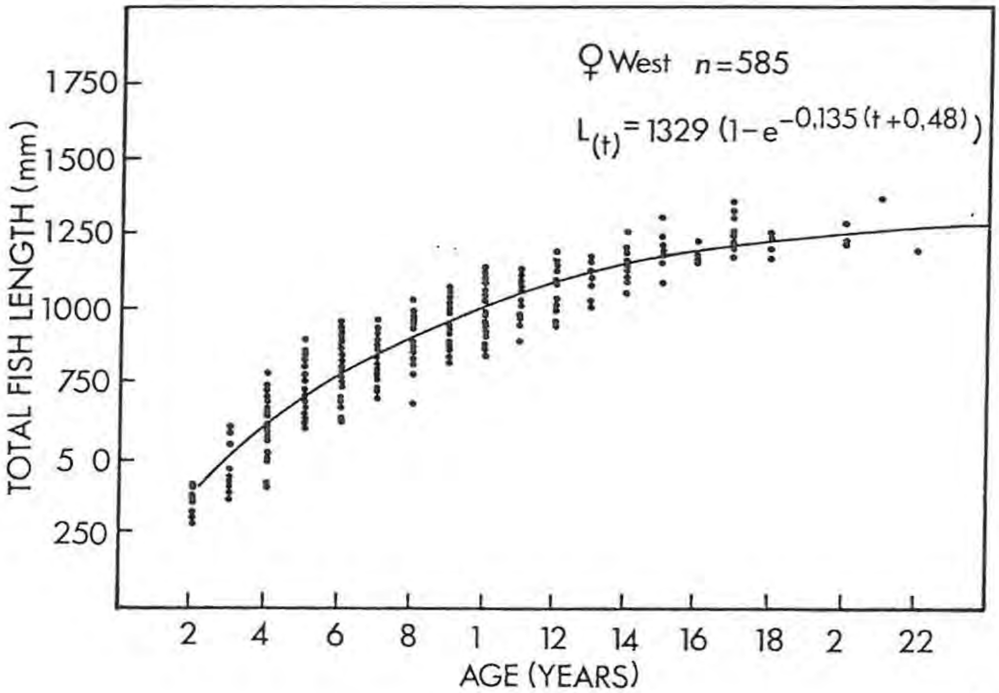

Fig. 17: Calculated Von Bertalanffy growth curve for kingklip (females) on the West Coast showing the distribution of observed lengths at age

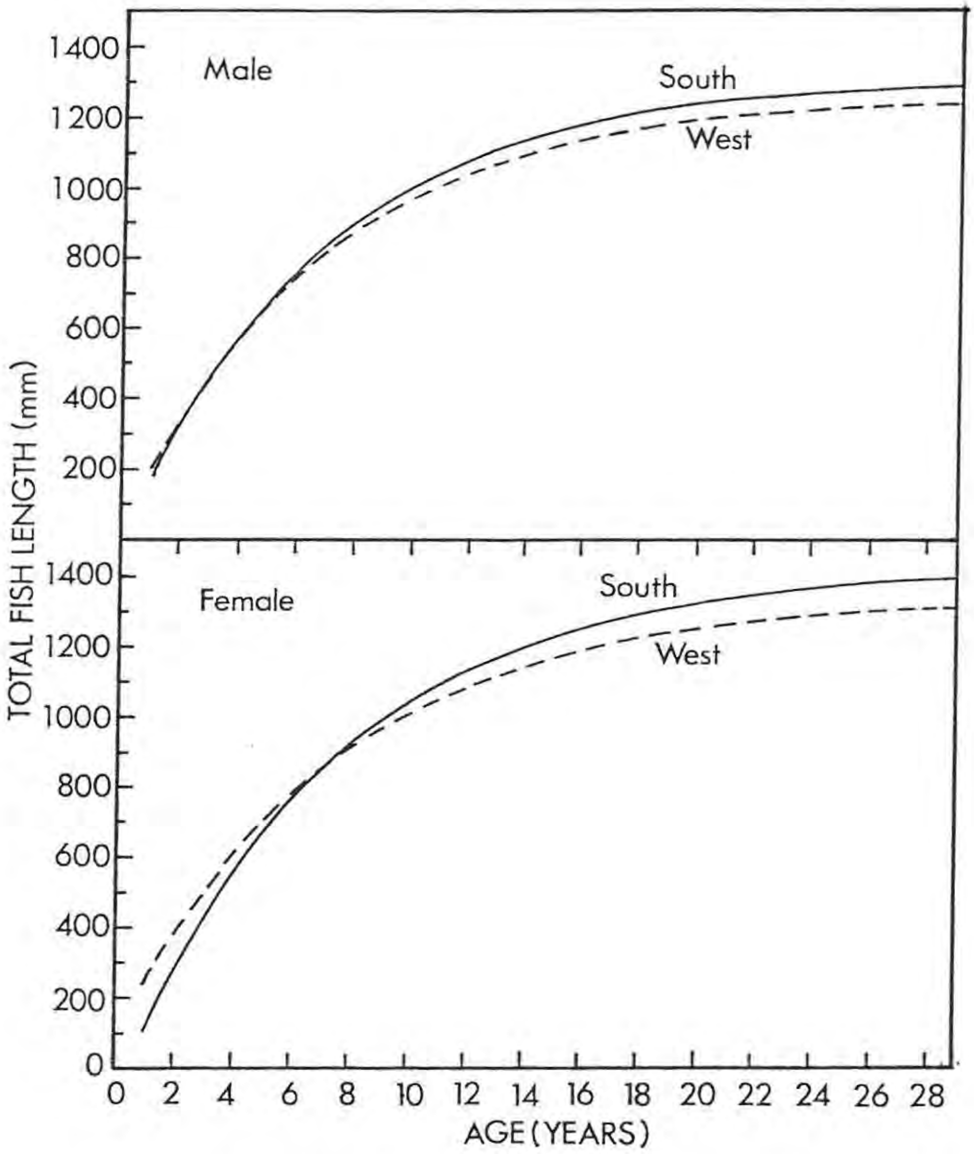

Fig. 18: Comparison of Von Bertalanffy growth curves obtained for kingklip males and females on the West and South Coasts

on the West Coast. These differences are however not seen as characteristic of two discrete kingklip stocks. The use of L_∞ as an indicator of stock differences is questionable. This parameter appears to have little consistency between researchers (Table 10) and it is likely that these often large differences can be attributed to the reading, fitting and statistical techniques employed. It is confidently predicted, however, that the advanced statistical analysis and otolith-sectioning techniques used in this study have resulted in more realistic approximations of kingklip age and growth than were possible previously.

Kingklip on the West Coast have a greater length:weight ratio than do kingklip on the South Coast. Hecht (1976) found that kingklip condition was relatively low during periods of intense reproductive activity and was also associated with an increase in GSI. In this study, the majority of South Coast samples were obtained in spring at the peak in kingklip reproductive activity or just after, whereas the West Coast sample was obtained mostly in the first half of the year when reproductive activity could be expected to be at its lowest. Therefore, kingklip caught on the West Coast in late summer and autumn are expected to be in better condition and to have a greater length:weight ratio than those on the South Coast in spring. This is the most likely explanation for the differences in the length:weight ratio and is not a characteristic of discrete kingklip stocks.

Kingklip growth, as suggested by the fish length:otolith length relationship, is diphasic but does not differ between the West and South Coasts. This pattern does however differ between the sexes and coincides with the onset of maturity and supports the findings on aspects of kingklip reproduction presented in the following chapter. Male maturation commences from approximately 580mm and females from about 600mm.

Table 9. Parameters values of the Von Bertalanffy growth equation required for the conversion of growth in length to growth in weight.

Area	Sex	W_∞(g)	b
South	male	19 200,5	3
West	male	12 379,8	3
South	females	25 022,1	3
West	females	15 030,0	3
South	males & females	21 974,5	3
West	males & females	13 661,5	3

Table 10. Comparison of Von Bertalanffy parameters obtained in this study with earlier studies on kingklip age and growth (all values for sexes combined).

Von Bert. parameters	Area Studied						
	All_1	SE_2	SE_3	S_4	$Cape_5$	$Cape_6$	$West_7$
L_∞(mm)	1 700	1 335	2 445	1 360	1 849	1 857	1 292
K	0,05	0,01	0,054	0,142	0,066	0,073	0,141
t_0	-1,203	+0,027	-0,603	+0,220	-0,619	-1,230	-0,320

1 = Whole South African coast - Wrzesinski (1975)

2 = South-East Coast - Hecht (1976)

3 = South-East Coast - Payne (1985)

4 = South Coast - Japp (this study)

5 = West Coast (Cape stock) - Isarev (1976c)

6 = West Coast (Cape stock) - Payne (1977)

7 = West Coast - Japp (this study)

8. ASPECTS OF KINGKLIP REPRODUCTION

Introduction

The reproductive biology of fish and the associated physiology and behavioural patterns are fundamental to understanding the dynamics of fish populations. These patterns may differ between geographical areas and different environments and may be stock-specific (Ihssen *et al.* 1981). The ideal stock has been defined by Cushing (1968) as one which has a single spawning ground to which the adults return year after year and which is contained within one or more current systems maintaining it within the same geographical area. It is possible therefore that a species, such as kingklip, that is distributed over a wide area but in two such different physical environments as the Agulhas (South Coast) and Benguela (West Coast) systems, are likely to have evolved variations in their reproduction in each area to maximize the chances of survival of their eggs and larvae. These factors alone may be a vital distinguishing feature of potentially discrete kingklip stocks.

Hecht (1976) studied kingklip trawled on the inshore trawling grounds near Port Elizabeth and made a detailed histological study of their gonads. He used Gonadosomatic Index (GSI) and condition factors to determine peak breeding periods. He concluded that two peaks in kingklip spawning occurred, one in June/July and a second in September/October. Payne (1986) assessed aspects of kingklip reproduction over a more extensive area on the South-East Coast. His results were basically similar to those of Hecht (op. cit.) and both these authors suggested that kingklip aggregate to spawn on the South-East Coast in spring.

Isarev (1986) studied kingklip fecundity in areas north of 26°S and concluded that kingklip there mature at a length of 525mm (5 years old). He suggested that kingklip have continuous asynchronous vitellogenesis and that spawning takes place in an area between 20 and 26°S from October to December. Badenhorst (1988) noted that the trend in longline kingklip catch rates on the South-East Coast exactly mirrored the rates made by research and commercial trawls and suggested that longline catch rates reflected aggregations and enhanced availability during the kingklip spawning season.

The introduction of longlining presented the opportunity to sample kingklip more extensively and to gain more detailed results on aspects of their reproduction. Kingklip GSI, age at maturity and the sex ratio of commercial longline catches is assessed in this study with particular emphasis on kingklip stock integrity on the West and South Coasts. It must be emphasized, however, that the sampling periods and areas were restricted to the movements of the longline vessels. Their fishing activities had a strong seasonal trend (Chapter 10). Also, no depth analysis was made because longlines were consistently set in deep water between 300 and 450m on rocky substrata.

Materials and Methods

Kingklip are dioecious but have no obvious characteristics that distinguishes the sexes. The ovaries are contained in a single thick elastic ovisac and the testes within a single tunica albuginea (Hecht 1976), and both gonads can be easily distinguished from approximately 200mm total length. Further, it is possible to identify the sex of headed and gutted specimens by the nature and size of their drumming muscles (mature fish only). Males have large brown (well vascularized) outer drumming muscles attached to the swim bladder and parasphenoid. Female kingklip have smaller outer drumming muscles that are paler in colour. The macroscopic maturity stages of kingklip gonads were classified according to the characteristics in Table 11, and are a modification of the maturity scales used by Payne (1986). For all samples obtained aboard longline vessels these estimates were made by the author. In the case of the samples obtained aboard the R.S. *Africana* the gonads were first estimated by a technician (fresh) then frozen, and later checked by the author. Therefore bias in the maturity estimates between observers was reduced.

Table 11. Characteristics used for the macroscopic estimation of kingklip maturity stages

Males: Testes

Maturity Stage	Macroscopic characteristics of gonads
Stage 1 : Inactive:	(Immature) Almost transparent thin and threadlike
Stage 2 : Inactive:	(Mature) Elongated, cylindrical, creamy white and opaque
Stage 3 : Active :	(Mature) Larger than the previous stage, still creamy white and opaque. Testes bulky and lumpy. Often bloodshot.
Stage 4 : Ripe & running :	(Mature) Similar to Stage 3 except sperm flows under slight pressure. Testes bloodshot.
Stage 5 : Spent :	(Mature) Testes deflated and darker in colour

Females: Ovaries

Stage 1 : Inactive:	(Immature) Ovary is small, globular and light pink. The tunica is transparent. No eggs can be distinguished.
Stage 2 : Inactive:	(Mature) The ovary is larger and speckled with minute eggs hardly discernible with the naked eye. The tunica is now opaque (whitish) and in some cases dark red or violet in colour.
Stage 3 : Active :	(Mature) The ovary is distended and filled with eggs. The eggs are small but can be clearly seen through the tunica. The tunica is opaque and has a speckled appearance, is often translucent and may have an orange or deep pink colour and is often bloodshot.
Stage 4 : Ripe & running :	(Mature) The eggs are large and translucent and can be extruded from the ovisac by slight pressure. Ovisac is bloodshot.
Stage 5 : Spent :	(Mature) Deflated and bloodshot

After estimation of their stage of maturity, the gonads were placed in labelled packets and frozen immediately. These gonads were later weighed to 0,1g in a laboratory ashore (the gonads were weighed frozen to prevent the loss of intercellular fluid). The GSI for each specimen was calculated as follows:

$$\text{Females: } GSI = \frac{\text{Ovary Weight(g)}}{\text{Total Fish Weight(g)}} \times 100$$

$$\text{Males: } GSI = \frac{\text{Testis Weight(g)}}{\text{Total Fish Weight(g)}} \times 1000$$

The mean monthly GSI was calculated for all male and female specimens on the West and South Coasts. As the larger, more fecund fish were expected to have a more pronounced shift in GSI, and also to test for size-dependent differences in GSI, all mature kingklip were separated into two size classes. The mean monthly GSI for all fish > 999mm total length was estimated and taken as the UPPER limit of the GSI index, and the mean monthly GSI of all fish < 1000mm total length was taken as the LOWER limit. The upper and lower GSI limits were then plotted to give an indication of the expected spawning period as well as the range between the smaller and larger fish.

The percentage of mature fish (maturity stage two and above) in 50mm length groups was calculated, and the total length and age at 0%, 50% and 100% maturity estimated graphically. Daily estimates were made of the sex ratios of the longline catches during the research cruises. Within the sample period, it proved extremely difficult to obtain samples from all areas around the entire coast for every month (Fig. 3). Sampling trips were restricted to the movements of the longline vessels which fished according to the dictates of weather, current and fish abundance. Consequently the samples were seasonally biased, but the inclusion of trawled samples from the R.S. *Africana* helped remove some of this. The total number of fish sampled for estimating reproductive activity is given in Table 12.

Table 12. Number of fish gonads used for maturity estimates

Maturity stage	Females		Males	
	West	South	West	South
1	184	115	77	71
2	367	233	99	143
3	34	168	51	173
4	0	0	0	6
5	2	7	1	1
Total	587	523	228	394

Total by area: West = 815 South = 917 All = 1 732

Results

1. Sex ratio

Longline kingklip catches sampled on the West Coast from March to July (Table 13) were dominated by inactive (stage 2 only) females (mean = 77%). In October, in the Intermediate Area between the Cape and South-East Coasts, the percentage of females in the catch was still high (80%), and mostly inactive. In sharp contrast, however, in the same month the proportion of females in longline catches on the South-East Coast declined to a mean of only 42%, although between 90 and 100% were active (stage 3 and above). It should be noted, however, that nothing can be inferred for the West Coast at the same time (spring), or for the South-East Coast in autumn. However, the sex ratio of the longline catches and the high percentage of active females on the South-East Coast compared to the Intermediate Area at the same time of year, suggests that there is a marked change in kingklip behaviour, and that this is related to enhanced reproductive activity on the South-East Coast.

Table 13. Proportion of females in daily longline catches. Abbreviations for fishing grounds as follows: SB = Saldanha Bay, CP = Cape Point, SA = South Agulhas (Intermediate Area) and SF = Cape St Francis.

Vessel	Month	Area	% Females in catch	% Mature females active
Alkar 2	March	West (SB)	85	0
	March	West (SB)	86	0
	March	West (SB)	67	5
	March	West (CP)	63	8
	March	West (CP)	79,5	5
	March	West (CP)	82	10
Orion	April	West (SB)	67	15
	April	West (SB)	66	11
	April	West (SB)	82,5	7
	April	West (SB)	87	6
	May	West (SB)	76	5
	May	West (SB)	80	5
	May	West (SB)	72	11
Pionier 1	July	West (CP)	67	5
	July	West (CP)	89	0
	July	West (CP)	82	5
	July	West (CP)	78,5	7
	July	West (CP)	66	20
	July	West (CP)	81	12
Alkar 2	October	Inter. (SA)	81	5
	October	Inter. (SA)	83	7
	October	Inter. (SA)	76	8
	October	S.East (SF)	45	90
	October	S.East (SF)	30	92
	October	S.East (SF)	45	100
	October	S.East (SF)	32	95
	October	S.East (SF)	49	96
	October	S.East (SF)	50	100

2. Gonadosomatic index

There was a pronounced increase in the female GSI on the South Coast (Fig. 19) starting in July, peaking in September before declining sharply in October. In contrast, on the West Coast from February to July the female GSI was low with no significant trend. For the period of overlap between the two coasts from May to July the female GSI was similar except that the range on the South Coast was narrower. The limitations of the data make it difficult to draw firm conclusions because the possibility of a peak in female GSI on the West Coast in spring or on the South Coast between February and May cannot be excluded, but it is considered unlikely. The trends in male GSI (Fig. 20), however, are somewhat different than for females. There is a peak in male GSI on the South Coast in spring, coinciding with that of the females (Fig. 19). There is also a peak in male GSI on the West Coast in April, a trend not found in the females. Once again the possibility of there being a peak in male GSI on the West Coast in spring or on the South Coast in autumn cannot be excluded.

Clearly kingklip on the South-East Coast have a discrete breeding season from August to November. On the West Coast it is likely that kingklip also spawn at this time although there is no direct evidence to suggest this. It is possible however that on that coast kingklip spawning is protracted and if aggregations do occur there, they are not as large or as well defined as on the South-East Coast.

3. Length at maturity

The estimated lengths at maturity for males and females on the West and South Coasts are shown in Fig. 21 (females) and Fig. 22 (males) and the equivalent ages at maturity are given in Table 14.

Maturation of male kingklip on the West and South Coasts commences from approximately the same length and age. Male kingklip on the West and South Coasts reach 50% maturity in their fifth year (Table 14), but males on the South Coast are smaller at this stage. All kingklip on the South Coast are predicted to be mature at a smaller length and younger age than on the West Coast.

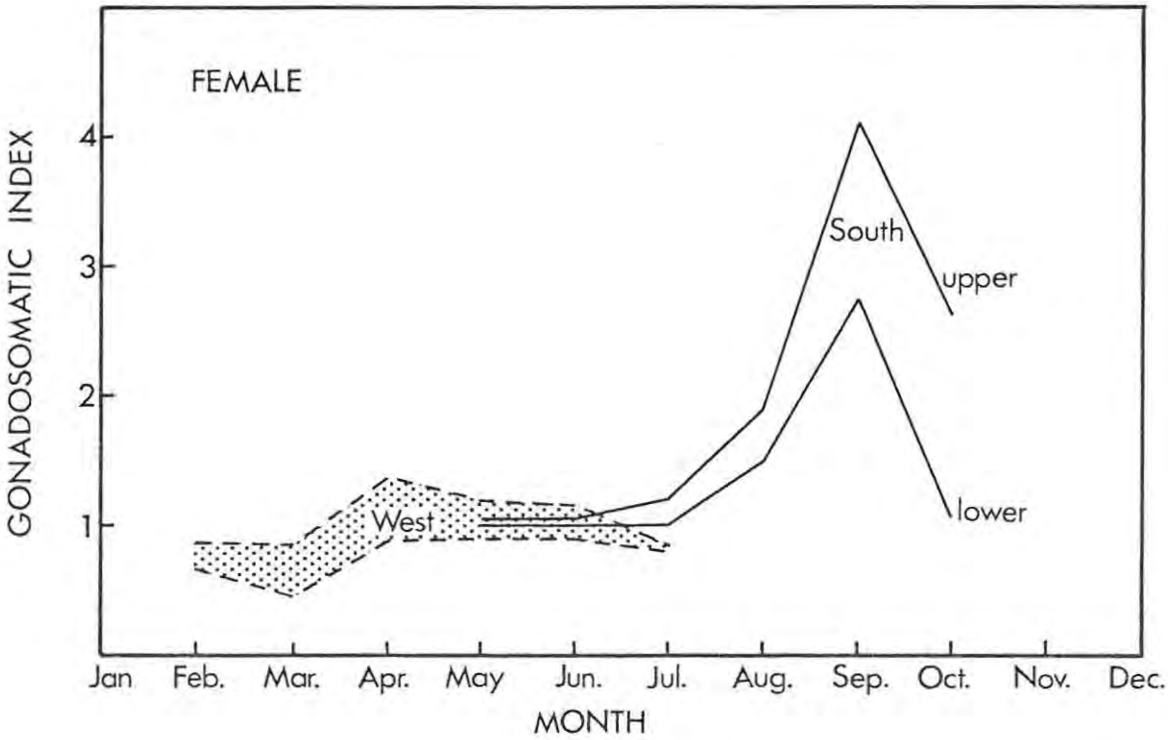

Fig. 19: Monthly trend in GSI of female kingklip on the West and South Coasts

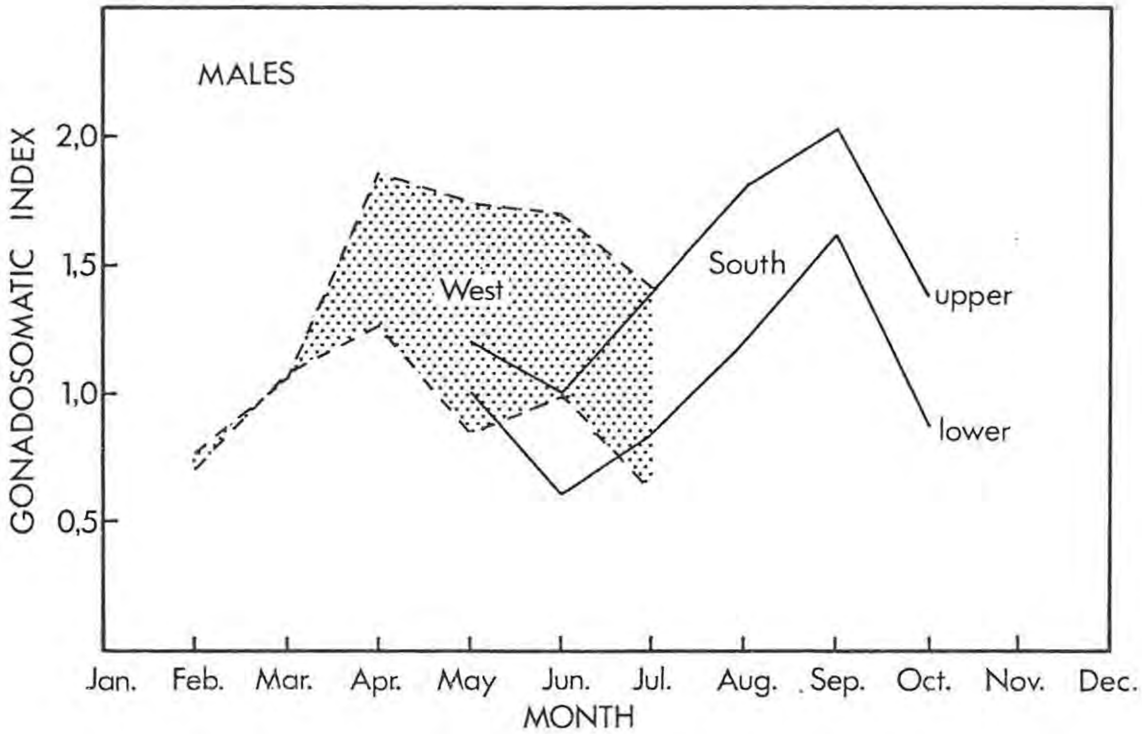

Fig. 20: Monthly trend in GSI for male kingklip on the West and South Coasts

Table 14. Kingklip length (mm) and age (years) at maturity (age in parenthesis)

	Length (Age) at percent maturity		
Sex/Area	Begin (0%)	50%	100%
Males:			
West	375 (2,2)	655 (4,8)	1 075 (13,0)
South	375 (2,3)	620 (4,4)	875 (7,6)
Females:			
West	575 (3,7)	810 (6,5)	1 075 (11,8)
South	525 (3,8)	725 (5,6)	1 025 (9,8)
Mean (Males & Females):			
West	475 (2,9)	732 (5,6)	1 075 (12,4)
South	450 (3,0)	672 (5,0)	975 (8,7)

On the South Coast females (Fig. 21) commence maturation at a smaller length than do females on the West Coast, although there is little difference between their ages at this time (Table 14). Females do, however, commence maturation a year later than do males. Females on the South Coast also reach 50% maturity at a smaller length (725mm) and approximately one year earlier (5,6 years) than do females on the West Coast (Fig. 14). Females on the West Coast are also estimated to reach an age at 50% maturity two years later (6,5 years) than males on the West Coast (4,8 years) and is in contrast to females on the South Coast who reach 50% maturity only a year later (5,6 years) than the males on that coast (4,4 years). As with males, females on the South Coast are estimated to be 100% mature at a smaller length and also two years later than on the West Coast.

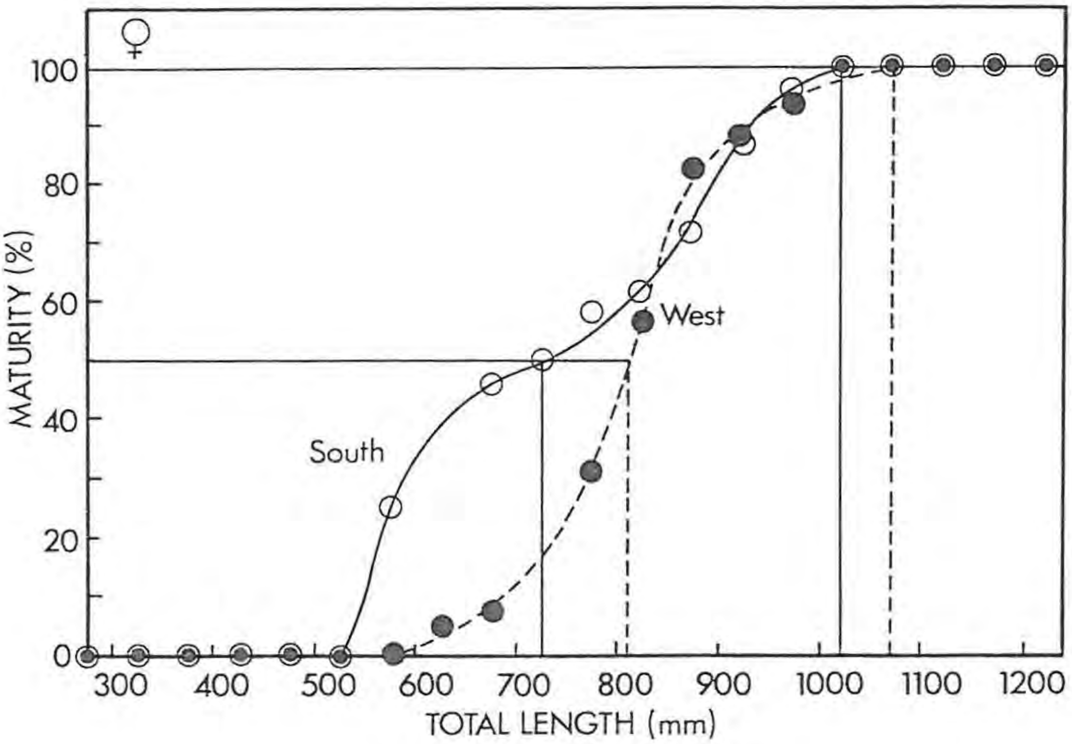

Fig. 21: Estimated lengths at maturity for female kingklip on the West and South Coasts

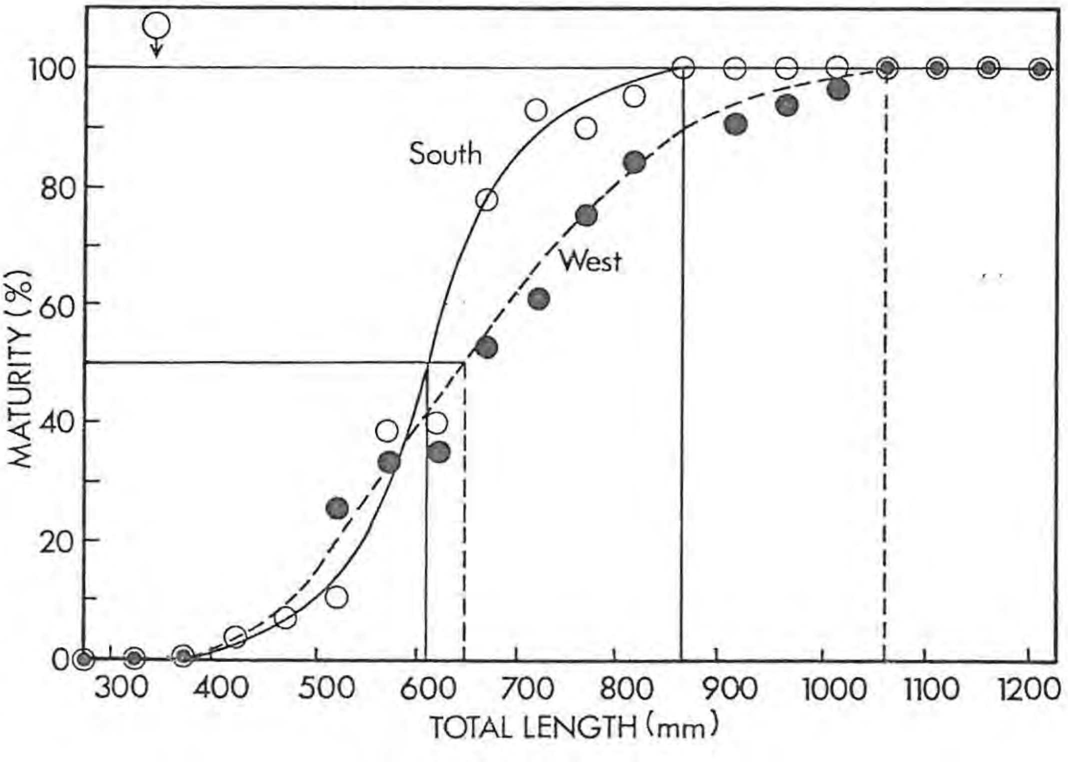

Fig. 22: Estimated lengths at maturity for male kingklip on the West and South Coasts

Discussion and Conclusions

There appear to be distinct differences between the maturation processes of the male and female kingklip. Although maturation of both sexes commences on the South and West Coasts at similar lengths and ages, the results suggest that the maturation process for male and female kingklip is a lot slower than estimated by either Hecht (1976) or Payne (1986). Further, the kingklip on the West Coast appear to mature more slowly than those on the South Coast. These characteristics alone are insufficient to classify the kingklip on the West and South Coasts as discrete stocks as the estimates of kingklip maturity stages is subjective and therefore dependent on the person making the estimates.

Significant differences are apparent in the spawning behaviour of the kingklip on the two coasts. Both GSI's and sex ratios suggest that spawning on the South Coast is pronounced in spring, and more specifically occurs within a relatively small area on the South-East Coast. Previous researchers have speculated on the existence of spawning aggregations on the South-East Coast and this study supports their views. It is suggested that to provide at least some protection for the kingklip resource, the South-East Coast be recognised as a discrete kingklip spawning ground until shown to be otherwise. At no other time or place on the southern African coast are such kingklip aggregations known and it must be assumed that these grounds are vital for the continued survival of kingklip as a commercially viable species.

On the West Coast there is no apparent peak in female GSI. However the absence of any pronounced upward trend in the female GSI would suggest that the peak breeding season on that coast is also in spring, or alternatively kingklip only spawn on the South-East Coast. If that were true then kingklip would have to undergo extensive migrations from the West to the South Coast. This is considered unlikely however as kingklip are sluggish fish and are benthic by nature (Macpherson 1983).

Similar aggregations are known to occur among the closely related

New Zealand ling, *Genypterus blacodes* (Roberts 1987). Increased levels of abundance of that species in September and October have been called "prespawning aggregations" (Roberts op.cit.) and were recorded when sampling with longlines. Ripe-and-running females were at no time recorded in this study, a finding also recorded by both Hecht (1976) and Payne (1986). It is concluded here that the increased levels of kingklip abundance on the South-East Coast constitute a "prespawning" aggregation because all fish examined were in close to peak gonad condition. Further, the fact that kingklip are so often caught on longlines suggests that the aggregation is probably associated with intense feeding.

Hecht (1976) has shown that kingklip condition peaks prior to the GSI peak. Thus, the apparent absence of longline-caught kingklip in ripe-and-running condition may be explained by the simple fact that they do not feed when actively spawning. This does not account for the lack of ripe-and-running kingklip in trawled samples. It is possible that kingklip move off the trawl grounds to aggregate and spawn on the rocky shelf margins. The possibility that kingklip migrate vertically to spawn, as suggested for hake by Botha (1973), should also be considered, but it is not considered likely because kingklip are benthic feeders (Macpherson 1983).

Male kingklip maintain a higher average GSI than females. It is speculated here that they maintain a near permanent state of "readiness" and respond spontaneously when the females are ready to spawn. Other deep-sea fish may also give clues to the reproductive behaviour of kingklip. Mead *et al.*(1964) state that fish in deep water environments are likely to have difficulty in locating mates. Kingklip are no exception, the available light at 300 to 550m being minimal. *Genypterus capensis* has large drumming muscles which are attached to a thick swim bladder. Male kingklip have much larger inner drumming muscles than females. These muscles are very red in colour indicating that they are well vascularized and are used extensively. Clearly, the muscles have a sound producing function and are used to locate mates in the dark environment. This characteristic has been recorded for other ophidiids and is considered a characteristic of the genus (Marshall 1960, Courtenay 1971).

The significance of the drumming muscles may become more apparent if the sex ratios and size frequencies of the longline and trawl catches are considered. Hecht (1976) stated that catches of kingklip on the South-East Coast inshore grounds consisted mainly of immature fish or fish having just attained sexual maturity. It is noteworthy that these fish were mostly less than 650mm total length prior to September and in the size range 690mm to 850mm from September to April. Hecht (op.cit.) suggested that this shift in the length frequency and the absence of ripe-and-running kingklip may possibly indicate that the kingklip are migrating from inshore to offshore in spring to spawn.

Payne (1986) suggested that there is a horizontal depth distribution of kingklip related to size on the South-East Coast, a fact recorded for kingklip on the West Coast by Botha (1985). It has been noted, although not officially recorded, that predominantly smaller kingklip are found in the shallower inshore trawling grounds and, as in the longline fishery, larger kingklip are caught in deeper water. Further, the kingklip caught on the inshore trawling grounds are mostly small males. This is in sharp contrast to the large females that predominate in the longline catches in deeper water. It is possible therefore that there is a migration of male kingklip onto the rocky grounds when the females are ready to spawn. Only in the prespawning aggregations does the sex ratio appear to change. Also of course, it may simply reflect an increase in activity associated with spawning and feeding thereby increasing their exposure to the gear.

In conclusion, the South-East Coast is clearly an important kingklip spawning ground. Kingklip aggregate to spawn there from August to November. The South-East Coast can therefore be regarded as a vital kingklip spawning area and, without evidence to the contrary, may well be responsible for the recruitment of this species onto the South Coast or even onto the West Coast.

Although it has been shown that differences occur in the age at maturity of kingklip on the West and South Coasts these differences are small and not likely to be characteristic of discrete stocks. The results are also likely to be biased by the seasonality of the fishery from which the samples were obtained and also by the subjectivity of the maturity stage estimates.

9. LONGLINE CATCH AND EFFORT AND CATCH RATES

Introduction

Estimating the abundance of a commercially important fish species is of vital interest to the fisherman and the fisheries manager. Catch and effort data are often the only available information on which to assess the status of "health" of a fishery, and catch rates should, if they are used and interpreted correctly give an indication of the relative stock abundance. Of primary importance is the catch itself, without which any stock assessment studies are meaningless (Gulland 1983). Of secondary importance is the effort expended to obtain the catch. Once the manager has the catch from a standard gear unit he can begin to consider catch rates, that is, the catch per unit of effort (CPUE).

Catch rates cannot always be used directly as an indicator of stock abundance. They may for example be significantly affected by seasonality, weather, fishing techniques and fish migration patterns. Further, if the catch rates differ between areas, it is possible they may be indicative of discrete stocks, which may require separate management strategies.

The relatively short time series of data available and the changing nature of the longline fishery over the first five years made it impractical to use the mean annual CPUE index for stock assessment. The techniques employed to assess the status of the kingklip stocks are addressed in Chapter 11. This chapter focusses only on the trends in catch, effort and catch rates placing emphasis on the differences between the West and South Coasts.

The relative simplicity of hook and line gear has contributed to the false impression that the hook is an uncomplicated measure of fishing effort (Skud and Hamley 1978). In most bottom and pelagic line fisheries fishing effort is often conveniently expressed in units, such as the 'skate' in the Pacific halibut fishery (Skud

1972). The South African equivalent, the'tub', was however not considered a suitable unit of effort for the local longline fishery because the number of hooks per tub varied between vessels. Consequently, the unit 'kilogramme caught per 1 000 hooks' (kg/1000 hooks) was adopted by Badenhorst (1988) and is also the standard CPUE unit used in this study. The implications of this index as a measure of abundance are discussed later in this chapter because caution needs to be exercised when interpreting longline catch-and-effort data.

Some attempts at estimating kingklip abundance have been made in the past, mostly in ICSEAF divisions 1.3, 1.4, 1.5 and 1.6, by Macpherson and Lloris (1977), Terré (1980) and Isarev (1980, 1981, 1983). These estimates do not refer directly to either the Cape or South-East Coast stocks, but are based on the exploitation of kingklip by foreign trawlers outside South African waters. Payne (1986), Badenhorst (1988) and Japp (1988) have made preliminary assessments of kingklip abundance on the West and South Coasts, using data from both the trawl and longline fisheries.

The highest recorded annual kingklip catches by the demersal trawl fleet in South Africa (5 800t and 5 300t) were made in 1973 and 1980 respectively (Badenhorst 1988). Thereafter total kingklip catches increased sharply (Table 15) with the introduction of longlining in 1983. As a rough indicator of the effect exploitation had on the kingklip resource prior to longlining, kingklip catch rates in the hake-directed trawl fishery were relatively stable over the period 1960-1977 and were followed by higher catch rates in subsequent years, whereas hake catch rates declined sharply (Badenhorst op. cit). Commercial kingklip catches, trawled on the South-East Coast between 1976 and 1985, were also fairly stable and fluctuated between 1 200t and 2 600t, peaking in September of each year (Payne 1986). This annual peak in catches was attributed to the seasonal weakening of the Agulhas Current (Scott 1950, Payne 1986) and the peak period of spawning (Hecht 1976, Payne op. cit). Generally, therefore, before the advent of longlining trawled catches appeared to have had no significant effect on the resource.

Table 15. Total longline-caught hake and kingklip compared with trawled kingklip catches from 1983 to August 1988 (nominal mass in metric tons).

Year	Longline Hake	Longline Kingklip	Total Longline	Trawled Kingklip	Total Kingklip
1983	230	1 042	1 272	3 093	4 135
1984	381	3 040	3 421	3 352	6 392
1985	1 495	6 970	8 465	3 757	10 727
1986	1 680	8 634	10 314	2 633	11 267
1987	3 924	6 452	10 376	3 254	9 706
1988*	4 304	2 619	6 923	1 398	4 017

* up to August only

Materials and Methods

Skippers of all longline vessels submitted catch-and-effort returns after each trip. The following information was recorded on a daily basis:

1. **Area fished:** The entire South African coast was divided into blocks of 20 x 20 nautical miles and the skipper of each vessel recorded the block in which he had set his lines.

2. **Depth** : The average depth in which the lines were set.

3. **Hooks** : The total number of hooks per line set.

4. **Shooting and hauling times** : The times at which the line was shot and hauled.

5. **Catch** : The skippers daily estimate of the mass of hake and kingklip caught (headed and gutted) and the whole mass estimate of any other species caught in significant quantities, including the species discarded (skippers estimates were based on the

quantity of fish processed and the average weight of the retainer used, eg. the number of freezer trays or cartons.

6. Remarks : For example, the percentage of the catch estimated to have been taken by seals as well as other relevant information, such as current strength and weather or sea conditions.

All the information was captured on a single data base. Landed catches were also monitored and the total headed and gutted mass per trip recorded. This information was then used to determine the accuracy of the skippers' estimates. Where necessary, a correction factor was applied. The landed catches were converted to nominal (live) mass by means of the conversion factors of Chalmers (1976):

Kingklip nominal mass = 1,52 x landed mass (headed and gutted)

Hake nominal mass = 1,46 x landed mass (headed and gutted)

The catch rates of kingklip and hake were considered separately for the West and South Coasts. Observations aboard commercial longline vessels on the South Coast showed that, on average, 90% of the catch was kingklip. In contrast on the West Coast, hake, as well as other species such as dogfish (*Squalus* spp.), were more abundant. This increased the hook competition between species making it impractical to combine or compare the CPUE indices for kingklip on the South and West Coasts. Hoag *et al*. (1984) have shown that set-line catchability of halibut in the North Pacific was seriously affected by increased competition between non-target species such as dogfish, and also by the activities of trawlers close to the longline grounds. Consequently, in that study, correction factors had to be applied to individual areas to make them comparable. Until more refined CPUE indices are developed that can adjust for species composition of the longline catches, the CPUE index used at present should be applied separately on the West and South Coasts. As will be shown in this analysis, the fishery developed a definite seasonal trend. Therefore, the data were analysed and are presented on a seasonal basis. The months used for each season were: summer(S) = November, December and January; autumn(A) = February, March and April; winter(W) = May, June, and July and spring(Sp) = August, September and October.

Results

1. Species composition

The Cape hakes *Merluccius capensis* and *M. paradoxus* and the kingklip *Genypterus capensis* were the principle target species of the longline fleet. Insignificant quantities of other species were also caught and these were, in order of importance: jacopever, *Helicolenus dactylopterus*, monk *Lophius*. sp., wreckfish *Polyprion americanus* and broadbill swordfish *Xiphias gladius*. Large quantities of dogfish were caught on occasions but they were discarded.

2. Effort

The areal distribution of longline effort from 1984 to 1987 is illustrated in Figure 23. As longline fishermen were still developing techniques and actively searching for productive grounds in 1984 effort was relatively low and was concentrated on the West Coast from the South Agulhas Bank to Saldanha Bay. In 1985, however, there was a marked shift in effort onto the South Coast particularly south of Cape St Francis (Fig. 23). Much effort was also expended on grounds due west of Saldanha Bay. In 1986 effort was once again high on the South Coast but on the West Coast effort shifted from Saldanha Bay to the grounds south-west of Cape Point. In 1987 kingklip-directed effort on the South Coast was more widely distributed than in previous years and also more concentrated for a longer period (from August to January). On the West Coast, hake-directed effort was concentrated between the months of December and August. The seasonal shifts in longline effort are further illustrated in Figure 24.

Total effort in the fishery increased steadily from 1984 but

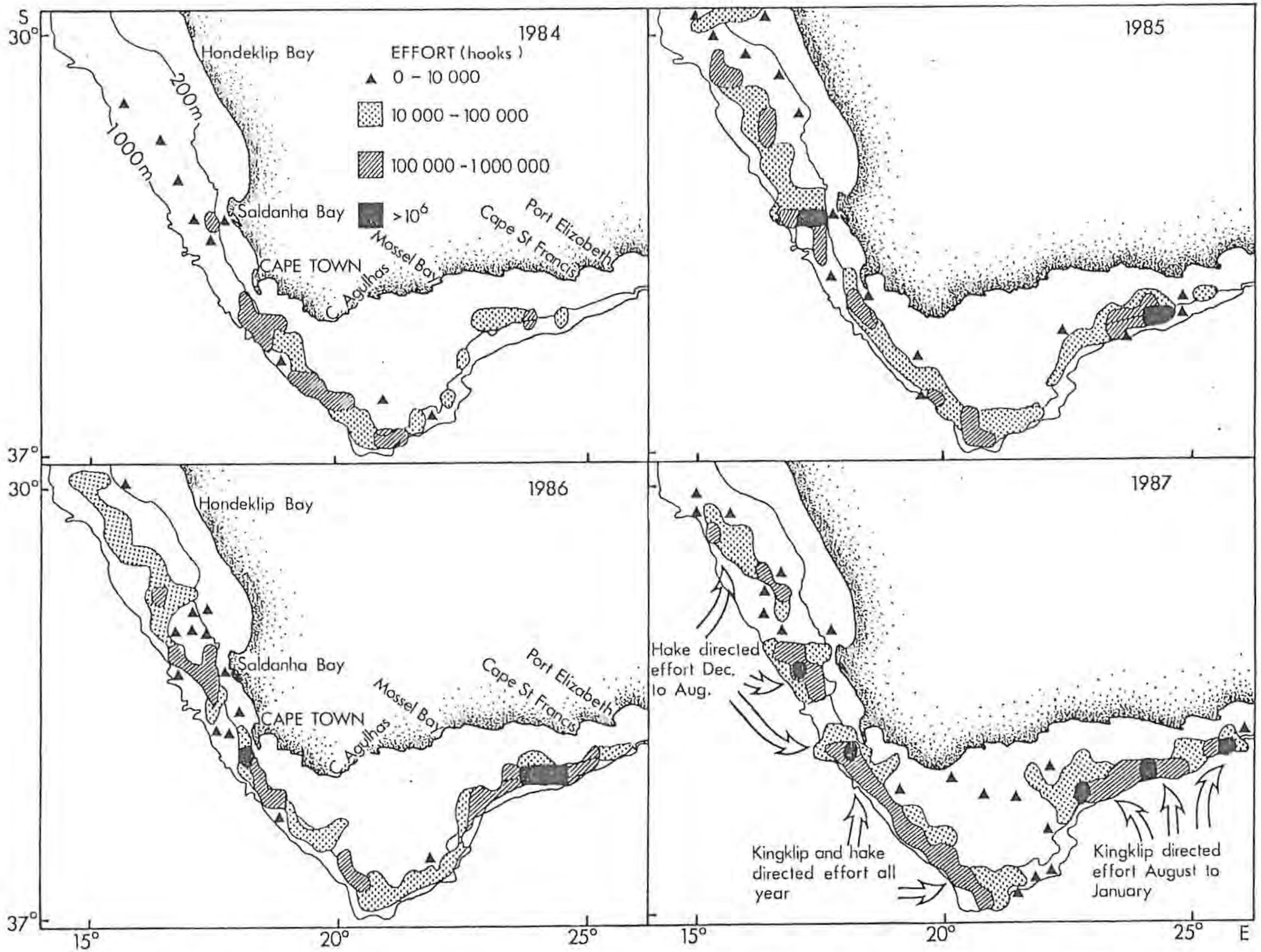

Fig. 23: Areal distribution of longline effort from 1984 to 1987

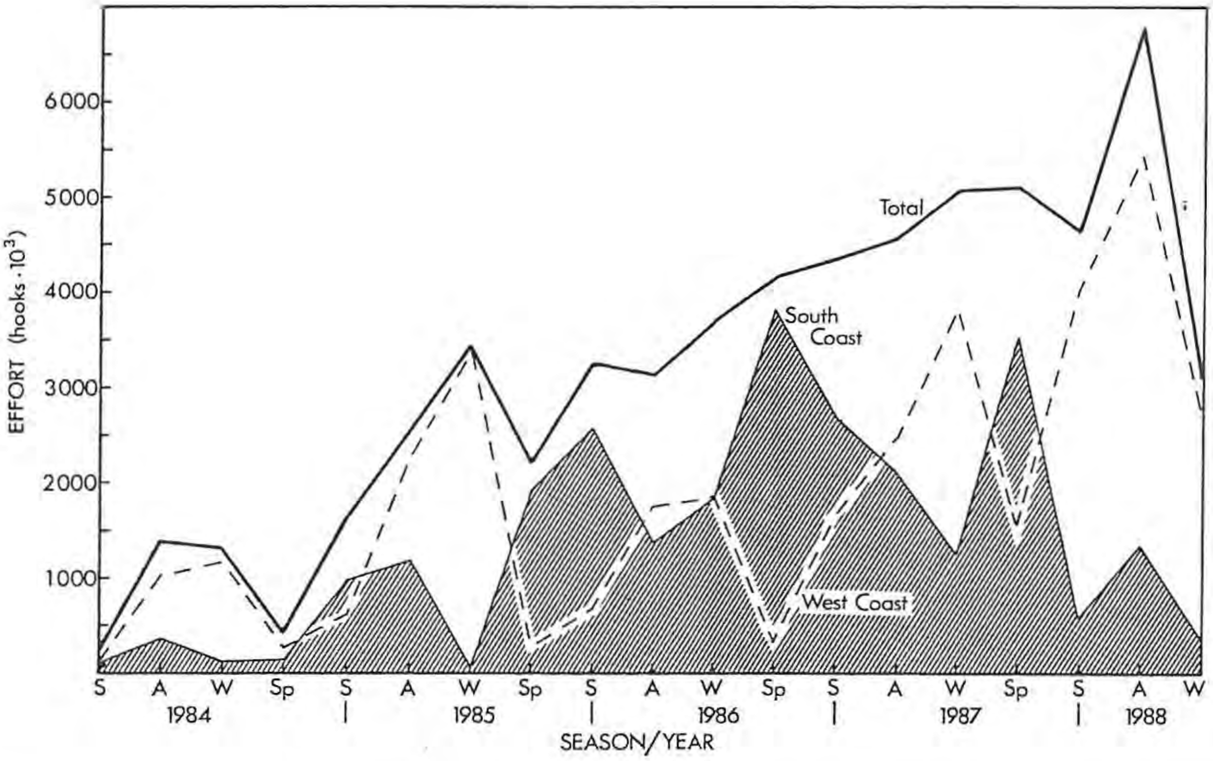

Fig. 24: Total longline effort (seasonal means) from summer 1983/1984 to winter 1988 showing also the difference between the South and West Coasts

increased sharply in autumn 1988 when considerable effort was directed at hake on the West Coast. If the data are separated by area (Fig. 24), the seasonality of the fishery is elucidated further. Maximum effort was expedended on the West Coast in autumn and winter and on the South Coast in spring.

3. Catch

The kingklip catch (Table 16; Fig. 25) on the South Coast increased sharply in spring 1985, when the grounds on the South-East Coast were first exploited. Despite a substantial increase in effort during 1986 (Table 16), the catch did not increase significantly. In spring 1987 the catch was lower (Fig. 25), despite a sustained high level of effort on that coast (Fig. 24). In contrast, kingklip catches on the West Coast remained relatively low, though they peaked in autumn and winter each year, except in

Table 16. Longline catch and effort by season from 1984 to 1988. The summer of each year includes November and December of the previous year (catch to the nearest ton). Note: % = percent hake in total catch.

Year/	Effort (Hooks x 10^3)			Nominal Catch(tons)			
				Hake		Kingklip	
Season	West	South	Total	West	South	West (%)	South (%)
1984							
Summer	101,0	89,5	190,5	4	0	79 (5)	148 (0)
Autumn	1 018,1	360,8	1 378,9	91	1	748 (5)	363 (3)
Winter	1 174,1	125,1	1 299,2	112	0	737 (5)	90 (1)
Spring	270,8	151,2	421,9	70	12	123 (36)	63 (16)
1985							
Summer	624,3	993,7	1 618,0	124	139	301 (29)	715 (16)
Autumn	2 261,0	1 181,9	1 442,9	349	22	581 (37)	521 (4)
Winter	3 369,8	64,0	3 433,8	732	0	575 (56)	65 (0)
Spring	286,6	1 921,6	2 208,2	55	142	28 (66)	1 991 (7)
1986							
Summer	681,1	2 572,2	3 253,3	48	117	189 (20)	3 181 (3)
Autumn	1 751,0	1 373,0	3 124,0	356	8	516 (20)	874 (1)
Winter	1 857,2	1 833,2	3 690,4	757	3	284 (73)	1 743 (0)
Spring	334,6	3 820,9	4 155,5	59	136	118 (33)	3 407 (4)
1987							
Summer	1 647,9	2 693,8	4 341,7	432	111	370 (54)	1 341 (8)
Autumn	2 466,4	2 101,2	4 567,5	1 059	36	464 (69)	955 (4)
Winter	3 823,6	1 243,6	5 067,2	1 123	4	683 (62)	485 (1)
Spring	1 558,6	3 541,2	5 099,8	350	123	213 (62)	1 936 (6)
1988							
Summer	4 048,4	585,4	4 633,8	1 374	149	839 (62)	1 104 (12)
Autumn	5 431,0	1 348,8	6 779,8	1 212	28	1 291 (48)	738 (4)
Winter	2 709,4	363,0	3 072,4	533	7	529 (50)	202 (3)

autumn 1988, where because of the low kingklip catch rates on the South Coast more effort was directed on the West Coast.

Hake catches (Fig. 26) remained low on the South Coast peaking only in spring at the time when kingklip-directed effort was at a maximum. On the West Coast, however, hake catches have clearly increased, with peak catches having been recorded in autumn and winter each year, with the exception of 1987/88 when they peaked in summer.

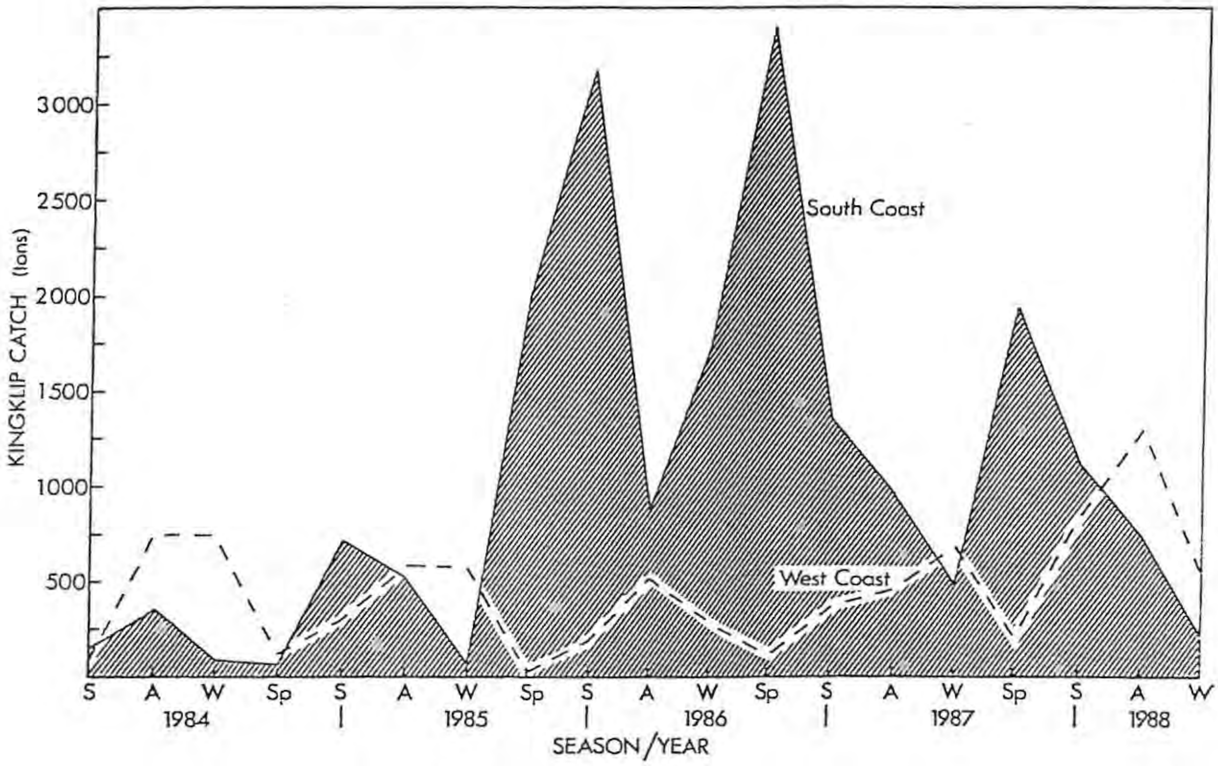

Fig. 25: Kingklip catch by season (nominal tons) 1984 to 1988 for the West and South Coasts

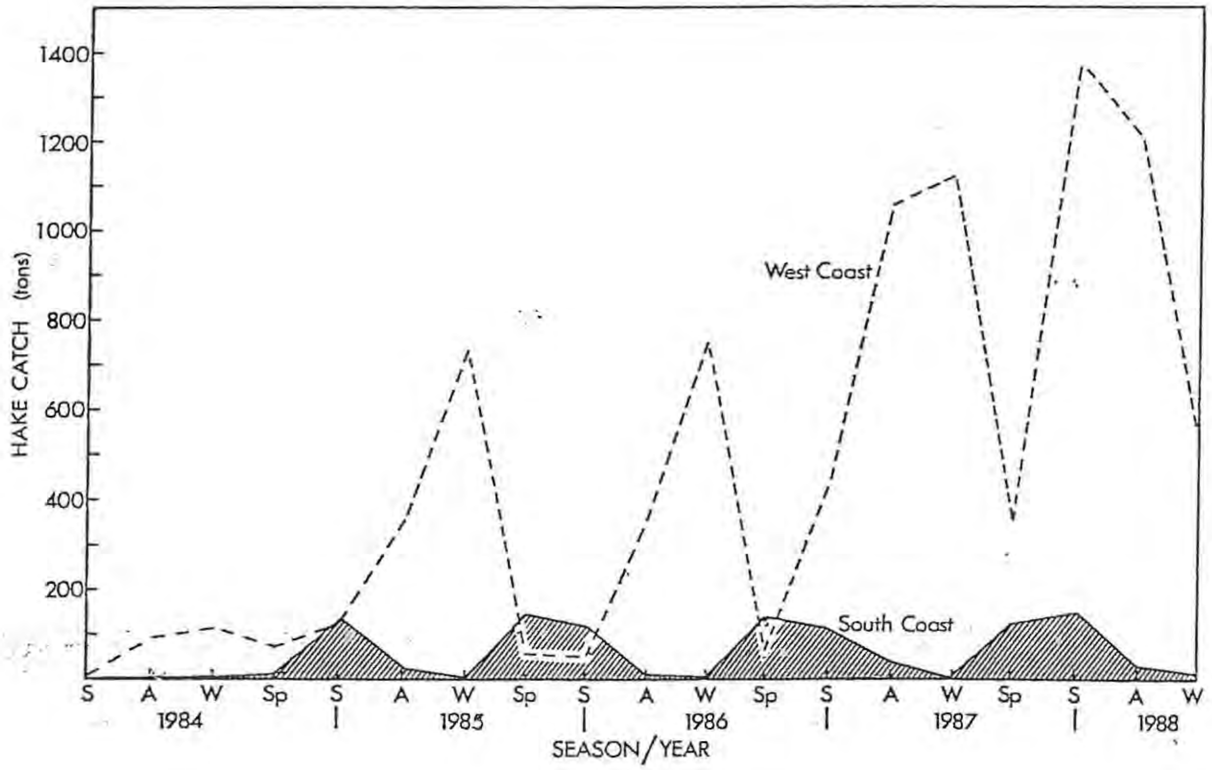

Fig. 26: Longline hake catch (nominal tons) from 1984 to 1988 for the West and South Coasts

4. Catch Rates

The areal distribution of the mean annual kingklip CPUE from 1984 to 1987 is shown in Figure 27. Generally the CPUE remained below 350kg/1000 hooks on the West Coast in 1984, though rates of up to 600kg/1000 hooks were recorded south-west of Cape Point, on the South Agulhas Bank and south of Cape St Francis. In 1985, exceptionally high catch rates of kingklip within a relatively small area were recorded on the South-East Coast grounds, often exceeding 600kg/1000 hooks, with catches of up to 20 tons per line. On the West Coast in 1985 the catch rate averaged between 100 and 350kg/1000 hooks. In 1986 and 1987 kingklip catch rates declined sharply on the South Coast. Throughout this period, the catch rates of the species on the West Coast remained stable. Seasonal shifts in kingklip CPUE are shown in Figure 28 and Table 17.

Table 17. Corrected CPUE (kg/1000 hooks) figures for target species in the demersal longline fishery

		Kingklip CPUE		Hake CPUE	
Year	Season	West	South	West	South
1984	Summer	186,5	429,7	25,7	3,5
	Autumn	231,7	309,7	52,3	8,2
	Winter	220,1	223,1	43,4	3,3
	Spring	129,2	144,1	54,8	45,3
1985	Summer	194,9	290,3	111,4	43,6
	Autumn	158,5	272,9	101,4	21,4
	Winter	108,1	556,4	144,0	-
	Spring	85,3	685,2	47,8	37,4
1986	Summer	194,3	878,0	48,2	29,2
	Autumn	186,9	376,6	141,2	21,8
	Winter	110,4	586,8	223,1	10,2
	Spring	172,2	560,2	38,3	21,8
1987	Summer	221,5	321,6	62,5	36,7
	Autumn	170,0	290,6	168,9	31,8
	Winter	141,7	272,2	144,6	9,5
	Spring	154,8	471,8	47,7	32,5
1988	Summer	155,4	313,2	161,3	74,7
	Autumn	108,9	205,8	195,9	32,8
	Winter	88,3	239,8	148,3	88,9

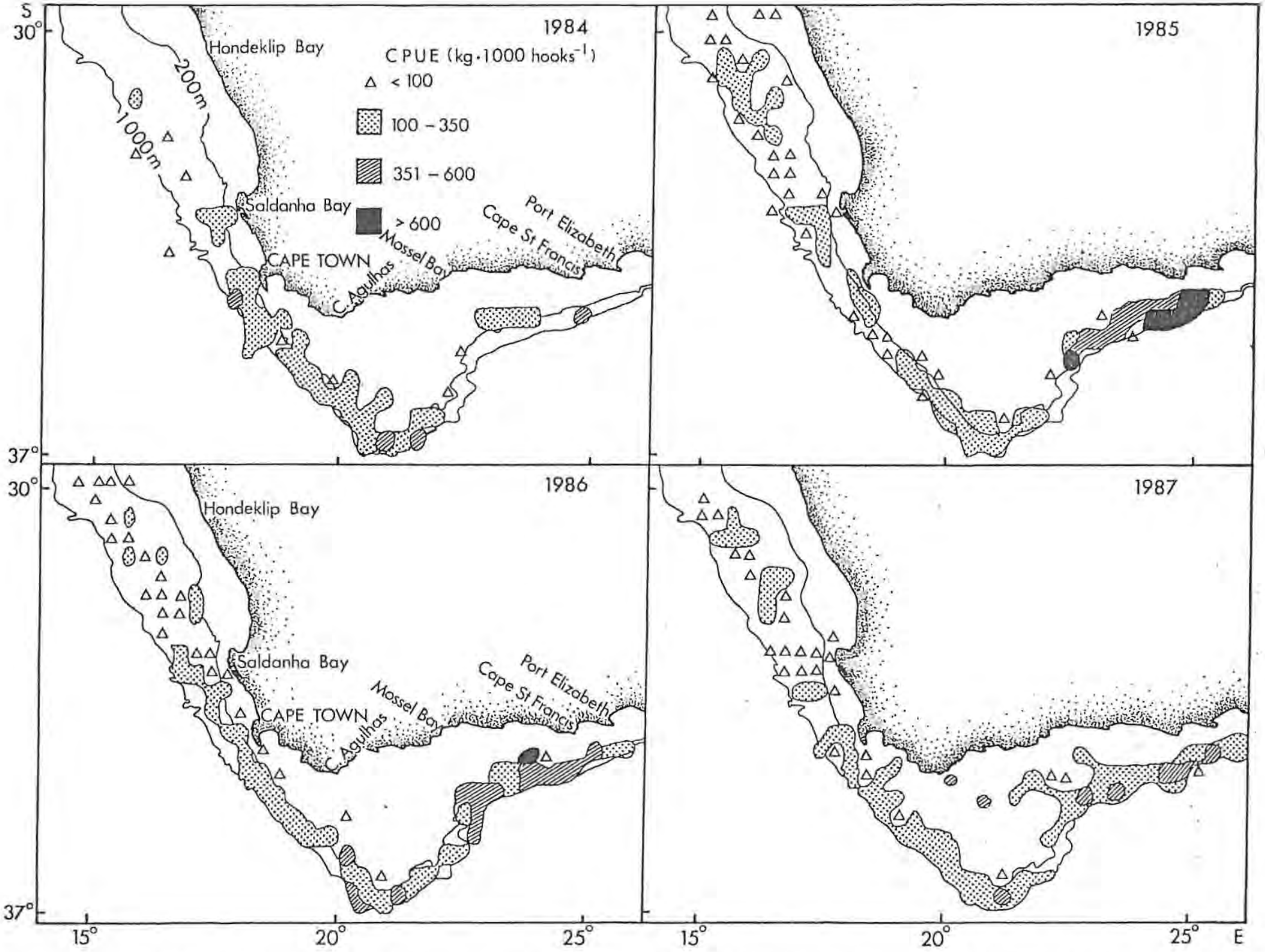

Fig. 27: Areal distribution of kingklip CPUE from 1984 to 1987

Kingklip catch rates declined steadily on the South Coast from 1985 but there were no significant trends on the West Coast. The seasonality in kingklip catch rates on the South Coast is also illustrated in Figure 28. Catch rates peak in spring on the South Coast and in summer on the West Coast.

Hake CPUE on the South Coast (Fig. 29, Table 17) was significantly lower than on the West Coast, peaking in spring at the time when effort was directed at kingklip. There was a noticeable increase in hake CPUE on the South Coast in 1988. Hake CPUE on the West Coast remained high and had no definite trend.

Discussion

Significant differences were found in the CPUE index between longline vessels and between areas. The six smaller vessels that entered the fishery in late 1985 were excluded from the CPUE analysis, although the tables and figures of catch and effort presented here are for the whole longline fleet. Only the seven larger vessels were used in the CPUE analysis. The principle reasons for doing this was that they all used similar gear (kingklip-directed DBL), had consistent hook spacing and they generally fished at the same time of day. Catches were often adversely affected by current or bad weather. As a result lines were often badly fouled, lost altogether or had to be left in the water for extended periods. In these cases the catch and effort was not used in the analysis and only 'successful' effort was considered.

Line saturation is considered to affect longline CPUE significantly (Gulland 1955, Beverton and Holt 1957, Murphy 1960). Random checks made during longline fishing operations showed that the line rarely approached 50% saturation. Consequently no correction for line saturation was necessary. Competition for hooks, bait loss and seal predation were considered more serious factors that influence the estimation of longline CPUE. The effect of hook competition on the CPUE index was largely overcome by treating the results from the West and South Coasts separately.

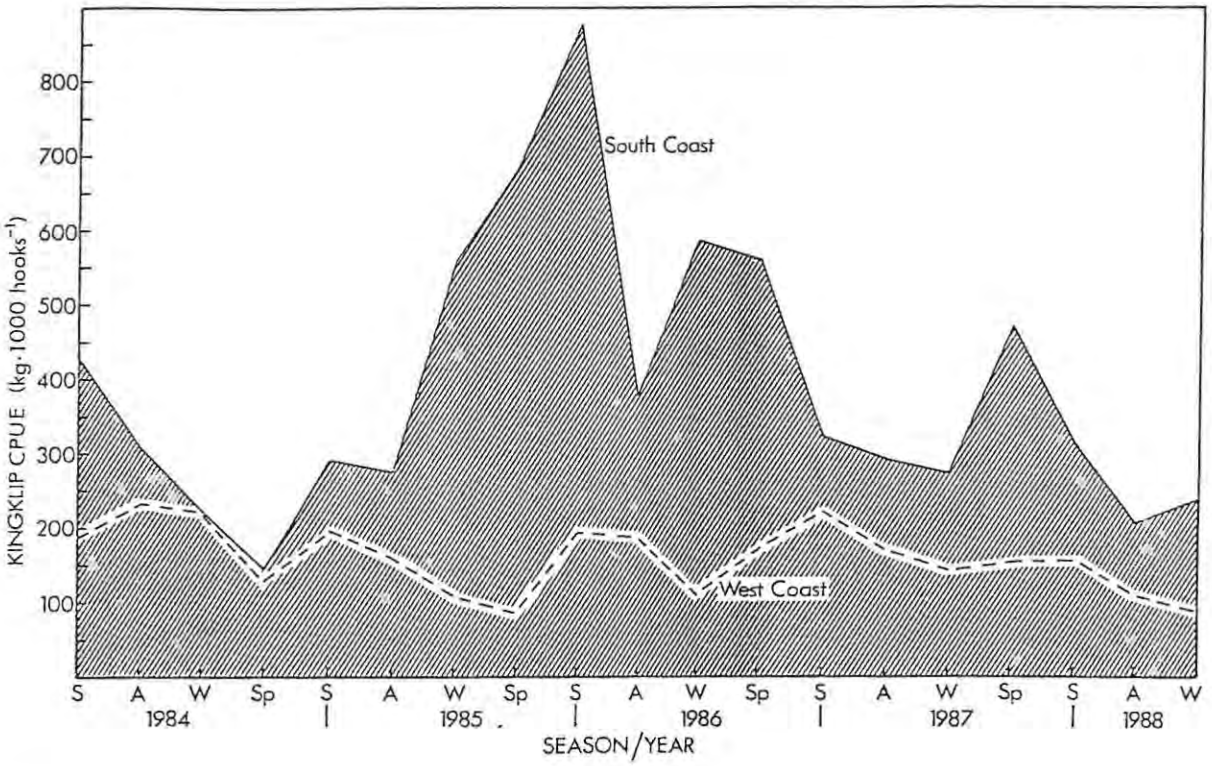

Fig. 28: Longline kingklip CPUE by season from 1984 to winter 1988 illustrating the marked difference between the West and South Coasts

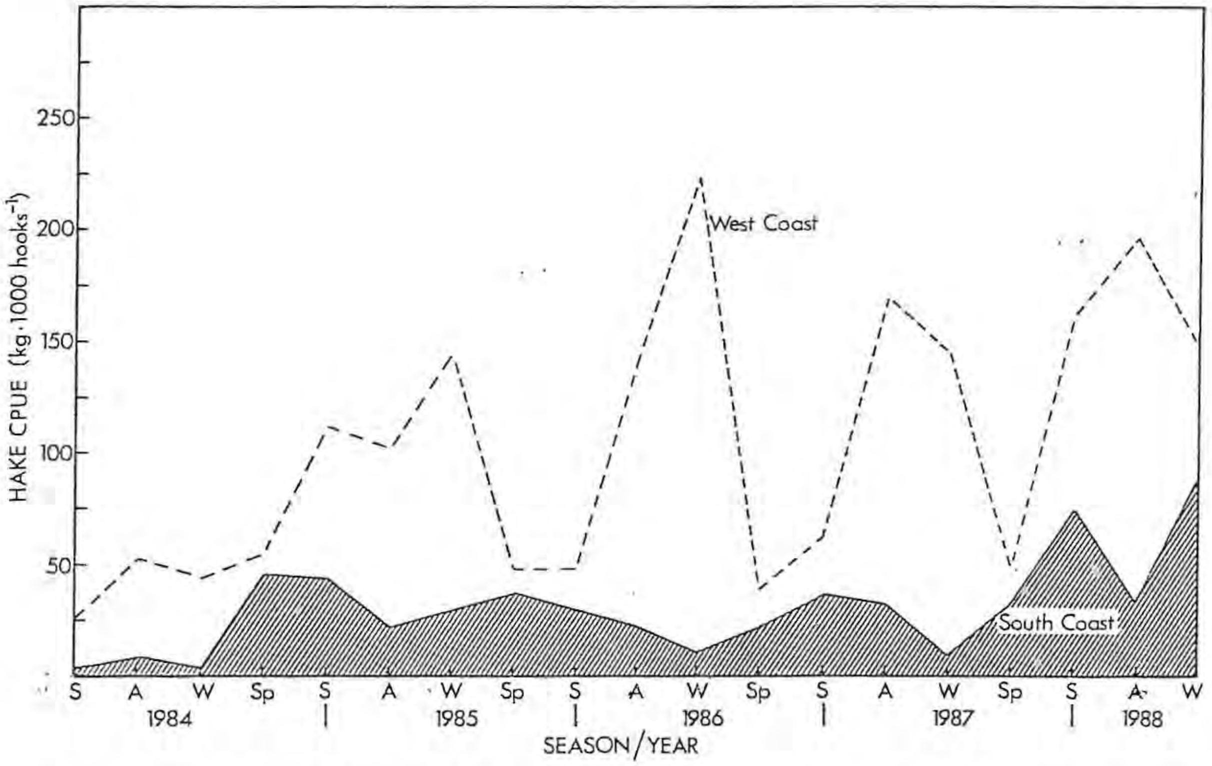

Fig. 29: Longline hake CPUE showing seasonal means from 1984 to winter 1988 for the West and South Coasts

The South Coast was considered a kingklip-dominated fishery, with little competition from other species. The proportion of hake in the total catch rarely exceeded 10% (Table 16). In contrast, on the West Coast the proportion of hake in the catch was higher (often exceeding 30%). This is partly a result of the greater abundance of hake on that coast and also due to the direct targetting on hake, particularly by the six smaller vessels that entered the fishery in 1985. The proportion of hake in the total catch increased steadily from 1985.

It is significant that, coupled with declining kingklip catch rates on the South Coast (Fig. 28), hake CPUE seems to be rising (Fig. 29) on that coast. There are indications that the declining kingklip abundance on the South Coast may result in hake becoming the dominant competitor for longline bait, a situation that already appears to exist on the West Coast. Further, kingklip abundance on the South Coast (as suggested by present catch rates) appears to have dropped to levels that yield similar catch rates as the West Coast, and it is forseeable that in the not to distant future, the CPUE indices on the two coasts might soon be comparable.

Bait loss may also significantly affect longline CPUE (Shomura 1955, Skud and Hamley 1978). However, as far as could be ascertained, the type of bait used locally did not make any significant difference. Pilchard *Sardinops ocellatus* came off the hooks more easily when the line was shot and also had a poorer soak time than the alternative bait, horse mackerel *Trachurus capensis*. Nevertheless, there was no significant difference between the CPUE indices of the vessels using pilchard and those that used horse mackerel. A correction to CPUE for bait loss or bait type was therefore not considered necessary.

Seal predation on longline-caught fish is severe at times and is a potential threat to the future of the fishery. It is also likely to have a significant, but as yet undetermined, effect on CPUE. All vessels were similarly affected on the West and South Coasts and it was decided that no adjustment to the CPUE index for seal predation could be reasonably applied. However, in view of the importance of this aspect on the longline fishery, it is given further consideration.

Fish hooked on longlines are particularly vulnerable to seal predation, because the hauling process is slow and the seals can pull fish off the line randomly. Of particular concern is that seal behaviour patterns appear to have changed to avoid attempts by longline fishermen to keep them away from the line. Observations revealed that, whereas the seals used to swim close to the longline vessels, they now swim some distance away, diving deeper and removing mostly large kingklip from the line. When kingklip catches are good (exceeding 5 tons per line set) the seals are soon satiated and damage the fish by only removing the large livers and discarding the rest of the fish. The removal of large quantities of fish by seals effectively reduces the CPUE. When longline catches are marginal (< 2 tons per day) the effect of seal predation appeared to be exacerbated, because they were estimated to remove a larger proportion of the catch. The CPUE would thus be negatively biased. Estimating the proportion of the catch taken by seals was not attempted as the objectivity of the skippers' estimates of losses to seals is questionable.

Conclusions

Analysis of longline catch and effort and the catch rates in their present format suggest the following:

1. There is a distinct seasonality in the longline fishery. Longliners target on kingklip on the South Coast in spring and shift to hake on the West Coast in summer and winter. Depending on the weather and catch rates these periods may overlap.

2. On the South Coast, kingklip catch rates have been higher than on the West Coast and there is a pronounced peak in spring. In contrast, on the West Coast, kingklip catch rates are considerably lower and with a less pronounced peak in summer. The catch rates off the two coasts are not necessarily comparable and may also

not be completely indicative of abundance.

3. Kingklip catch rates on the South Coast have declined sharply since 1985, but there has been no positive trend on the West Coast.

4. Effort is increasingly being directed at hake on the West Coast. Hake catches have increased steadily and, although most are made on the West Coast, the increase in hake CPUE on the South Coast is most likely a direct result of declining kingklip abundance in that area and the increasing tendency of longliners to target on hake.

5. The pronounced difference between catch rates of hake and kingklip off the two coasts suggests that the levels of abundance are sufficiently distinct for the longline resources on each coasts to be managed separately.

10. LENGTH-FREQUENCY ANALYSIS AND MORTALITY ESTIMATES

Introduction

Length frequencies of commercial fish catches can yield valuable information on the effects of exploitation on a fish stock. For example, they can be used to estimate growth parameters by following progression modes (Petersen 1982, cited in Pauly 1983), to estimate mortality rates (Ricker 1975, Gulland 1983, Vetter 1988), or simply to monitor shifts in the mean size of the fish caught. Most commercial catches are sampled routinely for their size distribution and this information is frequently available, but it is generally under-utilized (Pauly 1983).

If a known fish stock has been unexploited (pristine resource), or has been subjected to very little exploitation, then the total mortality of the population (Z) will approximate the natural mortality (M). However, with the introduction of exploitation (fishing), the total mortality would be expected to approximate the sum of the fishing mortality and the natural mortality, that is:

$$Z = F + M$$

Mortality rates are an important component of dynamic pool models (Vetter 1988). Fishing mortality will vary between different fish stocks depending on such factors as effort expended, the selectivity characteristics of the gear, fish availability (e.g. seasonal spawning aggregations) and the patterns of catchability-at-age. Mortality is known to vary between age classes. Marked changes in the age structure of a fish stock can occur with small changes in fishing effort, especially for long-lived species, such as has been shown for the lingcod, *Ophoidion elongatus* (Chatwin 1958).

Natural mortality is also expected to vary between species and age classes (Pauly 1980, Vetter 1988), but differences between, or even within stocks, may also exist (Vetter op. cit.). The total mortality of a commercially exploited fish stock may therefore differ from that of another similar stock, depending on the environment and the nature and level of exploitation. Mortality rates may therefore be used to assist in the identification of discrete stocks. However, the estimation of mortality rates may be confounded by emigration or immigration of fish into a particular area as they might result in different size/age structures (Armstrong, pers. comm. SFRI).

Recent research suggests that more than one method should be used to estimate mortalities of fish stocks and that simulations (models) should be conducted with a range of values of natural mortality (Vetter 1988) using assessment methods which are robust to uncertainties in M. In this chapter, several methods are employed to estimate and compare kingklip mortality on the South and West Coasts using data obtained from longline vessels. It is stressed that this analysis is preliminary and the nature of the available data and the relatively short time-series available make it impractical to use robust statistical techniques to determine, for example, age-structured mortality or the effects of immigration and emigration. This analysis of kingklip mortality rather aims at using the best available data to make approximations of Z using a range of values of M so that this information can be used to undertake a rough assessment of the kingklip stocks using dynamic pool models (Chapter 11).

Previous attempts at estimating kingklip mortality rates were all based on trawled fish (Wrzesinski 1975, Isarev 1976c, Frolinka 1977, Isarev 1979, Terré 1980, Payne 1985). The data used here for estimates of kingklip mortality are from longline catches only.

Materials and Methods

The size distribution of commercial longline catches was obtained by randomly measuring kingklip on board longline vessels as the catch was hauled and also by measuring samples of landed catches. Only data from 1986 and 1987 were used as the sample sizes measured prior to that were not considered large enough. Length measurements of commercial catches were concentrated on kingklip, although some hake length measurements were also made. The total number of fish measured per year is summarized in Table 18. Length frequencies were constructed in 2cm intervals i.e. any fish in the size range 33 - 34,9cm was placed in the 34cm size class.

Estimation of Total Instantaneous Mortality (*Z*)

Only the 1987 data were considered large enough to justify their use to estimate total kingklip mortality. Two methods were used to estimate *Z*. These were the catch curve method (Ricker 1975) and *the "integral"* method of Beverton and Holt (1957).

1. Construction of the catch curve (Ricker 1975)

The 1987 kingklip length frequency data were transformed into an age frequency distribution for the West and South Coasts using the appropriate growth parameters from Chapter 7 and the formula of Pauly (1983). That is:

$$\mathrm{Log}_e \frac{N_a}{dt_a} = a + bt \ ;$$

where: N_a = number in length class *a*;
dt_a = time required to grow through length class *a* (years);
t_a = mid-point of age range corresponding to length class *a* and
$b = Z$

dt_a is calculated by: $dt_a = t_u - t_l$

where t_l = age at upper limit of age class and
t_u = age at lower limit of age class.

The appropriate age for each length class (West and South Coasts considered separately) was calculated using the Von Bertalanffy growth formula (Chapter 7, equations 17 & 18). The time interval (age difference) dt_a is therefore calculated from the following relationship:

$$dt_a = (\mathrm{Log}_e(\frac{Lt_u}{L_\infty} - 1)) - ((\mathrm{Log}_e \frac{Lt_l}{L_\infty} - 1))$$

where, for example, in the 33cm length class:

$$Lt_a = 33\mathrm{cm} \text{ and } Lt_l = 32\mathrm{cm} \text{ and } Lt_u = 33{,}9\mathrm{cm}$$

Thus the length frequency distribution was transformed into an age frequency distribution. The number of fish (frequency) in each age class was then calculated and this figure was transformed into natural logs. The age class was therefore plotted against the $\log_e$ of the numbers (N) in each age class (Fig. 32). Total mortality was then estimated using the descending portion of the catch curve. This was done precisely by iteration to obtain the best fit to the data. Thus the upper limit of the catch curve (Fig. 30) so obtained for the West Coast was 750mm and for the South Coast was 810mm. These values were assumed to be the length at full recruitment to the fishery and is the value L′ used in the Beverton and Holt method (1957) that follows.

2. The integral method of Beverton and Holt (1957):

$$Z = \frac{K(L_\infty - \bar{L})}{\bar{L} - L'}$$

L_∞ and K are the Von Bertalanffy growth parameters, $\bar{L}$ is the mean length of the catch as a whole and L' is the smallest length fully represented in the catch (as estimated in "1" above. The mean value of Z for both methods was then calculated.

Estimation of Kingklip Natural Mortality (*M*)

Two methods were used to estimate the total instantaneous rate of natural mortality. These were the methods of Pauly (1980) and Rikhter and Efanov (1977).

1. The Pauly method (1980)

Based on data determined from 175 different species, Pauly (1980) established the following empirical relationship to derive the instantaneous natural mortality rate of a species:

$$\mathrm{Log}_{10}(M) = -0{,}0066 - 0{,}279\mathrm{Log}_{10}(L_\infty) + 0{,}6543\mathrm{Log}_{10}K + 0{,}4634\mathrm{Log}_{10}T$$

where T = mean bottom sea temperature (9,4°C for kingklip, after Payne 1985) and "K" and L_∞ (in cm) are the appropriate growth parameters for the West and South Coasts.

2. The Rikhter and Efanov method (1977)

This uses an empirical relationship based on the relationship between natural mortality and the age at 50% maturity as follows:

$$M = \frac{1{,}521}{T_m^{0{,}72}} - 0{,}155$$

where T_m = age at 50% maturity (mean value for the sexes combined extracted from Table 14; West Coast = 5,65 years, South Coast = 5,0 years).

Fishing mortality (*F*) on the fully exploited age classes was then calculated using the following relationship:

$$F = Z - M .$$

Results

The total number of fish measured is given in Table 18. A comparison was made of the length frequency distributions between 1986 and 1987. If all measures are combined for the whole South African coast, then it is clear that there has been no significant change in the mean size of kingklip caught.

Table 18. Summary of length frequency analysis of longline-caught kingklip and hake (n = number of fish measured; L = mean length)

	Kingklip			Hake		
Year	n	$\bar{L}$(cm)	Mean age(years)	n	$\bar{L}$(cm)	Mean age(years)
All Areas						
1983	1 699	91,0	8,1	986	69,9	7,3
1984	422	96,0	9,0	0	-	-
1985	1 299	89,0	7,8	854	70,8	7,4
1986	3 453	97,6	9,3	2 108	70,4	7,3
1987	15 503	93,3	8,5	0	-	-
Total	22 376	93,4	8,5	3 952	70,4	7,3
WEST COAST						
1986	1 532	82,6	6,9			
1987	4 894	88,2	7,8			
SOUTH COAST						
1986	1 921	107,3	11,1			
1987	10 609	95,7	8,8			

This data may be misleading, because longlining effort shifted from year to year as well as seasonally between areas. If the

South and West Coasts are separated (Figs 30 & 31 and Table 18) a distinct difference in the mean size of kingklip caught is apparent. Kingklip caught on the South Coast were significantly larger than on the West Coast. Also, there has been an increase in the mean size of kingklip caught on the West Coast (Fig. 30), though this may be a sampling artifact because the 1986 sample size was small. Finally there has been a significant decline in the mean size of kingklip caught on the South Coast (Fig. 31), from 1 073mm (11,1 years) to 957mm (8,8 years).

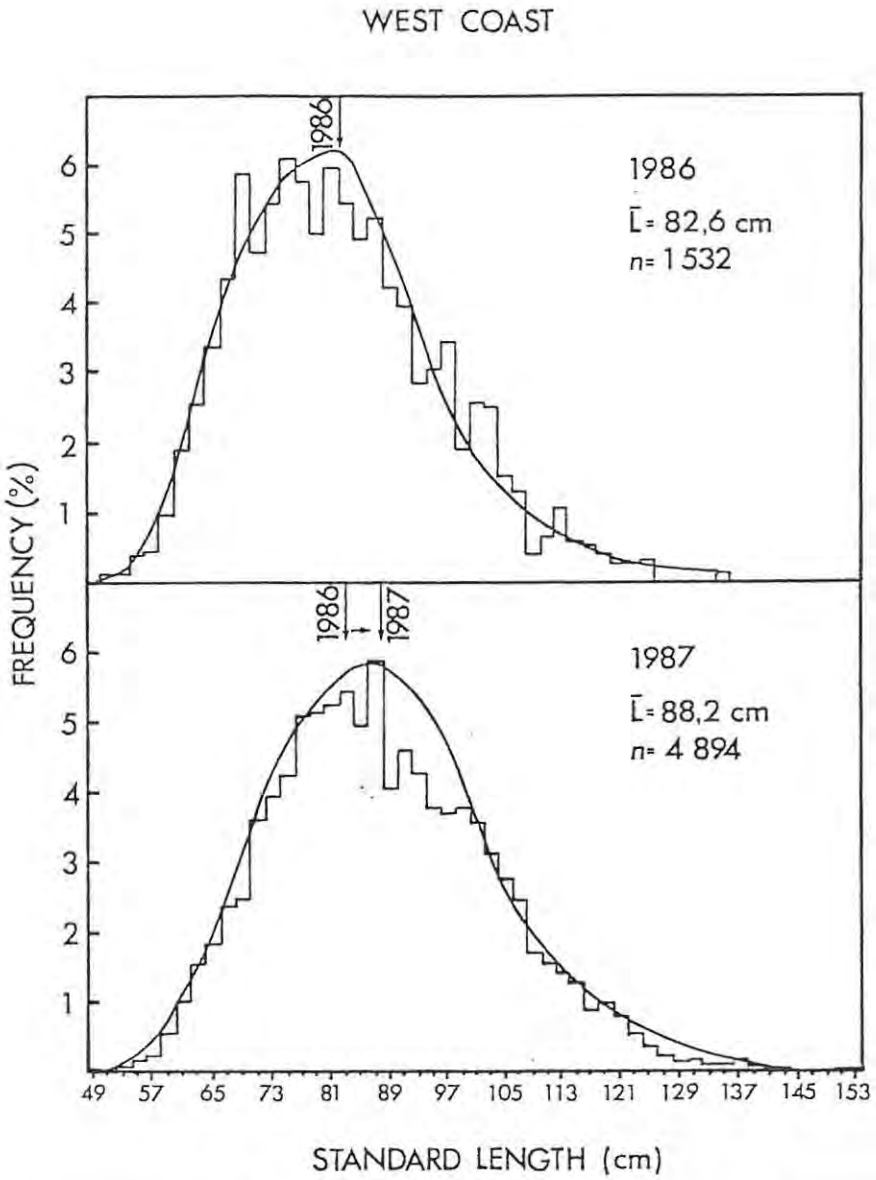

Fig. 30: Comparison between the 1986 and 1987 longline-caught kingklip length frequency distributions on the West Coast. Note: mean length increased in 1987.

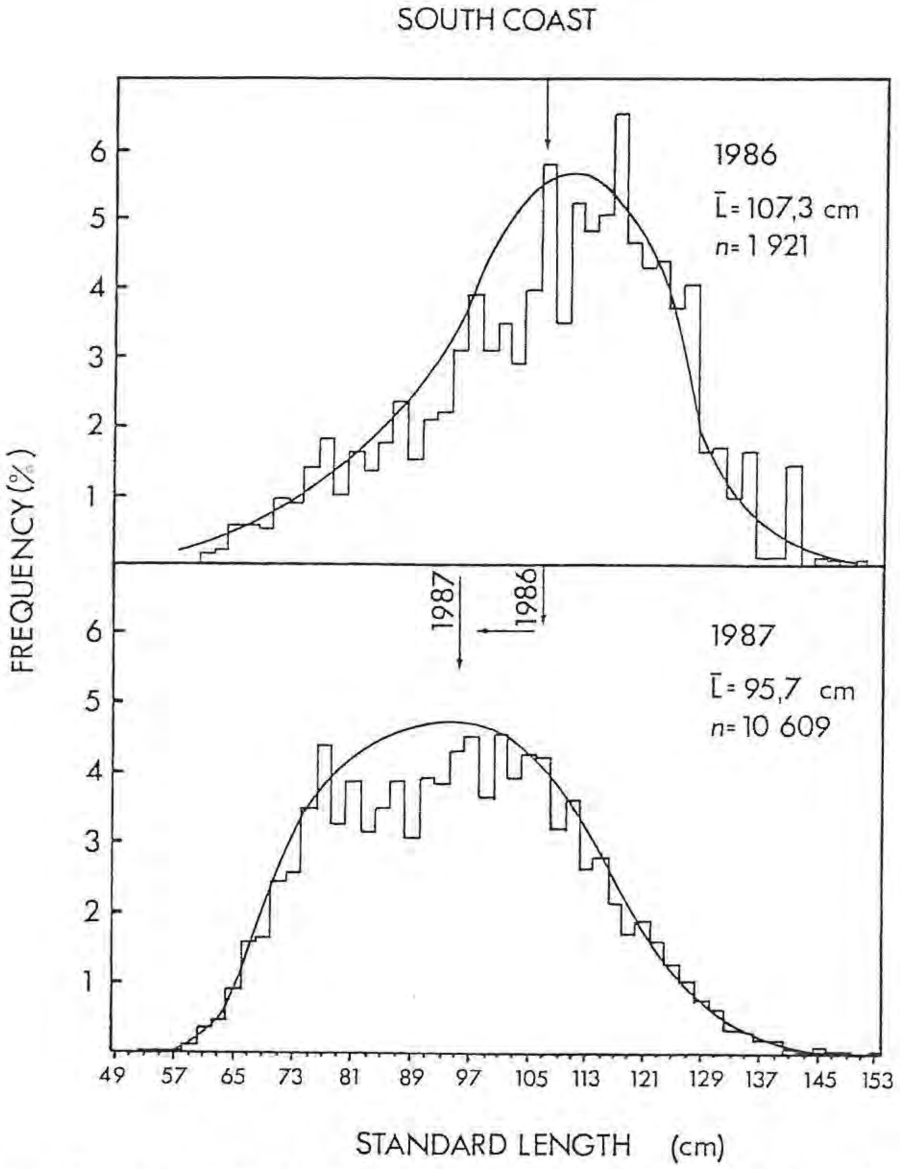

Fig. 31: Comparison between the 1986 and 1987 longline-caught kingklip length frequency distributions on the South Coast. Note: the mean length has declined from 107,3cm to 95,7cm.

The 1987 monthly mean lengths are given in Table 19. When fishing was concentrated on the South Coast (in spring), the kingklip caught were larger than on the West Coast. It should be pointed out however, that in some months, the sample sizes were small and probably not fully representative of the true catches. It is also noted that the hake caught were all large mature specimens averaging 704mm total length (7,3 years- age key after Leslie, 1985).

Table 19. Number of kingklip measured per month to obtain length distribution of long-line catches. The area sampled and the mean length of the fish caught is also given.

Month	n	L(cm)	Area
January	406	96,1	mixed
February	795	100,3	mixed
March	1 828	87,2	West
April	2 276	85,6	West
May	343	91,9	West
June	352	86,7	West
July	2 248	93,7	mixed
August	1 179	98,7	South
September	1 037	99,8	South
October	3 342	94,8	South
November	1 299	95,1	South
December	398	101,7	South

No precise position on the length frequency distribution could be found to establish the age at full recruitment to the fishery. However for the purposes of the stock assessment in Chapter 11 the age at first recruitment to the fishery (T_c)is required. Few fish smaller than 600mm were caught. This may have been a function of for example, the hook size (hooks too large for the smaller fish), of competition between the larger and smaller fish (the smaller fish were outcompeted for the bait) or simply that the smaller fish were not caught in the deeper water. However, as a first estimate, 600mm was used as an approximation to T_c for the West and South Coasts. This corresponded to the ages of 4,3 years and 4,1 years on the South and West Coasts respectively.

Estimation of total mortality:

1. Catch curves

The descending part of the catch curves (Fig. 32) were tested for linear correlation. Both the West and South Coasts were significantly correlated ($P > 0{,}001$; $r^2 = 0{,}98$) and are described by the following linear relationships:

West Coast: $\mathrm{Log}_e \frac{N}{dt} = 8{,}96 - 0{,}316t$ 20

South Coast: $\mathrm{Log}_e \frac{N}{dt} = 9{,}74 - 0{,}284t$ 21

Therefore, the total mortality for kingklip on each coast estimated from the catch curves was:

West Coast: $Z = 0{,}32$

South Coast: $Z = 0{,}28$

2. Beverton - Holt method

Assuming that kingklip are fully recruited at 750mm and 810mm on the West and South Coasts respectively, the Beverton and Holt method gave a total kingklip mortality of 0,44 and 0,39 for the West and South Coasts respectively.

Thus, taking a mean of the two methods, the total instantaneous rate of mortality was estimated to be:

West Coast: $Z = 0{,}38$

South Coast: $Z = 0{,}34$

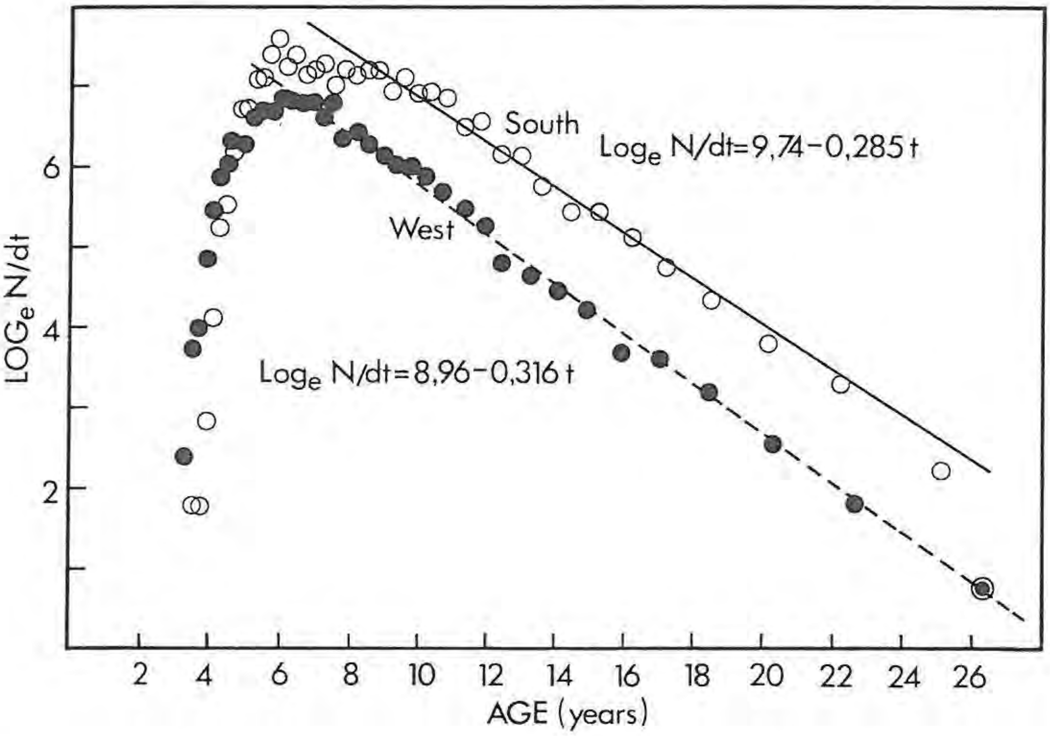

Fig. 32: Catch curves derived from 1988 longline-caught kingklip length frequency distributions to estimate total instantaneous mortality (*Z*)

Estimation of natural mortality

The Pauly (1980) method of estimating natural mortality gave a value of 0,2 for both the West and South Coasts and the Rikhter and Efanov method 0,28 and 0,32 respectively. Again, taking a mean, the calculated values for natural mortality were:

West Coast: $M = 0,24$
South Coast: $M = 0,20$

The estimated rate of Fishing Mortality (F) was calculated to be:

West Coast: $F = 0,14$
South Coast: $F = 0,08$

Conclusions

The value of *M* calculated for the West Coast was the same as Isarev's (1979) estimate but was lower than the value accepted by Terré (1980) for kingklip in South West African waters (0,3) and by Payne (1985) for the South-East Coast (0,39). It is also higher than the value estimated by Wrzesinski (1975) for kingklip on the whole of the South African Coast (0,1 - 0,15). It has been shown that *M* derived from different methods may vary widely within many fish stocks (Vetter 1988). The value for natural mortality obtained here (0,2) is therefore not considered a precise estimate. Rather, his recommendation (Vetter op. cit.) that a single "best" estimate of *M* not be applied to fisheries models but rather a range above and below the "best" estimate is considered appropriate. Therefore values above and below the best estimate were applied in the dynamic pool models for kingklip stock assessment in Chapter 11 i.e. $M = 0{,}15$, $0{,}20$ and $0{,}25$).

The mortality estimates used in this study were not considered suitably accurate or statistically sound to distinguish between discrete kingklip stocks. The difference between *Z* on the West and South Coasts (0,38 and 0,34 respectively) is small, and the roughness of the estimates combined with the large variances associated with the parameters used make it impractical to use mortality to separate stocks.

Analysis of the length frequency data showed that the kingklip caught on the South Coast are generally larger and in greater abundance than on the West Coast. Ricker (1963) pointed out that even relatively low levels of effort may have a disastrous effect on the stocks of long-lived species. For example, in the waters of the eastern Pacific Ocean the fishery for the lingcod *Ophiodon elongatus* (Chatwin 1958), which includes fish spawned 12 - 15 years before exploitation, is very sensitive to low levels of exploitation (as little as a 5% catch of the total biomass per annum will cause a major reduction in the relative weight of the older fish in the stock). By comparison, the kingklip are an even longer-lived species (as found in this study, up to 25 years). Within one year of longline exploitation on the South Coast the average age of fish caught decreased by three years from 11 to 8 years.

Several explanations can be given for the apparent increase in the size of fish caught on the West Coast. The most likely is that the sample size in 1986 was not completely representative of the longline catch in that year (it was small by comparison to the sample size in 1987). It is also possible that there is a migration of the larger South Coast fish to the West Coast. Effort in 1986 was concentrated on the South Coast and in 1987 shifted back to the West Coast. Thus the longline fleet may possibly have exploited the migration patterns of the kingklip (if they exist) more effectively.

However the distribution of age classes on the South Coast remained fairly broad, but the frequency of older fish in the population was noticeably reduced. By comparison, the characteristics of the length frequency distribution of kingklip on the West Coast clearly show that very few older fish remain and that in 1988 the stock remaining had a narrower size range. Based on the results presented in this chapter the following conclusions are drawn:

1. Based on the decline in length frequency, it was theorized that, at the present rate of exploitation, the age structure of the kingklip on the South Coast will ultimately approximate that of the West Coast.

2. Longline fishermen exploit only mature kingklip > 600mm whereas the demersal trawl fleet catch mostly juveniles < 600mm (this applies mostly to the inshore trawling fleets on the West and South Coasts and to the off-shore trawling fleets on the West Coast. Trawlers are known to exploit large kingklip in deeper waters in spring on the "Chalk Line Grounds" - Scott 1950). A situation therefore exists where both the juvenile and adult stages of the kingklip life cycle are exploited.

3. The difference in the size of the kingklip caught on the West and South Coasts and in the level of fishing effort suggests that the longline kingklip fishery should, for the time being, be managed as separate units i.e the West and South Coasts.

4. The available data on the length frequency of the hake exploited by the longline fleet suggests that they are targetting on 'the spawning stock.

11. KINGKLIP STOCK ASSESSMENT

Introduction

When experimental longlining was initiated in South Africa in 1983, it was decided that, because the fishery targetted on kingklip, the data generated would be used for a kingklip stock assessment. This objective was complicated by the inclusion of six additional vessels in the experiment in 1985 as the level of effort in the fishery increased. These later entrants also targetted on hake rather than kingklip, meaning that the data generated from their performance had to be excluded from the assessment. In addition to that complication, because the fishery was in a development phase, it took some time before techniques and levels of efficiency stabilized.

None of these problems are unique to a developing fishery. The longline fishery went through an initial phase of rapid growth and development with very little research input. Thereafter, development slowed down and fishing was concentrated on definite fishing grounds and was directed at kingklip. At the same time, research into the fishery, particularly on kingklip, increased. Now, however, it would seem that the fishery is in a transition phase, whereby the maximum profitable stock (Gulland 1983) is shifting from kingklip to hake.

On no previous occasion has data been available that could be considered reasonably suitable for stock assessment of the species. Terré (1980) and Isarev (1980, 1983) made an assessment of the stocks on the South West African and South African coasts using dynamic pool models. However they based their information on the kingklip by-catch in the hake-directed trawl fishery. Their catch data were thus to a large extent nothing more than estimates. Only on the South-East Coast, on the "Chalk Line Grounds" (Scott 1950), do trawlers target directly for kingklip, a fact also recorded by Hecht (1976) and Payne (1986).

Despite its changing trends, the longline fishery has, for the first time, in the case of the kingklip, provided data that can be considered suitable to make a rough stock assessment. The relatively short time-series available ruled out the use of surplus yield models such as those of Schaefer (1954) and Fox (1970). However, sufficient information has been obtained from this study to use the more biologically orientated analytical models for the assessment. Analytical models of the yield-per-recruit and biomass-per-recruit type (eg Beverton and Holt 1957) were considered to be the most appropriate.

It has been shown that prior to the advent of longlining, the demersal trawl fishery exploited mostly juvenile kingklip (a by-catch only) and that this had had no apparent detrimental effect on the resource. In contrast, the longliners catch almost exclusively mature kingklip more than 600mm long (refer to Chapter 10), that is first-time maturing kingklip four years of age and older. Thus a situation exists whereby two fisheries exploit different life history stages of the same species. A precarious situation therefore exists and the following questions may be asked. To what level should the longliners be allowed to reduce the kingklip spawner stock? Will this reduction affect the recruitment to the demersal trawl fishery? If the kingklip biomass does decline to "marginal" levels, will the exploitation of the juveniles by the trawling fleet significantly affect the recruitment to the longline fishery? i.e. the spawner stock

As little can be done about the kingklip caught in the trawl fishery, stock assessment and the management of this valuable resource should therefore aim at the protection of the spawning stock (the stocks exploited predominantly by the longline fleet) therefore ensuring recruitment to both the longline and trawl fisheries. A three-pronged approach was used to assess the kingklip stocks on the South and West Coasts using the longline data.

First, using the biological parameters the effect of fishing mortality (*F*) on the spawner biomass at different levels of natural mortality (*M*) was modelled, and the fishing mortality (*Fopt*) required to ultimately retain 50% of the unexploited spawner biomass (assuming constant recruitment on average) was estimated (referred to as the spawner biomass-per-recruit model).

Second, the predicted rate of decline of the kingklip spawner biomass was modelled as a function of *Fopt* to determine the time needed to reach 50% of the pristine stock level. This was done for three values of *M* above and below the mean *M* estimated in Chapter 10.

Third, using available CPUE data in the manner described in the methods section, the mean depletion of the kingklip resource due to longlining was calculated and compared with the expected rate of depletion to determine if the past levels of fishing effort have been above or below that corresponding to *Fopt* (again assuming constant recruitment).

In this manner, the kingklip stock assessment presented here is, at best, a first attempt and rough estimate of the effect longlining has had on the kingklip stocks. It aims at giving advice that may ultimately conserve the kingklip resource for future rational exploitation.

Methods

1. Spawner biomass-per-recruit (SB/R)

The models presented here are based on the assumption that the biomass of spawning kingklip should not be allowed to fall below 50% of its unexploited level. This assumption derives from the density-dependent (logistic growth) model of Schaefer (1954), whereby the biomass of a population is expected to reach optimum levels of exploitation (the so-called maximum sustained yield) at 50% of its carrying capacity (0,5K). In the present context the shape of the production curve is unknown, and it has been necessary to assume constant recruitment levels - i.e. that the stock has remained in the asymptotic region of a stock-recruit curve of the

Beverton and Holt (1957) type. Trends in the catch rates of juvenile kingklip in the trawl fishery have not exhibited any marked trends, supporting this hypothesis (the dependence of the method on this assumption underlies the need to monitor the abundance of juvenile kingklip before they enter the longline fishery - Armstrong, SFRI. pers. comm.). The SB/R of kingklip was modelled using the *PC-Yield* computer package of Hughes and Punt (1987). The model used is a variation of the Beverton and Holt (1957) yield-per-recruit model and requires the input of the Von Bertalanffy growth parameters (K; t_o; L_∞) as well as the age at 50% maturity (t_m), the estimated age at first capture in the longline fishery (t_c) and the conversion of fish length to weight.

The spawning biomass is defined as the total biomass of fish older than the age-at-maturity, t_m (Butterworth *et al.* 1988). Values of t_m were extracted from Table 14 (West = 5,65 years and South = 5,0 years). The value of t_c should be chosen carefully (Butterworth *et al. op cit.*). From the length frequency distributions (Figs 30 and 31) it is clear that kingklip are caught with longlines from a total length of 470mm. The length at full recruitment, however, is problematical and no length could be selected with any degree of certainty. The age-at-recruitment to the fishery was therefore approximated and assumed to be 600mm for the West and South Coasts (refer to Chapter 10 for further explanation). This corresponded to 4,1 years on the West Coast and 4,3 years on the South Coast. For the purposes of the models used, it is assumed that knife-edge selection occurs at t_c. Derivation of the SB/R model therefore assumes that the age at recruitment to the fishery is less than the age at maturity, in which case the SB/R will approach zero as *F* becomes large (Butterworth *et. al.* 1988). The spawner biomass is derived as follows;

$$SB = \int_{t_m}^{t_\infty} N(t).W(t)\,dt \qquad \text{for } (t_m \geq t_c) \quad \ldots\ldots 22$$

where SB = spawner biomass, N(t) = numbers of fish at age t, W(t) = mean mass of fish at age, t_m = age at 50% maturity and t_∞ is the maximum age.

Assuming knife-edge selection operating at the age-at-first-capture the number N remaining at a time t after birth is derived as follows. The number of fish in a stock at any time t is expected to be the product of the recruitment *R* and the losses prior to first capture i.e. e^{-Mtc} and the losses during the period between first capture and time *t* i.e. $e^{-(M+F).(t-tc)}$, therefore;

$$N(t) = Re^{-Mt_c}.\ e^{-(M+F).(t-t_c)}$$

which is reduced to,

$$N(t) = R.e^{Ft_c - (M+F).t} \qquad \ldots\ldots\ldots\ldots\ldots\ldots \quad 23$$

Substituting equation 19 (the Von Bertalanffy growth equation for weight assuming *b* = 3) and equation 23 into equation 22, and integrating and dividing by R (recruitment to the fishery), gives the spawning biomass-per-recruit:

$$SB/R = W_\infty e^{-Mt_m - F(t_m - t_c)} \left[\frac{1}{(M + F)} - \frac{3e^{-k(t_m - t_o)}}{(M + F + k)} + \frac{3e^{-2k(t_m - t_o)}}{(M + F + 2k)} - \frac{e^{-3k(t_m - t_o)}}{(M + F + k)} \right] \quad \text{for } (t_m \geq t_c)$$

F = fishing mortality; *M* = natural mortality (0,15 - 0,25);

Thus, the rate of decline of the spawner biomass-per-recruit as a function of *F* is calculated and plotted for three levels of *M* and the value of F at 0,5K may be estimated for each value of *M*.

2. Predicted rate of depletion of kingklip stocks:

A regenerating dynamic pool model was used to estimate the effect of *Fopt* on the kingklip stocks at the selected values of *M*. The model was deterministic, that is it simulated the population by projecting forwards in time assuming an initial unexploited spawner biomass (with the appropriate age structure at the given natural mortality and no fishing effort). Thus, the expected rate of depletion of the kingklip spawner biomass was modelled and could be compared with the actual rate of depletion. For example, for $F = 0{,}08$; $M = 0{,}15$ and assuming constant knife-edge recruitment to the longline fishery at three years (500mm) then:

Year	Number of recruits	Number at Age				Spawning Biomass	% of initial Biomass
		4	5	6	7		
1984	1 000	878	771	677	594	46 430	100
1985	1 000	818	718	631	554	43 352	93,4
1986	1 000	818	670	588	516	40 554	87,3
1987	1 000	818	670	548	481	38 039	81,9
↓							↓
↓							↓
↓							↓
∞							0,5K

3. Actual rate of decline of kingklip spawner biomass

The available CPUE information on the longline fishery was then used to assess the state of the kingklip resource on the South and West Coasts. Because good data were only available for the West Coast from 1984 and for the South Coast from 1985, only the CPUE estimates from these years and later for each coast was used.

The South African coast was divided into contiguous square 20 x 20 nautical mile blocks and each skipper reported his daily catch in whatever block he fished. The total catch in each statistical square was divided by the total effort to give a CPUE value for each square per year (refer to Chapter 8 for the CPUE index used). CPUE data were available for most blocks, particularly in more recent years. Certain blocks were targetted more often, and therefore they had high catch and effort levels. Had the overall catch rate been estimated from the total catch divided by the total effort off either the South or West Coasts, the CPUE would likely have been biased, as it would have been dominated by these small areas despite the much larger distributional range of the stock. These smaller, intensely exploited blocks suffered substantial declines over several years, whereas the other, less intensively fished blocks showed smaller declines or even increases in CPUE over the experimental period. The blocks were therefore treated in a manner analagous to a systematic sampling plan for a research survey. The abundance in each block was given by:

$$Catch_i = q_i . E_i . B_i \quad ,$$

where q_i = catchability coefficient in block i,

E_i = effort in block i during the year and

B_i = average biomass in the block during the year, assuming no emigration or immigration during the fishing season.

Thus,

$$\bar{B}_i = \frac{1}{q_i} . \frac{C_i}{E_i}$$

The total biomass over all the blocks would then be given as

$$\hat{B}_i = \sum_i \frac{1}{q_i} . \frac{C_i}{E_i}$$

and the average biomass per block as,

$$\bar{B} = \frac{1}{N} \sum_i \frac{1}{q_i} . \frac{C_i}{E_i}$$

If it is assumed that the catachability varied randomly between blocks during that year, then:

$$\hat{\bar{B}} \simeq \frac{1}{N} . \frac{1}{q_i} \sum_i \frac{C_i}{E_i}$$

Variance in $\frac{1}{q}$ would then translate into variance in $\hat{\bar{B}}$. The relative depletion (D) between year 1 and year j would then be:

$$D = \frac{\frac{1}{N} \sum_i \frac{C_{ij}}{E_{ij}}}{\frac{1}{N} \sum_i \frac{C_{i1}}{E_{i1}}}$$

This provides a less biased method of comparing CPUE values over the respective periods on the West and South Coasts than that where total catch and effort data are used.

Ideally, all blocks should have had data, although the "sampling" effort differed substantially between blocks. An optimum situation would arise if effort per block was proportional to the fish abundance, but this is almost certainly not the case. In practice, effort is likely to have spread outwards as catch rates fell in the initially occupied blocks. Hence, the samples in each year were not a random sample of the population density. This situation could have been rectified at least partially by varying the sizes of the blocks across the range of the stock to ensure that the whole area was covered by those blocks which contain a minimum number of samples, and then giving the samples weighting values corresponding to the area they represent. However, such a procedure would still not have been entirely satisfactory because of heterogeneity in the catch rates. In other words, had all the area of one of these enlarged blocks been sampled, the overall catch rate may have been very different from the catch rate in the smaller area which had been fished, if the fishermen had some *a priori* reason to expect good catch rates in the smaller area.

It was decided not to weight the data from the individual blocks and the following procedure was adopted. For the South Coast, where only three years of good data were available (longliners only began exploiting the South Coast fully from 1985) and the West Coast, for four years from 1984, the CPUE values were averaged for each block in each year and a standard error computed.

The relative depletion in CPUE was therefore determined for the South Coast from January 1985 to December 1987 and from January 1984 to December 1987 on the West Coast. This was achieved by linear regression because, although biomass would be expected to decline non-linearly, effort had increased over the years and this acted to remove the curvature. The variance of the relative depletion was determined by means of a Monte Carlo model (Hammersley and Handscomb 1967). Values of mean CPUE for each year were selected randomly from normal distributions specified by the means and standard errors computed from the data. A regression was computed for the three or four values (depending on the coast) so obtained, and the ratio of the final to expected CPUE was calculated. This was repeated 1 000 times (the Monte Carlo method) and the mean and variance of the relative depletion was calculated. The number of regressions in which the depletion was less than 1,0 , 0,9 , 0,8 etc. was recorded and the probability of the depletion being below 50% calculated.

Results

Kingklip SB/R declines sharply at relatively low levels of fishing effort both on the West (Fig. 33) and South Coasts (Fig. 34). There is no difference between the values of *Fopt* obtained on the two coasts (Table 20) for the same values of *M*.

Table 20. Table showing parameters estimated from spawner biomass-per-recruit. K = pristine stock biomass, 0,5K = 50% pristine stock biomass, fishing mortality *F* at 0,5K and total mortality *Z* estimate.

Area	M	K	0,5K	Fopt	Z
South					
	0,15	32 746	16 373	0,07	0,22
	0,20	16 846	8 423	0,085	0,29
	0,25	9 536	4 768	0,10	0,35
West					
	0,15	21 576	10 788	0,07	0,22
	0,20	11 310	5 655	0,085	0,29
	0,25	6 339	3 169	0,10	0,35

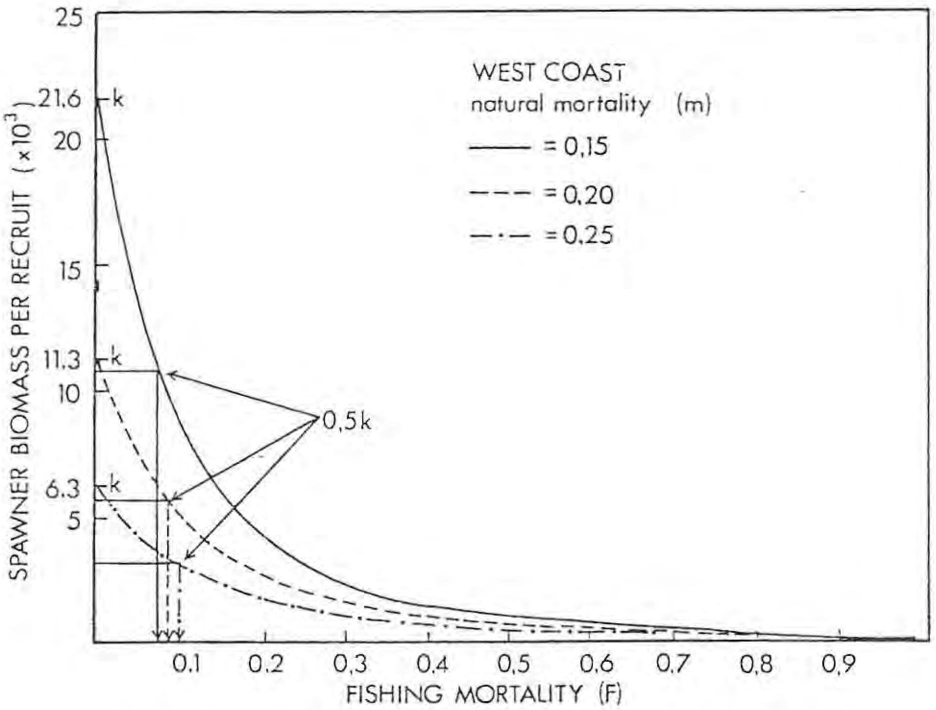

Fig. 33: Spawner-biomass-per-recruit model for kingklip on the West Coast at three levels of natural mortality. The fishing mortality at 0,5K is indicated.

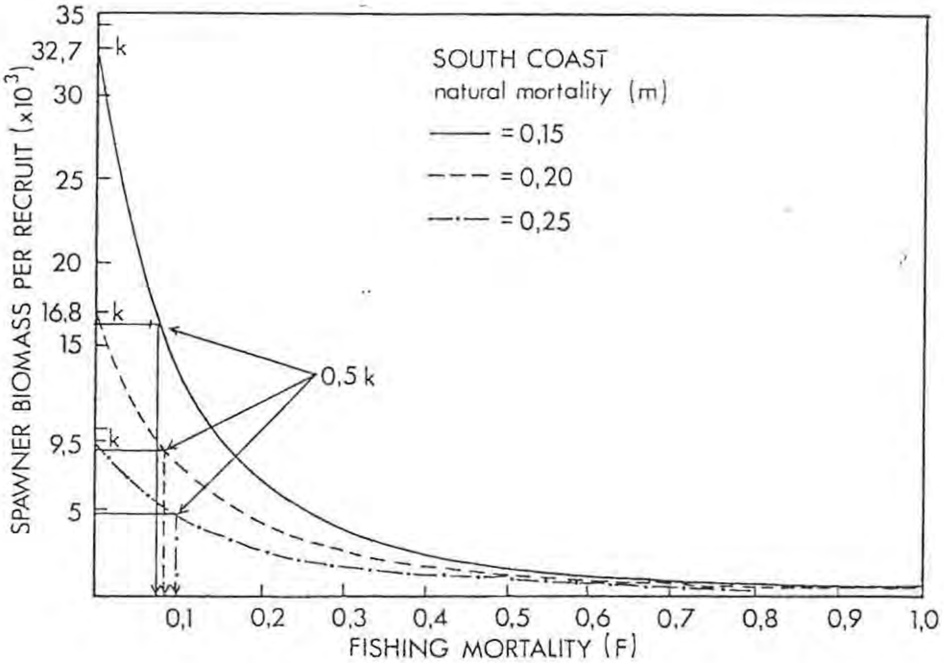

Fig. 34: Spawner-biomass-per-recruit model for kingklip on the South Coast at three levels of natural mortality. The fishing mortality at at 0,5K is indicated.

Predicted rates of decline of the spawner biomass at *Fopt* are presented in Figure 35 for the West and South Coasts. The model predicts that the kingklip stocks on both coasts will approximate 0,5K by the year 2 000. The kingklip resource on the South Coast is estimated to have declined to 62% (SE ±10,6%) of its original biomass and on the West Coast to 88,7% (SE ±9,9%). The probability that the kingklip on the South Coast has already declined below 0,5K is high (17,6%) but it is zero on the West Coast (Table 21).

Table 21. Probability of level of depletion of kingklip stocks on the South and West Coasts.

	Probability stock is at estimated level	
Percentage Stock Remaining	South Coast	West Coast
K	0,993	0,865
0,9K	0,973	0,583
0,8K	0,906	0,173
0,7K	0,759	0,022
0,6K	0,486	0
0,5K	0,176	0
0,4K	0,014	0
0,4K	0,001	0
0,2K	0	0

The rate of exploitation of kingklip on the South Coast is considerably greater than the desired rate of exploitation at *Fopt* (Fig. 35) with the upper limit of the 95% confidence range well below that rate considered optimum at the highest level of natural mortality. In contrast, on the West Coast, the lower limit of the 95% confidence range suggests that the actual depletion of the kingklip spawner biomass may also have exceeded the rate at *Fopt*.

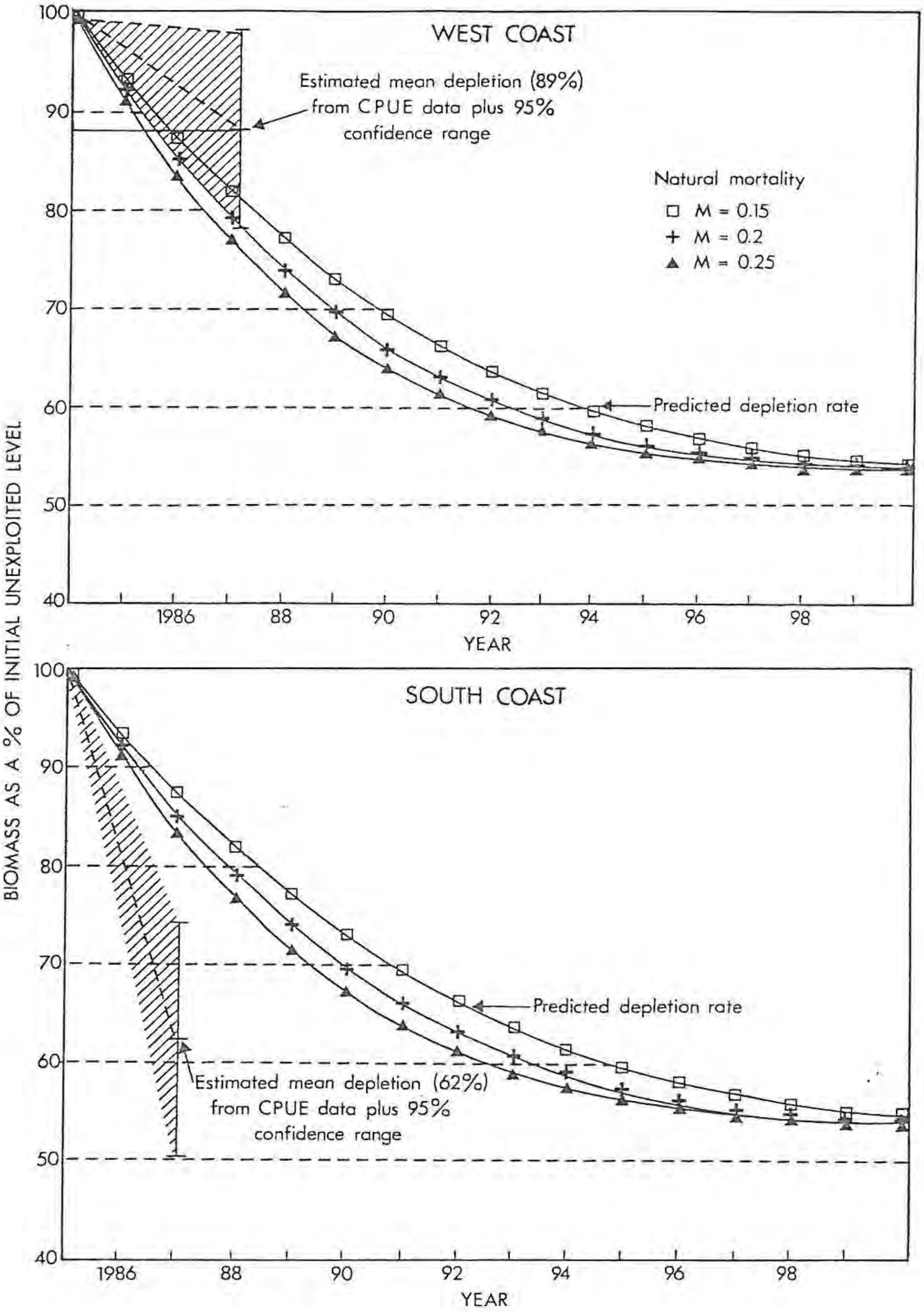

Fig. 35: Expected and actual rates of depletion of kingklip stocks on the West and South Coasts.

Conclusions

The kingklip spawner biomass on the South Coast has been exploited at a rate considerably greater than that required to retain 50% of the unexploited biomass. Further, analysis of the available information, suggests that the kingklip resource on the South Coast has already declined well below that level (with a 17,6% probability). A sharp reduction in the effort directed at that coast, particularly in the kingklip spawning season, is vital. The total kingklip catch on that coast should be reduced to a level well below the mean annual catch since 1985 (discussed in Chapter 12).

The situation is not so serious on the West Coast, where the rate of depletion of the kingklip resource is less than that required to retain 50% of the unexploited biomass. However, at the 95% confidence level, there is a possibility that the rate is close to or greater than that required at *Fopt*. Effort should not be allowed to increase on the West Coast and the allowed catch should not exceed the mean annual catch on that coast since 1984 (the recommended levels are discussed in the following chapter).

12. CONCLUSIONS AND RECOMMENDATIONS FOR THE MANAGEMENT OF THE LONGLINE FISHERY

One of the objectives of this study were to establish the viability of demersal longlining in South African territorial waters. This thesis has looked at the results of the longline experiment as well as aspects of the biology of the main species exploited by the fishery, kingklip *Genypterus capensis*. In so doing, aspects of both the commercial and ecological viability of the fishery were assessed. A second objective was to test the hypothesis that the kingklip exploited in South African waters is a unit stock. The research directed at resolving these issues was also intended to provide information that could be used to manage the longline fishery with particular emphasis on kingklip. From the results of the longline experiment and also the biological component of this study, three main conclusions were drawn. These are:

1. **Demersal longlining in South African waters is viable.**

2. **Kingklip on the South African coast are continuously distributed and comprise a unit stock.**

3. **Although longliners exploit a single kingklip stock, the characteristics of the fishery are such that it should be managed as two separate units (i.e. the West and South Coasts should, for the time being, be managed apart).**

The viability of demersal longlining in South African waters has been proven beyond doubt. Despite the fact that the future of the fishery was somewhat uncertain, entrepreneurs went to great expense and effort to demonstrate that longlining is both economical and offers a useful alternative method of catching hake and kingklip.

Experienced longline fishermen and skippers recruited from Portugal and Spain have trained local crews to the point where the formers expertise is no longer required. A unique system has been developed (the double line) specifically for South African conditions. Longline entrepreneurs have demonstrated their ability to adapt fishing gear by developing techniques that are species specific. Consequently, longliners can adjust their gear to target either on kingklip or hake.

Rather than competing with each other, demersal longlining and demersal trawling are seen as complimentary. Longline fishermen target mostly on large kingklip on specific grounds at specific times of the year. More recently, longline fishermen have begun to do the same with hake. Longline-caught kingklip and hake are considered to be of a better quality than the trawled equivalents as the fish are larger and are not damaged in the catch process. Longline- caught fish therefore command a higher market price locally and are highly valued as an export commodity. Longlining has thus effectively raised the level of fishing expertise in South Africa. Fishing managers can now cater for a broader market base, providing good quality longline-caught fish to a select clientele, while also retaining the already developed markets for the generally smaller and poorer quality trawl-caught kingklip and hake. From a management perspective, there is however a trade-off.

The targetting by the longliners on kingklip and more recently on the hake spawning stock should be given serious attention (refer to chapters 4, 9, 10 & 11). Although longlining was initially intended to catch hake, this situation changed with the discovery that large kingklip are vulnerable to the technique. Until the advent of longlining in South Africa, very little was known of the kingklip resource. Past research on kingklip considered only the trawled stocks and conclusions were drawn that, in retrospect, may have been artifacts of the sampling strategy employed at the time. The same may be said of past hake research. Clearly, by using trawled data alone, scientific knowledge may have been restricted to specific areas. Consequently, conclusions and assumptions were made in ignorance of the possible much wider distribution of both hake and kingklip. The same reservations may apply to the current research, but to a lesser extent. The results presented here should therefore be accepted with the realization that kingklip may extend beyond the areas sampled in this study.

Major Findings With Respect To Kingklip

Past kingklip research identified at least three kingklip stocks on the southern African coast. The results of this study apply to the South African coast only and therefore do not include the "Walvis" stock (Payne 1977) or the "Tropical" stock of Isarev (1976a, 1976b, 1976c). As sampling in the past was restricted to trawl or research vessels, gaps existed in the sample distribution and without testing for continuity, kingklip stocks could quite easily have been identified as discrete. The results presented here used a much wider distribution of samples.

Analysis of gross morphology, otolith morphology, age and growth, and reproductive strategies has shown that whereas differences do exist between kingklip on the West and South Coasts, these are not significant and can probably be attributed to differences in the environment. As far as could be ascertained these differences are not characteristics of discrete stocks (as defined in Chapter 1). Although it was not shown directly, the results suggest that the characteristics investigated change gradually around the coast. It is likely therefore, that variations in, for example, body morphology or age and growth, are characteristics associated with the immediate environment of the fish and are not distinguishing features of discrete stocks. Kingklip in one area may differ slightly from those in an adjacent area, but this does not mean that they are reproductively isolated. The conclusion of Leslie (pers comm.) that there is no genetic differences between kingklip stocks on the South African coast is therefore supported.

It is proposed here that at the depths occupied by longline-caught kingklip (300 to 550m), the environment is relatively stable compared to the pelagic environment. Water temperature on the deeper continental shelf margins, for example, is probably more stable and response times to atmospheric forcing delayed and not as pronounced as on the sea surface. Thus hydrographic differences between the West and South Coast systems are likely to have little effect on the continuity of the distribution of the <u>adult</u> kingklip population. In contrast, the <u>early</u> life history stages are likely to be significantly affected by changes in the surface water environment.

Future research on kingklip should therefore be directed at the early life history of the species. Sufficient data on aspects of kingklip reproduction have been presented in this thesis demonstrating that the South Coast is a unique spawning ground. The reasons for this are not entirely clear but assumptions based on the oceanography in the area may go a long way to providing insight into the early life history of the species. As the results presented here are to a large extent limited by the sampling strategy, assumptions on various aspects of the biology of the species and the physical processes to which they have being adapted have been made and will provide useful hypotheses on which to base further research. These are:

1. The South-East Coast is an unique kingklip spawning ground;

2. Kingklip spawning on the South-East Coast is protracted, starting in August and ending in November;

3. Kingklip spawning on the South-East Coast has evolved partly in response to atmospheric forcing. The onset of strong easterly winds in spring, results in the inshore advection of water. Kingklip spawn at this time, thereby increasing the chances of survival of their eggs and larvae which are advected towards shallower water of the Agulhas Bank. This is also a mechanism for preventing the loss of eggs and larvae to the Agulhas Return Current;

4. Kingklip larvae settle on the Agulhas Bank from where they

migrate into deeper water and onto rocky grounds to commence spawning in their fourth and fifth years.

5. Kingklip aggregate to spawn. These aggregations involve a presently unknown migration pattern. It is speculated that male kingklip feed extensively on the trawling grounds and move onto the rocky grounds in the spawning season in response to favourable oceanographic conditions. The structure and function of specialized drumming muscles in both the male and females of the species and the roles these muscles play in aggregations requires further investigation.

6. Spawning on the West Coast is clearly not as pronounced as on the South-East Coast. It is likely that spawning aggregations exist on the West Coast as well, but due to the broader shelf margin they are not as easy to locate.

7. It should be assumed that kingklip migrate to spawn. It is likely however that these migrations are not extensive, as the benthic nature of the species suggests that it is not well suited to swimming long distances. It is most likely therefore that short migrations to preferred spawning and feeding areas take place. Prespawning aggregations are therefore likely to be a localised phenomenon. Thus the high catch rates on the South Coast, particularly on the South-East Coast are a direct result of these localised prespawning aggregations. The movement or increased activity of the animals in spring on the South-East Coast enhances their vulnerability to the longline gear. Consequently, the exploitation of kingklip within relatively small areas, as has been accomplished by the longline fishermen, effectively exploits the resource from a much wider area. In this respect the findings in this study that the kingklip resource is likely to have been depleted below 50% of the pristine stock level is significant. The fact that this is the spawner stock and that this stock is most likely responsible for the kingklip recruitment onto the Agulhas Bank and possibly onto the West Coast means that positive and firm management action is required.

Major Findings With Respect To The Hake Resource

Little attention has been paid to the consequences of longlining on the hake resources, as the experiment and the research was primarily directed at kingklip. However, several factors caused a greater emphasis to be placed on the exploitation of hake. These were:

1. Declining kingklip catches and catch rates gave the longline fishermen added incentive to fish for hake;

2. Hake are more easily caught than kingklip on the West Coast. These hake were mostly large mature specimens in the process of spawning. The proximity of the longline hake grounds to the landing ports (i.e. Cape Town and Saldanha Bay), increased the turn around time of the vessels thereby reducing fuel costs. Further, the good market value of large hake both locally and overseas made hake a more attractive proposition;

3. The inclusion of six new permit holders in 1985 was unnecessary and complicated the experiment. These vessels targetted almost completely on hake and did not fish in the "true spirit" of the experiment;

4. Since the initial intention of the longline fishery was to catch hake, it was inevitable that once the kingklip resource declined, effort would be switched back to hake.

The ability of the longliners to target directly on large spawning hake is a serious cause for concern as the consequences of this exploitation are unknown and are likely to be significant. Little is known about hake spawning behaviour, and longlining has provided an opportunity, in much the same way as for kingklip, to hypothesize and make assumptions which can be tested in future research and will, for the time being, provide the resource with some measure of protection.

Presently, the demersal trawl hake fishery is the most valuable fishery in South African waters, and concern for its stability as a result of exploitation of the spawning stock by longliners appears well founded. The following hypotheses with respect to the hake resource can therefore be made:

1. Hake spawn on the rocky grounds on the West Coast presently exploited by the longline fleet. The exact period during which spawning takes place is not known, but it is probably protracted, extending from late summer to winter;

2. Spawning hake have in the past benefitted from some measure of protection on the rocky deeper continental shelf margins. It must be assumed for the time being that these areas were responsible for most of the hake recruitment and that this has sustained the presently stable and well established demersal trawl fishery. In this respect, longline grounds southwest of Cape Point and due West of Saldanha Bay are of particular concern.

Criticism of the Longline Experiment

As shown in this study, the longline experiment certainly provided information that could be used for kingklip stock assessment. The fishery however, developed so rapidly, that it became misdirected and difficult to control. This should be seen as a fault of all concerned and should not be blamed on the legislators only. The companies involved in the fishery need to accept a degree of responsibility towards the resource they exploit. Further, they are in a better position to detect changes in the fishery (i.e. with respect to catches, changes in gear and species targetted for) than are researchers, who invariably work with data that is processed several months after any change may have taken place. The major criticisms are:

1. The terms of the experiment were too loosely defined. Longline fishermen were for example, requested to direct catches at kingklip, and to avoid exploiting certain grounds intensively. Little attention was paid to these requests and the term "spirit of the experiment" was meaningless. An "experiment" of this

nature should have appropriate legislation attached to it, such that immediate measures can be taken to respond to, for example, changing trends or sharply declining catch rates.

2. The inclusion of six new permit holders in 1985 was a mistake for the reasons already described.

3. Full-time research into the fishery, and to monitor the experiment, should have started at the beginning of the experiment. With a fishery of this nature continuous and active participation by research staff aboard the vessels and with the management involved in the fishery is essential from the beginning.

4. Monitoring of landed catches should have been more rigorously controlled.

Management Recommendations

Management of a fish resource is often a complex undertaking involving the pursuit of varied and sometimes conflicting biological, social, economic and political objectives (Andrew 1986). Further, commercial fisheries are prone to a high degree of economic risk (Bross 1987).

Only on one previous occasion have management proposals been suggested for kingklip. Isarev (1980) used the Beverton and Holt Yield-Per-Recruit model to determine the optimum age of exploitation and the best exploitation regime for kingklip in ICSEAF divisions 1.3, 1.4, 1.5 and 1.6. His recommendations were intended for the demersal trawl fishery. The management recommendations proposed here are directed at the longline fishery and the protection of the kingklip spawner stock, thus ensuring continued recruitment to both the demersal trawl and longline fisheries. The objectives of the management strategy proposed here are intended to be as simple as possible so that they are clear and enforceable (*cf.* Andrew 1986). The opportunity is taken to express in the strongest possible terms, that the kingklip on the South-East Coast (the spawner stock), are not likely to be able to sustain the present rate of exploitation by the longline fleet. If the fishery remains kingklip-directed and the conditions suggested below are not met, the kingklip fishery is unlikely to remain economically viable.

Recommendations With Respect to the Fishery in General

1. The longline experiment should be concluded and the fishery accepted as a permanent one.

2. No further effort should be allowed into the fishery. No new permits should be issued and preferably there should be some reduction in overall effort. The switching of permits to bigger vessels should not be allowed as this will effectively increase overall effort in the fishery.

3. The fishery should be managed as two units. That is the West Coast (West of 20°E) and the South Coast (East of 20°E).

4. The fishery should remain kingklip directed.

Recommendations With Respect To Kingklip

1. The South Coast should be recognized as a kingklip-directed fishery and a 10% by-catch of hake should be allowed (as demonstrated in Chapter 9, when targetting only on kingklip, on average, a 10% by-catch of hake is taken). Only Demersal Bottom Line Gear (as defined in Chapter 4) should be permitted.

2. The West Coast should also be recognized as a kingklip-directed fishery, but with a higher hake by-catch. The total hake by-catch should not exceed 30% of the total landed catch (refer to Chapter 9 - longliners take a larger proportion of hake on that coast when targetting on kingklip and it is unlikely that a hake by-catch of less than 30% is possible).

3. A TAC for kingklip should be introduced. The total nominal catch for 1989 should not exceed 5 000t. The nominal catch on the South Coast should not exceed 3 000t i.e. a figure lower than the mean average landed catch (whole mass) on that coast since 1985 (4 241t). The nominal catch on the West Coast should approximate the mean annual landed catch on that coast since 1984 (1 832t) and should not exceed 2 000t (refer to Chapter 11).

4. A closed season for kingklip should be introduced on the South-East Coast. No longlining for kingklip should be allowed from 1st August to 30th September in an area between longitudes 23° 15′ and 23° 00′E and between latitudes 34° 15′ and 35° 15′S (refer to Chapters 8 and 9 on the distribution of catches and prespawning aggregations).

Recommendations With Respect To Hake

1. Direct targetting using longline gear on hake should not be allowed. The hake by-catch, as recommended above, should not exceed 10% on the South Coast and 30% on the West Coast and should be monitored when the catches are landed.

2. The TAC for hake should not be exceeded and the hake caught should be deducted from the quota of the permit holder.

3. Only those vessels that demonstrated throughout the experiment their ability to target on kingklip should be allowed in the fishery. This includes the first seven permit holders, all of whom had hake quotas. However, non-hake quota holders may be allowed, provided they demonstrate their ability to target on kingklip only. The same restrictions should then be applicable as for the other permit holders and the 10% and 30% hake by-catch should be strictly enforced. If non-quota holders are allowed to fish, then provision should be made for their hake and kingklip catches within the TAC for both species.

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