AGE AND GROWTH OF THE QUEEN MACKEREL (*SCOMBEROMORUS PLURILINEATUS*) AND SEVENTY-FOUR (*POLYSTEGANUS UNDULOSUS*) OFF KWAZULU-NATAL, SOUTH AFRICA.

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PREFACE

The work described in this study was carried out at the Oceanographic Research Institute, University of Natal, Durban from January 1995 to December 1996, under the supervision of Drs Lynnath Beckley and Anesh Govender.

These studies represent the original work by the author and have not been submitted in any form to another university. Where use is made of the work of others, it has been duly acknowledged in the text.

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FINALLY, THE ALMIGHTY FOR LIFE ITSELF.

ABSTRACT

This study provides information on the age and growth of two important linefish species, *Scomberomorus plurilineatus* and *Polysteganus undulosus*. Age determination for both species was carried out using otoliths and growth was modelled using age- and length-based methods. For the age-based method various growth models were evaluated to determine which growth function best described the age-length data, whilst Shepherd's Length Composition Analysis was used to estimate growth parameters from length-frequency data. Preliminary stock assessments, based on limited catch data, were also attempted for both species.

Age estimates for the pelagic migrant *S. plurilineatus*, derived from reading whole otoliths, ranged from 0+ to 6+ years. As validation by marginal increment analysis was inconclusive because of the seasonal occurrence of this species in KwaZulu-Natal waters, it was assumed that a single opaque band was laid down in the otolith annually. Reproducibility of age estimates evaluated using the average percentage error (APE) technique was good (9.4%).

Von Bertalanffy growth parameters were poorly estimated from length-frequency data because multiple maxima were encountered on the fitting surface. However, from the age-length data, growth was adequately modelled by the von Bertalanffy growth equation:

$$L_t = 935\,mmFL\left(1 - e^{-0.583yr^{-1}(t+0.991yr)}\right)$$

S. plurilineatus are fully recruited to the fishery at the age of 1+ year and the age-at-50% maturity is 2+ years. Preliminary per-recruit analyses indicated that the spawner biomass of *S. plurilineatus* is at 50% of its unfished level.

Polysteganus undulosus is an endemic, reef-dwelling sparid and large catches were made earlier in the century. Age determination was carried out using sectioned otoliths collected in 1962 and 1963 before the collapse of the fishery. Age estimates ranged from 3+ to 20+ years. Marginal increment analysis indicated that active deposition of opaque bands occurred during winter but, because of the seasonal occurrence of *P. undulosus* in KwaZulu-Natal, validation was inconclusive. Reproducibility of the age estimates was low (APE = 18.2%) because of difficulties with band interpretation as a result of stacking on otolith margins in old fish.

Von Bertalanffy growth parameters could not be adequately estimated from length-frequency data because of the slow growth and longevity of this species. However, from the age-length data, no difference in growth rate between the sexes was observed, and growth for the combined sexes is described by the following logistic equation:

$$L_t=\frac{942mmTL}{1+e^{-0.277yr^{-1}(t-5.178yrs)}}$$

The age at full recruitment was found to be 12+ years and the age-at-50% maturity was 8.8 years. A preliminary stock assessment revealed that the spawner biomass of *P. undulosus* was already at 25% of its unfished level in the early 1960s.

CONTENTS

CHAPTER 1: INTRODUCTION

KwaZulu-Natal boasts a 600 km long coastline that extends from Kosi Bay in the north to the Mtamvuna River near Port Edward in the south. This section of the South African coastline provides a variety of habitats including estuaries, sandy shores, rocky reefs and coral reefs, on which a wide range of biota depend (van der Elst, 1988). The occurrence of many of the organisms that inhabit these areas is influenced by the warm Agulhas current which flows in a south-westerly direction along the edge of the continental shelf (Shannon, 1989; Beckley and van Ballegooyen, 1992).

A diverse marine ichthyofauna occurs off the coast of KwaZulu-Natal, and many of the species found here are Indo-Pacific in origin (van der Elst, 1981). The resources in this region are harvested by various fishery sectors ranging from traditional subsistence fishers to commercial operations. Recreational angling is also popular along the KwaZulu-Natal coastline.

The most valued KwaZulu-Natal marine fish resources are the 'linefish', a term which refers to those teleosts and elasmobranchs that are mostly caught by hook and line. Some 300 linefish species have been recorded in the catch (van der Elst, 1981). The catch of the linefishery can be divided into two major components, namely, pelagic gamefish (mainly Scombridae), and reef fish which includes numerous endemic species belonging to the family Sparidae.

The KwaZulu-Natal offshore linefishery first developed in about 1890 (van der Elst and de Freitas, 1988). The initial steam-driven harbour-based vessels were later replaced by 15 to 20 diesel-powered lineboats, each with a complement of about 20 fishers (van der Elst and de Freitas, 1988). After the second World War, the introduction of small boats powered by outboard motors, locally known as ski-boats, allowed fishers to launch from beaches and rivermouths. This finally freed the linefishery from being harbour-based. In later years, technological advancements such as echosounders and electronic navigation aids were introduced and made it easy for fishers to target those species which aggregated in certain areas (Penny *et al.*, 1989).

Early records of KwaZulu-Natal commercial linefish catches were held by the Natal Fisheries Department (NFD) who were also responsible for the issue of fishing licences. In 1910, the seventy-four, *Polysteganus undulosus* comprised 70% of the KwaZulu-Natal commercial linefish catch, with 1 550 tons being landed (Penny *et al.*, 1989). Although catches of *P. undulosus* fluctuated over the years, the annual percentage contribution between the years 1921 and 1933, when up to 337 tons were caught, ranged between 30 and 50%, showing that this species was the mainstay of the catches of KwaZulu-Natal commercial fishers (NFD 1921 - 1933). There are no data available on the linefishery from the late 1930s to the early 1980s. Recent records of commercial catches in KwaZulu-Natal, which date back to the mid 1980s are kept by the National Marine Linefish System (NMLS) of the Sea Fisheries Research Institute. These data show a disturbing decline in the catches of *P. undulosus* with the annual catch in 1985 of 5.4 tons contributing only 1% of the total catch (Fig. 1.1). By 1988 the species had virtually disappeared from the fishing grounds, and in 1995 annual commercial catches barely reached 2 tons, contributing about 0.2% of the total annual catch.

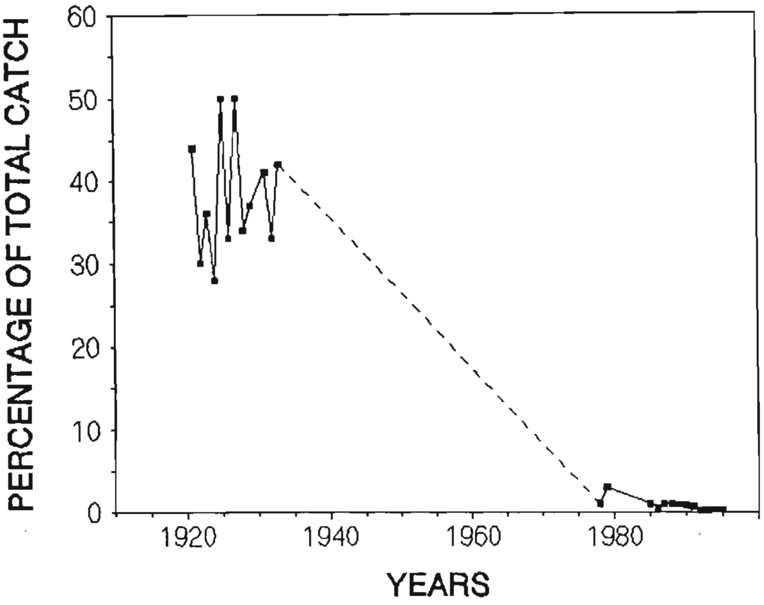


Figure 1.1: Contribution by *Polysteganus undulosus* in the KwaZulu-Natal commercial linefish catches between 1921 and 1995. Data were obtained from historic annual reports of the Natal Fisheries Department and the National Marine Linefish System.

This decline in the catches of *P. undulosus* resulted in commercial fishers shifting effort to previously less desirable fish such as slinger *Chrysoblephus puniceus* and santer *Cheimerius nufar* which soon comprised the bulk of the commercial linefish catches (Fig. 1.2) of KwaZulu-Natal (van der Elst, 1989).

Early signs of the declines in *P.undulosus* catches were taken seriously by commercial fishers, who requested protection for this species, and this initiated a study by Ahrens (1964) on the biology of *P. undulosus*. However, effective protection was not forthcoming, despite her study, and a collapse of the fishery occurred. A closed season was proclaimed in 1985 prohibiting the capture of *P. undulosus* between 1 September and 30 November when these fish aggregate for spawning, a feature which makes them exceptionally vulnerable to capture. In addition, a minimum size limit of 40 cm TL and a bag limit of two *P. undulosus* per person per day were promulgated for all fishery sectors.

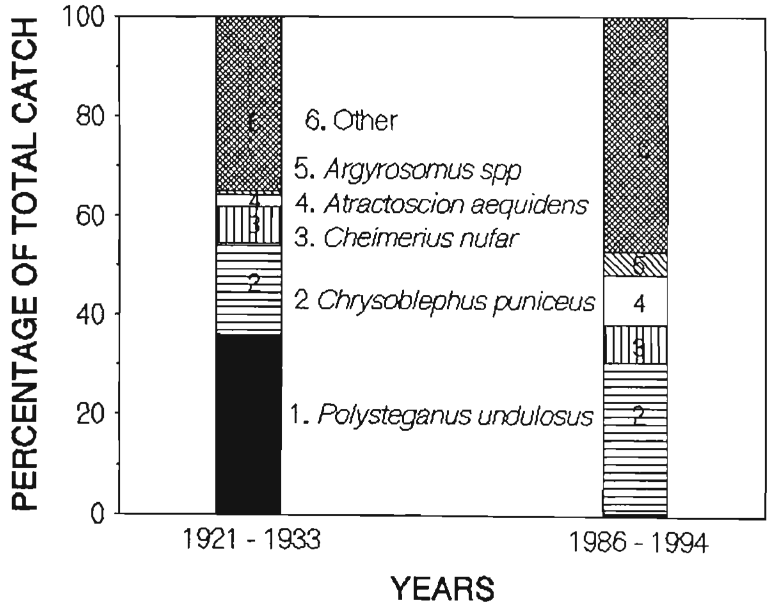
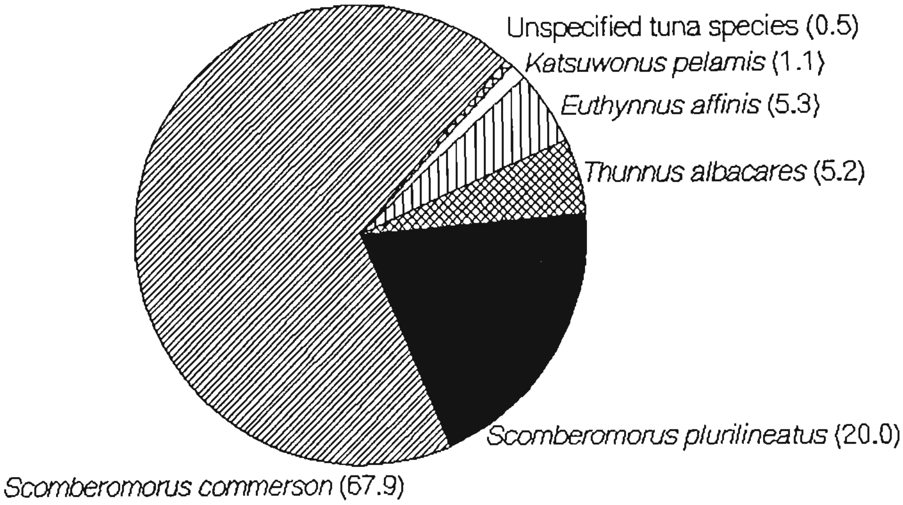


Figure 1.2: **Changes in species composition of commercial linefish catches in KwaZulu-Natal, between the years 1921 and 1994. Data were obtained from historical records of the Natal Fisheries Department and the National Marine Linefish System.**

In KwaZulu-Natal, recreational ski-boat fishing is considerably more important, in terms of the number of boats and anglers, than commercial linefishing (Garratt and van der Elst, 1990). Pelagic gamefish, comprised largely of scombrids are the most important group in the recreational linefishery (van der Elst, 1990). Of the scombrids that frequent KwaZulu-Natal waters, the king mackerel *Scomberomorus commerson*, queen mackerel *S. plurilineatus* and various tuna species are popular target species. Guastella and Nellmapius (1993) indicated that scombrids comprised up to 60% of the annual recreational catch in KwaZulu-Natal and the high proportion of gamefish in the catch is most probably due to the prohibition of fishing for reef fish in the KwaZulu-Natal marine reserves.

Based on data on scombrid catches obtained between 1987 and 1995 from voluntarily completed NMLS catch return cards by the KwaZulu-Natal recreational ski-boaters, *S. commerson* (67.9%) was found to be the most important species by weight, followed by *S. plurilineatus* (20%), eastern little tuna *Euthynnus affinis* (5.3%), yellowfin tuna *Thunnus albacares* (5.2%) and skipjack *Katsuwonus pelamis* (1.1%) (Fig. 1.3).

Although demand for *S. plurilineatus* has grown over the past years, minimum reported catches show a decline since the early 1980s. A sharp drop was noted from about 12 tons in 1984 to just about a ton in 1995 (Fig. 1.4), in the catches obtained at various areas in KwaZulu-Natal excluding marine reserves. A similar trend is also evident in the marine reserves showing that over the past eight years annual catches were generally less than half a ton (Fig. 1.4).



1987 - 1995

Figure 1.3: **Percentage composition (by weight) of the scombrids in the catches of the KwaZulu-Natal recreational ski-boats. Data were obtained from voluntarily completed catch return cards (NMLS) and excludes catches in marine reserves.**

Scomberomorus plurilineatus is also an important target species in the spearfishery (van der Elst, 1981). Van der Elst and Collette (1984) reported that approximately 1 500 spearfishing licence holders in KwaZulu-Natal rated this fish as the fifth most important target species in the early 1980s. In the early 1990s, large catches of *S. plurilineatus* were reported by the spearfishing community, and this fish was found to rank second by number (21%) to *S. commerson* (27%) (Guastella and Nellmapius, 1993). A recent questionnaire study of spearfishers in KwaZulu-Natal has indicated that *S. plurilineatus* currently dominates (11.0%) the catches (by number) followed by garrick *Lichia amia* (10.8%) with *S. commerson* rated third

(9.4%) (Scott, 1995).

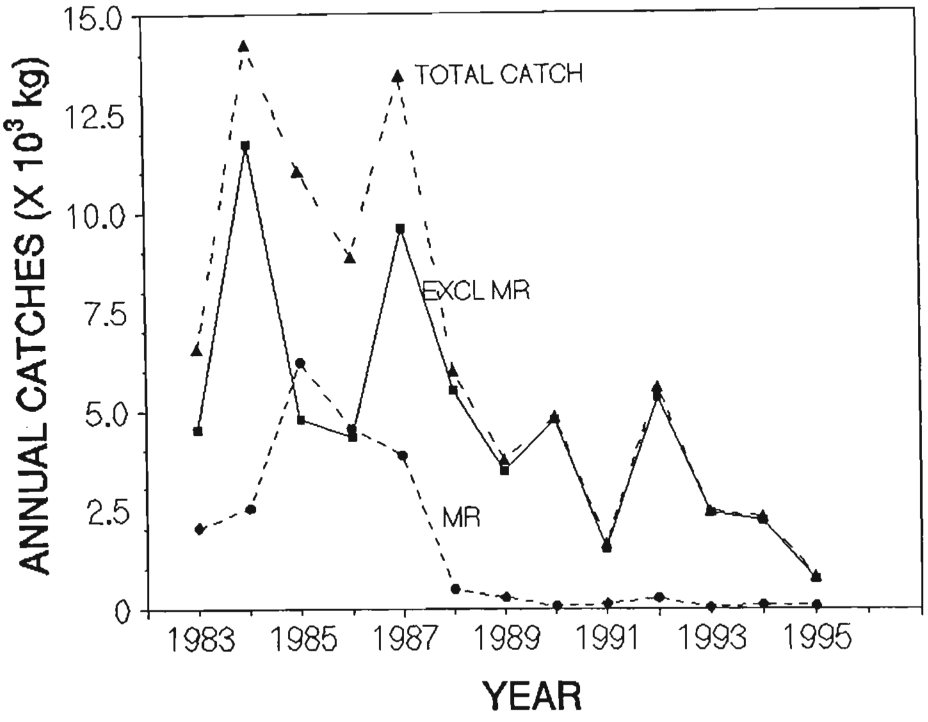


Figure 1.4: Trends in the annual *Scomberomorus plurilineatus* catches by KwaZulu-Natal recreational ski-boats. Data were obtained from records of catch return cards (NMLS). MR designates marine reserves only and EXCL MR designates catches from outside marine reserves.

In spite of their importance to the recreational fishery, studies on scombrids in KwaZulu-Natal are limited and much of the information known about this group has been obtained from other areas outside southern Africa where these fish also occur (van der Elst and Adkin, 1991). *S. commerson* is the only scombrid in KwaZulu-Natal for which both the biology and stock assessment have been studied (Govender, 1994; Govender, 1995).

The biology of various endemic reef dwelling sparids such as *C.puniceus* and *C. nufar* (Garratt, 1985), Englishman *Chrysoblephus anglicus* and Scotsman *Polysteganus praeorbitalis* (Garratt *et al.*, 1994) and *P. undulosus* (Ahrens, 1964) have been studied in KwaZulu-Natal waters. Although, growth studies and stock assessments have been carried out on a number of sparids in Eastern Cape waters, e.g. Roman *Chrysoblephus laticeps* and dageraad *C. cristiceps* (Buxton, 1993) red steenbras *Petrus rupestris* (Smale and Punt, 1991), *C. nufar* (Coetzee and Baird, 1981), blue hottentot *Pachymetopon aeneum* (Buxton and Clarke, 1986), poenskop *Cymatoceps nasutus* (Buxton and Clarke, 1989), bronze bream *P. grande* (Buxton and Clarke, 1992), blacktail *Diplodus sargus capensis* and zebra *D. cervinus hottentotus* (Mann, 1992), *C. puniceus* is at present the only reef fish that has received appreciable attention in terms of population dynamics in KwaZulu-Natal (Garratt *et al.*, 1993; Punt *et al.*, 1993).

Attempts were made previously to model the growth of *P. undulosus* (Birnie *et al.*, 1994) based on length-at-age data from Ahrens (1964). This proved to be inadequate as age estimates were from scales (Ahrens, 1964) which have been shown in several cases to underestimate the age of a fish (Beamish, 1973; Barnes and Power, 1984; Craig and Poulin, 1975; Beamish and McFarlane, 1987).

As there is usually incomplete information on total catch or total effort on linefish species harvested in South Africa, stock assessment analyses are usually based on dynamic pool models (Smale and Punt, 1991; Buxton, 1992; Bennett, 1993; Punt *et al.*, 1993; Govender, 1995). Stock assessment using dynamic pool models such as yield-per-recruit (Beverton and Holt, 1957) however, require information regarding the age structure, estimates of the parameters of an appropriate growth model, natural and fishing mortality rates as well as parameters relating to length and weight of the fish.

This study aims to provide information on the growth of two of the important species in the KwaZulu-Natal linefishery, the queen mackerel *S. plurilineatus* and seventy-four *P. undulosus*. Aspects on the biology of both species, *P. undulosus* (Ahrens, 1964) and *S. plurilineatus* (van der Elst and Collette, 1984), have been previously studied, but nothing pertaining to their age and growth has yet been published.

The objectives of this study are to:

- estimate the ages of *S. plurilineatus* and *P. undulosus* from otoliths,
- validate deposition of the seasonal bands using marginal zone analysis,
- fit suitable growth curves to the age-length data,
- estimate mortality rates and
- assess status of the stocks using per-recruit analyses.

CHAPTER 2: QUEEN MACKEREL, *SCOMBEROMORUS PLURILINEATUS*

2.1 INTRODUCTION

The queen mackerel, *Scomberomorus plurilineatus* is an epipelagic species (Collette and Nauen, 1983) common in coastal waters especially near rocky and coral reefs (van der Elst, 1981). It is confined to the western Indian Ocean from Kenya and Zanzibar to KwaZulu-Natal (Collette and Russo, 1984; van der Elst and Collette, 1984) (Fig. 2.1).

The taxonomic status of this species was previously confused with *S. lineolatus* until Fourmanoir (1966) distinguished it as a separate species. Much of the confusion stemmed from the similarity in appearance, but *S. plurilineatus* has a pattern of short wavy lines and spots while *S. lineolatus* has only short lines on its side (Collette and Russo, 1984). Recently, Srinivasa-Rao and Lakshmi (1993) have claimed that *S. lineolatus* is an interspecific natural hybrid of *S. commerson* and *S. gattatus* and not a valid species. This claim was, however later dismissed by Collette (1994) on the basis that they failed to take into consideration the various taxonomic aspects used to characterize the species.

Scomberomorus plurilineatus is known by different common names in various parts of its distribution range, namely, kanadi (Tanzania), tefo (Madagascar), bowrega (Kenya) and queen mackerel, spotted mackerel or Natal snoek (South Africa).

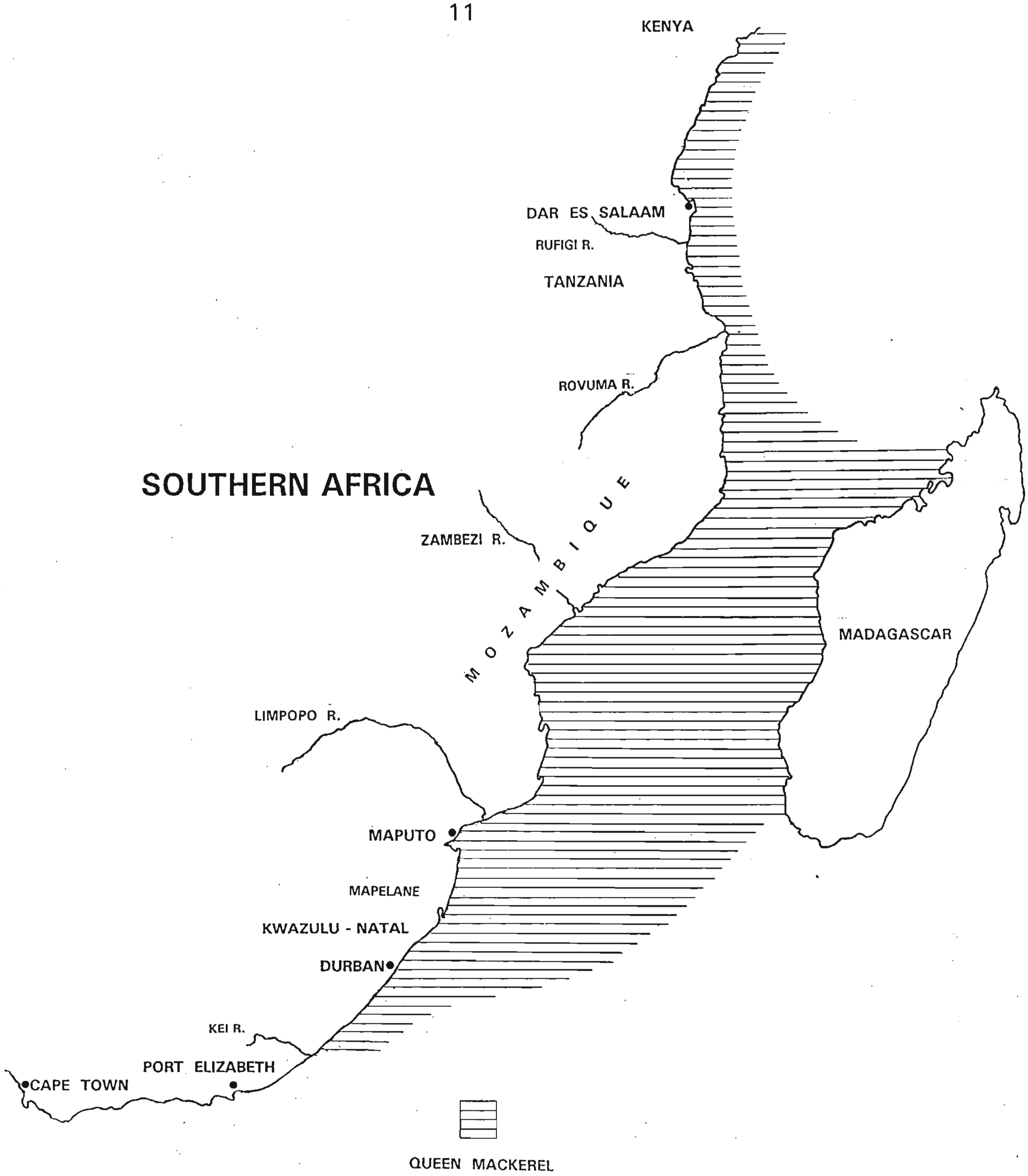


Figure 2.1: Map of Southern Africa showing the distribution of queen mackerel, *Scomberomorus plurilineatus*.

This fish is caught using a variety of fishing gears. In KwaZulu-Natal it is caught by trolling and spear (van der Elst, 1981) while in the Malindi area of Kenya, catches are made mainly by trolling (Williams, 1962). In Tanzania, where it is a staple food fish, it is caught with gill nets or using handlines baited with live sardines (Collette and Nauen, 1983).

Information regarding the biology of this species was first published from Zanzibar by Williams (1962) under the name *S. lineolatus*. Later, van der Elst and Collette (1984) reported on the biology and the systematics of *S. plurilineatus* caught in KwaZulu-Natal waters. They noted that catches off KwaZulu-Natal were seasonal. Based on their observation that fish migrating southwards into this region had either partly spawned or spent gonads, van der Elst and Collette (1984) proposed that *S. plurilineatus* spawns somewhere towards the north (probably in Mozambique) and not in KwaZulu-Natal waters. For this reason, it seems unlikely that the migration of these fish into KwaZulu-Natal is related to spawning. It could, however, be connected to feeding as their time of migration coincides with the appearance of one of their prey species (*Sardinops sagax*) along the KwaZulu-Natal coast (Shannon, *et al.*, 1989).

Scomberomorus plurilineatus is currently classified in the South African linefish management regulations as an exploitable species, and recreational anglers and spearfishers are restricted to a maximum of ten *S. plurilineatus* per person per day if no other fish in the exploitable class are caught (Sea Fishery Act, No. 12 of 1988). There is no catch limitation for either semi-commercial and commercial fishers (Sea Fishery Act, No. 12 of 1988). There is no size limit or closed season imposed on any of the fishery sectors regarding harvesting of this fish.

In view of the fact that *S. plurilineatus* is one of the most intensively pursued species in KwaZulu-Natal waters, and that the current status of the stock is uncertain, information about growth is of paramount importance in evaluating the sustainability of the *S. plurilineatus* stock.

2.2 MATERIALS AND METHODS

2.2.1 Sampling area and general sampling methods

Sampling of biological material for *S. plurilineatus* formed part of the gamefish project undertaken by the Oceanographic Research Institute. Over two decades, biological information was collected on several species such as *Pomatomus saltatrix* (van der Elst, 1976), *S. plurilineatus* (van der Elst and Collette, 1984), *Lichia amia* (van der Elst *et al.*, 1993) and *S. commerson* (Govender, 1994; Govender, 1995). Biological sampling of *S. plurilineatus* occurred on an irregular basis from 1981 to 1996, mainly at fishing competitions in the KwaZulu-Natal region. Due to the lack of manpower during data collection, detailed biological information (length, weight, sex, gonad weight and gonad state) was not always recorded. In many cases only the head region of specimens were collected, from which otoliths were later removed in the laboratory. In these cases, measurement of the maxillary (lower jaw) length provided an estimate of fish length (Appendix A). Table 2.1 summarizes the data as used in this study.

Table 2.1: **Summary of data for *Scomberomorus plurilineatus* as used in this study.**

TYPE	TOTAL	USES	SOURCE
Length frequency	n = 4 998	Length-based growth (S.L.C.A.); Catch curve; Transformed to weight frequencies	van der Elst and Collette (1984)
Weight frequency	n = 388	Weight frequency distribution	National Marine Linefish System
Maxillary lengths with corresponding fork lengths	n = 205	Fork length maxillary length relationship	This study
Weight frequency	n = 508	Weight frequency of aged sample	This study
Otoliths	n = 547	Age estimation; Validation; Growth model	This study

2.2.2 Collection and processing of otoliths

Otoliths (n = 547 pairs) were collected between the years 1981 and 1996 with more than 60% of these collected from the Mapelane area (northern KwaZulu-Natal). Otoliths from fish of various sizes were removed after breaking away the lower section of the skull. Each pair of otoliths was rinsed with water to remove connective tissue, dried with a paper towel and placed in a gelatin capsule. Each capsule was stored in a small envelope on which all the relevant information (maxillary length, area of capture, date of capture and in some cases the fish length) about the specimen was written.

Using a selected subsample of *S.plurilineatus* otoliths (n = 20), four ageing techniques were evaluated to determine which was the best in terms of providing consistent age estimates. These techniques consisted of reading otoliths whole and burnt against a black background using reflected light as well as subjecting whole and burnt otoliths to transmitted light. Age determination was carried out using whole otoliths as they were thin and easy to interpret, thus did not require any method of preparation such as grinding or sectioning.

The technique of reading whole otoliths using reflected light was found to be the best of the four evaluated methods, thus the entire sample was read using this method. This technique when compared to the others, yielded band structures that were easier to interpret.

Age estimates were obtained by counting the number of opaque bands in the otoliths under a dissecting microscope at 12X magnification. Otoliths were immersed in a solution of 70% ethanol to enhance visibility of the rings. The term opaque as used in this study refers to otolith zones that do not transmit light, that is, they reflect light, while the hyaline zones transmit light (Hecht and Smale, 1986).

One otolith was read from each pair. Three sets of readings, approximately three weeks apart, were made for each otolith. Readings were made without reference to the previous reading and with no knowledge of the fish's length or weight.

The average percentage error (APE) (Beamish and Fournier, 1981; Chang, 1982) was used to evaluate the precision of the three sets of age readings. The APE provides an indication of how well age estimates for a particular species are reproducible and is described by the following equation:

$$100\left[\frac{1}{N}\sum_{j=1}^{N}\left[\frac{1}{R}\sum_{i=1}^{R}\frac{|X_{ij}-X_j|}{X_j}\right]\right] \tag{2.1}$$

where

N = the number of fish aged,

R = the number of times each fish was aged,

X_{ij} = ith age determination of the jth fish, and

X_j = the average age calculated for the jth fish.

If three or two readings for each fish coincided then this was taken as the best age estimate.

As factors such as food availability could influence growth of fish, it is of fundamental importance that age and growth studies are validated (Beamish and McFarlane, 1983; Fletcher and Blight, 1996; Newman *et al.*, 1996). Validation that recognisable opaque rings are laid down annually in the otoliths of *S.plurilineatus* was evaluated by using the technique of marginal zone analysis (Hecht and Smale, 1986; Hyndes *et al.*,1992). This was carried out by pooling monthly samples together and examining them for the active deposition of opaque bands on the margins of the otoliths.

2.2.3 Growth model

Growth parameter estimates for *S. plurilineatus* were determined using two techniques, namely, an age-based method which requires estimates of age and a length-based method which provides estimates of growth by following modal age classes through a monthly series of length frequency data.

2.2.3.1 Age-based method

The functional relationship between fish length and age is referred to as a growth model. As most of the fish that were aged had only accompanying maxillary length data, it was therefore necessary to convert the maxillary lengths to estimates of fork length. This was achieved by fitting a linear regression to the observed fork lengths (FL) and their corresponding maxillary lengths (L_{max}) for those fish from which measurements of both these lengths were recorded (n = 205) (Appendix A).

There are various growth models such as the Gompertz, Richards and von Bertalanffy that have been applied to describe fish growth (Bagenal, 1974; Summerfelt and Hall, 1987). Schnute (1981) pointed out that these growth models were usually selected subjectively and he therefore proposed a new growth model that casts commonly applied growth models as submodels. This allows the researcher to objectively choose between submodels (Schnute, 1981)

Estimation of the growth parameters for *S. plurilineatus* was carried out by initially fitting the Schnute (1981) growth model to the age-length data of the combined sexes to determine which submodel with the least number of parameters could adequately describe the growth of this species. The Schnute (1981) model is a four parameter general growth model and the relationship in which the values of the parameters *a* and *b* are not equal to zero is given by the following expression:

$$L_t = [l_1^b + (l_2^b - l_1^b)\frac{1-e^{-a(t-t_1)}}{1-e^{-a(t_2-t_1)}}]^{1/b} \qquad \textbf{(2.2)}$$

where

L_t = length of fish aged t yrs,

l_1 and l_2 = mean lengths of fish aged t_1 and t_2 (which are the observed youngest and oldest fish aged), and

a and b = constants that determine the shape of the growth curve, for example, if $b = 1$ and $a > 0$, then the special von Bertalanffy growth function is defined (Schnute, 1981).

To evaluate which of the various alternative submodels best described the growth of *S. plurilineatus*, a log-likelihood ratio test (Draper and Smith, 1966) was used to compare model fits. Various age-length fits were performed assuming two error structures. The absolute error structure which assumes that variance-at-age is constant with age and the relative error structure which assumes that variance-at-age increases with age. Standard errors of the growth parameters were estimated using the bootstrap technique (Efron, 1981) and 95% confidence intervals were obtained using the percentile method (Punt, 1992). The above analyses were carried out using the computer package, PCYIELD version 2.2 (Punt, 1992).

2.2.3.2 Length-based method

From raw monthly length frequency data collected by van der Elst and Collette (1984) the parameters of the special von Bertalanffy were estimated using Shepherd's (1987) length composition analysis (S.L.C.A.). The length frequencies were for the years 1975 to 1977, and were grouped in 50 mm FL size classes (Appendix B).

S.L.C.A attempts to detect modal peaks in the length frequency data and relies on finding those special von Bertalanffy parameters that lead to a maximum of a goodness-of-fit function. As implemented in S.L.C.A., the special von Bertalanffy is described by the following relationship:

$$L_t=L_\infty(1-e^{-k(t-t_o)}) \qquad \textbf{(2.3)}$$

where

L_t = mean length-at-age,

L_∞ = asymptotic length,

k = growth rate parameter,

t_o = theoretical age at which fish length equals zero and

t = age of the fish.

A test function is calculated from a likely range of L_∞ and k that are seeded in by the researcher and is calculated as:

$$T_L=\frac{\sin(\pi Q)}{\pi Q}\cos 2\pi\,(t_a-t_s) \qquad \textbf{(2.4)}$$

where

Q = (t_{max} - t_{min}) and t_{max} and t_{min} are the ages corresponding to the upper and lower bounds of each length class L,

t_a = (t_{max} - t_{min})/2 and

t_s = the proportion of the year that elapsed between recruitment and the time the sample was taken.

Likely growth parameters were evaluated by calculating a score function for various combinations of k and L_∞. The goodness-of-fit score function (S) is expressed by the equation:

$$S=\sum_{L=1}^{f} T_L\sqrt{N_L} \qquad \textbf{(2.5)}$$

where

N_L = the number of fish in each length class

T_L = test function (Equation 2.4)

f = number of size classes.

The highest value of the goodness-of-fit score function calculated for a given combination of growth parameters indicates that these parameters best fit the data from which they were generated.

As t_o of equation 2.3 cannot be estimated from length frequency data alone

(Shepherd, 1987), the estimates of age using S.L.C.A. are relative rather than absolute ages. Other limitations of this length-based method are that, (i) it assumes that all fish grow according to the von Bertalanffy growth function; (ii) there is occurence of multiple maxima at the fitting surface and (iii) it has a tendency of overestimating the growth coefficient (*k*) (Pauly and Arreguin-Sanchez, 1995). The computer package L.F.D.A. (Holden and Bravington, 1992) was used to implement the S.L.C.A. analyses.

2.2.4 Weight frequency distribution

Length frequency data from van der Elst and Collette (1984) (n = 4 998) (Appendix B) were compared with recent data from the National Marine Linefish System (NMLS)(n = 388), which were the reported recreational ski-boat catch data obtained for the years 1985 to 1995 (excluding 1987 and 1988, as only total annual weights and not actual weight per fish were recorded for these years). As data in Appendix B were only available as measurements of length, these had to be converted to weight using equation $W = 1.26 \times 10^{-5} L^{2.94}$ given by van der Elst and Collette (1984). Length measurements from the present study (n = 508) were also converted to weights using the same equation.

Weight frequencies of each of these three sets of data were divided into 1 kg classes in accordance with the data resolution from the NMLS. The frequency of occurrence of fish in each class was expressed as a percentage. These weight frequency distributions were plotted independently (i.e. not combined) on the same system of axes.

2.2.5 Mortality estimates

The instantaneous total mortality rate (*Z*) for *S. plurilineatus* was estimated using two different techniques, namely, catch curve analysis and a length-based method.

2.2.5.1 Catch curve analysis

A catch curve was constructed by using the length frequency data collected between the years 1975 and 1977 (n = 4 998) (van der Elst and Collette, 1984) and the age-length key determined from otolith reading. This was carried out by transforming fish lengths to age estimates using a normalized age-length key (Butterworth *et al.*, 1989; Buxton, 1987). The slope of the descending limb of the catch curve gave an estimate of *Z*.

2.2.5.2 Length-based method

Estimates of *Z* were also determined using the method of Beverton and Holt (1957) which is described by the following equation:

$$Z=k*\frac{(L_\infty-L_{av})}{(L_{av}-L')} \qquad \textbf{(2.6)}$$

where

L_∞ and k are parameters as described in equation 2.3,

L' = mean length-at-full recruitment, and

L_{av} = mean length of fully recruited fish.

Best estimates of L_∞ and k that were obtained from both the age- and length-based Sheperd's (1987) Length Composition Analysis (S.L.C.A) methods were substituted in the above equation 2.6. L' was the corresponding mean size (in mm FL) of the age-at-full-recruitment, while L_{av} was the mean length of fish of length L' and longer. The best length-based growth parameters were those that yielded the highest score function (Equation 2.5), while of the age-based method were those obtained from the model that provided the best fit. Standard errors of the Z estimates were calculated.

The instantaneous natural mortality (M) was estimated from the empirical equation given by Pauly (1980):

$$LogM=-0.0066-0.279\log L_\infty+0.6543\log k+0.463\log T \qquad \textbf{(2.7)}$$

where

T = mean temperature of the environment of *S. plurilineatus*. Other parameters are described in equation 2.3.

The input parameters used for the calculation of *M* were the best von Bertalanffy growth parameters obtained from both the length- and age-based methods for three different temperatures (23.5, 25 and 26.5°C) that fall within the range of the coastal environment inhabited by *S. plurilineatus* (van der Elst and Collette, 1984). The *M* values for the three temperatures (for either the length- or age-based methods) provided a mean estimate for *M*. The difference between *Z* and *M* gave an estimate of the instantaneous fishing mortality rate *F*. The method by Rikhter and Efanov (1977) of estimation of *M* was also attempted, but was rejected as it yielded an extremely high value of *M*.

2.2.6 Preliminary Yield-per-recruit (YPR) and Spawner-biomass-per-recruit (SBR)

Per-recruit models such as yield-per-recruit (Beverton and Holt, 1957) describe the rate of change (by weight) in a year class (cohort) following recruitment. These models are based on the assumption that under equilibrium conditions (i.e growth, recruitment and mortality rates are constant) the annual yield from a single year class equals total yield from a year class of fish that has been fished throughout its entire life-span (Beverton and Holt, 1957; Gulland, 1983).

Assessment of fish stocks using per-recruit models becomes meaningful when using specific fishing levels as biological reference points (Sissenwine and Shepherd, 1987; Butterworth *et al.*, 1989). The commonly used reference points are F_{MSY} which is fishing mortality at maximum sustainable yield (Gulland, 1983), $F_{0.1}$ which is fishing mortality at which marginal yield per recruit drops 10% of its value for the unexploited stock (Butterworth *et al.*, 1989) and $F_{50\%}$ which refers to the level of fishing that reduces the spawner biomass by 50% of its unfished state (Butterworth *et al.*, 1989).

The YPR model is described by the following integral equation:

$$YPR=\int_0^{\infty} S(t)\,.F.N'(t)\,.w(t)\,.dt \qquad \textbf{(2.8)}$$

where

$S(t)$ = selectivity of the fishing gear used,

F = instantaneous fishing mortality on fully recruited cohorts,

$N'(t)$ = $N(t)/R$, where $N(t)$ = number of t year old fish in the population and

R = number of recruits (which is set to one), and

$w(t)$ = mean mass of a fish of age t.

and the SBR by the following equation:

$$SBR=\int_0^{\infty} ß(t)\,.N'(t)\,.w(t)\,.d(t) \qquad \textbf{(2.9)}$$

where $ß(t)$ is the fraction of fish of age t which are mature.

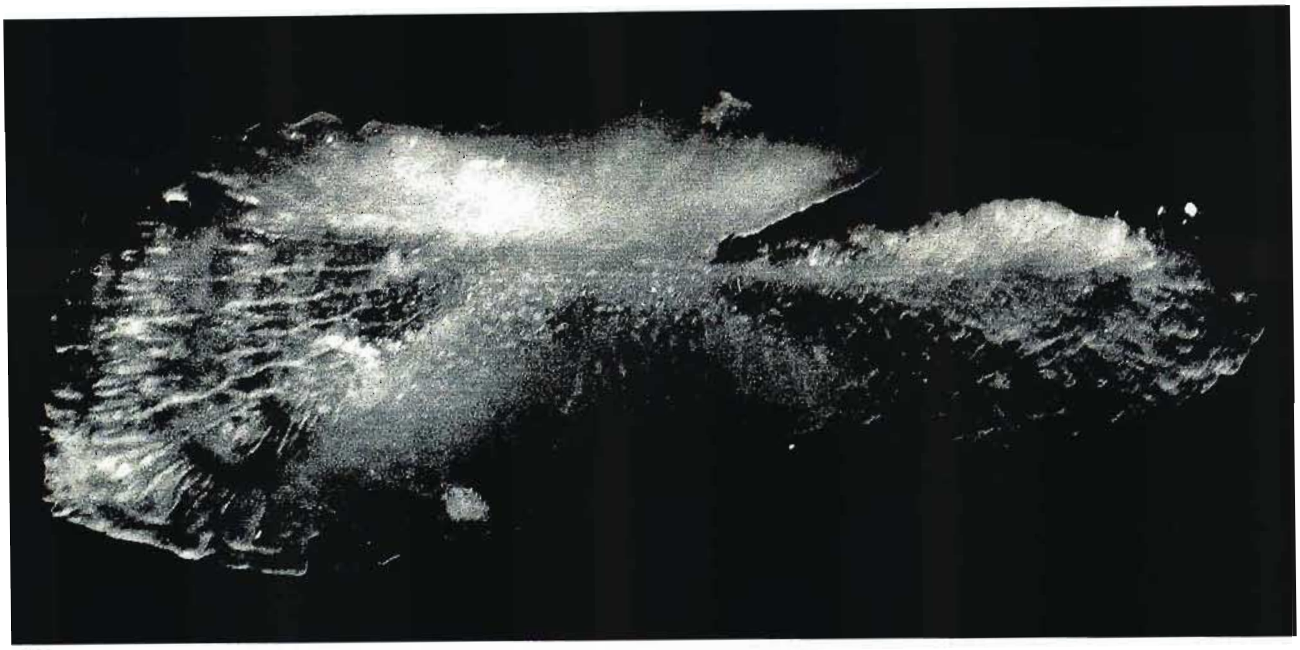
These two models require the age-at-first-capture (t_c) and also the age-at-50%-maturity (t_m). The t_c was obtained from the catch curve, while t_m was obtained by converting to age, the length-at-50%-maturity obtained from van der Elst and Collette (1984). The models were constructed assuming that both maturity and selectivity are knife-edged. Sensitivity of the models towards variation in instantaneous natural mortality (*M*) was also tested. $F_{0.1}$, $F_{50\%}$ and F_{MSY} were calculated at different levels of *M*. The yield-recruit (YPR) and the spawner-biomass-per-recruit (SBR) models were generated for *S.plurilineatus* using PCYIELD version 2.2 (Punt, 1992).

2.3 RESULTS

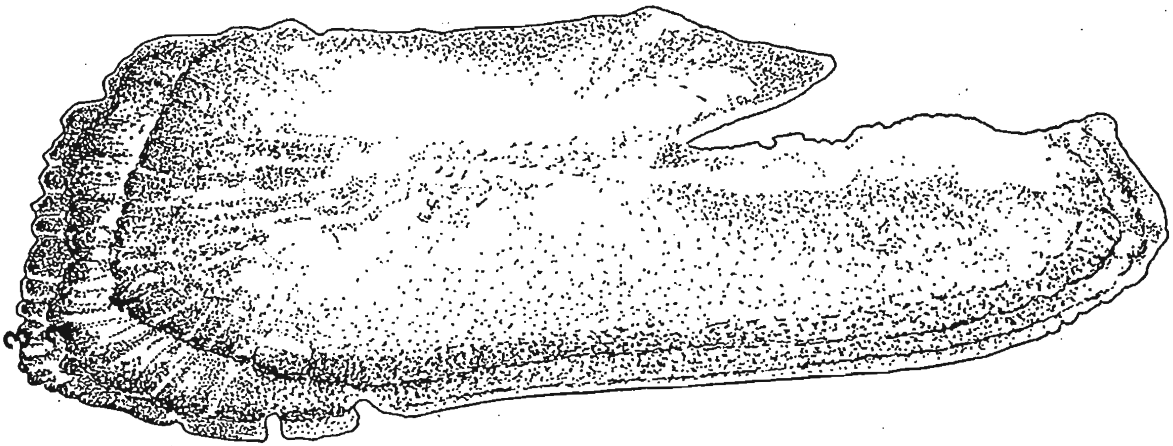
2.3.1 Age estimates

Of the 547 pairs of otoliths that were examined, 496 yielded useful age estimates (70% had three readings that coincided and 21% had two readings that coincided) and 51 (9%) were discarded as they were either broken or difficult to read. Figures 2.2a and 2.2b show a photograph and a drawing of a whole otolith of *S. plurilineatus*.

Age estimates ranged from 0 to 6 years, with more than 50% of the sample having an age estimate of one year. Table 2.2 gives the summary of the age-length key shown in Appendix C.



2a



2b

Figures 2a and 2b: A photograph (2a) and a drawing (2b) of a whole otolith of *Scomberomorus plurilineatus*, showing three rings.

Table 2.2: The observed minimum and maximum lengths-at-age, mean lengths-at-age and their standard deviations for *Scomberomorus plurilineatus*. Standard deviations are in parenthesis.

AGE	Min FL	Max FL	MEAN FL	n
0	246	585	401 (71)	69
1	435	870	621 (57)	311
2	613	905	763 (73)	53
3	715	947	848 (52)	17
4	839	961	895 (34)	19
5	860	967	910 (35)	18
6	900	992	942 (28)	9

An average percentage error (APE) for the three sets of readings was found to be 9.4% for *S. plurilineatus*. Validation of the occurrence of seasonal bands in the otoliths of *S. plurilineatus* using marginal zone analysis is shown in Fig. 2.3. As a result of seasonality of this species in KwaZulu-Natal waters, monthly samples were limited and except for the months of February to July, there were less than 10 specimens for all other months. Although samples were few in some months, it is apparent that active opaque deposition does not occur during winter (March to August), but probably occurs in summer possibly during the months of December and January. However, this could not be shown conclusively. It was therefore assumed that this fish only lays down one opaque band per year and all other analyses are based on this assumption.

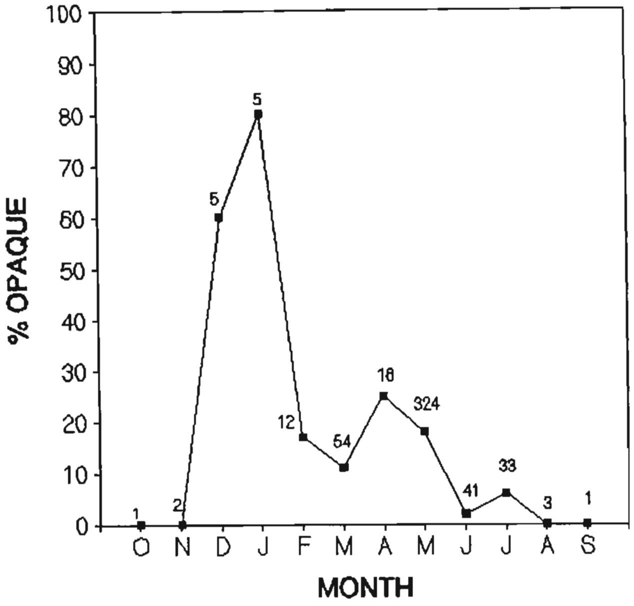


Figure 2.3: **The percentage of otoliths with opaque margins in *Scomberomorus plurilineatus* from KwaZulu-Natal. Numbers indicate sample size of otoliths in each month.**

2.3.2 Growth model: Aged-based method

Fitting of the observed age-length data to the Schnute (1981) growth model indicated that the generalised von Bertalanffy and the special von Bertalanffy submodels were appropriate to describe the growth of *S. plurilineatus*. This was based on the initial observation of the Schnute (1981) a and b values of 0.50 and 1.39, respectively, which were close to the a and b values defined for the general von Bertalanffy ($a > 0$ and $b > 0$) and the special von Bertalanffy ($a > 0$ and $b = 1$). The general von Bertalanffy is a four parameter model while the special von Bertalanffy is a three parameter model and the log-likelihood ratio test indicated that there was little difference between these two submodels. It was decided to use the special von Bertalanffy growth function because it has a lower number of parameters when compared to the generalised von Bertalanffy or the Schnute growth model. For the special von Bertalanffy model, it was found that the absolute error model resulted in residuals that were normally distributed when compared to the relative error model.

In Table 2.3 the parameter and variance estimates for both the special and general von Bertalanffy functions are given for *S. plurilineatus*. The age-length relationship for *S. plurilineatus* based on the special von Bertalanffy growth function is shown in Figure 2.4.

Table 2.3: ***Scomberomorus plurilineatus*** **growth parameters for the general and special von Bertalanffy growth curves as defined for the Schnute (1981) growth function for the absolute error structure, their standard errors and 95% confidence intervals.**

PARAMETER	VALUE	S.E	LHS 95% CI	RHS 95% CI
SPECIAL VON BERTALANFFY				
a	0.583	0.029	0.527	0.640
b	FIXED (1)	-	-	-
l_1 (mm)	410.252	7.324	396.246	424.719
l_2 (mm)	919.419	8.713	902.822	936.263
t_o (yrs)	-0.991	0.055	-1.117	-0.888
L_∞ (mm)	935.333	11.265	914.336	959.020
k (yr^{-1})	0.583	0.029	0.526	0.640
GENERAL VON BERTALANFFY				
a	0.504	0.076	0.299	0.726
b	1.371	0.348	0.221	2.264
l_1 (mm)	407.318	6.26	394.909	419.714
l_2 (mm)	930.328	9.949	912.003	953.525
t_o (yrs)	-0.755	0.837	-2.504	-0.408
L_∞ (mm)	955.055	20.913	925.902	1017.489
k (yr^{-1})	0.504	0.076	0.299	0.726

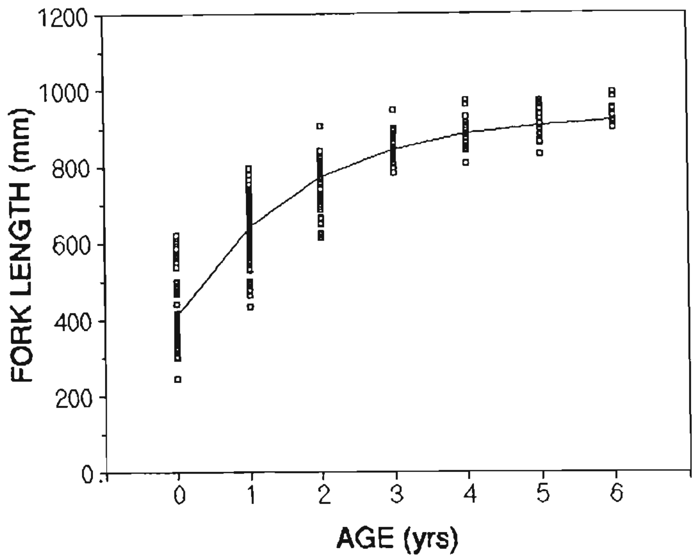


Figure 2.4: The special von Bertalanffy growth function fitted to the observed length-at-age for ***Scomberomorus plurilineatus*** caught in KwaZulu-Natal waters.

2.3.3 Growth model: Length-based method

Table 2.4 gives various combinations of L_∞ and k and their respective scores. The highest score was obtained for the combination L_∞ = 1 244.44 mm FL and k = 0.31 yr^{-1}. As indicated by the shaded areas in the Table 2.4, S.L.C.A. also yielded various combinations of L_∞ and k that are amongst the likely growth parameters (multiple maxima at fitting surface). For example, 1 216.67 mm FL, 0.32 yr^{-1} and 1 272.22 mm FL, 0.29 yr^{-1} are also likely values. By restricting calculation of growth parameters to 0.28 - 0.32 yr^{-1} and 1 220 - 1 280 mm FL, the best parameter estimates generated were L_∞ = 1 265 mm FL, k = 0.29 yr^{-1} and t_o = -0.137 yr at a maximum score of 26.26.

Table 2.4: Normalised score function showing various combinations of L_∞ and k. Elements were divided by the maximal element of 26.54092.

L_∞ (mm)	VALUE OF k (yr^{-1})							
	0.25	0.27	0.29	0.31	0.32	0.34	0.36	0.38
1050.00	0.469	0.486	0.425	0.449	0.713	0.895	0.809	0.601
1077.78	0.499	0.326	0.527	0.816	0.807	0.644	0.562	0.654
1105.56	0.255	0.572	0.798	0.718	0.581	0.612	0.704	0.776
1133.33	0.551	0.754	0.660	0.593	0.618	0.692	0.812	0.909
1161.11	0.698	0.650	0.599	0.583	0.698	0.873	0.961	0.917
1188.89	0.656	0.596	0.544	0.706	0.912	0.984	0.905	0.723
1216.67	0.607	0.507	0.688	0.923	0.995	0.903	0.712	0.486
1244.44	0.482	0.635	0.906	1.000	0.915	0.727	0.506	0.295
1272.22	0.545	0.856	0.998	0.939	0.762	0.546	0.338	0.160
1300.00	0.761	0.976	0.968	0.812	0.603	0.396	0.209	0.091

2.3.4 Weight frequency distribution

Figure 2.5 gives the weight frequency distributions of data collected between 1975 and 1977 (A), recent NMLS data of 1985 to 1995 (B) and of the weights of the sample used for age determination (C). Although data used for ageing was selectively collected during sampling, the size distribution of sample used for age determination strongly resembles the distribution of data collected from 1975 to 1977 (A) which is also similar to the distribution of the data collected between 1985 and 1995 (B).

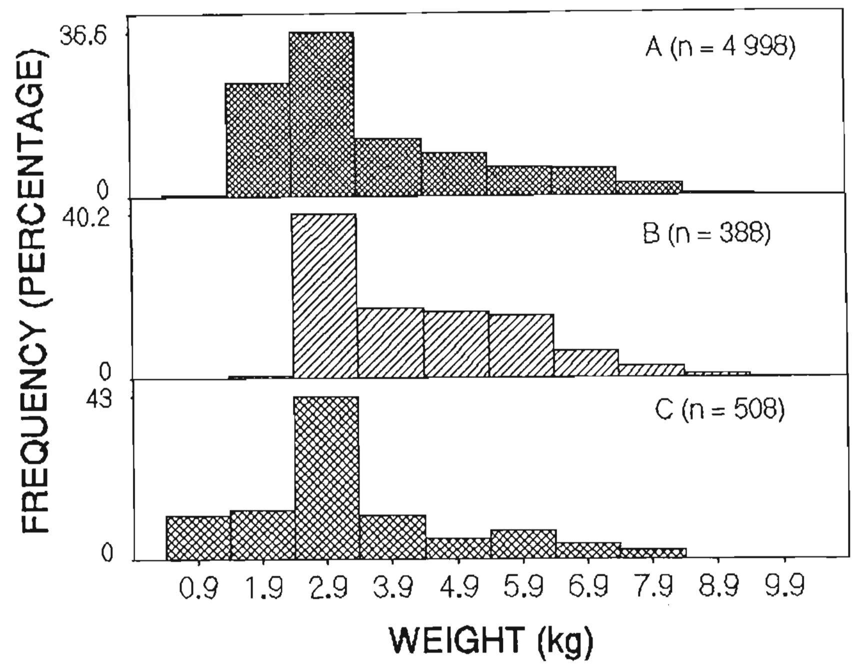


Figure 2.5: **The weight frequency disributions of *Scomberomorus plurilineatus*. Annotations in the figure designate data from van der Elst and Collette (1984) (A), reported ski-boat catches (B) and ageing sample (C).**

2.3.5 Mortality estimates

The age at which *S. plurilineatus* is fully recruited to the fishery (t_c) was found to be 1 year. Figure 2.6 gives the catch curve of *S. plurilineatus*, with a linear regression fitted to the descending limb of the curve. Mortality estimates and the standard errors of the instantaneous total mortality rates (Z) obtained by both the length- and age-based methods are given in Table 2.6. The instantaneous total mortality rate (Z) values estimated using the Beverton and Holt (1957) equation were found to be considerably higher than the Z value (0.73 yr^{-1}) estimated from the catch curve (Table 2.5), although the standard errors of these (B & H) estimates were low. The Z estimates of B & H method were therefore not used as they yielded high values of *F*. Mortality estimates used for assessment of the *S. plurilineatus* stock were $F = 0.28$ yr^{-1} and $M = 0.45$ yr^{-1}.

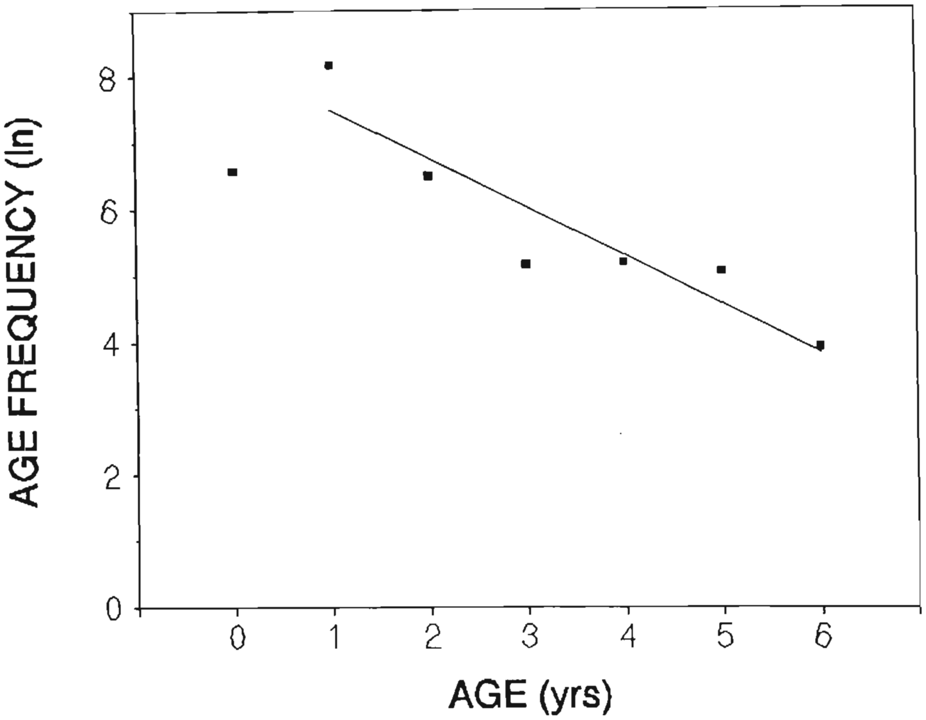


Figure 2.6: The catch curve of ***Scomberomorus plurilineatus*** with the linear regression fitted to the descending limb.

Table 2.5: Mortality estimates of the ***Scomberomorus plurilineatus*** caught in KwaZulu-Natal waters. B & H refers to Beverton and Holt (1957) equation C.C. designates catch curve.

METHOD	*Z* (yr^{-1})	SE of *Z*	*F* (yr^{-1})	*M* (yr^{-1})
Length-based	1.80 (B & H)	0.021	1.53	0.27
Age-based	1.50 (B & H)	0.021	1.05	0.45
Age-based	0.73 (C.C.)	0.149	0.28	0.45

2.3.6 Preliminary Yield-per-recruit (YPR) and the Spawner biomass-per-recruit (SBR)

The input parameters used for generating the YPR and the SBR models are given in Table 2.6. The per-recruit models used require as input parameters the age-at-50% maturity (t_m). The t_m of 2 years was estimated as the corresponding age of the length-at-50% maturity given by van der Elst and Collette (1984).

Table 2.6: Input parameters used for generating the yield-per-recruit and spawner biomass-per-recruit models of *Scomberomorus plurilineatus* caught in KwaZulu-Natal waters. Parameters *a* and *b* are from the weight-length relationship of van der Elst and Collette (1984).

PARAMETERS	ESTIMATES
F_{curr}	0.28 yr^{-1}
M	0.45 yr^{-1}
t_c	1 yr
t_m	2 yrs
a	0.0000126
b	2.94

Figures 2.7 and 2.8 give the curves of yield-per-recruit and spawner biomass-per-recruit for *S. plurilineatus* (at two different levels of *M*). The values of *M* used were 0.45 yr^{-1}, which is assumed to be the reasonable estimate for *S. plurilineatus* and the 0.27 yr^{-1} (calculated using length-based parameters) was used as an alternative to evaluate sensitivity of per-recruit models towards variation in *M*. Yield-per-recruit curves at both *M* estimates revealed no obvious points of maximum sustainable yield (F_{MSY}). It was observed that considerably higher yields are obtainable at low levels of *M* (0.27 yr^{-1}) than at high *M* estimates (0.45 yr^{-1}). The

SBR curve (Fig. 2.8) revealed that at a low *M* (0.27 yr^{-1}), the spawner biomass was sustainable even at levels of fishing mortality that are greater than $F_{50\%}$ (0.26 yr^{-1})., whereas for *M* = 0.45 yr^{-1}, levels of *F* greater than $F_{50\%}$ (0.29 yr^{-1}) decrease the spawner biomass considerably. Estimated biological reference points are summarized in Table 2.7.

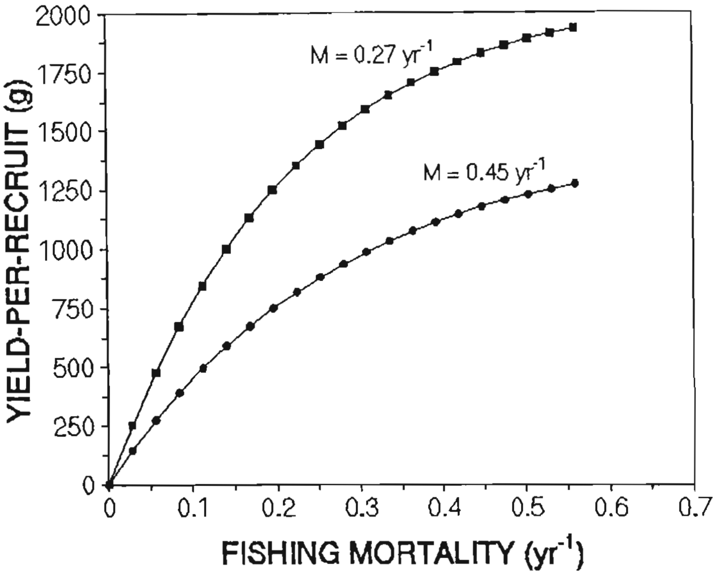


Figure 2.7: The yield-per-recruit for *Scomberomorus plurilineatus* at two levels of natural mortality (*M*).

Table 2.7: Estimates of biological reference points for *Scomberomorus plurilineatus* at different levels of natural mortality rate. *M* values used are those of Table 2.5. Units = yr^{-1}

M	F_{MSY}	$F_{50\%}$	$F_{0.1}$
0.27	1.06	0.26	0.49
0.45	2.23	0.29	0.65

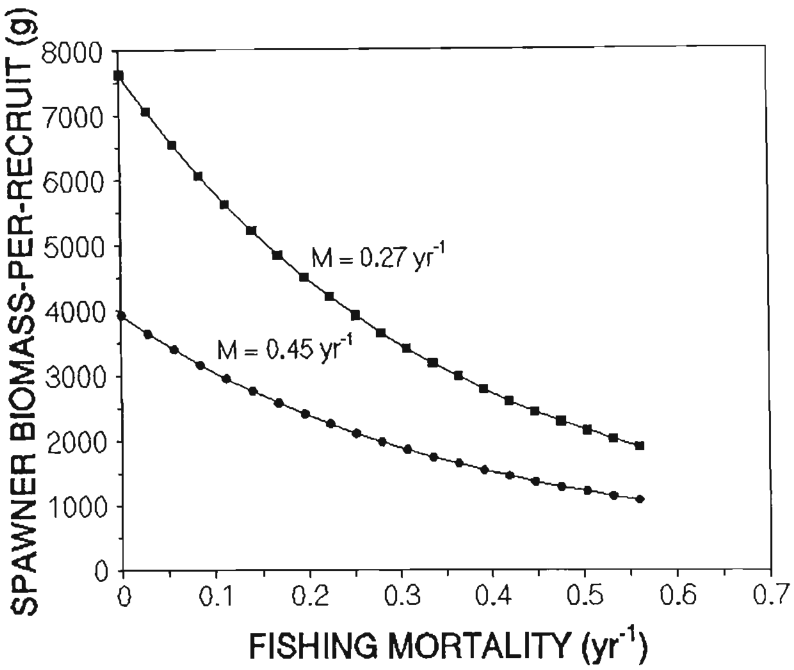


Figure 2.8: **The spawner biomass-per-recruit for *Scomberomorus plurilineatus* at two different levels of natural mortality (*M*).**

At both levels of natural mortality *M*, optimal exploitation ($F_{0.1}$) is attained at levels of fishing that are higher than *M* (Table 2.7). At an estimated *M* of 0.45 yr^{-1}, the measure of fishing mortality at which the stock is considered to be optimally exploited ($F_{0.1}$ =0.65 yr^{-1}) was found to be 57% higher than the F_{curr} (0.28 yr^{-1}) estimate. The estimated current fishing mortality of 0.28 yr^{-1} was found to be similar to the value of $F_{50\%}$ (0.29 yr^{-1}), suggesting that the spawner biomass of *S. plurilineatus* is currently at 50% when compared to the pristine state.

2.4 DISCUSSION

2.4.1 Age estimates

Estimation of age using otoliths of *Scomberomorus* species has been carried out using a variety of techniques ranging from sectioning (Johnson *et al.*, 1983; Fable *et al.*, 1987) to reading otoliths whole (Powell, 1975; Manooch *et al.*, 1987; Sturn and Salter, 1990; McPherson, 1992; Govender, 1994). Another technique used is burning of otoliths prior to reading (Christensen, 1964), but Hecht (1990) criticized this technique on the basis that it has the effect of highlighting not only annual marks but secondary rings as well. In this study it was found that the method of reading *S. plurilineatus* otoliths whole under reflected light using a dark background produced rings that were easy to interpret when compared to the other methods evaluated. No attempt was made to section *S. plurilineatus* otoliths as they were easy to read whole.

Precision of the age estimates was satisfactory, with a low APE value (Beamish and Fournier, 1981) of 9.4%, confirming that the age estimates were reasonably reproducible. This APE value was found to be appreciably low compared to the 20.25% obtained for *S. commerson* in KwaZulu-Natal (Govender, 1994). However, McPherson (1992) also working on *S. commerson* in Australia recorded an APE of 0.9%, indicating better precision than that recorded in this study. Although in the present study, the sample was dominated by otoliths from young fish (less than 3 years) which were much easier to interpret, otoliths from larger fish revealed extensive overlapping and variation of age readings in these otoliths may have influenced the determination of APE for *S. plurilineatus*. Overlapping at the otolith margins was also encountered by Govender (1994) for *S. commerson*.

It was evident from the catch curve that *S. plurilineatus* is fully recruited to the fishery at the age of one year (Fig. 2.5). *S. commerson* in KwaZulu-Natal was found to recruit earlier (age = 0.5 year) (Govender, 1995) than *S. plurilineatus*, although the size-at-full-recruitment (860 mm FL) for *S. commerson* is relatively larger than of *S. plurilineatus* (621 mm FL).

The age-at-50% maturity of two years recorded in this study for *S. plurilineatus* has also been reported for other species namely, *S. lineolatus* from India (Deveraj, 1986) and *S. cavalla* from Trinidad (Sturn and Salter, 1990). Govender (1995) recorded 2.8 years as the age-at-50% maturity for *S. commerson* in KwaZulu-Natal. As about 77% of aged *S. plurilineatus* had an age estimate in the region of 0+ and 1+ years, and assuming that the aged sample was representative of the catch, it can be seen that mature fish contribute only a small proportion to the catch. This tendency to have young fish dominating the catch has also been reported by various other workers on *Scomberomorus* species (Manooch *et al.*, 1987; McPherson, 1992; Govender, 1994; Arreguín-Sánchez *et al.*, 1995).

2.4.2 Validation

Although it has been assumed, based on marginal zone analysis, that this fish only lays down one band per year, this interpretation is inconclusive, due to limited monthly samples. Unavailability of adequate monthly samples has also been encountered by many researchers in validating the age of other seasonal species using marginal zone analysis (Beaumarriage, 1973; Johnson *et al.*, 1983; Sturn and Salter, 1990; Noble *et al.*, 1992; Govender, 1994). Among the *Scomberomorus* species, some have been shown to lay just one band per year as in *S. cavalla* (Beaumarriage, 1973) and *S. maculatus* (Powell, 1975) from Florida, *S. cavalla* from Southern United States (Johnson *et al.*, 1983) and *S. cavalla* from Trinidad (Sturn and Salter, 1990), while others have been reported to lay two bands per year as in *S. commerson* from KwaZulu-Natal (Govender, 1994) and *S. commerson* from Australia (McPherson, 1992). However, McPherson (1992) reported a single band in age groups 1, 2 and 3. Deveraj (1981), in India also worked on *S. commerson* and *S. lineolatus*, and observed that band formation occurs four times a year in the otoliths of these fish. However, in conjunction with modal progression analysis of length frequency data he concluded that only two bands were laid down per year.

It is evident from the seasonality of *S. plurilineatus* that the method of validation by marginal zone analysis is not practical for this species and other *Scomberomorus* species (Beaumarriage, 1973; Johnson *et al.*, 1983; Govender, 1994). Other validation techniques such as those involving measurements of otolith radii (Liew, 1974; Deveraj, 1981; Manooch *et al.*, 1987), tetracycline labelling using animals in captivity (Geffen, 1987; Speare, 1992), laboratory rearing of fish (Jones and Brothers, 1987) or growth analysis of recaptured tagged fish (Govender, 1994) have provided indirect means of validation, but these were beyond the scope of this study.

Although the occurrence of rings in the hardened structures of teleost fish has been shown in a number of studies (Summerfelt and Hall, 1987), the processes that trigger formation of these rings are still poorly understood (Casselman, 1987). However, some of the factors that are associated with reduction in somatic growth such as temperature and limited food have been identified (Casselman, 1987). Other researchers have also shown that deposition of rings in *Scomberomorus* species corresponds with the period of greatest spawning intensity (Beaumarriage, 1973; Sturn and Salter, 1990). Sturn and Salter (1990) proposed that if the process of annulus formation is related to spawning, and that spawning only takes place from the age of two years, it may hold that annulus formation in immature (age one) fish may be a result of the same environmental changes that trigger spawning in mature fish.

2.4.3 Growth model: Age-based method

The special von Bertalanffy was found to be the best fitting model for *S. plurilineatus*, and suggested a fast growth rate for this species. Despite the small sample size of large fish, it was evident from the fit of the special von Bertalanffy model that the rate of growth in older fish is slower when compared to young fish. This observation is consistent with the fact that once fish reach maturity, the available energy is mostly used for reproduction rather than continued growth, thus resulting in decrease in somatic growth (Weatherly, 1972).

The high values of *k* observed in various *Scomberomorus* species (Table 2.8) show that members of this family are generally fast growing and short-lived (McPherson, 1992; Govender, 1994; this study), although *S. cavalla* from Florida has been reported to live up to 13 years (Beumarriage, 1973), while *S. cavalla* from North Carolina may live as long as 20 years (Noble *et al.*, 1992).

Table 2.8: Growth parameter estimates of *Scomberomorus plurilineatus* and those of other related species obtained by other workers. Lengths are fork lengths

SOURCE	SPECIES	L_∞ (mm)	k (yr^{-1})	METHD
This study	*S. plurilineatus*	935	0.58	Age-based
This study	*S. plurilineatus*	1265	0.29	Length-based
Govender, 1994	*S. commerson*	1344	0.29	Age-based
Beaumarriage 1973	*S. cavalla*	♂ = 903 ♀ = 1243	0.35 0.21	Age-based
Powell, 1975	*S. maculatus*	♂ = 555 ♀ = 694	0.48 0.45	Age-based

A wide range of length-at-age as observed in young *S. plurilineatus* (0+ to 2 years) results in overlapping of lengths between age groups. This was also reported by Fable *et al.* (1987) for *S. maculatus* from the Gulf of Mexico, Powell (1975) for *S. maculatus* from Florida and Johnson *et al* (1983) for *S. cavalla* from the southeastern United States. They proposed that this trend was a result of the tendency towards a prolonged spawning season in these fish. A similar observation was also noted by Govender (1994) for the KwaZulu-Natal *S. commerson*. *S.lineolatus* which is a close relative of *S. plurilineatus* was also found to be a protracted spawner with the spawning season extending from January to May or even July (Deveraj, 1986).

2.4.4 Growth model: Length-based method

Although S.L.C.A does not require too many input parameters and is a fast and simple program to use, it holds one major disadvantage, which is the occurrence of multiple maxima at the fitting surface (Holden and Bravington,1992). In this study, several combinations of L_∞ and k were estimated by this method as likely growth parameters for *S. plurilineatus* (Table 2.4). This method has also been criticized by other workers on the basis that it tends to overestimate the value of k and does not incorporate seasonal oscillations (Basson *et al.*, 1988). Recently, Pauly and Arreguín-Sánchez (1995) proposed a new version of S.L.C.A. that may counteract the problem of overestimation of the k value. In this study, however, the value of k was underestimated when compared to the k value obtained for special von Bertalanffy, which has been shown to be the best fitting model.

Another complicating factor observed when applying the S.L.C.A method to *S. plurilineatus* is that age classes in the form of modal progressions were not clearly distinguishable in the length frequency data. An inability to distinguish modal age classes was also encountered by Deveraj (1981) for *S. commerson*, *S. guttatus* and *S. lineolatus* from India when using another length frequency analysis technique. Pollock (1982) stated that growth determination of a fish population by length-frequency analysis is particularly applicable when spawning occurs during a short period of time each year. This method (S.L.C.A) was also found to be inappropriate for *S. commerson* (Govender, 1994).

2.4.5 Weight frequency distributions and mortality estimates

The total mortality rate *Z* estimated using the Beverton and Holt (1957) technique was high, and yielded a high fishing mortality *F* value which predicted a collapsed stock. This scenario of a collapsed fishery is unlikely for *S. plurilineatus* as these fish are still being caught in large numbers along the KwaZulu-Natal coast. The *Z* value estimated from the catch curve was thus regarded as a reasonable estimate for *S. plurilineatus*.

The *M* value of 0.27 yr^{-1} estimated using length-based growth parameters (of the S.L.C.A.) was not regarded as an appropriate estimate as the growth parameters used did not model *S. plurilineatus* satisfactorily. The *M* value of 0.45 yr^{-1} regarded as a reasonable estimate for *S. plurilineatus* is similar to the *M* estimated for *S. commerson* (0.50 yr^{-1}) from KwaZulu-Natal (Govender, 1995) and *S. commerson* (0.48 yr^{-1}) from Djibouti (Bouhlel, 1986). The values of $F = 0.28$ yr^{-1} and $M = 0.45$ yr^{-1} were therefore regarded as reasonable estimates to describe the *S. plurilineatus* stock status for the years 1975 to 1977.

Since the distribution of data (1975 to 1977) from which the catch curve was derived (hence, *Z*) is virtually identical to the distribution for the years 1985 to 1995, it would appear that fishing mortality has not changed considerably since then. Limited fish of less than 1.9 kg in the reported recreational ski-boat catches could be due to the tendency for anglers to release small fish (Fig. 2.5).

The ratio of *F/Z* or exploitation rate *E* is regarded as a measure of the intensity of exploitation (Mansor and Abdullah, 1995). Gulland (1983) suggested that a fish stock is considered to be optimally exploited if the fishing mortality is equal to natural mortality ($F = M$), thus implying that $E = 0.5$. In the case of *S. plurilineatus* E is estimated to be 0.38, which is below the level of optimum exploitation as suggested by Gulland (1983).

2.4.6 Preliminary Yield-per-recruit and Spawner-biomass-per-recruit

The yield-per-recruit model revealed no obvious point of maximum sustainable yield (F_{MSY}) (Fig. 2.7), and the calculated values of F_{MSY} were extremely high. Apart from this difficulty of estimating F_{MSY} (Punt, 1992), the use of *MSY* as a management reference point has been criticized on the basis that it ignores any other influences on the population other than those caused by man e.g. changes in population size as a result of changes in environmental conditions (Gulland and Boerema 1973). Hilborn and Walters (1992) are also opposed to *MSY* arguing that very high levels of fishing are usually required to reach *MSY*, and even when attained *MSY* is not sustainable. This reference point does not take into account the possible reduction of spawner biomass that may be a result of increased fishing pressure (Beddington and Cooke, 1983).

A more practical reference point, $F_{0.1}$ is therefore, usually used as an alternative target fishing mortality level, and biological overexploitation is considered to have occurred if fishing intensity exceeds the $F_{0.1}$ level (Butterworth *et al.*, 1989; Hilborn and Walters, 1992). $F_{0.1}$ is the rate at which the slope of the yield-per-recruit curve falls to 10% of its value at the origin. It has been proposed as an alternative as it produces as much yield as F_{MSY} and at the same time conserving the spawner biomass (Sissenwine and Shepherd, 1987). $F_{0.1}$ is usually much lower than F_{MSY} thus less likely to deplete the spawning stock (Clark, 1991). However, in this study it has been shown that the $F_{0.1}$ strategy will not conserve the spawner stock ($F_{0.1} >> F_{50\%}$).

The calculated $F_{0.1}$ (0.65 yr^{-1}) is more than twice the F_{curr}, suggesting that the stock in terms of yield harvested is not utilized to its full potential. However, if optimal exploitation is attained at a level of fishing that equals M (0.45 yr^{-1}) as suggested by Gulland (1983), then it can be shown further that $F_{0.1}$ is not suitable for *S. plurilineatus*, hence not an appropriate target management reference point for this species.

It should be noted that the estimated F_{curr} (0.28 yr^{-1}) is similar to the $F_{50\%}$ (0.29 yr^{-1}), suggesting that the *S. plurilineatus* spawner stock may currently be at 50% of the unfished level. This is considered sufficient spawner biomass to maintain adequate annual recruitment (Butterworth *et al.*, 1989). Other researchers such as Clark (1991) recommend that maintaining a spawner biomass at 35% of its unfished level would provide high yields at low risk even if no knowledge of the yield curve or spawner-recruit relationship is known.

When per-recruit models were evaluated at different values of M, it was noted that high values of M resulted in low yields and low spawner biomass with the opposite being observed at low values of M. Sensitivity of stock assessment models towards variation in *M* estimates have been previously documented and it has been shown that poorly estimated *M* values often result in wrong perceptions of the stock status (Hildén, 1988). Hence proper estimation of *M* is one of the most vital steps in stock assessment (Gunderson and Dygert, 1988; Farebrother, 1988).

2.5 CONCLUSIONS

As age estimates were not satisfactorily validated in this study, future research should be directed towards validation of growth marks in this species. This will require sampling in other areas, such as Southern Mozambique in order to obtain material throughout the year.

The special von Bertalanffy growth model adequately modelled growth in *S. plurilineatus*. This study has shown that this species grows relatively fast and has a short life span. Growth modelling using length-based methods such as S.L.C.A. are not appropriate for *S. plurilineatus*.

Dominance of young fish in the sampled catch serves as an indication that young fish are actively targeted before they reach maturity, and this may have negative effects on the spawner biomass and may affect long term recruitment. Per-recruit analyses indicated that currently this species is biologically optimally exploited in KwaZulu-Natal with the spawner biomass being at 50% of the unfished level.

CHAPTER 3: SEVENTY-FOUR, *POLYSTEGANUS UNDULOSUS*

3.1 INTRODUCTION

The seventy-four, *Polysteganus undulosus* (Regan, 1908) belongs to the family Sparidae, commonly known as sparids or seabreams. *P. undulosus* has been reported to be found only from the Cape to Maputo (Fig 3.1) (Smith and Heemstra, 1986) and is thus endemic to the south-east coast of Africa (Garratt, 1988). The centre of adult distribution is the offshore banks (deeper than 40 m) of the Transkei coast, while juveniles may be found as far as the southern Cape in water deeper than 20 m (Penny *et al.*, 1989). This species is also known to frequent deep-water reefs and it is often caught at depths of about 200 m (van der Elst, 1981).

Polysteganus undulosus is the only South African sparid that has a pattern of undulating blue lines (hence *undulosus*) and a conspicuous black mark lying across the lateral line (van der Elst, 1981). *P. baissaci* from Mauritius was for many years confused with *P. undulosus*, but lacks the black blotch on the side (Smith and Heemstra, 1986). There are several interesting explanations as to how *P. undulosus* got its common name, seventy-four. One is that this name was derived from lines on the body which resemble rows of gun ports along the sides of the old seventy-four man-of-war ship (Smith and Heemstra, 1986). Another is that the fish was caught by someone fishing from a seventy four gun frigate, and there is also a claim that there are seventy-four scales along its lateral line (Ahrens, 1964).

Figure 3.1: Map of Southern Africa showing the distribution of seventy-four, *Polysteganus undulosus*.

The biology of this species was investigated by Ahrens (1964), who observed that *P. undulosus* was seasonal in KwaZulu-Natal waters, and that these fish are especially abundant during the months of July to November. There is evidence to suggest that *P. undulosus* adults undertake seasonal migrations from the Eastern Cape to KwaZulu-Natal waters to breed (Ahrens, 1964; Garratt, 1988). These fish are also known to form large spawning aggregations (Ahrens, 1964), a behaviour which makes them extremely vulnerable to capture.

The importance of the *P. undulosus* fishery and its subsequent collapse have been described in Chapter 1. While the threat of overexploitation of *P. undulosus* was documented by Ahrens (1964) and strict management measures were somewhat belatedly applied to provide protection to this species (Chapter 1), there has not been any published work on the growth of this species. This study aims at providing information on the age and growth of *P. undulosus* as well as a preliminary assessment on the status of the stock in the early 1960s. As the fishery is heavily depleted, recent data are scarce. Thus historical data were used to generate information which will be useful in implementing stock rebuilding strategies.

3.2 MATERIALS AND METHODS

3.2.1 Sampling area and general sampling methods

Recent data on catches of *P. undulosus* are limited because of the collapsed state of the fishery. However, a useful data set, collected during the study on the biology of this species undertaken by Ahrens (1964), was archived by the Oceanographic Research Institute (ORI). Samples were collected from catches made at different areas extending from Umzumbi in the south to Zinkwazi in the north of the KwaZulu-Natal coastline (Fig. 3.1) during the period June 1962 to May 1963 (Appendix D). From these samples, measurements of standard and total lengths, body and gonad weights were made and otoliths collected. However, in some cases, dates on which samples were collected were not recorded. Table 3.1 summarizes the data as used in this study.

Table 3.1: Summary of archived data for *Polysteganus undulosus* used in this study.

DATA SET	TOTAL SAMPLE	USE IN THE PRESENT STUDY
Weight frequency	n = 1 702	Weight frequency distribution
Length frequency	n = 1 517 Male: n = 733 Female: n = 784	Catch curve; Length frequency distribution
Length frequency data with corresponding dates	n = 832	Length-based growth (S.L.C.A.)
Otoliths	n = 1 339	500 (Selected)
Otoliths used in the present study	Male: n = 219 Female: n = 208	Age estimation; Validation; Age-at-50% maturity

3.2.2 Collection and processing of otoliths

A total of 1 339 otoliths was collected during the 1962 to 1963 study period. A sample of 500 otoliths was carefully selected to represent the size classes of the sampled catch. As *P. undulosus* otoliths were large and robust, and thus difficult to read whole, it was therefore necessary to section them prior to use. From the selected sample, a subsample of 20 otoliths was sectioned. Half of the subsample was sectioned longitudinally while transverse sections were obtained from the remaining portion. Transverse sections yielded better resolution of ring counts than longitudinal sections, thus all subsequent sectioning was carried out transversely.

Sectioning was undertaken in the manner described below, and is a modification of the method of Bedford (1983). Otoliths were mounted in rods of casting resin from which sections of about 0.45 mm thickness were obtained using a mono-bladed diamond saw. Resin moulds were prepared in 10 mm diameter PVC pipes which were cut longitudinally to facilitate easy handling of the moulds. Sections were mounted on labelled plain glass slides using DPX mountant and left to dry for 48 hours. Bands deposited in the otoliths were counted under a dissecting microscope at 12X magnification using transmitted light.

Four readings were made for each section with a minimum period of two weeks between readings. The average of the ring counts was taken as an estimate of age. If the calculated average had a decimal point, the age estimate was rounded up or down to the nearest whole number. If two or more readings differed by more than three units the otolith was discarded.

The average percentage error (Chapter 2, Equation 2.1) was used to evaluate the precision of age estimates. Validation of the periodicity of band deposition was assessed using marginal zone analysis (Hecht and Smale, 1986), and was carried out by pooling together monthly samples and determining the monthly frequency of occurrence of the opaque band.

3.2.3 Age-at-50% maturity (t_m)

Understanding of growth of a species is usually complemented by knowledge of its maturation (Finkelstein, 1969; Punt and Leslie, 1991). An estimate of the age-at-50% maturity (t_m), is particularly important when assessing the status of the stock (Butterworth *et al.*, 1989). This parameter is very useful because, in an exploited, but regulated fishery, the age at which fish are first caught (t_c) is usually set higher than the age-at-50% maturity (i.e $t_c > t_m$) to ensure first spawning prior to capture (Gulland, 1983).

Of the sample used for age determination, 219 were from males while 208 were from females. During the original data collection by Ahrens (1964), fish were classified macroscopically into various stages of maturity (inactive, active, active-ripe, ripe running or spent). In the present study, it was necessary to establish whether fish were mature or immature. Consequently, gonad weight versus fish weight was plotted to check if there were any inactive, but mature fish that would be incorrectly labelled to be immature.

The proportion of mature fish sampled was estimated by calculating percentage frequencies of mature fish per age class. The age-at-50% maturity (t_m) was estimated from these frequencies by fitting a logistic curve (Butterworth *et al.*, 1989; Punt and Leslie, 1991) which is described by the following equation:

$$M_t = \frac{1}{1+e^{\frac{-(t-t_m)}{\delta}}} \qquad \textbf{(3.1)}$$

where

M_t = the model estimate of the proportion of mature fish in age-class t

t_m = the age corresponding to 50% maturity

δ = the parameter which determines the width of the maturation ogive

Equation 3.1 was fitted using a nonlinear optimisation routine, that finds best estimates by minimising the sum of squared residuals. The t_m values were estimated for separate and for combined sexes of *P. undulosus*.

3.2.4 Growth model

Growth parameters for *P. undulosus* were estimated using both the length-based (S.L.C.A.) (Shepherd, 1987; Holden and Bravington, 1992) and an age-based (PCYIELD version 2.2) (Punt, 1992) methods. Both these techniques have been described in detail in Chapter 2.

3.2.4.1 Aged-based method

The Schnute (1981) growth model and its associated submodels such as von Bertalanffy, Richards and logistic, were fitted to the age-length data for both male (n = 219) and female (n = 208) as well as for the combined sexes (n = 427). Length measurements were total lengths (TL). A log-likelihood ratio test (Draper and Smith, 1966; Zar, 1974) was performed to check if there was any difference between the male and female model fits.

Model estimates were performed assuming both the absolute and relative error structures (section 2.2.3.1). Standard errors and 95% confidence limits were obtained for separate and combined sexes of *P. undulosus* using a bootstrap technique (Efron, 1981; Punt, 1992).

3.2.4.2 Length-based method

The length frequency data (n = 832) used for estimation of growth parameters in S.L.C.A. were extracted from Ahrens (1964). These data are shown in Appendix E. As Ahrens (1964) used standard lengths, estimated L_∞ values were converted to total lengths using the equation given in Appendix F.

3.2.5 Size frequency distribution

The length frequency distributions for *P. undulosus* were constructed for separate (male: n = 733; female: n = 784) and combined (n = 1 517) sexes (Table 3.1) using 50 mm TL size classes, and plotted on the same system of axes.

Weight frequency distributions of the total sample (n = 1 702) and of aged fish (n = 427) were also plotted to assess if the selected sample used for age determination represented the entire sampled catch. Weights were grouped into 500 g (0.5 kg) size classes.

3.2.6 Mortality estimates

The instantaneous total mortality rate (*Z*) for *P. undulosus* was estimated from the catch curve which was constructed using the age-length key and length frequency data (Table 3.1). Construction of the catch curve is described in section 2.2.5. The *Z* value was also estimated using the equation of Beverton and Holt (1957) (Equation 2.6) using growth parameter estimates from the length-based method.

The instantaneous natural mortality rate (*M*) was estimated using growth parameters (L_∞ and k) from the length-based method as inputs parameters in the empirical equation (Equation 2.7) given by Pauly (1980). A temperature of 18°C was selected as a mean temperature for the *P. undulosus* marine environment (Beckley and van Ballegooyen, 1992) and used as an input parameter. *M* was also estimated from the Rikhter and Efanov (1977) equation:

$$M=\frac{1.521}{t_m^{0.72}}-0.155 \qquad \textbf{(3.2)}$$

where

t_m = the age-at-50%-maturity.

Instantaneous fishing mortality rate (*F*) was calculated by subtracting *M* from *Z*.

3.2.7 Preliminary Yield-per-recruit (YPR) and Spawner biomass-per-recruit (SBR)

Descriptions of YPR and SBR are given in section 2.2.6. Per-recruit fits were performed for three different ages-at-first-capture. Sensitivity of per-recruit models towards variation in natural mortality was tested using different values of *M*. Biological reference points (F_{MSY}, $F_{0.1}$ and $F_{50\%}$) were estimated for three different ages-at-first-capture and for different levels of *M*.

3.3 RESULTS

3.3.1 Size frequency distribution

Figure 3.2 gives the length frequency distribution for separate and combined sexes of *P. undulosus*. The length frequency distributions for male and female *P. undulosus* were similar. Two peaks were noticed in the distributions, with the primary peak at 850 mm TL while the secondary peak is between 350 and 400 mm TL.

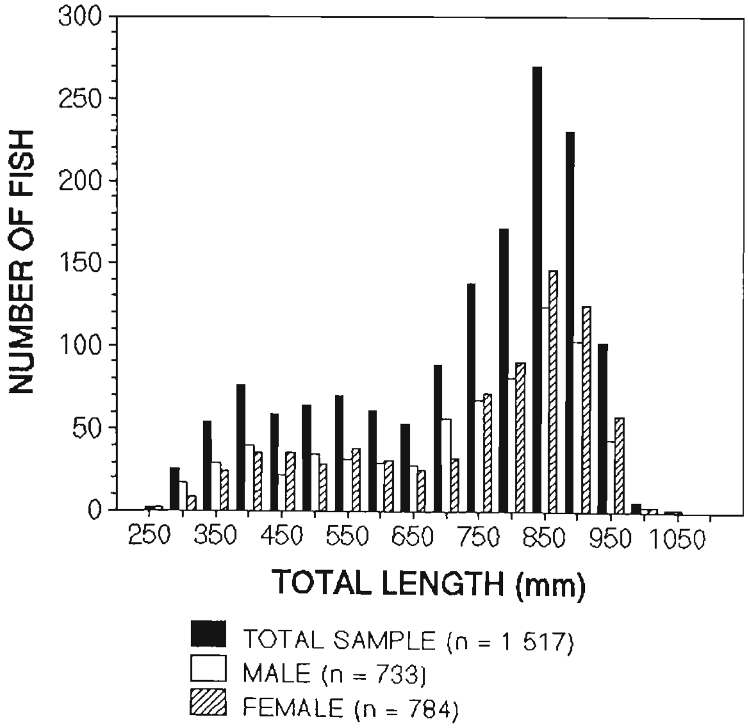


Figure 3.2: **The length frequency distributions for separate and combined sexes of *Polysteganus undulosus* sampled in KwaZulu-Natal waters in 1962 - 1963.**

Weight frequency distributions of the total sample and of the sample used for age determination are given in Figure 3.3. A bimodal distribution was noticeable at 1 kg and also at 7.5 kg. The similarity of the distributions indicated that the sub-sample used for ageing was representative of the sampled catch.

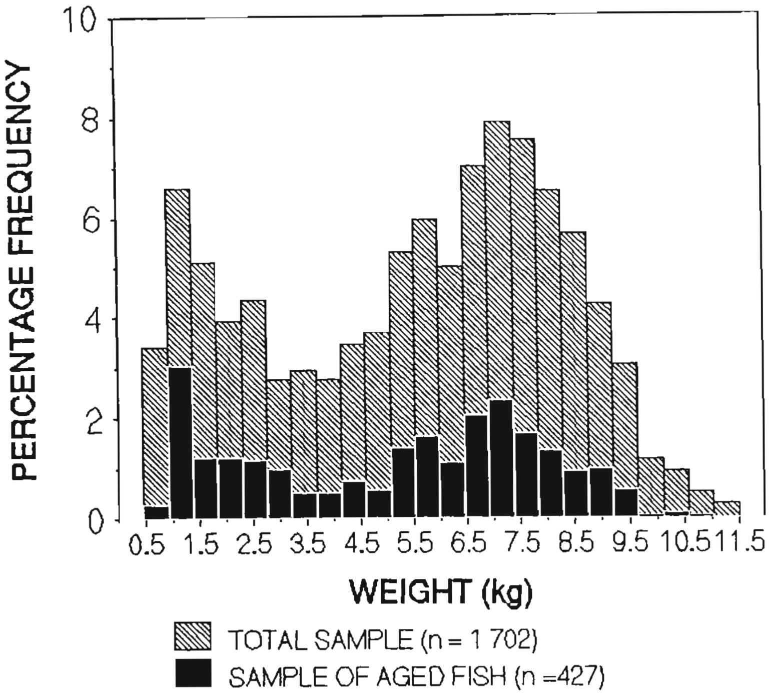


Figure 3.3: The weight frequency distribution of the total sample and of the sample used for age determination, for *Polysteganus undulosus* caught in KwaZulu-Natal waters.

3.3.2 Age estimates

Of the 500 otoliths that were sectioned, 427 (85%) provided useful age estimates while 73 (15%) were rejected as they were either broken during sectioning or difficult to read. Figure 3.4 shows a photograph of a sectioned *P. undulosus* otolith viewed under transmitted light.

The maximum age observed was 20 years and there were no fish with an age estimate of less than 3 years. Table 3.2 gives the summary of the age-length key shown in Appendix G. Wide ranges of lengths-at-age yielded high standard deviations. The APE value calculated for the four sets of age determination was found to be 18.23%.

Table 3.2: The observed minimum and maximum lengths-at-age as well as mean lengths-at-age and their standard deviations for ***Polysteganus undulosus*.**

AGE (yrs)	TL (mm) MIN - MAX	MEAN TL (mm)	STANDARD DEVIATION	n
3	289 - 530	386	66.33	15
4	296 - 610	421	67.50	26
5	339 - 655	446	84.63	37
6	328 - 640	478	88.21	23
7	450 - 752	554	71.80	15
8	450 - 873	624	110.83	17
9	428 - 924	694	132.83	20
10	527 - 944	756	130.86	43
11	618 - 982	818	97.06	33
12	704 - 958	838	70.05	44
13	708 - 969	851	71.44	36
14	723 - 983	858	60.69	39
15	773 - 989	874	61.12	24
16	786 - 999	883	55.59	23
17	786 - 960	894	41.56	14
18	796 - 984	903	45.94	11
19	881 - 946	914	32.50	2
20	897 - 974	939	26.33	5

Figure 3.4: A photograph of a sectioned *Polysteganus undulosus* otolith, showing thirteen rings.

Figure 3.5 shows the marginal zone analysis for sectioned *P. undulosus* otoliths. As *P. undulosus* is a distinctly seasonal fish in KwaZulu-Natal, monthly samples were only available for the months of June to December. However, marginal zone analysis revealed a peak between July and November suggesting that active deposition of an opaque band occurs during winter.

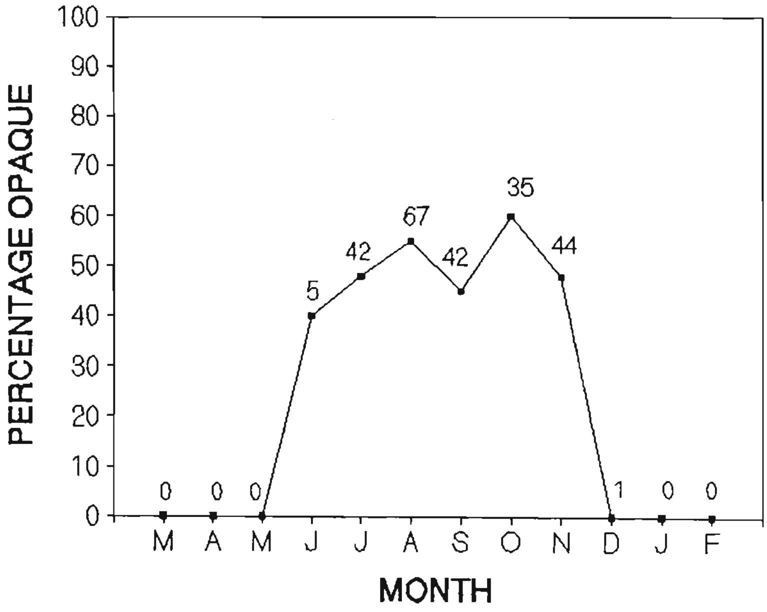


Figure 3.5: **Percentage of otoliths with opaque margins in *Polysteganus undulosus* caught in KwaZulu-Natal waters. Numbers designate sample size in each month.**

3.3.3 Age-at-50% maturity (t_m)

Figure 3.6 gives the relationship between gonad weight and fish weight. Of the sample (n = 427) used for estimation of t_m, 138 (32%) were immature fish and most of these weighed less than 3 kg.

Determination of the age-at-50% maturity revealed that female *P. undulosus* tend to mature at 7.7 years, about a year earlier than male fish (8.9 yrs) . Table 3.3 gives a summary of ages at maturity for both male and female fish as well as for the combined sexes of *P. undulosus*.

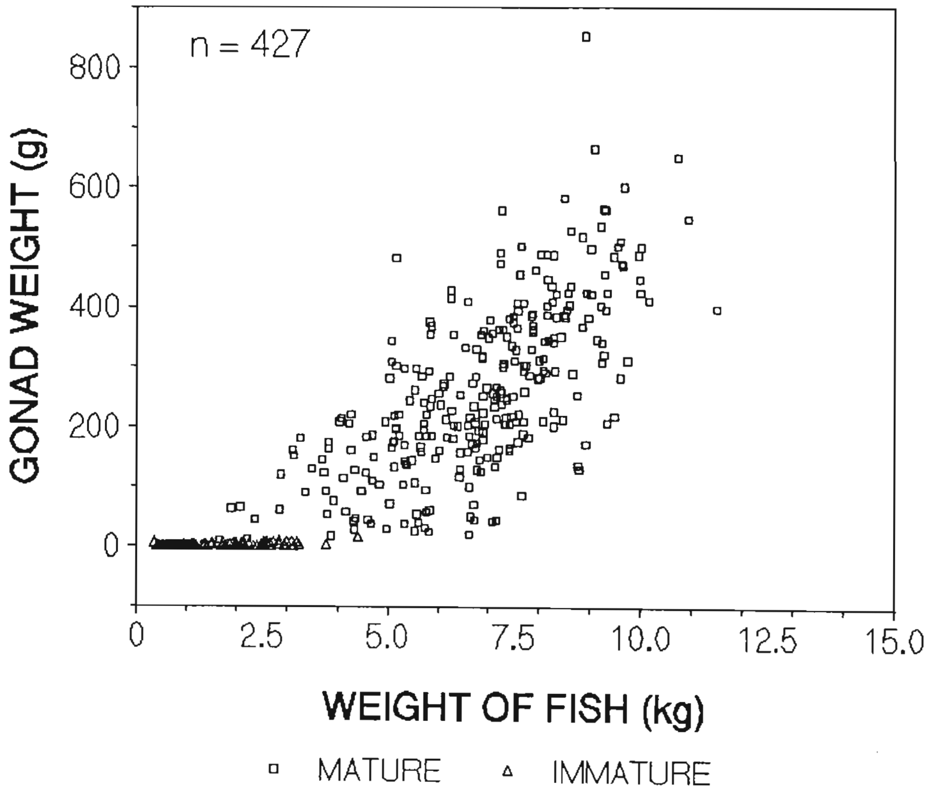


Figure 3.6: **Relationship between gonad weight and fish weight for mature and immature *Polysteganus undulosus* caught in KwaZulu-Natal waters.**

Table 3.3: Age-at-first maturity and age-at-50% maturity estimates for separate and combined sexes of *Polysteganus undulosus*.

SEX	AGE (yrs)		
	1st MATURITY	t_m	δ
MALE	4	8.9	0.92
FEMALE	4	7.7	1.54
COMBINED SEXES	4	8.8	1.21

A graphical representation of the trend in maturation for the combined sexes of *P. undulosus* is given in Figure 3.7.

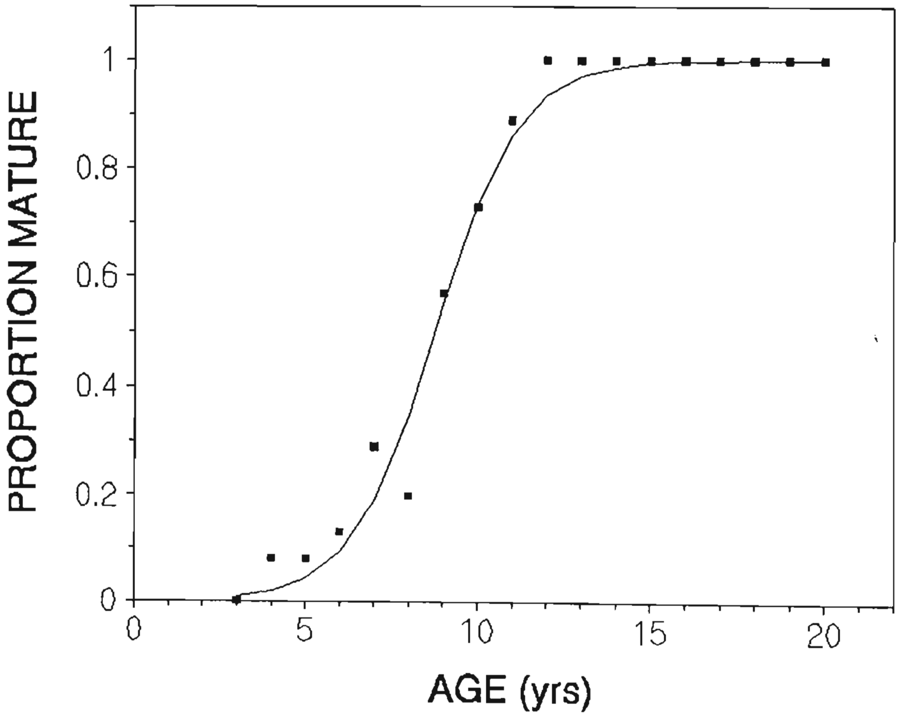


Figure 3.7: A logistic plot showing reproductive maturation relative to age for the combined sexes of *Polysteganus undulosus* caught in KwaZulu-Natal waters.

3.3.4 Growth model: Age-based method

Fitting of various submodels revealed that the logistic model provided the best fit. A loglikelihood ratio test revealed that logistic fits between male and female are not significantly different. The age-length data for combined sexes fitted to the logistic model with an absolute error structure is given in Figure 3.8. Growth parameters estimated for *P. undulosus* for combined sexes were L_∞ = 942 mm TL, k = 0.28 yr^{-1} and t_* = 5.18 yrs. Growth parameters for separate and combined sexes of *P. undulosus* are given in Table 3.4.

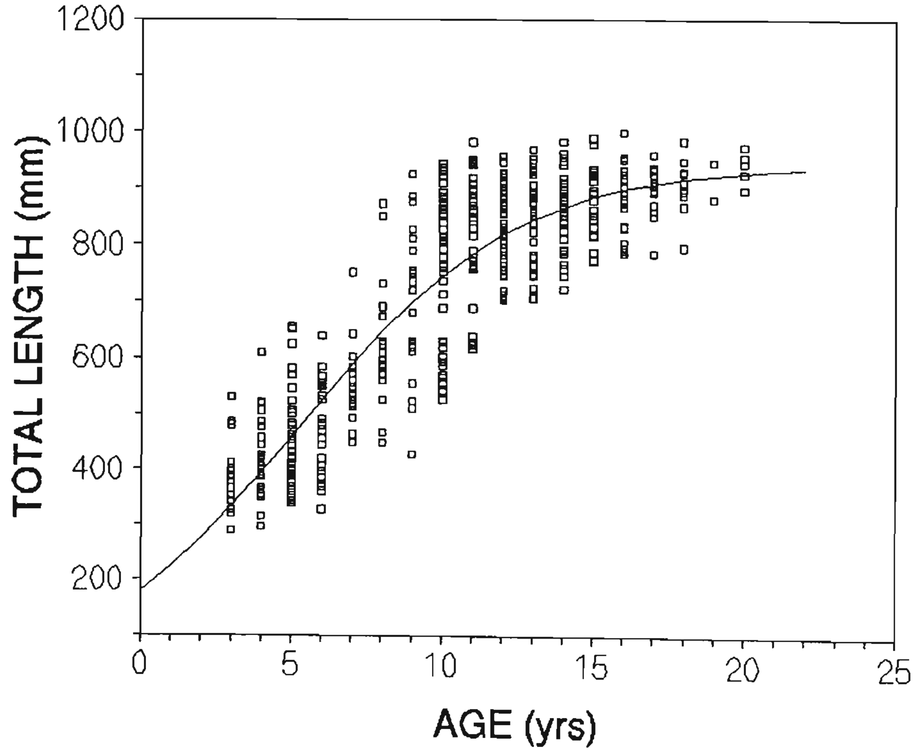


Figure 3.8: The age-length data fitted to the logistic growth equation for the combined sexes of *Polysteganus undulosus* caught in KwaZulu-Natal waters.

Table 3.4: *Polysteganus undulosus* growth parameter estimates, their 95% confidence intervals and standard errors for the logistic model as defined for Schnute's (1981) growth equation. Parameter estimates are for separate and combined sexes of *P. undulosus* caught off KwaZulu-Natal waters. SE designate standard error.

PARAMETER	VALUE	LHS 95% CI	RHS 95% CI	SE
MALE (n = 219)				
a	0.28	0.24	0.33	0.02
b	FIXED (-1)			
l_1 (mm)	324.28	295.06	354.28	15.17
l_2 (mm)	926.73	897.57	957.94	15.25
L_∞ (mm)	940.85	904.57	957.94	20.32
k (yr^{-1})	0.28	0.24	0.33	0.02
t_* (yrs)	5.26	4.90	5.74	0.21
FEMALE (n = 208)				
a	0.27	0.23	0.33	0.03
b	FIXED (-1)			
l_1 (mm)	341.07	307.15	375.15	16.80
l_2 (mm)	930.66	896.19	971.77	19.26
L_∞ (mm)	947.10	903.82	1 006.58	26.41
k (yr^{-1})	0.27	0.23	0.33	0.03
t_* (yrs)	5.12	4.64	5.70	0.03
COMBINED SEXES (n = 427)				
a	0.28	0.24	0.31	0.02
b	FIXED (-1)			
l_1 (mm)	333.19	309.46	356.03	12.06
l_2 (mm)	927.23	901.93	950.79	12.09
L_∞ (mm)	942.48	911.42	976.31	16.10
k (yr^{-1})	0.28	0.24	0.31	0.02
t_* (yrs)	5.18	4.86	5.53	0.17

3.3.5 Growth model: Length-based method

S.L.C.A. yielded various combinations of L_∞ and k as probable parameters for *P. undulosus* and these are summarised in Table 3.5. The growth parameter estimates L_∞ = 1 190 mm TL, k = 0.20 yr^{-1} and t_o = -0.577 yrs were selected and used in this study as they had the highest maximum score of 17.69 when compared with other parameters shown in Table 3.5.

Table 3.5: Combinations of L_∞, k and t_o, and their respective scores yielded by the program (S.L.C.A) as best parameters for *Polysteganus undulosus*.

L_∞ (mm TL)	k	t_o	SCORE
1 190	0.20	-0.577	17.69
1 201	0.19	-0.602	12.45
1 019	0.23	-0.667	12.06

3.3.6 Mortality estimates

Polysteganus undulosus are fully recruited to the fishery at the age of 12 years. Figure 3.9 shows the catch curve for *P. undulosus* with a linear regression fitted to the descending limb. A value of instantaneous total mortality rate (Z) of 0.33 yr^{-1} was estimated from the slope of this limb. A similar value (0.33 yr^{-1}) was obtained when using the Beverton and Holt (1956) equation.

Natural mortality rate M values estimated from the length-based (0.18 yr^{-1}) and age-based (0.16 yr^{-1}) methods were also similar. Fishing mortality rate F was estimated to be 0.15 yr^{-1} for the length-based method and 0.17 yr^{-1} for the age-based method. Table 3.6 summarizes mortality values and standard errors of the

Z estimate calculated from both the length- and age-based methods.

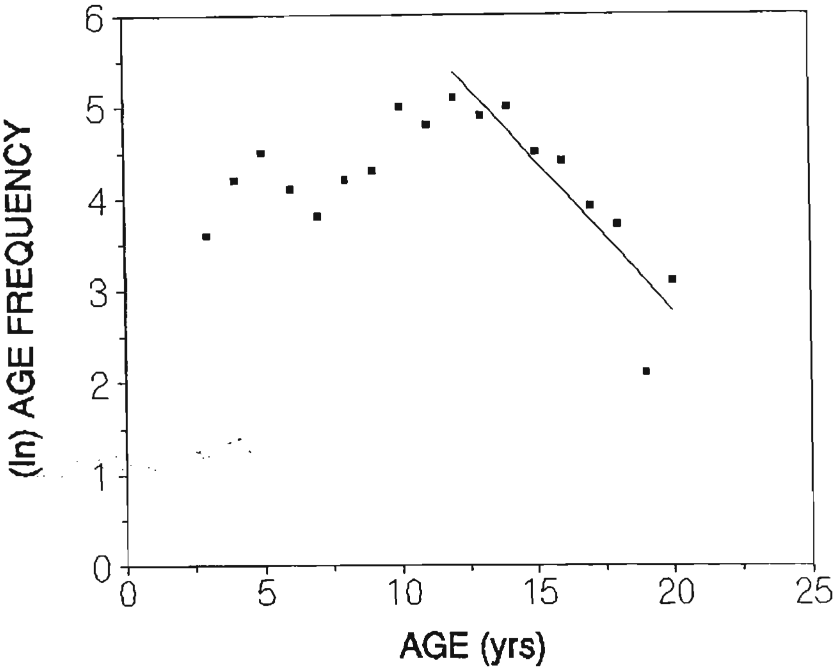


Figure 3.9: The catch curve of ***Polysteganus undulosus*** caught in KwaZulu-Natal waters in 1962 - 1963, with a linear regression fitted to the descending limb.

Table 3.6: Mortality values and standard errors of Z estimated for ***Polysteganus undulosus*** using both the length- and age-based method. SE designate standard error.

METHOD	Z (yr^{-1})	SE of Z	M (yr^{-1})	F (yr^{-1})
Length-based	0.33	0.016	0.18	0.15
Age-based	0.33	0.060	0.16	0.17

In this study, mortality estimates determined from the age-based method (Table 3.6) were regarded as likely parameters to describe the situation for *P. undulosus* in the early 1960s, as growth parameters of the length-based methods which served as input parameters were poorly estimated.

3.3.7 Preliminary Yield-per-recruit (YPR) and Spawner biomass-per-recruit (SBR).

Input parameters used to generate YPR and SBR models are given in Table 3.5.

Table 3.5: Input parameters used to generate per-recruit models of *Polysteganus undulosus*. Parameters *a* and *b* are of the length-weight relationship (Appendix E).

PARAMETER	ESTIMATES
F	0.17 yr^{-1}
M	0.16 yr^{-1}
t_c	5 yrs
t_m	8.8 yrs
a	0.00104
b	2.67

Figures 3.10 and 3.11 give the yield-per-recruit and spawner biomass-per-recruit curves for *P. undulosus* at three different ages-at-first-capture (t_c). The three t_c values selected were the age at which *P. undulosus* enter the fishery (5 years), the age at-50% maturity (8.8 years) and the intermediate age between the two (7 years). Yield-per-recruit revealed that a t_c of 7 yrs resulted in more yield when compared to a t_c of 5 yrs, only at F values greater than 0.2 yr^{-1}. A t_c of 8.8 yrs, results in loss of yield when compared to a t_c of 7yrs.

The spawner biomass-per-recruit curves revealed that the spawner biomass of *P. undulosus* was already at 25% of its unfished level in the early 1960s for a t_c of 5 yrs. Increasing the t_c results in conservation of the spawner biomass. For a t_c of 8.8 yrs (which is the age-at-50% maturity), it was noticed that, provided F is kept at 0.17 yr^{-1}, the spawner biomass would increase to 50% of its pristine level over the long-term.

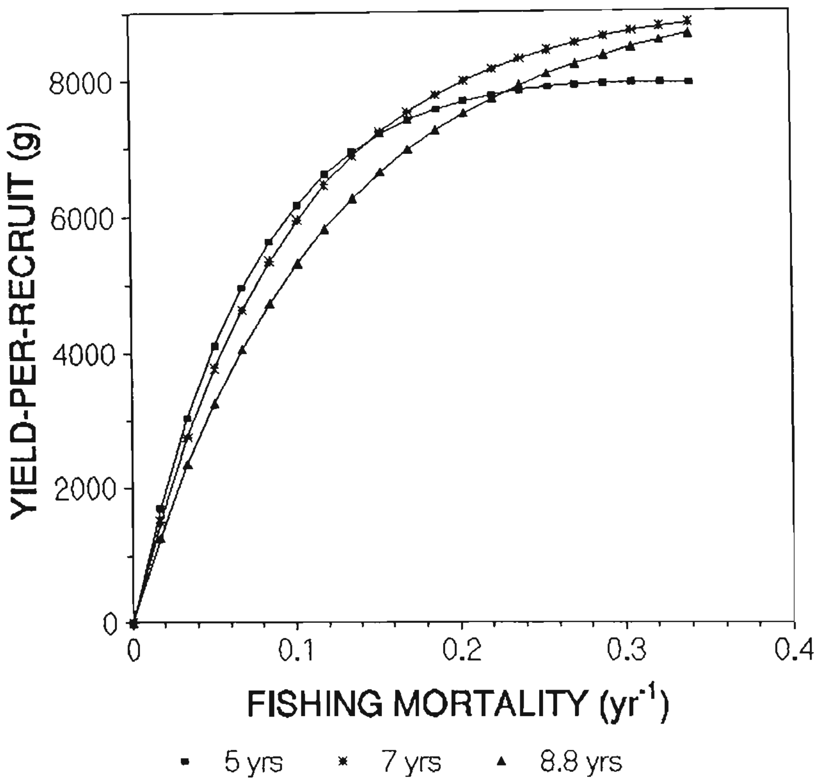


Figure 3.10: **Yield-per-recruit at three different ages-at-first-capture (t_c) for *Polysteganus undulosus* caught in KwaZulu-Natal waters.**

Table 3.6 summarizes biological reference points estimated at three different ages-at-first-capture. $F_{0.1}$ of 0.167 yr^{-1} is similar to the estimated fishing mortality rate ($F = 0.17$ yr^{-1}), suggesting that the fishery, in terms of yield alone, was at optimal exploitation in the early 1960s.

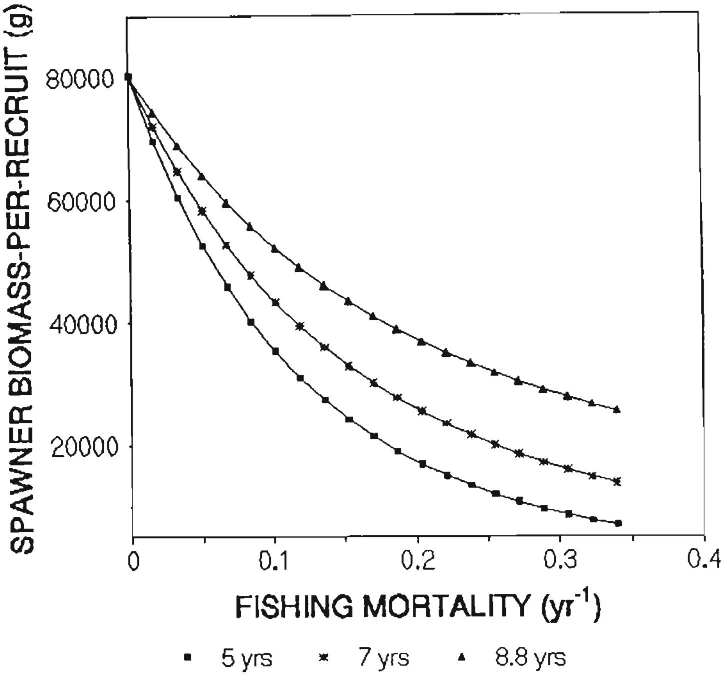


Figure 3.11: **Spawner biomass-per-recruit at three different ages-at-first-capture (t_c) for *Polysteganus undulosus* caught in KwaZulu-Natal waters.**

Table 3.6: Biological reference points estimated at three different ages-at-first-capture for *Polysteganus undulosus* caught in KwaZulu-Natal waters.

AGE (yrs)	F_{MSY} (yr^{-1})	$F_{50\%}$ (yr^{-1})	$F_{0.1}$ (yr^{-1})
5	0.316	0.085	0.167
7	UNDEFINED	0.116	0.220
8.8	1.30	0.176	0.316

Both per-recruit models were sensitive towards varying values of natural mortality rate (*M*). As fishing mortality increased, high yields were observed at $M = 0.16$ yr^{-1} when compared to $M = 0.18$ yr^{-1} (Fig. 3.12). A high *M* value also resulted in the spawner biomass being considerably reduced (Fig. 3.13).

Biological reference points estimated at two different values of *M* are give in Table 3.7.

Table 3.7: Estimates of biological reference points at two different levels of natural mortality (*M*) for ***Polysteganus undulosus*** caught in KwaZulu-Natal waters.

M (yr^{-1})	F_{MSY} (yr^{-1})	$F_{50\%}$ (yr^{-1})	$F_{0.1}$ (yr^{-1})
0.16	0.316	0.085	0.167
0.18	UNDEFINED	0.087	0.180

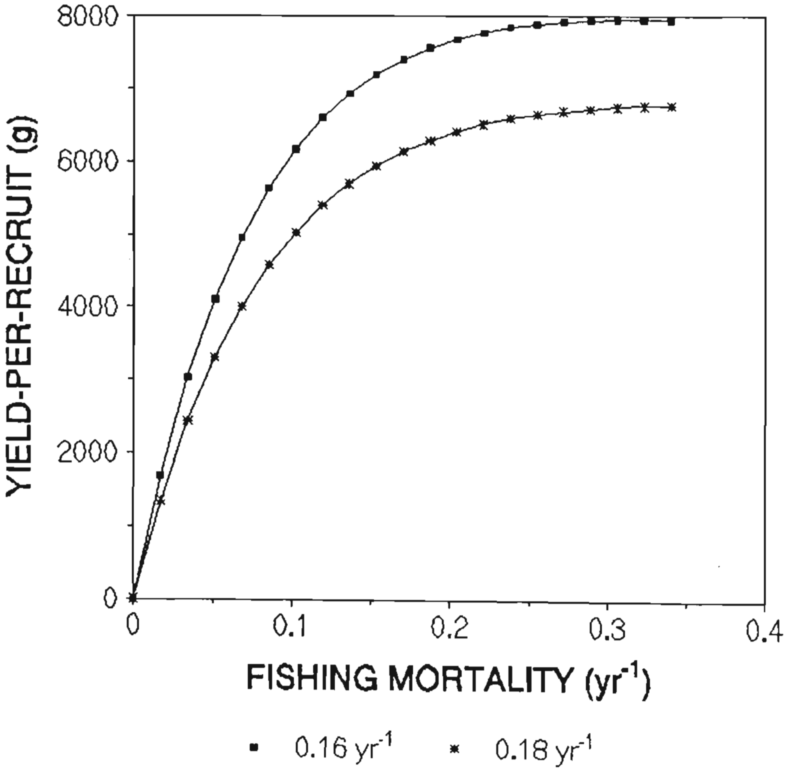


Figure 3.12: Yield-per-recruit plotted at two different levels of natural mortality (M) for ***Polysteganus undulosus*** caught in KwaZulu-Natal waters.

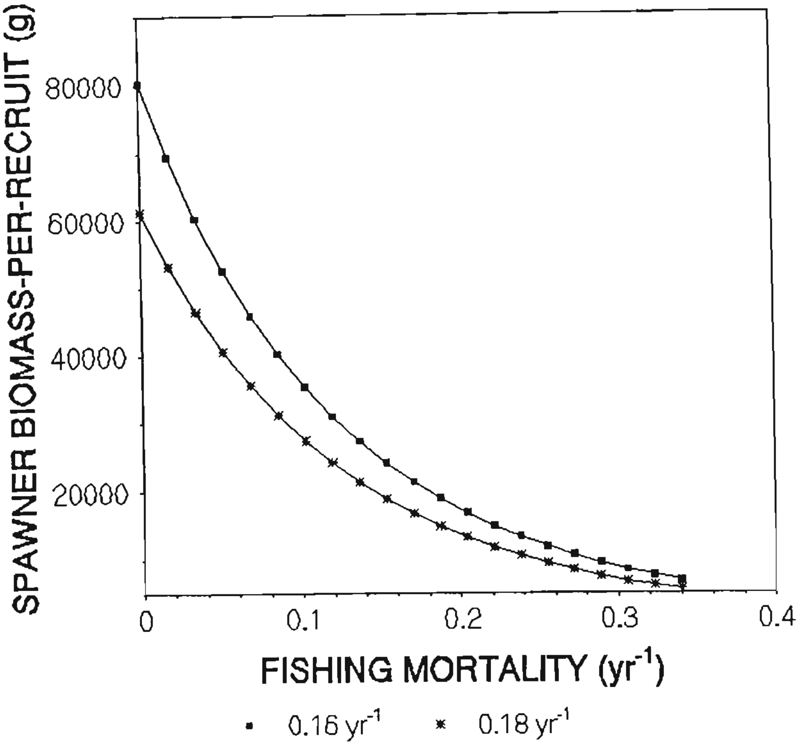


Figure 3.13: **Spawner biomass-per-recruit plotted at two different levels of natural mortality (*M*) for *Polysteganus undulosus* caught in KwaZulu-Natal waters.**

3.4 DISCUSSION

3.4.1 Size frequency distributions

Both the length and weight frequency distributions of *P. undulosus* revealed bimodal peaks (Figs. 3.2 and 3.3). This pattern is however, more evident in the weight frequency plot. The occurrence of double peaks in these distributions could be a result of previous strong recruitment. It could also be that some size classes were not available to the fishery as a result of size-specific migratory behaviour.

Large fish were dominant in the sampled catch of *P. undulosus* in the KwaZulu-Natal region, and this is probably attributable to the annual migrations of adult fish coinciding with peak fishing effort (Ahrens, 1964; Garratt, 1988; Butterworth *et al.*, 1992). Kerstan (1995) suggested that bimodal peaks may be due to intraspecific competition caused by high densities, thus resulting in slower growth rates. Occurrence of multiple modes is quite common in migratory species (Lambert *et al.*, 1994; Griffiths and Hecht, 1995; Kraljević *et al.*, 1996). In some sparids such as *Pagellus bellottii* from Ghana bimodal distribution was reported to be a consequence of biannual cohorts (Koranteng and Pitcher, 1987).

3.4.2 Age estimates

As otoliths of *P. undulosus* were dense, they required sectioning before they could be used for age determination. The configuration of otoliths is influenced by allometric growth (Tesch, 1968), where there is little increase in length as the fish grows older. This condition results in otoliths increasing in thickness rather than in length.

Recent developments in methods of ageing fish bearing thick ageing structures have emphasized the use of thin sections (Beamish, 1979; McCurdy, 1985; Augustine and Kenchington, 1987). Other researchers have showed preference to staining (Bouain and Siau, 1988) or burning of ageing structures prior to sectioning (Christensen, 1964; Pearson *et al.*, 1991).

In this study, estimation of age using transversely sectioned otoliths was successfully achieved although edges were sometimes difficult to interpret as a result of closeness of the rings at the margins. Sectioning techniques similar to that by Bedford (1983) have been previously used for several South African sparids (Buxton 1987; Buxton and Clarke, 1989, 1991; Smale and Punt, 1991; Garratt *et al.*, 1993) and were shown to provide improved resolution of the rings.

In this study, it was estimated that *P. undulosus* may live as long as 20 years. Considering that Smith and Heemstra (1986) have reported that these fish may grow as large as 15 kg, and that the heaviest fish in this study weighed about 11 kg, it is possible that the maximum attainable age of this species may be over the estimated 20 years. Sparids are generally long-lived, with species such as *Sparodon durbanensis* being reported to live as long as 31 years (Buxton and Clarke, 1991), *Petrus rupestris* 33 years (Smale and Punt, 1991) while *Cymatoceps nasutus* may even reach 45 years (Buxton and Clarke, 1989).

The absence of young fish (<3 years) in this study could be a result of the migrations undertaken by *P. undulosus* (Ahrens, 1964; Garratt, 1988). Penny *et al.* (1989) stated that juvenile *P. undulosus* are found off the southern Cape coast. However, it is also possible that the scarcity of young fish could be a consequence of gear selectivity during fishing.

Using scales, Ahrens (1964) estimated the maximum age for *P. undulosus* to be 13 years. From the results of the present study, it is clear that this fish exhibits greater longevity than previously suggested. Scales have been shown to underestimate the age of a fish, by various workers (Beamish, 1973; Craig and Poulin, 1975; Barnes and Power, 1984). Francis *et al.* (1992) maintains that scales underestimate the age of older fish particularly in long-lived fish and recommended the use of sectioned otoliths for ageing sparids.

Tests for precision of the four sets of age determination yielded an APE value of 18.23%, which is higher than that obtained by van der Walt (1995) for another South African sparid *Sarpa salpa*. Validation of ring counts by examining opaque margins, was successfully carried out, although interpretation of the margins was sometimes difficult due to stacking at the edges, particularly in otoliths from larger fish. This is due to slowing or cessation of somatic growth as fish get older, thus resulting in narrowing of the spacing between rings (Beamish, 1979). Stacking of marginal rings has also been shown to be common in other long-lived sparids (Pulfrich and Griffiths, 1988a; Buxton and Clarke, 1989; Beckman *et al.*, 1991; Buxton and Clarke, 1991; Smale and Punt, 1991).

Although samples were not available for all the months of the year, it was evident from marginal zone analysis that this fish only lays down one opaque band per year. This interpretation was confirmed by tagging data from the two recaptured *P. undulosus* which were at liberty for a period of about a year each (E. Bullen, ORI/Sedgwick's tagging programme, pers comm. 1996). By substituting the lengths at mark and at recapture of these two fish into the logistic equation, it was established that the time at liberty corresponded with the fit of the logistic growth model (Fig. 3.8). This technique was described by Kirkwood (1983). Researchers on other South African sparids have also reported the occurrence of one opaque and one hyaline band per year in sparid otoliths (Buxton and Clarke, 1986, 1989; Smale and Punt, 1991; Buxton, 1992). Other studies on sparids outside South African waters have also reported one ring being laid down per year (Beckman *et al.*, 1991; Ferell *et al.*, 1992).

The period of active deposition of an opaque band coincides with the peak spawning season (September) of this fish as identified by Ahrens (1964). Mann-Lang and Buxton (in press) conducted a review of previously studied South African sparids and concluded that annulus deposition coincides with the period of greatest spawning intensity for these fish.

3.4.3 Age-at-50% maturity

In previous studies on maturity assessment for South African sparids (Bennett, 1993; Pulfrich and Griffiths, 1988a; Smale, 1988; Buxton and Clarke, 1991; Punt *et al.*, 1993; van der Walt, 1995) age-at-50% maturity was estimated by converting the length-at-50% maturity to age using an appropriate growth curve. There do not appear to be any published South African studies in which t_m was directly estimated from age data. In this study t_m (Table 3.3) was estimated from age data using a logistic maturity curve (Butterworth *et al.*, 1989).

Polysteganus undulosus like other sparids such as *Sparodon durbanensis* (Buxton and Clarke, 1991), *Petrus rupestris* (Smale and Punt, 1991) and *Lithognathus lithognathus* (Bennett, 1993) matures late in life. Late maturity is one of the principal contributing factors towards overexploitation of long-lived species.

One of the characteristic features of sparids is their tendency to change sex at some stage in their life cycle, and this feature has been identified in several South African sparids such as *Chrysoblephus puniceus* (Garratt, 1986), *Sparodon durbanensis* (Buxton and Clarke, 1991), *C. laticeps* and *C. cristiceps* (Buxton, 1992). Garratt (1986) has identified five reproductive patterns among the Sparidae, namely, gonochorism, rudimentary hermaphroditism, protogynous hermaphroditism, protandrous hermaphroditism and single functional hermaphroditism. There has been considerable confusion regarding reproductive patterns of sparids, and Sadovy and Shapiro (1987) have shown that while simultaneous hermaphroditism is easily distinguishable by the presence of mature gonadal tissue of both sexes, several criteria have to be met in order that a species qualify as a sequential hermaphrodite (protandry and protogyny).

The work by Ahrens (1964) on the biology of *P. undulosus* does not suggest any possibility of sex change. According to Smale (1990), sexual development in *P. undulosus* may be similar to that of its close relative *Petrus rupestris* (Smale, 1988) where juveniles have both male and female gonadal tissue, and development into either a functional male or female is triggered later as the fish grows (Smale, 1988). This reproductive strategy is known as rudimentary hermaphroditism (Garratt, 1986). Observations made in this study, namely, the insignificant differences between the size distribution of male and female and between their ages at maturity, suggest that this fish is less likely to undergo sex change.

However, as there has not been any detailed work on histology of the gonads, the reproductive pattern of *P. undulosus* cannot be ascertained with certainty.

3.4.4 Growth model: Age-based method

Polysteganus undulosus, as is the case with other South African sparids (Coetzee and Baird, 1981; Buxton and Clarke, 1989, 1991; Smale and Punt, 1991; Buxton, 1992; Garratt *et al.*, 1993), is slow growing and long-lived. However, unlike other sparid studies, in which the von Bertalanffy growth model was used (Buxton and Clarke, 1989; 1991; Horvath *et al.*, 1990; Smale and Punt, 1991; Garratt *et al.*, 1993), in this study, it was found that growth of *P. undulosus* was adequately modelled by a logistic growth function. Growth parameters estimated for the male and female *P. undulosus* were similar and fell within 95% confidence limits of each other (Table 3. 4) showing that the rate of growth between the two sexes is similar.

Figure 3.14 shows a comparison of the fits obtained by reading scales (Birnie *et al.*, 1994) and by otolith reading (this study). It can be seen from the two fits that the von Bertalanffy parameters estimated by Birnie *et al.* (1994) do not fit the age-length data recorded in the present study. It is clear that the scale readings underestimated the age of this fish when compared with the otolith readings from this study, and this bias resulted in the over-estimation of the growth rate by Birnie *et al.* (1994).

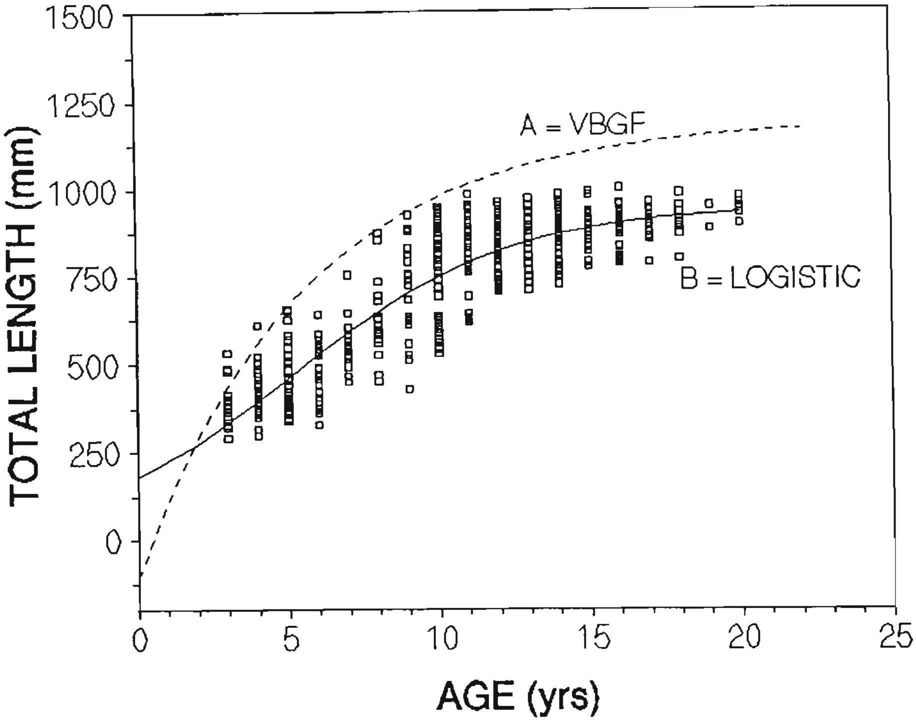


Figure 3.14: **Comparison between the von Bertalanffy fit (A) (Birnie *et al.*, 1994) and the logistic growth model (B) (this study) for *Polysteganus undulosus*.**

3.4.5 Growth model: Length-based method

Determination of growth parameters by Shepherd's (1987) Length Composition Analysis (S.L.C.A.) was not satisfactory for *P. undulosus* as it yielded several combinations of L_∞ and k values as best parameters, that is, each time the program was run, different growth parameters were obtained (Table 3.5). Another problem encountered when using this method was that, there were no obvious modal progressions in the length frequencies, from which age classes could be distinguished. The inability of this method to describe the growth of *P. undulosus* can be attributed to allometric growth and longevity of this species, which cause overlapping of the age modes, particularly in older fish, thus making distinction of the modes difficult (Tesch, 1968). Distinction into modal progressions has also been shown to be impossible for other long-lived species, particularly sparids (Pollock, 1982; Koranteng and Pitcher, 1987).

Although length-based methods have been widely used as they are easy to use and less laborious when compared to aged-based methods, they make the critical assumption that all fish follow the growth pattern of the VBGF (Pauly and Morgan, 1987). This constraint is probably too restrictive and makes it difficult for the model to seek the best-fitting values by optimization routine. In this study it has been shown that growth of *P. undulosus* is well described by a logistic model and not by the VBGF. Similarly, the VBGF was reported to be unsuitable for *Lichia amia* (van der Elst *et al.*,1993). Length-based methods have also been widely criticized for overestimating k values and for providing a poor estimate of the location parameter t_o, thus resulting in age estimates that are relative and not absolute (Pollock, 1982; Basson *et al.*, 1988; Acosta and Appeldoorn, 1992; Kerstan, 1995).

3.4.6 Mortality estimates

The instantaneous total mortality rates Z estimated by both methods were similar and gave low values of standard error thus yielding narrow ranges of Z. Estimates of instantaneous natural mortality (M) and fishing mortality (F) rates did not differ significantly from each other. However, the Z value of 0.33 yr^{-1} recorded in this study, differed substantially from the 1.24 yr^{-1} estimated by Birnie *et al.* (1994)

who used a catch curve constructed from the scale readings of Ahrens (1964). The overestimation of Z by Birnie *et al.* (1994) is most probably due to under-estimates of age.

Polysteganus undulosus, like many other long-lived species (Pulfrich and Griffiths, 1988b; Smale and Punt, 1991; Pearson *et al.*, 1991; Vassilopoulou and Papaconstantinou, 1992) has a low value of natural mortality rate. This indicates that if these fish are not harvested or eaten by a predator, they may live to attain their maximum age.

Fishing mortality of *P. undulosus* almost equalled natural mortality, suggesting that this fishery was not overexploited in the early 1960s (Gulland, 1983). However, as a large proportion of *P. undulosus* in the KwaZulu-Natal catch were mature (Ahrens, 1964), it is probable that the collapse of this fishery was a consequence of targeting the spawning stock.

3.4.7 Preliminary Yield-per-recruit (YPR) and Spawner biomass-per-recruit (SBR)

Per-recruit analyses such as YPR and SBR are essential tools in understanding the relationship between the spawner biomass and yield, from which a stock recruitment relationship can be established, bearing in mind that recruitment will decrease when stock decreases (Gulland, 1983). While simple alteration of parameters such as a decrease in fishing mortality or an increase of age-at-first-capture (t_c) will certainly benefit the spawner biomass, it is very important to understand the effect of these changes on total catches (Gulland, 1983).

In this study it has been observed that increasing t_c benefits both the YPR and SBR. Provided fishing mortality is kept at the estimated level of 0.17 yr^{-1}, an increase of the age-at-first-capture to 8.8 years (about 650 mm TL) will result in high yields at fishing mortality greater than 0.2 yr^{-1}. The t_c of 8.8 years also conserves the spawner biomass (Fig. 3.10). Although the effectiveness of increasing the age/size-at-first-capture may be reduced by catch-and-release mortality as a result of barotrauma or poor handling of the fish, this measure has been shown to be very useful (Waters and Huntsman, 1986).

The fishery for *P. undulosus* in terms of yield was already at the level of optimal exploitation ($F = F_{0.1} = M$) (Gulland, 1983; Clark, 1991) in the early 1960s, although the spawner biomass was already at 25% when compared to the unfished level. This implies that *P. undulosus* was biologically overexploited ($F >> F_{50\%}$) (Butterworth *et al.*, 1989) in the early 1960s. If F did not increase considerably since the early 1960s, then it appears that *P. undulosus* becomes susceptible to overexploitation even at low levels of fishing mortality, and the $F_{0.1}$ strategy (Sissenwine and Shepherd, 1987; Clark, 1991) may not be applicable to the *P. undulosus* fishery. This is supported by the low fishing mortality rate at which the stock is considered to be at 50% of its unfished level ($F_{50\%} = 0.085$ yr^{-1}) . Acosta and Appeldoorn (1992) have also noted that long-lived species are generally susceptible to overexploitation even at low levels of fishing.

Bearing in mind that catches comprising mostly small *P. undulosus* were caught in the Eastern Cape (van der Elst and Garratt, 1984; Penny *et al.*, 1989) and that spawning aggregations were previously targeted off the KwaZulu-Natal coastline (Ahrens, 1964), the collapse of *P. undulosus* could also be due to recruitment overfishing. Unfortunately, as the per-recruit analyses employed in this study assume constant recruitment, this could not be investigated.

Comparing stock assessment in this study with the assessment performed by Birnie *et al.* (1994), it was noted that their model predicted a virtual collapse of the fishery in the early 1960s. This interpretation appears to be incorrect as commercial fishers such as Irvin and Johnson were still actively catching the species at that time.

3.5 CONCLUSIONS

The distribution of *P. undulosus* catches in KwaZulu-Natal in the early 1960s was bimodal, and comprised mostly mature fish. This study has shown that *P. undulosus* is long-lived and slow- growing, and the growth of this species is adequately modelled by a logistic growth function. *P. undulosus* appears to be susceptible to overexploitation even at low levels of fishing mortality. From per-recruit analyses undertaken in this study, it appears that the spawning stock of *P. undulosus* was at 25% of its unfished level in the early 1960s, and suggests that the collapse of this fishery was due to targeting of the spawner stock.

CHAPTER 4: FINAL DISCUSSION

This study provided detailed information regarding the age and growth of two different species, namely, *S. plurilineatus*, which is a long-distance migrant from western Indian Ocean waters and *P. undulosus*, which is a reef-dwelling, short-distance migrant, endemic to Southern African waters. The presence of both these species in KwaZulu-Natal is seasonal, with *S. plurilineatus* being abundant during the warmer months of the years (van der Elst and Collette, 1984), while *P. undulosus* favours cooler months (Ahrens, 1964).

Both these species are important in the KwaZulu-Natal linefishery, with *S. plurilineatus* being particularly important to the recreational sector, because of its fighting abilities (van der Elst, 1981), while *P. undulosus* was an important food fish caught by the commercial fishery (Penny *et al.*, 1989), and prior to its collapse, yielded catches that far exceeded those of other bottom fish in this region.

Age determination of *S. plurilineatus* using whole otoliths revealed that this fish is fast growing and short-lived. Age determination using sectioned otoliths of *P. undulosus* concurred with studies on other South African sparids that slow growth and longevity to be the norm for this group. Early maturity of *S. plurilineatus* is an advantage in that when the fishery is overexploited, the rate of stock replacement will be fast. In contrast, species such as *P. undulosus* and various other late maturing sparids, will have a slow stock recovery. Thus unlike their fast growing counterparts, fisheries management of these slow growing fish has to be extremely cautious if a threat of overexploitation is noticed.

The growth estimation technique used in this study requires availability of all age groups, which becomes a problem when work is carried out on a migratory species. For example, modelling of *P. undulosus* using the von Bertalanffy growth function was not possible because of the difficulty of estimating the location parameter t_o, as the youngest fish observed was 3 years old. Samples for fish in age groups of 6 to 10 years were also limited. This problem of missing age groups, would require that sampling be carried out in other areas as well, where these fish occur, such as the Eastern Cape (Penny *et al.*, 1989). However, this was not possible as the *P. undulosus* fishery has collapsed and data used have been archived since 1960s. Fortunately, growth of *P. undulosus* was adequately described by the logistic model.

Another short-coming of this study, resulted from the seasonality of the species studied, and led to data being limited only to certain months of the year. Unfortunately, this resulted in other methods such as validation by marginal zone analysis not being appropriate for these species. Growth modelling using a length-based technique is also not suitable for seasonal species (Pollock, 1982). This method analyses the length frequency data to estimate the growth parameters of the von Bertalanffy equation. It requires availability of adequate monthly samples, in order to provide a reasonable relationship between length and age in the form of modal progressions.

In the South African fisheries regulations the capture of *S. plurilineatus* is restricted to 10 fish per person per day for recreational anglers and spearfishers. *S. plurilineatus* and various other scombrids that inhabit KwaZulu-Natal waters have become increasingly important to recreational anglers as capture of reef fish in the extensive marine reserves in northern KwaZulu-Natal is prohibited (Sea Fishery Act No 12 of 1988). However, there is considerable evidence that indicates that catches of this species are declining. As the primary concern of the recreational anglers is to catch large fish (van der Elst, 1989), this practice could result in reduced numbers of adult stock. The observation that old *S. plurilineatus* are relatively scarce and that catches are comprised largely of young fish, serves as an indication that all may not be well in the fishery. Considering that *S. plurilineatus* is currently biologically optimally exploited, increase in fishing effort may reduce the spawner biomass.

Polysteganus undulosus is provided protection by using the most stringent management measures available which include a size limit (40 cm TL), a limited catch of two fish per person per day for commercials, semi-commercials and recreational anglers, a closed season and marine reserves (Sea Fishery Act No 12 of 1988). However there is still no evidence of stock recovery. While this could be attributed to the slow growth of this species, it should be noted that the minimum size (40 cm TL) allowed for this species is far smaller than the size at maturity of 65 cm TL (size corresponding to t_m), thus fishers can legally catch *P. undulosus* several years before fish spawn.

Per-recruit analyses have shown that a size limit of 65 cm TL would result in increased yield and also conserve the spawner biomass. As a result of its late age-at-maturity and slow growth, this species is extremely vulnerable to capture. For this reason, it is strongly recommended that if a size limit is considered as a management measure, the minimum limit should be increased to 65 cm TL to provide adequate time for the fish to reach maturity and to eventually spawn. Although it may be argued that because large fish inhabit deeper waters thus may die from barotrauma when brought to the surface, fishers can move away from the shoals to another fishing ground if they unintentionally catch an undersized fish.

Other than late maturity, other limitations that contributed towards depletion of *P. udulosus* are its limited distribution (endemism) and the tendency to form spawning aggregations which also make the species extremely vulnerable to capture. Fortunately, the closed season (1 September to 30 November) proclaimed for *P. undulosus* which coincides with the spawning period, protects these fish when they are particularly vulnerable. Thus, effectiveness of a closed season will imply that fishers have to forfeit part of their catch. *P. undulosus* and various other reef fish are also protected by means of marine reserves which are located in the northern KwaZulu-Natal. Marine reserves can protect fish stocks during their spawning seasons if the protected areas correspond to the spawning grounds. *P. undulosus* are known to spawn in the Durban Illovo region (Ahrens, 1964), thus the marine reserves in the northern KwaZulu-Natal do not necessarily protect them during their peak spawning period. There is also a bag limit (2 fish/person/day) for *P. undulosus* promulgated on all fishery sectors, the reason behind which is to sustain the parent stock by limiting the catch.

Although the above management measures are sound, it should be taken into consideration that the current state of *P. undulosus* is critical and that the outlined management measures may only be effective once the stock has recovered. Despite the collapsed state of the fishery, some *P. undulosus* are still occasionally being caught, showing that reviving this fishery is not impossible. One of the primary steps to be taken is the de-commercializing of this species which has also been requested by other marine scientists (Brouwer *et al.*, 1996).

It is suggested in this study, that effective stock recovery will require that the *P. undulosus* fishery be closed to all fishery sectors. However, it should be born in mind that this stock rebuilding strategy will require a long-term sacrifice (Gulland and Boerema, 1972). The period of closure of the fishery may be as long as 30 years, with stock assessment procedures being conducted within every 5 years to check if there has been any improvement. Although the closure of a fishery may have socio-economic implications, particularly for commercial fishers, this problem is less likely to occur in the case of *P. undulosus* as fishers have shifted their effort to other reef fish such as *C. puniceus* and *C. nufar* (van der Elst, 1989).

As the two species studied in this thesis are important in the KwaZulu-Natal line fishery, detailed biological information on these species is necessary for appropriate management. It is therefore recommended that future research and management should focus on:

- Validation of growth marks in the otoliths using direct methods such as oxytetracycline labelling for both *S. plurilineatus* and *P. undulosus*;
- Detailed assessment of maturity using microscopic gonadal examination to provide better understanding of the reproductive strategies of these two species;
- Regular monitoring of both commercial and recreational catches for length frequency distributions to provide information on population structure that can be used in stock assessments;
- Implementation of a stock rebuilding strategy for *P. undulosus*.

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Appendix A: **Morphometric equations for *Scomberomorus plurilineatus*. W, FL and Lmax designate weight of fish, fork length and maxillary length, respectively.**

EQUATION	SOURCE
$W(g) = 1.26 \times 10^{-5}\ FL(mm)^{2.9411}$	van der Elst and Collette (1984)
$FL(mm) = 12.7\ Lmax(mm) - 80.3;$ $r^2 = 0.974$	This study

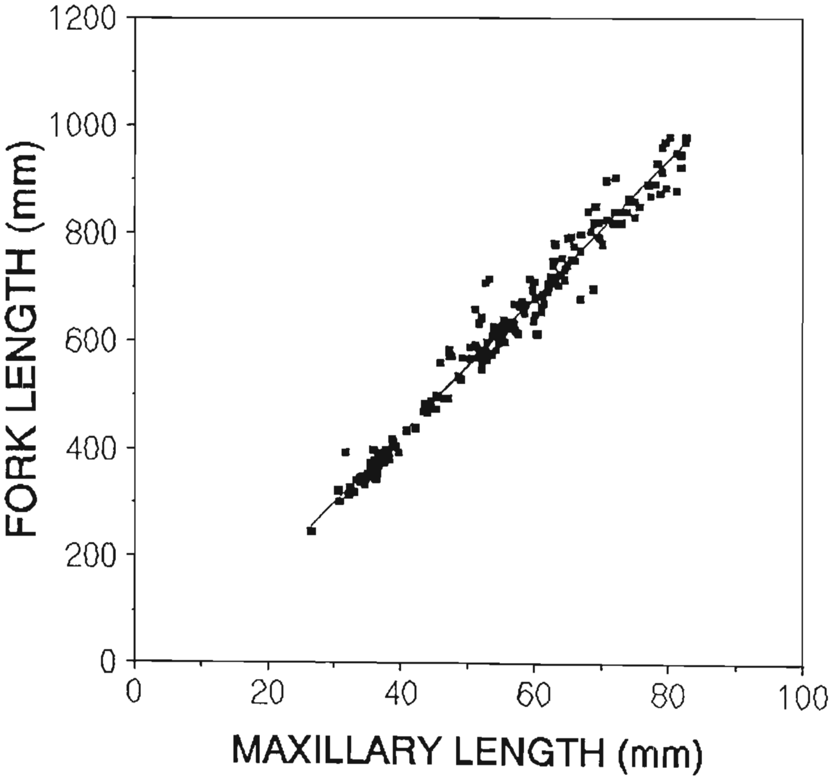

Figure A: The maxillary length versus fork length relationship for *Scomberomorus plurilineatus* (n = 205).

Appendix B: The length frequency data used in estimating the parameters of the length-based method for *Scomberomorus plurilineatus* caught in KwaZulu-Natal waters. These data were collected by van der Elst and Collette (1984).

1975

FL (mm)	J	F	M	A	M	J	J	A	S	O	N	D
150	0	0	0	0	0	0	0	0	0	0	0	0
200	0	0	0	0	0	0	0	0	0	0	0	0
250	0	0	0	0	0	0	0	0	0	0	0	0
300	0	0	0	0	0	0	0	0	0	0	0	0
350	0	0	0	0	0	0	0	0	0	0	0	0
400	0	0	0	0	0	0	0	0	0	0	0	0
450	0	0	0	0	0	0	0	0	0	0	0	0
500	0	1	0	0	0	1	0	7	0	2	1	4
550	0	7	3	11	6	7	1	61	0	0	1	7
600	0	2	6	5	14	16	4	225	0	14	8	6
650	0	0	4	0	6	15	3	72	0	5	23	8
700	0	2	6	2	1	4	2	8	0	2	6	9
750	0	0	20	0	9	13	8	7	0	1	2	5
800	2	1	9	1	30	9	9	1	0	1	3	4
850	0	0	7	6	84	15	17	1	0	2	3	5
900	1	0	6	3	91	5	6	0	0	1	0	5
950	0	0	0	0	35	2	1	0	0	0	2	2
1000	0	0	0	0	6	0	0	1	0	0	0	0
1050	0	0	0	0	0	0	0	0	0	0	0	0

Appendix B (Continued): The length frequency data used in estimating the parameters of the length-based method for *Scomberomorus plurilineatus* caught in KwaZulu-Natal waters. These data were collected by van der Elst and Collette (1984).

1976

FL (mm)	J	F	M	A	M	J	J	A	S	O	N	D
150	0	0	0	1	2	0	0	0	0	0	0	0
200	0	0	0	0	0	0	0	0	0	0	0	0
250	0	0	0	0	0	0	0	0	0	0	0	0
300	0	0	0	0	0	0	0	1	0	0	0	0
350	0	0	0	0	0	0	0	0	0	1	0	0
400	1	5	1	0	0	1	0	0	0	0	0	0
450	6	12	8	0	1	1	0	4	0	0	0	0
500	16	28	111	7	3	24	0	53	4	4	0	0
550	46	20	278	15	7	47	0	159	30	14	0	3
600	35	46	382	34	34	66	0	108	34	16	0	8
650	10	19	151	56	67	83	0	32	17	3	0	7
700	13	10	42	31	168	75	0	19	18	1	0	2
750	5	1	14	14	201	22	0	18	6	1	2	1
800	1	1	9	1	194	12	0	5	5	1	0	2
850	0	1	5	1	113	1	0	1	2	1	1	0
900	1	0	3	0	11	0	0	0	4	1	0	2
950	0	0	0	0	24	0	0	0	0	0	1	0
1000	0	0	0	0	1	0	0	0	0	0	0	1
1050	0	0	0	0	0	0	0	0	0	0	0	0

Appendix B (continued): The length frequency data used in estimating the parameters of the length-based method for *Scomberomorus plurilineatus* caught in KwaZulu-Natal waters. These data were collected by van der Elst and Collette (1984).

1977

FL (mm)	J	F	M	A	M	J	J	A	S	O	N	D
150	0	0	0	0	0	0	1	0	0	0	0	0
200	0	0	0	0	0	0	0	0	0	0	0	0
250	0	0	0	0	0	0	0	0	0	0	0	0
300	0	0	0	0	0	0	0	0	0	0	0	0
350	0	0	0	0	0	0	0	0	0	0	0	0
400	0	0	0	0	0	0	0	0	0	0	0	0
450	0	0	0	0	0	0	0	0	1	0	0	0
500	0	0	0	0	0	0	0	0	0	0	0	0
550	0	4	4	3	13	0	41	4	4	0	0	0
600	0	1	5	3	36	0	71	7	7	1	2	0
650	1	0	0	1	19	0	54	3	5	0	1	0
700	2	3	0	0	38	0	10	1	4	0	0	0
750	2	4	0	0	82	0	3	3	3	0	0	0
800	0	0	0	0	90	0	4	3	2	1	0	0
850	0	1	0	0	40	0	0	4	3	0	0	0
900	1	0	0	1	7	0	0	2	2	0	0	0
950	0	0	0	0	1	0	0	0	0	0	0	0
1000	0	0	0	0	0	0	0	0	0	0	0	0
1050	0	0	0	0	0	0	0	0	0	0	0	0

Appendix C: AGE-LENGTH KEY FOR *SCOMBEROMORUS PLURILINEATUS*

SIZE CLASS (mm FL)	0	1	2	3	4	5	6	AGE FREQUENCY
150-250	1							1
250-350	13							13
350-450	41	1						42
450-550	9	16						26
550-650		146	5					151
650-750		146	14	1				161
750-850		8	29	5	2	1		45
850-950				10	17	15	5	47
950-1050					2	5	3	10

Appendix D: Data of *Polysteganus undulosus* for which dates and localities were recorded (Ahrens, 1964).

Date	Locality	Depth (m)	No. of fish
12.06.1962	Kelso and Macwasa	55	3
02.07.1962	Illovo	55	1
05.07.1962	Amanzimtoti	46	5
06.07.1962	Amanzimtoti	-	3
07.07.1962	Umgababa	-	1
08.07.1962	Illovo	59	2
09.07.1962	Umgababa	73	3
09.07.1962	Isipingo	40	1
09.07.1962	Umzumbi	55	4
11.07.1962	Isipingo	80	2
12.07.1962	Illovo	40	4
14.07.1962	Illovo	-	2
15.07.1962	Umgababa	-	4
15.07.1962	Umbogintwini	51	2
15.07.1962	Umgababa and Illovo	52	2
16.07.1962	Umgababa and Karridene	40	4
17.07.1962	Karridene	46	3
20.07.1962	Illovo and Umgababa	55	3
21.07.1962	Karridene	46	2
21.07.1962	Illovo and Umgababa	77	1
22.07.1962	Umgababa	55	4
22.07.1962	Umgazi Bay	101	2
23.07.1962	Illovo and Umgababa	77	5
24.07.1962	Port St. Johns	-	4
30.07.1962	Tongaat	73	7

08.08.1962	Umhlali and Tongaat	77	2
15.08.1962	Warner beach	40	2
15.08.1962	Stanger and Amanzimtoti	40	2
16.08.1962	Umgababa	64	2
16.08.1962	Umgababa	64	11
17.08.1962	Umgababa	55	2
18.08.1962	Karridene	55	1
18.08.1962	Umgababa	59	21
20.08.1962	Karridene	46	2
21.08.1962	Amanzimtoti	-	1
21.08.1962	Amanzimtoti	-	21
22.08.1962	Umbogintwini	48	2
23.08.1962	Umbogintwini	46	1
23.08.1962	Illovo	59	19
24.08.1962	Illovo	-	1
24.08.1962	Isipingo	59	8
03.09.1962	Umgababa	59	4
06.09.1962	Umgababa	-	71
07.09.1962	Stanger	77	27
08.09.1962	Illovo	59	41
13.09.1962	Umhlali	55	2
14.09.1962	Umkomaas	77	2
15.09.1962	Umhlali	55	2
20.09.1962	Sinkwazi	-	107
21.09.1962	Tongaat	77	30
25.09.1962	Tongaat	82	17
27.09.1962	Umkomaas	-	42
02.10.1962	Reunion	69	16
03.10.1962	Isipingo	73	7
03.10.1962	Mtwalumi	66	32
04.10.1962	Amanzimtoti	77	6
05.10.1962	Amanzimtoti	-	18
17.10.1962	Isipingo	77	2
21.10.1962	Amanzimtoti	-	3
23.10.1962	Illovo	73	6
24.10.1962	Umgababa	73	13
26.10.1962	Tongaat	77	3
27.10.1962	Isipingo	73	6
29.10.1962	Reunion	73	2
31.10.1962	Isipingo	73	32

04.11.1962	Isipingo	73	16
06.11.1962	Amanzimtoti	77	12
07.11.1962	Sinkwazi	-	82
08.11.1962	Umgababa	55	19
09.11.1962	Umgababa	55	12
12.11.1962	Umgababa	55	12
22.11.1962	Sezella	55	6
02.12.1962	Umhlali	82	3
03.03.1963	Umhlali	73	2
03.05.1963	Umhlali	-	2
21.05.1963	Isipingo	73	3

Appendix E: The length frequency data extracted from Ahrens (1964) which were used in estimating growth parameters from Shepherd's (1987) Length Composition Analysis for *Polysteganus undulosus*. These data were collected between 1962 and 1963.

TL (mm)	J	F	M	A	M	J	J	A	S	O	N	D
220	0	0	0	0	0	0	1	0	0	0	0	0
240	0	0	0	0	0	1	0	0	0	0	0	0
260	0	0	0	0	0	0	0	0	0	0	0	0
280	0	0	0	0	0	0	0	0	0	0	1	0
300	0	0	0	0	0	0	0	0	0	0	0	0
320	0	0	0	0	0	0	0	0	0	0	2	0
340	0	0	0	0	0	0	1	0	1	0	0	0
360	0	0	0	0	0	1	0	0	0	0	0	0
380	0	0	0	0	0	0	0	0	0	0	1	0
400	0	0	0	0	0	0	0	0	0	0	0	0
420	0	0	0	0	0	0	1	1	0	0	0	0
440	0	0	0	0	0	0	0	0	1	2	0	0
460	0	0	0	0	0	0	0	0	1	2	1	0
480	0	0	1	0	0	0	0	0	1	0	1	0
500	0	0	0	0	0	0	0	0	1	1	0	0
520	0	0	0	0	0	0	3	0	4	1	1	0
540	0	0	0	0	0	0	1	0	1	1	0	0
560	0	0	0	0	0	1	1	0	2	2	1	0
580	0	0	0	0	0	0	0	0	13	2	2	0
600	0	0	1	1	1	0	0	2	8	4	2	0
620	0	0	0	0	0	0	0	9	8	4	3	0
640	0	0	0	0	0	0	5	8	16	7	5	1
660	0	0	0	1	1	0	6	12	17	9	6	1
680	0	0	0	0	1	0	5	11	29	8	11	1

Appendix E (continued): The length frequency data extracted from Ahrens (1964) which were used in estimating growth parameters by Shepherd's (1987) Length Composition Analysis for *Polysteganus undulosus*. These data were collected between 1962 and 1963.

TL (mm)	J	F	M	A	M	J	J	A	S	O	N	D
700	0	0	0	0	0	0	8	15	32	24	7	0
720	0	0	0	0	0	0	7	12	36	15	12	0
740	0	0	0	0	1	0	8	12	39	16	24	0
760	0	0	0	0	1	0	10	13	36	14	17	0
780	0	0	0	0	0	0	6	17	41	13	18	0
800	0	0	0	0	0	0	5	5	16	12	20	0
820	0	0	0	0	0	0	3	3	13	12	8	0
840	0	0	0	0	0	0	0	3	9	6	6	0
860	0	0	0	0	0	0	0	0	3	0	1	0
880	0	0	0	0	0	0	0	0	1	0	0	0
900	0	0	0	0	0	0	0	0	0	0	0	0
920	0	0	0	0	0	0	0	0	0	0	0	0

Appendix F: Morphometric equations for *Polysteganus undulosus*. TL, SL, FL and W designate total length, standard length, fork length and weight, respectively.

SEX	EQUATION	r^2	n
MALE	$TL = 1.14SL + 20.47$ $SL = 0.86TL - 12.95$ $W = 1.01 * 10^{-4} TL^{2.67}$	0.992 0.992 0.969	733 733 733
FEMALE	$TL = 1.15SL + 19.75$ $SL = 0.87TL - 14.36$ $W = 1.05 * 10^{-4} TL^{2.67}$	0.996 0.996 0.977	784 784 784
COMBINED SEXES	$TL = 1.14SL + 21.21$ $SL = 0.87TL - 13.59$ $W = 1.04 * 10^{-4} TL^{2.67}$	0.993 0.993 0.977	1 517 1 517 1 517

pendix G: **AGE-LENGTH KEY FOR *POLYSTEGANUS UNDULOSUS*** (n = 427)

ZE CLASSES	AGE									
m TL)	3	4	5	6	7	8	9	10	11	AGE FREQUENCY
50-300	1	1								2
00-350	4	2	3	1						10
50-400	5	6	12	5						28
00-450	2	10	8	3						23
50-500	2	3	5	5	3	2	1			21
00-550	1	3	4	3	6	1	2	3		23
50-600			2	4	3	6	1	6		22
00-650		1	2	2	2	3	5	5	4	24
50-700			1			2	1	1	1	6
00-750					1	1	2	3		7
50-800							1	5	9	15
00-850						1	2	6	4	13
50-900						2	2	10	8	22
50-1000							2	5	5	12
000-1050							1		2	3

	12	13	14	15	16	17	18	19	20	AGE FREQUENCY
50-300										
00-350										
50-400										
00-450										
50-500										
00-550										
50-600										
00-650										
50-700										
00-750	6	5	2							13
50-800	7	5	6	4	3	1	1			27
00-850	10	3	7	5	3					28
50-900	11	14	15	6	7	7	4	1	1	66
00-950	9	7	6	7	6	5	5		2	47
50-1000	1	2	3	2	3	1	1	1	2	16