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AN ASSESSMENT OF THE CURRENT STATUS AND POTENTIAL YIELD OF NAMIBIA'S NORTHERN WEST COAST STEENBRAS *LITHOGNATHUS AURETI* POPULATION

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Two distinct populations of West Coast steenbras *Lithognathus aureti* are found in Namibian waters; one, the northern population, is exploited recreationally and commercially. Data collected between 1995 and 1999 were used to evaluate its current state and potential yield, using two yield-per-recruit approaches. A Beverton and Holt model was used to study the effect of different fishing mortalities, natural mortality and age-at-first-capture schedules on yield-per-recruit, and also to derive fishing mortality levels for prescribed biological reference points. A Thompson and Bell model was used to test the performance of some fisheries regulations, e.g. the effects that implementation of a minimum size could have on the sustainable exploitation of the stock, within safe biological limits. Results from the Thompson and Bell model estimated maximum sustainable yield for the northern population of *Lithognathus aureti* at between 109 and 173 tons. The best estimate was some 134 tons, a value also proposed as the limit reference point. Current depletion is 42%, and a minimum size limit of 40 cm for West Coast steenbras off Namibia is proposed. This restriction would only slightly increase spawner stock biomass, but the spawning potential of the population would increase considerably.

Key words: biological reference points, management, per-recruit models, West Coast steenbras

Managing a fish stock without knowledge of its magnitude and the life history of the individuals is not viable or in the best interest of the users. Usually some form of numerical stock assessment is used to aid fisheries managers in formulating appropriate fisheries regulations for a specific fish stock. Prior to 1998, none of Namibia's linefish stocks had been assessed, despite their economic and ecological importance. Kirchner (1998) conducted the first assessment of Namibian silver kob *Argyrosomus inodorus* and Holtzhausen (1999) carried out the first assessment of the northern stock of West Coast steenbras *Lithognathus aureti*. It is generally perceived among Namibian rock-and-surf anglers that the West Coast steenbras resource has declined, in both quality and quantity. For historical reasons, current management regulations for the Namibian linefishery are not based on scientific investigations on local species, but are mainly adapted from South African legislation for southern African species.

To complicate management options further, Van der Bank and Holtzhausen (1998/1999) found two distinct populations of West Coast steenbras in Namibian waters, a southern population around Meob Bay and a northern population in the central and northern regions of the Namibian coast (Fig. 1). The southern population inhabits a coastal area that falls within a restricted (closed to the public) Nature Conservation area (the Namib Naukluft Park – NNP) and is therefore not subjected to any fishing mortality by rock-and-surf anglers, except for research purposes. Therefore, that population could not be assessed using conventional fishery models, no total annual catch being available. Namibian Sea Fisheries regulations prohibit recreational fishing in such restricted areas as around Meob Bay and near Rocky Point in the north – the Skeleton Coast Park (SCP) – but they do allow commercial linefishing boats to fish along the entire Namibian coastline (Ministry of Fisheries and Marine Resources 1993). Because of this concession to linefishing boats, the closed or restricted areas, which cover approximately 80% of the coastline, cannot be classified as marine protected areas, or as areas where linefish stocks are totally protected from fishing.

On the other hand, recreational rock-and-surf anglers are only allowed to fish in the central region (the West Coast Recreational Area – WCRA) and in a small area of the northern region. Mark-recapture results have shown that West Coast steenbras move from the SCP to the WCRA, seeding the latter area (Holtzhausen 1999). Alarmingly, results from roving

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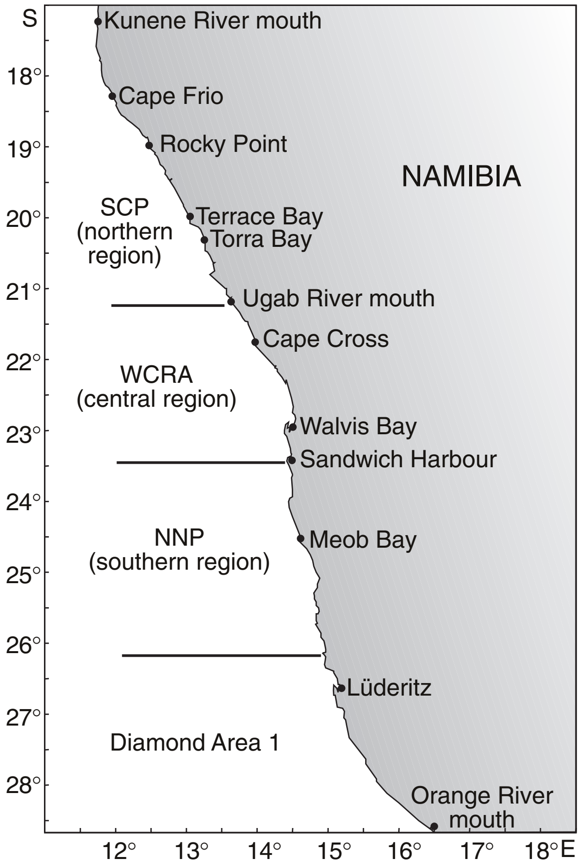

Fig. 1: Map of Namibia showing the sampling regions and the localities mentioned in text

creel surveys for the 1998/99 season indicated that more than half the total catch of recreational rock-and-surf anglers was in Terrace Bay, a stretch of shoreline of only 25 km in the northern region, compared to the 245 km open to angling in the WCRA. Therefore, from a management point of view, it became imperative to assess the northern West Coast steenbras population.

Globally, the topic of a precautionary approach in fisheries research, management and technology has become an important issue (F.A.O. 1995, Gabriel and Mace 1999, Mace and Gabriel 1999, Matlock 1999, Serchuk *et al.* 1999). Appropriate data collection on Namibian West Coast steenbras only started in 1995, so adequate information in terms of extended time-series of catch and effort, or data for fishery stock assessment models for use in spawner-biomass recruitment relationships, were not available. However, this should not be a reason for not taking appropriate conservation and management measures (Mace and Gabriel 1999); for example, there is currently a daily bag limit of 30 fish per recreational angler in Namibia (Ministry of Fisheries and Marine Resources 1993). Such a bag limit has been shown by Kirchner and Beyer (1999) to be too high and therefore ineffective. Moreover, the greater the uncertainties in the data and the assessments, the greater the need for a precautionary approach (Serchuk *et al.* 1999).

To be in line with the Code of Conduct for Responsible Fisheries (F.A.O. 1995), conservative biological reference points with high yield and low risk should be chosen. A biological reference point is a single measurement of the stock that reflects growth, recruitment, natural mortality and fishing mortality (Gabriel and Mace 1999). By raising or lowering fishing mortality *F*, the appropriate action would be to maintain the stock at some described level, for example the maximum sustainable yield *MSY*. Such a stock level could be labelled a reference point, limit and target reference points being the most commonly used. In cases where the results of an assessment were considered to be "uncertain", the advice of various workers (e.g. Mace and Gabriel 1999, Serchuk *et al.* 1999) is that the limit reference point (*LRP*) should be defined as F_{MSY} (the fishing mortality rate that maximizes the yield from the system), which in the past was often used as a target reference point. A more conservative $F_{SB(50)}$ (i.e. *F* at half the stock biomass) reference point is proposed here as the target reference point (*TRP*) when recommendations for the sustainable exploitation of the Namibian West Coast steenbras resource are to be made to the Fisheries Management Authority in Namibia.

Any attempt to assess the potential yield of a fish stock should be based on scientific "stock assessments" of the resource concerned, which in turn entails determining the status and the productivity of the resource by means of mathematical models (Punt *et al.* 1993). However, for most models, an extended time-series of catch and effort as well as a relationship between spawner biomass and recruitment are required. Such information was unavailable for most linefish stocks, including West Coast steenbras, until recently.

Yield-per-recruit models can, however, be used in a relative sense for assessing linefish stocks on a continuous basis. Such a procedure has been used in some South African studies on linefish, e.g. for stocks of two reef-dwelling sparids, *Chrysoblephus laticeps* and *C. cristiceps* (Buxton 1992), and panga *Pterogymnus laniarius* (Booth and Buxton 1997). Further, stock assessments of silver kob *Argyrosomus inodorus* have been made in this manner for South

Africa and Namibia by Griffiths (1997) and Kirchner (1998) respectively. A yield-per-recruit model assumes that the total annual yield of a population is equivalent to the lifetime yield of a single year-class.

Data from continuous seasons (1995–1999) are used here to evaluate the status of the northern West Coast steenbras stock in Namibia using two yield-per-recruit approaches. A Beverton and Holt (1957) model was used to study the effect of different fishing mortalities, natural mortality and age-at-first-capture schedules on yield-per-recruit, and also to derive levels of fishing mortality at prescribed biological reference points. The Thompson and Bell (1934) model used requires an array of fishing mortalities-at-age as well as annual recruitment estimates (estimated by cohort analysis) and information on size-specific natural mortality. Both models were used to describe the current state of the northern stock and to study the effects that implementation of a minimum size limit could have on the sustainable exploitation of the stock within safe biological limits.

In terms of yield, effort and stock size, some South African linefish stocks have been evaluated with regard to minimum size limits, bag limits, closed areas and closed seasons. Attwood and Bennett (1990) evaluated the effects of a minimum size limit and a closed season on galjoen *Dichistius capensis*. Buxton (1992) investigated the application of yield-per-recruit models to two reef-dwelling sparid species, with special consideration given to sex change. Attwood and Bennett (1995) investigated a procedure for setting daily bag limits, and Booth and Punt (1998) considered the effect of introducing a minimum size limit in an effort to rebuild the panga stock.

The present paper gives an account of how the current state of the northern West Coast steenbras population was estimated using two yield-per-recruit fishery models. Also investigated are the effects that the introduction of a minimum size limit would have on the sustainable exploitation of this population, within safe biological limits.

MATERIAL AND METHODS

Sampling

The total annual catch of the northern stock of West Coast steenbras in Namibian waters by recreational rock-and-surf anglers was estimated by roving-roving creel surveys (described by Kirchner and Beyer 1999) from 1 October 1995 to 30 September 1999. Shore-anglers were intercepted and interviewed while actively fishing. Data on the total catch per species was therefore estimated as the product of total effort and catch rate. Length measurements (fork length *FL*, cm) of anglers' catches were also taken where possible. In all, 2 410 length measurements were taken from the WCRA and 3 431 from the SCP. Length measurements for Torra Bay and Terrace Bay were augmented with measurements taken during tag-and-release surveys in the SCP during the study period.

A catch-at-age array was used in place of a cohort. The assumption was made that the northern stock exists in a steady state, i.e. that there were no major changes in recruitment, growth or mortality over a range of years corresponding to the lifespan of the fish. This assumption underlies yield-per-recruit models (Punt *et al.* 1993).

Natural mortality

Instantaneous average natural mortality and age-converted size-specific natural mortality were used as input parameters for the Beverton and Holt (1957) and Thompson and Bell (1934) models respectively.

SIZE-SPECIFIC NATURAL MORTALITY AT AGE

Using preliminary growth data, the size-specific natural mortality of West Coast steenbras was estimated by Beyer *et al.* (1999) for the southern population. With additional data generated during this study, improved estimates of K and L_∞ were derived (i.e. $K = 0.065$ in place of $K = 0.083$, and $L_\infty = 73.5$ cm in place of $L_\infty = 70$). For the northern population, K was estimated as 0.088 and L_∞ as 84.6 cm (Table I). Using length-based catch curve analyses with the revised parameters (Fig. 5 of Beyer *et al.* 1999), the catch curve can be described as $y = 2.7604x + 12.359$ ($n = 5$, length range 43.75–56.75 cm, $r^2 = 0.98$), and M_∞, the natural mortality for infinitely old fish, is 0.21 year^{-1}. Using this information, the M_∞ needed for the assessment of the northern West Coast steenbras population was obtained by raising the M_∞ of the southern population (SS) proportionally to the L_∞ of the northern population (SN) using the formula

$$M_{\infty SN} = M_{\infty SS}\, L_{\infty SS}/L_{\infty SN} \quad .$$

The size-specific natural mortality of West Coast steenbras was converted to natural mortality-at-age following the equation

$$M_t = M_\infty \,/\, (1 - e^{-K[(t + 0.5) - t_0]}) \quad , \qquad (1)$$

where M_∞ is 0.208 year^{-1} and t is the age of the fish. This mortality value was used in Pope's (1972) cohort

Table I: Parameter estimates and the range/best estimates of values used in the models for assessment of the West Coast steenbras stock

Parameter	Range/best estimate	Source/background information
K	0.088 year^{-1}	(95% *CI*: 0.069, 0.107)
L_∞	84.6 cm	(95% *CI*: 66, 103)
t_0	-2.756	(95% *CI*: -3.356, -2.156)
T	14–23°C	Satellite data (MFMR)
W_∞	14.19 kg	$W_\infty = 0.00003\ L_\infty^{2.9444}$
M	0.23 year^{-1}	(95% percentiles: 0.18–0.27)
F	0.11 year^{-1}	$F = Z–M$ (95% percentiles: 0.05–0.17)
Z	0.35 year^{-1}	Catch curve analysis (range: 0.30–0.43)
M_∞	0.21 year^{-1}	Method: updated value
F_{term}	0.11 year^{-1}	$N(0.11, 0.03)$ equal to F
t_r	1 year	Age at recruitment (first appearance in fishery)
t_c	2 years	Age corresponding to the peak in the catch curve
a	0.00003	(n = 1 194) averaged over the years 1995–1999
b	2.9444	(n = 1 194) averaged over the years 1995–1999
t_m	5 years	Holtzhausen (1999)
t_f	10 years	Holtzhausen (1999)

Table II: Estimated mean catch-at-age and standard error (*SE*) of the northern stock of West Coast steenbras for the period 1995–1999 caught by rock-and-surf anglers in the WCRA and Torra Bay/Terrace Bay areas of the Namibian coast

Age	Average catch (numbers)	*SE* (average catch)
1	1 442	122
2	16 099	1 347
3	9 122	622
4	12 383	926
5	6 859	473
6	5 101	377
7	3 616	226
8	1 408	106
9	1 107	95
10	2 192	175
11	1 146	98
12	313	51
13	657	71
14	439	76
15	89	17
16	188	37
17	218	39
18	220	35
19+	2 522	109

analysis (Sparre and Venema 1992), the model used for computing fishing mortality rates per age-class.

AVERAGE INSTANTANEOUS NATURAL MORTALITY

Pauly's (1980) formula was used to estimate M:

$$\log M = -0.0152 - 0.279\ \ell n\ (L_\infty) + 0.6543\ \ell n\ (K) + 0.463\ \ell n\ (T) \quad , \quad (2)$$

where T denotes sea surface temperature (°C). To account for some uncertainty in L_∞, K and T, and in order to make the best estimate possible, a repetitive Monte Carlo technique was used, drawing 3 000 values randomly from a distribution of values. These values were appropriately distributed between realistically possible upper and lower bounds of water temperature (U[14–23°C]) – Kirchner and Holtzhausen (2001) – and a normal distribution for both L_∞(N[84.6, 9.3]) and K (N[0.088, 0.01]) – Holtzhausen and Kirchner (2001).

Fishing mortality

Average instantaneous fishing mortality and a fishing mortality-at-age array were used as input data for the Beverton and Holt and Thompson and Bell models respectively.

AVERAGE INSTANTANEOUS FISHING MORTALITY

Catch-at-age data were obtained for four fishing seasons (1 October – 30 September), between 1995 and 1999. Because yield-per-recruit models are steady state in nature, each year was treated as a pseudo-cohort. Total mortality (Z) was estimated for each year from catch curve analysis (Ricker 1975), all fully exploited ages being regressed against ln(numbers at age in the catch). The slope of the linear regression represents Z and instantaneous F is given by $F = Z–M$. A range of values of fishing mortality were estimated by Monte Carlo analysis, with 3 000 draws from a uniform distribution of Z, ranging from the lowest to the highest estimate obtained from catch curve analysis. A normal distribution of M was used, described by a mean and a standard error, obtained from the Monte Carlo simulation described under the average instantaneous natural mortality above.

FISHING MORTALITY AT AGE

Fishing mortality at age was estimated using Pope's (1972) cohort analysis. The range of values estimated for average instantaneous fishing mortality was used as the range for the parameter F_{term}. F-at-age arrays were generated 250 times, each with a randomly (with replacement) selected value out of a normal distribution describing a range of catch-at-age, F_{term} and M (Tables I and II).

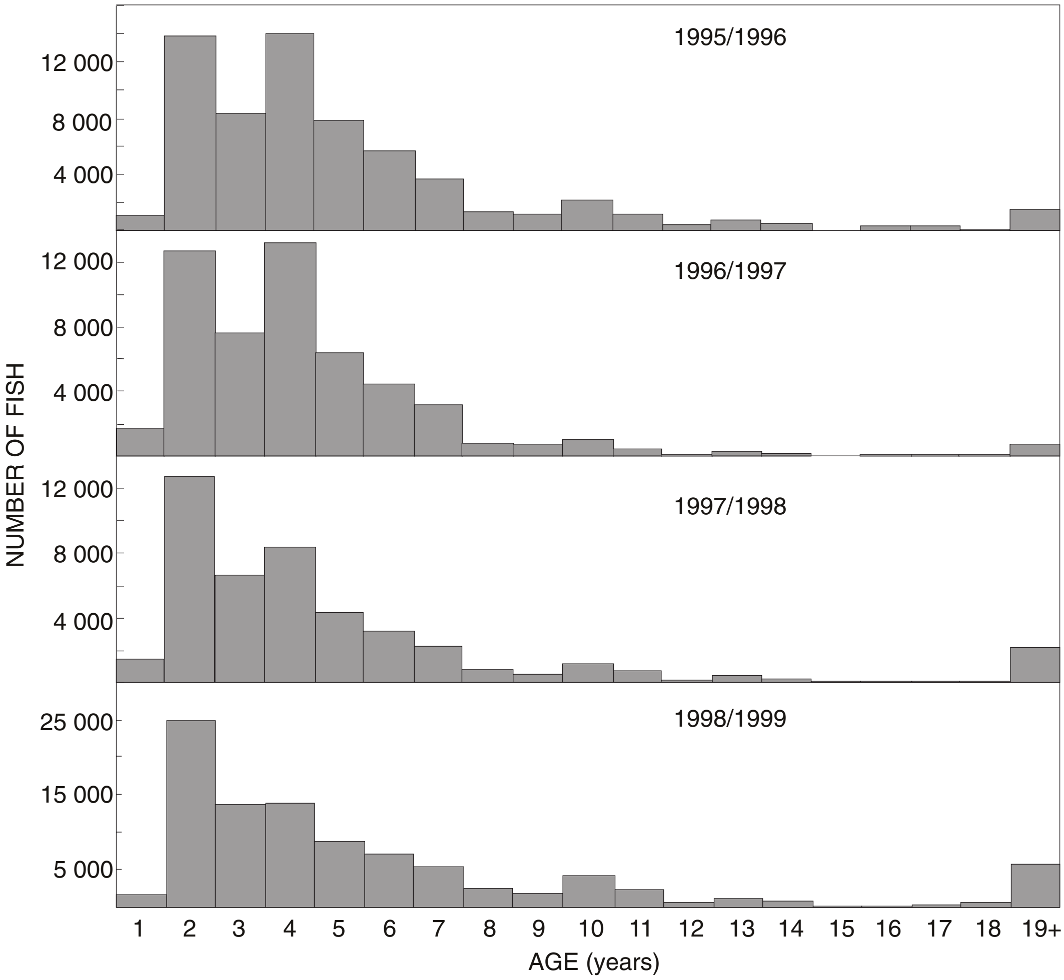

Fig. 2: Estimated total catch (by number) at age of West Coast steenbras caught by anglers during four seasons in the WCRA and the Torra Bay/Terrace Bay areas of the Namibian coast

Stock assessment models

In the absence of long-term catch data and knowledge on the spawner-recruitment relationship, Beverton and Holt yield- and spawner biomass-per-recruit models are considered to be the most suitable for stock assessment of this species. These models require values for somatic growth, natural mortality, fishing mortality and age at first capture (t_c) as input parameters. The models permit evaluation of different combinations of F and t_c on yield-per-recruit over the lifetime yield of a cohort. Reference points derived from these analyses are F_{MSY}, which denotes the fishing mortality rate that produces the maximum yield-per-recruit used as limit reference point, and $F_{SB(50)}$ as target reference point.

The term "depletion" used below describes the current state of the stock and is calculated by dividing spawner stock biomass by pristine spawner biomass. Yield-per-recruit models using different values of M (0.18, 0.23 and 0.27 year^{-1}) were run to determine the fishing mortalities at reference points.

AGE-BASED THOMPSON AND BELL MODEL

A Thompson and Bell model was used to test the

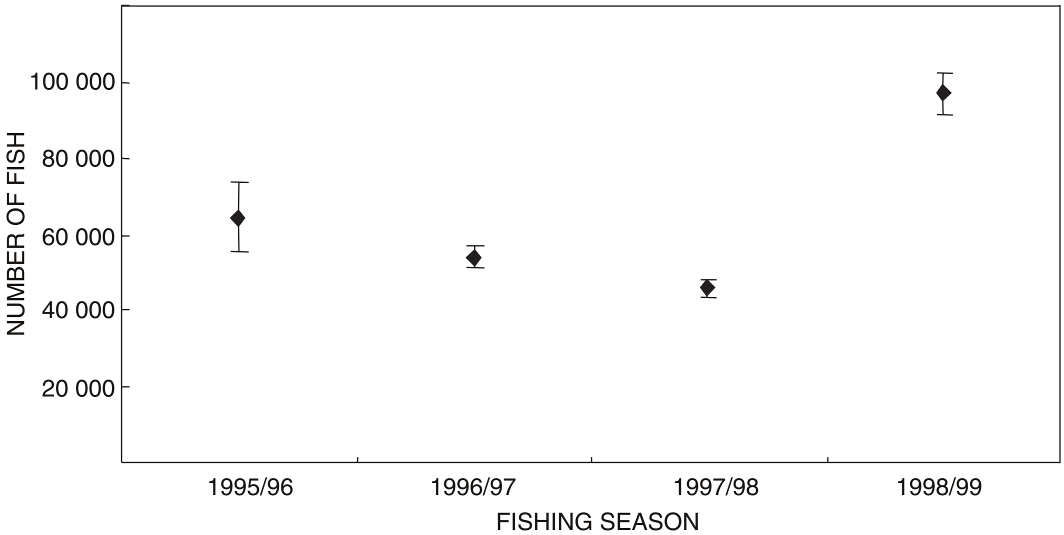

Fig. 3: Total catch (by number ±*SE*) of West Coast steenbras landed per season by recreational rock-and-surf anglers in the WCRA and Torra Bay/Terrace Bay areas of the Namibian coast

performance of some fisheries regulations. Age-specific schedules of fishing and natural mortality, growth in mass and sexual maturity, as well as the number of recruits (obtained with Pope's cohort analysis) were required as input to the model. Recruitment of West Coast steenbras to the fishery was assumed to be knife-edged, i.e. $S_t = 0$ if $t < t_c$ and 1 if $t \geq t_c$, where *S* denotes selectivity. The current percentage of females in the spawner stock biomass was calculated by assuming a knife-edge cut-off age between males and females, i.e. $P_t = 0$ if $t < t_f$ and 1 if $t \geq t_f$, where *P* denotes the proportion of females in an age-class.

New values of *F* were obtained by multiplying the reference *F*-array as a whole by a certain factor, usually called *X*, or by applying such factors only to a part of the reference array. The effects of changes in fishing mortality on the yield and the average biomass on introducing a minimum size limit of 40 cm (by changing *F* at age 1–4 to 0.0001) was investigated by carrying out a series of calculations with different values for *X* (*F*-factors).

Length-mass relationship

The relationship was calculated from the equation

$$W = aL^b \quad , \qquad (3)$$

where *W* is the mass (kg) and *L* is the fork length of the fish (cm). Parameters a and b were calculated by fitting Equation 3 to length-at-mass data collected from the northern population (n = 1 194).

RESULTS

Parameter values

From the Monte Carlo simulations, natural mortality for the northern Namibian population of West Coast steenbras ranged between 0.16 and 0.3 year^{-1}, with an estimated mean of 0.23 year^{-1} (95% percentiles between 0.18 and 0.27 year^{-1}). Total mortality was calculated from catch curve analysis based on catch-at-age data for the period 1995–1999 (Fig. 2), and it ranged from 0.30 to 0.43 year^{-1} with a mean estimate of 0.35 year^{-1}. By considering the ranges of *M* and *Z* in a Monte Carlo analysis, the average instantaneous fishing mortality (*F*) was estimated at 0.11 year^{-1}, with 95% percentiles between 0.05 and 0.17 year^{-1} (Table I).

Catches estimated from the roving-roving creel survey data are presented in Figure 3. Fish lengths were converted to age by use of an age-length key determined for the northern West Coast steenbras population (Holtzhausen and Kirchner 2001). After a decline over two years, catches increased markedly

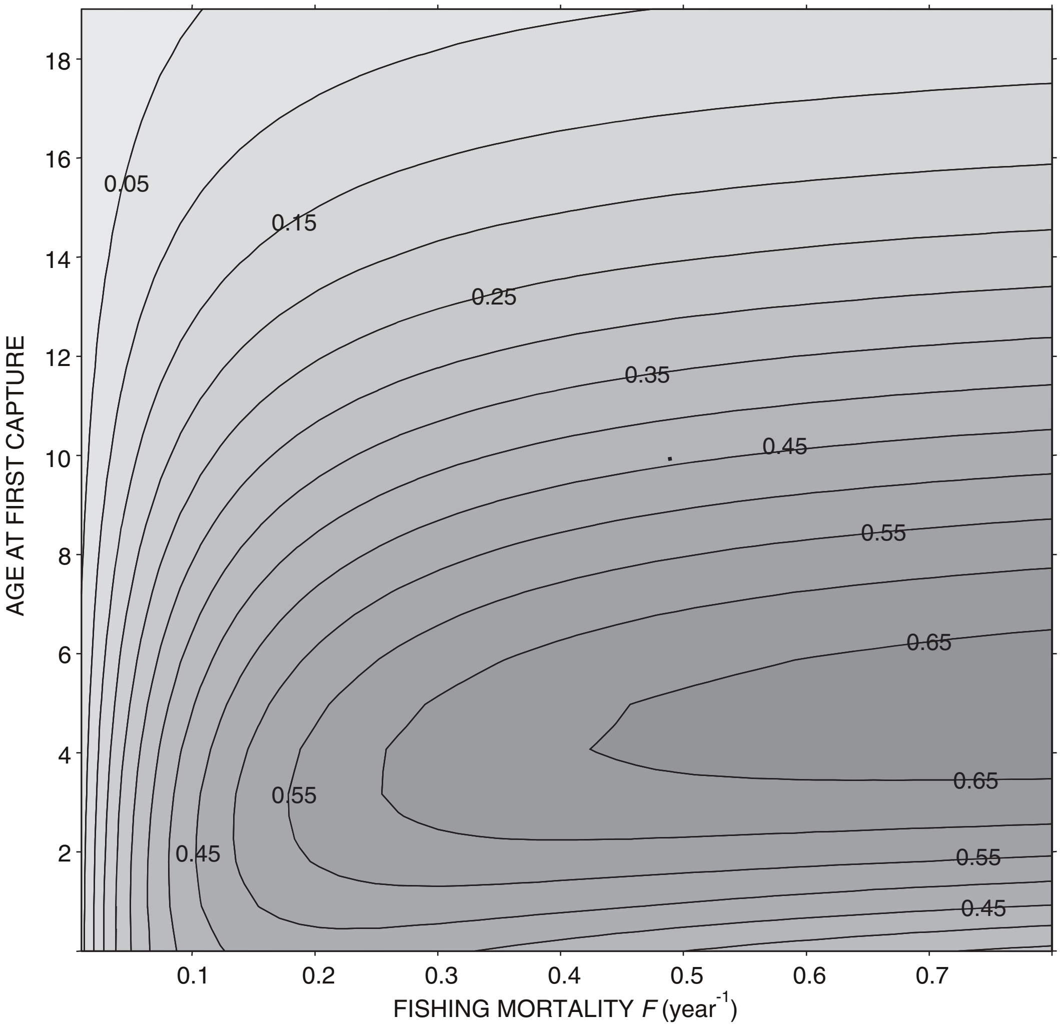

Fig. 4: Isopleths describing the response of yield-per-recruit to different combinations of fishing mortality and age-at-recruitment to the fishery schedules for the northern West Coast steenbras population (M = 0.23 year^{-1})

during the 1998/99 season, probably as a result of increased catches in the Torra Bay/Terrace Bay area. Catches from that area generally constitute up to 20% of the total catches of West Coast steenbras for the northern region, but in the previous season the proportion of the catch increased to 50%.

Catches at age, averaged over the study period, are presented in Table II and are assumed to be distributed normally within each age. These catches and their uncertainty, expressed in the form of a standard error, were used in a Pope's (1972) cohort analysis to estimate the F-at-age array 250 times with a Monte Carlo analysis, which was subsequently used in the Thompson and Bell model. Catches declined markedly after Age 11, with age-classes 2, 3 and 4 present in highest numbers (Table II). Bimodality in the age frequency, at Ages 2 and 4 (Fig. 2), appeared in all but the last season. This bimodality could be attributable to the complicated life history of a protandrous hermaphrodite such as West Coast steenbras (Holtzhausen 1999).

Table III: Results from the Beverton and Holt yield- and biomass-per-recruit models applied to the northern West Coast steenbras stock of Namibia

Parameter	Value		
	$M = 0.18$	$M = 0.23$	$M = 0.27$
Current *F*	0.17	0.12	0.08
$F_{SB(25)}$	0.23	0.29	0.35
$F_{SB(40)}$	0.13	0.17	0.2
$F_{SB(50)}$	0.09	0.12	0.14
MSY	0.24	0.37	0.52
Biomass level at *MSY*	23%	20%	17%
Current depletion	33%	50%	67%

Beverton and Holt assessment

The current fishing mortality of 0.12–0.17 year^{-1} for the recreational West Coast steenbras fishery in Namibia resulted in a depletion of between 33 and 67% of its unfished level. Fishing mortalities of reference points using the three natural mortality values (0.18, 0.23 and 0.27 year^{-1}) were calculated and are presented in Table III.

Yield isopleths (Fig. 4) displaying the response of the yield-per-recruit to different fishing mortalities and age at first capture, showed that yield-per-recruit increased rapidly for low values of *F*, for most of the age range. The response isopleths indicated that the maximum yield-per-recruit of 0.65 kg could be obtained by increasing the current level of t_c (i.e. 1) to 4 and increasing the fishing mortality to 0.4 year^{-1}. A t_c of 4 years equates to 40 cm, 5 cm more than the historical minimum size limit, which was recently abolished (Ministry of Fisheries and Marine Resources 1993). Currently, *F* is approximately 0.11 year^{-1} with a t_c of 2 years, and the isopleths show that the current yield-per-recruit is 0.45 kg.

At low values of t_c (1–3 years), reasonable yield-per-recruit (e.g. 0.55 kg) can only be obtained by fishing mortalities >0.2 year^{-1}. At present fishing mortalities, and if the current age at first capture of 2 years is changed by regulation to 4 years (40 cm), no increase in yield-per-recruit can be expected. It is only at higher fishing mortalities that yield-per-recruit would be greater, at a t_c >2 years (Fig. 4).

Thompson and Bell assessment

This model provided output values of the current level of depletion of the stock (i.e. ratio of the current spawner stock biomass to the pristine spawner biomass, where *F* = 0), current spawner biomass, current proportion of females in the total biomass, spawner biomass and *MSY*. Probability density functions for these outputs are presented in Figure 5.

Table IV: Estimated values for depletion, long-term spawner stock biomass, proportion of females in the spawner stock and total biomass, and the maximum sustainable yield of the northern stock of West Coast steenbras off Namibia

Parameter	Best estimate	95% percentiles
Depletion (%)	42	29–56
SSB (tons)	772	538–1 121
Females in *SSB* (%)	42	38–47
Females in biomass (%)	22	19–26
MSY (tons)	134	109–173

Probability density functions were obtained by estimating each output 250 times, each time using new randomly selected values as input values for a Pope's (1972) cohort analysis of catch at age (Table II), *M* and F_{term} (Table I). The mean current biomass level relative to the unfished level was estimated at 42%, with 95% percentiles at between 29 and 56% (Table IV); the current spawner biomass is some 772 tons. The maximum sustainable yield was estimated to be 134 tons. The proportion of females in the spawner biomass was estimated at 38–47%, with the best estimate at 42%. By introducing a minimum size limit of 40 cm, spawner stock biomass would increase by approximately 8%, so improving the spawning potential of the population in the long term. The depletion of the stock would also increase to 56%, with 95% percentiles between 43 and 68%.

The percentage fishing mortality against natural mortality per age group, which was obtained using age-specific natural mortality, is presented in Figure 6. Occasionally, for poorly understood fish stocks, a management procedure for keeping $F \approx M$ is used (Gulland 1970). This is possible as it has been shown that it is an adequate approximation of the optimal $F_{0.1}$ criteria in cases when $1 < M/K < 4$ (Deriso 1987); M/K for northern West Coast steenbras is approximately 2.6. Mortalities as a result of fishing for ages 1–8 do not exceed 20% for each of the age-classes (Fig. 6). Between ages 10 and 16, i.e. mostly females, the fishing mortality increases to 40%. The high fishing mortalities of fish >16 years are the result of the increased availability of large fish in Terrace Bay, where they aggregate every year in shallow water and present easy targets for recreational rock-and-surf anglers.

DISCUSSION

The results of the Beverton and Holt yield- and biomass-

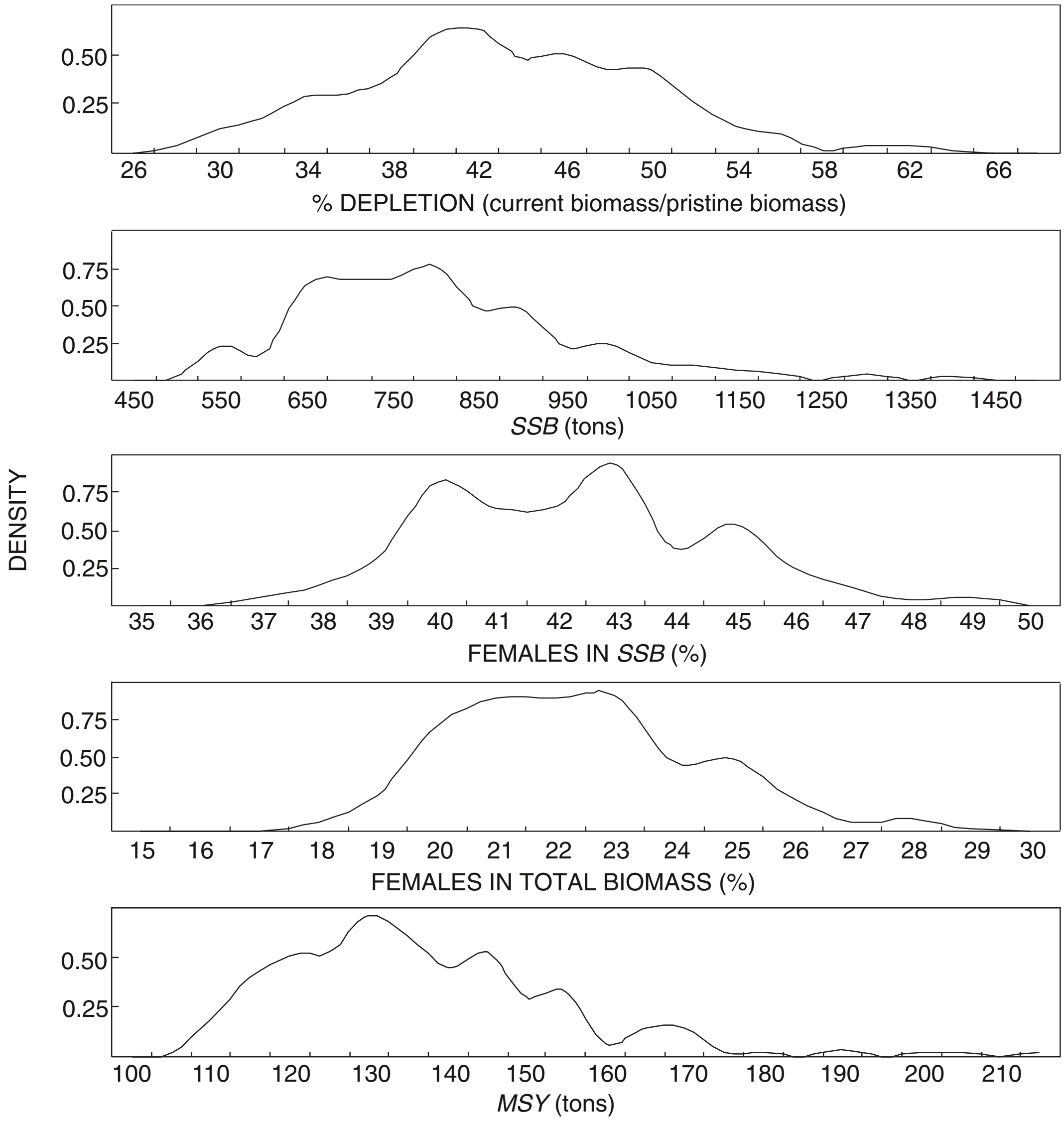

Fig. 5: Probability density functions of depletion, spawner stock biomass (*SSB*), *MSY* and proportions of females in the total and northern spawner stock biomass

per-recruit models indicate that the limit reference point for northern West Coast steenbras lies between 17 and 23% depletion (Table III). The current depletion using this model was estimated to be between 33 and 67%, with the best estimate at 50%, coinciding with the target reference point. These results show that the northern West Coast steenbras stock is fished optimally, and that there is no apparent damage to the stock structure (i.e. sex ratio, depletion and exploitation) so far (Table III).

The results of the Thompson and Bell model, however, point to a slightly different situation. For example, current biomass is estimated to be 42% of pristine (Table IV). If the result of this model were to be taken into consideration for management purposes, fishing mortality should be decreased slightly, i.e. by reducing

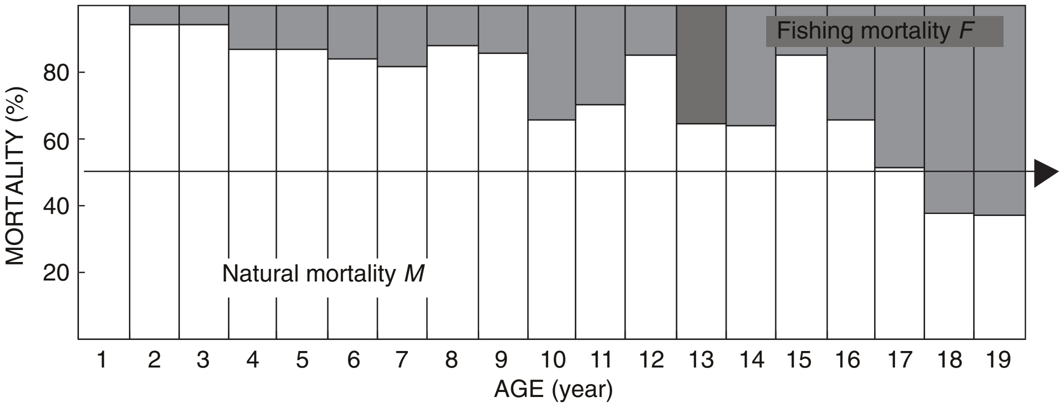

Fig. 6: Percentage mortality of northern West Coast steenbras of different ages attributable to natural causes *M*(*t*) and to fishing mortality by recreational rock-and-surf anglers off the Namibian coast

the daily bag limit. Real catches were used in this model, and some of the uncertainties associated with terminal fishing mortality, natural mortality and estimates of the recreational catch are accounted for by means of Monte Carlo simulations. Advice to management should therefore be based on the Thompson and Bell model. However, that model was based on an average of only four years of catch-at-age data and it would be appropriate to use a cautious approach in implementing any management measures based on the present results. The probability density functions for the different biological parameters are flat (Fig. 5), indicating the uncertainty of their estimates. The multiple peaks in these figures have no biological meaning. They appear because the simulations were most probably not sufficient to obtain smooth probability density functions.

The *MSY* for the northern stock of West Coast steenbras was estimated at between 109 and 173 tons, with a best estimate of 134 tons (Table IV). *MSY* has been denoted as the limit reference point, and catches should not exceed this value. However, in the 1995/96 season, the recreational yield equalled this value and in the 1998/99 season the total annual yield amounted to 245 tons, almost double the predicted *MSY*. If similar yields were taken in future, the West Coast steenbras stock would soon become overexploited.

The response of the isopleths (Fig. 4) suggested an age at first capture of 4 years (approximately 40 cm) and a fishing mortality of 0.4 year^{-1} to realize the full yield-per-recruit potential. As the age at which 50% of the steenbras are sexually mature is about 5 years, or 41 cm *FL*, a minimum size limit of 40 cm (approximately 4.5 years) would be sensible. If yield-per-recruit were to be improved by increasing the minimum size limit to 40 cm (4.5 years), the spawning potential of the stock would be greatly increased. More adult males would be able to fertilize females and more males would be available to change sex to become females.

Fishing mortalities appear to be too high for fish older than 16 years (65 cm *FL* – Fig. 6); fishing mortalities should ideally be equal to natural mortality for all age-classes (Gulland 1970). This statement has special relevance for West Coast steenbras because most females of the stock are 10 years and older, so older fish should be protected to provide a stable stock structure for optimal recruitment. Optimal recruitment should be obtained if there are more females than males in a population. This implies that, under ideal conditions, a population should consist of 50% or more females to ensure optimum egg production. Currently, 42% of spawner stock biomass is female. Although the results of the assessment indicate that the overall stock appears to be in a fairly healthy state, there are cautionary signals that suggest that the older part of the population should be protected.

West Coast steenbras inhabit the surf zone and are seldom found in water deeper than 10 m (JAH pers. obs.). This is further evidenced by the fact that commercial and recreational skiboats operating just behind the surf zone generally do not catch them, and only occasionally catch large specimens. Therefore, even without taking the model assessments into account, it is clear that the size of the stock is extremely small. West Coast steenbras are vulnerable to overfishing because of their life history, i.e. slow growth and longevity, protandry, in which older fish are all female, and high natural mortality. Information from this study should assist in developing and improving current fishery regulations, in order to preclude possible overexploitation of the species.

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LITERATURE CITED

ATTWOOD, C. G. and B. A. BENNETT 1990 — A simulation model of the sport-fishery for galjoen *Coracinus capensis*: an evaluation of minimum size limit and closed season. *S. Afr. J. mar. Sci.* **9**: 359–369.

ATTWOOD, C. G. and B. A. BENNETT 1995 — A procedure for setting daily bag limits on the recreational shore-fishery of the south-western Cape, South Africa. *S. Afr. J. mar. Sci.* **15**: 241–251.

BEYER, J. E., KIRCHNER, C. H. and J. A. HOLTZHAUSEN 1999 — A method to determine size-specific natural mortality applied to westcoast steenbras *Lithognathus aureti* in Namibia. *Fish. Res.* **41**(2): 133–153.

BEVERTON, R. J. H. and S. J. HOLT 1957 — *On the Dynamics of Exploited Fish Populations*. *Fishery Invest., Ser. 2* **19**. London; Her Majesty's Stationery Office: 533 pp.

BOOTH, A. J. and C. D. BUXTON 1997 — The biology of the panga, *Pterogymnus laniarius* (Teleostei: Sparidae), on the Agulhas Bank, South Africa. *Environ. Biol. Fishes* **49**: 207–226.

BOOTH, A. J. and A. E. PUNT 1998 — Evidence for rebuilding in the panga stock on the Agulhas Bank, South Africa. *Fish. Res.* **34**: 103–121.

BUXTON, C. D. 1992 — The application of yield-per-recruit models to two South African sparid reef species, with special consideration to sex change. *Fish. Res.* **15**: 1–16.

DERISO, R. B. 1987 — Optimal $F_{0.1}$ criteria and their relationship to maximum sustainable yield. In *Proceedings of an International Symposium on Stocks Assessment and Yield Prediction*. Christie, W. J. and G. R. Spangler (Eds). *Can. J. Fish. aquat. Sci.* **44**(Suppl. 2): 339–348.

F.A.O. 1995 — *Code of Conduct for Responsible Fisheries*. Rome; F.A.O.: 41 pp.

GABRIEL, W. L. and P. M. MACE 1999 — A review of biological reference points in the context of the precautionary approach. In *Proceedings of the Fifth National NMFS Stock Assessment Workshop: Providing Scientific Advice to Implement the Precautionary Approach under the Magnuson-Stevens Fishery Conservation and Management Act*. Restrepo, V. R. (Ed.). *NOAA tech. Memo*. **NMFS-F/SPO-40**: 34–45.

GRIFFITHS, M. H. 1997 — The application of per-recruit models to *Argyrosomus inodorus*, an important South African sciaenid fish. *Fish. Res.* **30**: 103–115.

GULLAND, J. A. 1970 — The fish resources of the ocean. *F.A.O. Fish. tech. Pap.* **97**: 425 pp.

HOLTZHAUSEN, J. A. 1999 — Population dynamics and life history of westcoast steenbras (*Lithognathus aureti* (Sparidae)), and management options for the sustainable exploitation of the steenbras resource in Namibian waters. Ph.D. thesis, University of Port Elizabeth: 213 pp.

HOLTZHAUSEN, J. A. and C. H. KIRCHNER 2001 — Age and growth of two populations of West Coast steenbras *Lithognathus aureti* in Namibian waters, based on otolith readings and mark-recapture data. In *A Decade of Namibian Fisheries Science.* Payne, A. I. L., Pillar, S. C. and R. J. M. Crawford (Eds). *S. Afr. J. mar. Sci.* **23**: 169–179.

KIRCHNER, C. H. 1998 — Population dynamics and stock assessment of the exploited silver kob (*Argyrosomus inodorus*) stock in Namibian waters. Ph.D. thesis, University of Port Elizabeth: 276 pp.

KIRCHNER, C. H. and J. E. BEYER 1999 — Estimation of total catch of silver kob *Argyrosomus inodorus* by recreational shore-anglers in Namibia using a roving-roving creel survey. *S. Afr. J. mar. Sci.* **21**: 191–199.

KIRCHNER C. H. and J. A. HOLTZHAUSEN 2001 — Seasonal movements of silver kob *Argyrosomus inodorus,* (Griffiths and Heemstra) in Namibian waters. *Fish. Mgmt Ecol*. **8**: 239–251.

MACE, P. M. and W. L. GABRIEL 1999 — Evolution, scope, and current applications of the precautionary approach in fisheries. In *Proceedings of the Fifth National NMFS Stock Assessment Workshop: Providing Scientific Advice to Implement the Precautionary Approach under the Magnuson-Stevens Fishery Conservation and Management Act*. Restrepo, V. R. (Ed.). *NOAA tech. Memo.* **NMFS-F/SPO-40**: 65–73.

MATLOCK, G. C. 1999 — The need for guidance on the precautionary approach and the proposed national standards guidelines. In *Proceedings of the Fifth National NMFS Stock Assessment Workshop: Providing Scientific Advice to Implement the Precautionary Approach Under the Magnuson-Stevens Fishery Conservation and Management Act*. Restrepo, V. R. (Ed.). *NOAA tech. Memo*. **NMFS-F/SPO-40**: 74–76.

MINISTRY OF FISHERIES AND MARINE RESOURCES 1993 — Sea Fisheries Regulations. *Government Gazette of the Republic of Namibia.* Act 29 of 1992 (Section 32): 55 pp.

PAULY, D. 1980 — On the interrelationships between natural mortality, growth parameters, and mean environmental temperature in 175 fish stocks. *J. Cons. int. Explor. Mer* **39**(2): 175–192.

POPE, J. G. 1972 — An investigation of the accuracy of virtual population analysis using cohort analysis. *Res. Bull. int. Commn NW. Atl. Fish.* **9**: 65–74.

PUNT, A. E., GARRATT, P. A. and A. GOVENDER 1993 — On an approach for applying per-recruit methods to a protogynous hermaphrodite, with an illustration for the slinger *Chrysoblephus puniceus* (Pisces: Sparidae). *S. Afr. J. mar. Sci.* **13**: 109–119.

RICKER, W. E. 1975 — Computation and interpretation of biological statistics of fish populations. *Bull. Fish. Res. Bd Can.* **191**: 382 pp.

SERCHUK, F. M., RIVARD, D., CASEY, J. and R. K. MAYO 1999 — A conceptual framework for the implementation of the precautionary approach to fisheries management within the Northwest Atlantic Fisheries Organization (NAFO). In *Proceedings of the Fifth National NMFS Stock Assessment Workshop: Providing Scientific Advice to Implement the Precautionary Approach Under the Magnuson-Stevens*

Fishery Conservation and Management Act. Restrepo, V. R. (Ed.). *NOAA tech. Memo*. **NMFS-F/SPO-40**:34–45.
SPARRE, P., URSIN, E. and S. C. VENEMA 1989 — Introduction to tropical fish stock assessment. 1. Manual. *F.A.O. Fish. tech. Pap.* **306/1**: 337 pp.
SPARRE, P. and S. C. VENEMA 1992 — Introduction to tropical fish stock assessment. 1. Manual. *F.A.O. Fish. Tech. Pap.* **306/1**(Rev.2): 376 pp.
THOMPSON, W. F. and F. H. BELL 1934 — Biological statistics of the Pacific halibut fishery. 2. Effect of changes in intensity upon total yield and yield per unit of gear. *Rep. int. Fish. (Pacific Halibut) Commn* **8**: 1–49.
VAN DER BANK, F. H. and J. A. HOLTZHAUSEN 1998/1999 — A preliminary biochemical genetic study of two populations of *Lithognathus aureti* (Perciformes: Sparidae). *Sth. Afr. J. aquat. Sci.* **24**(1/2): 47–56.