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INVESTIGATION ON THE EFFECTS OF DIFFERENT LEVELS OF EFFORT AND OF THE CLOSED SEASON IN THE JIG FISHERY FOR CHOKKA SQUID *LOLIGO VULGARIS REYNAUDII*

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After effort control, the closed season is the most important management tool used to regulate fishing mortality in the South African jig fishery for chokka squid *Loligo vulgaris reynaudii*. The dynamics of the stock biomass on the spawning grounds were modelled in order to assess the effects of current effort levels and the existing closed season on the resource. The model assumes that process error dominates over observation error. The model has three parameters: *g,* a parameter which combines natural mortality, emigration and somatic growth; *q,* the catchability; *I,* which represents immigration to the spawning grounds. Estimates of the parameters were obtained by fitting the model to catch per unit effort data, and were used to project the stock biomass forward in time to evaluate the impact of various effort levels both with and without a closed season. Results from the study indicate that the biological and economic gains provided by the current closed season are small and that there is little justification for urgent action to curtail current effort levels. However, in view of the apparently high risk associated with the current levels of effort and the great sensitivity of the results to basic model assumptions, both maintenance of the closed season and avoiding increases above the current level of effort are recommended. Further, the level of effort may need to be reduced, and the option of lengthening an existing closed season to effect this may well prove easier to implement than any attempt to reduce the present number of participants in the fishery.

The chokka squid *Loligo vulgaris reynaudii* is widely distributed along the west and south coasts of South Africa (Augustyn 1989). The jig fishery targets primarily on inshore spawning concentrations, in waters generally no deeper than 50 m. The area where spawning is more intense is situated between Plettenberg Bay and east of Port Elizabeth (Fig. 1). There is still uncertainty about the extent of spawning offshore, although viable eggs have been found in waters as deep as 150 m (Roberts and Sauer 1994).

There are also many other unknowns in the life cycle and population dynamics of the chokka squid. The typical lifespan for males and females, the various somatic growth parameters, the factors that regulate chokka migratory processes and the timing and spatial distribution of the immigration to the spawning grounds are all issues that have to be considered when modelling the resource dynamics, but which are still poorly understood for this stock. Furthermore, no estimates in absolute terms of the total stock biomass or of the spawning biomass have yet been obtained, and only relative indices of stock biomass from demersal surveys are available from 1986 to date. The level of uncertainty generated by these outstanding issues translates to the reliability of any resource assessment.

Although annual chokka catches have not yet surpassed 11 000 tons, the jig fishery is one of South Africa's most valuable fisheries. Most of the catch is exported to Europe (mainly Italy and Spain), and the estimated wholesale value at first sale in 1995 was close to R104 million or US $22 million in 1997 (Cochrane *et al.* 1997). The fishery is regulated by means of a closed season of variable length, and effort restrictions in the form of limits on the number of vessels and number of men on board. Furthermore, it is forbidden to catch chokka in the Tsitsikamma National Park (Fig. 1), where intensive spawning has been observed in the past. However, in spite of the fact that entry to the fishery was closed in 1987, there has been a subsequent creeping increase in effort, as measured by the numbers of hours fishing (Fig. 2). Together with this increase, there has been an expansion of the fishing grounds to cover areas farther offshore where adult squid are also found (G. Christy, South African Squid Management Industry Association, pers. comm.) After overall effort control, the most important management tool in the jig fishery is the closed season, which was first implemented in 1988. For the first three years of implementation the closed season was enforced for the whole of November, but since 1991 it has extended from about the last week of October to mid November.

In this paper, the effects on the stock of various

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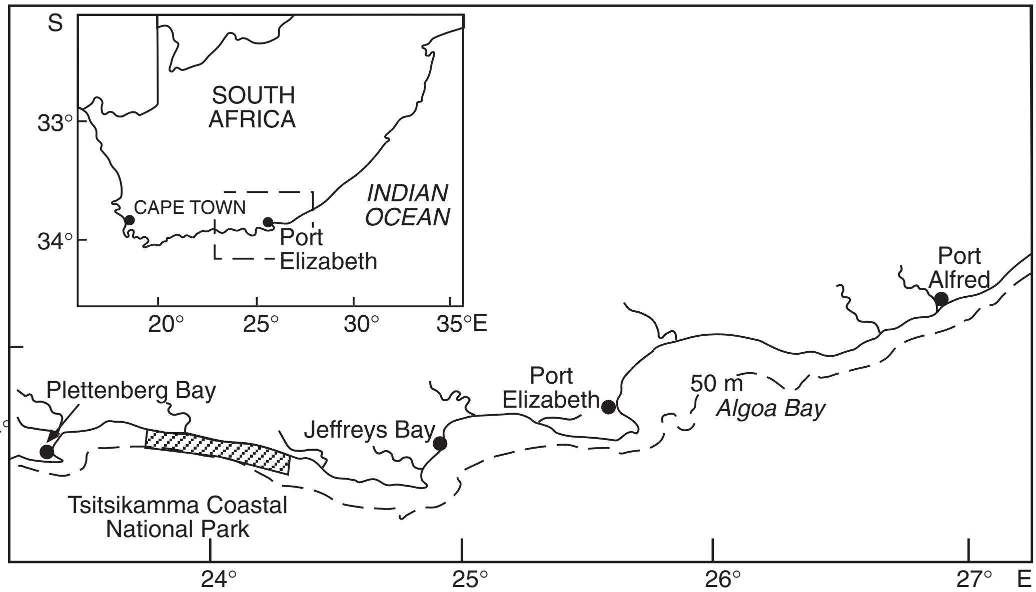

Fig. 1: Main area of operation of the jig fishery for chokka squid *Loligo vulgaris reynaudii*

levels of effort, both with and without a closed season, are modelled. In order to do so:

- a biomass dynamic model with monthly timescale was developed;
- catch per unit effort (*cpue*) was used as an abundance index;
- the sensitivity to key model assumptions was evaluated;
- the impact on the resource of varying effort levels was projected.

The objective of the exercise is to use the information available about the fishery and what is known about chokka squid dynamics to assess the consequences of these factors for quantities that could be relevant to both the squid fishing industry and for managing the resource.

MATERIAL AND METHODS

Data

The data used for the study were the catches and corresponding effort from 1985, the year when the boat owners or skippers first submitted such data, until the end of 1996. The original data consist of daily records of catch in mass and effort expressed in terms of number of men on board multiplied by the hours spent at sea, which is roughly proportional to effective effort. Calculations of *cpue* were based on data from boats carrying between 4 and 20 men on board; data from boats carrying more men were excluded. The rationale for this is that boats carrying more than 20 men have some involved in packing and handling and therefore that the boat's catch would no longer be directly proportional to the number of men on board. The time unit chosen for analysis was one month, which was considered suitable for the approach taken and given the relatively short life of chokka. The monthly effort data were averaged for each month from 1988 to 1995 to determine the monthly pattern of effort deployed in the fishery. This period was selected because the closed season was first implemented in 1988 and, although there has been an increase in effort since then, the assumption is made that the monthly effort pattern has not changed over the period. The monthly pattern of relative effort levels is indicated by the vector $\{\lambda_{Jan}, \lambda_{Feb}, \dots \lambda_{Dec}\}$, where $\lambda_{Sep}=1$, because September is the month in which most effort is applied.

Modelling the biomass on the spawning grounds

Given the sparseness of information available for the study, it was considered impossible to distinguish between the effects of natural mortality, emigration

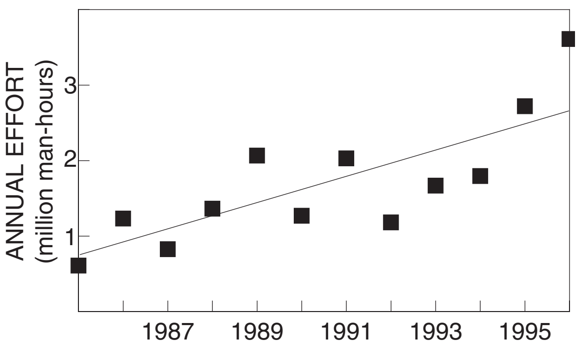

Fig. 2: Annual jigging effort in the South African chokka squid fishery, 1985–1996

and somatic growth in the resource. The approach taken was therefore to aggregate these processes in a single parameter g, treated as an annual rate, which would account for their net effect on the biomass. For this type of short-lived organism, the value of the instantaneous rate of natural mortality is expected to be high. For example, Beddington *et al.* (1990) used a value of $3{\cdot}1{\cdot}\text{year}^{-1}$ in their assessment of *Illex argentinus* around the Falkland Islands. Another possible scenario for chokka squid is low constant mortality while on the spawning grounds, followed by high mortality or emigration at the end of the spawning season. There has been much speculation about post-spawning mortality in chokka, such as has been found for other species of cephalopods, but it has not yet been documented. In contrast, dispersal after spawning and before death may be more prevalent in chokka (Augustyn 1990).

The association of egg capsules with the inshore runs of chokka, together with the fact that the state of maturity of the animals caught in the jig fishery indicates that they are either mature or, in the case of males, spent, give ample evidence that inshore presence in the study area is related to spawning migration (Augustyn 1990). Immigration to the spawning grounds seems to take place in the form of discrete runs (Augustyn 1990). Although this can take place year-round, there is normally one peak in spawning intensity, in spring and early summer, with a variable smaller peak in autumn or winter (Augustyn 1990, Sauer 1991). Monthly chokka squid catches from the jig fishery therefore reflect largely the changing abundance of chokka on the spawning grounds.

Immigration is modelled as a pulse arriving at the fishing grounds at the beginning of each month during the "spawning season", which takes place from May to December. The period selected was based on the decrease in the average mantle lengths (taken to reflect immigration of younger animals) observed in length frequency samples of the catches analysed by Sauer (1991). The expected monthly recruitment or immigration to the spawning grounds (I_m) is assumed to remain constant throughout the season and from year to year, i.e.

$$\begin{aligned} I_m &= I, \text{ for } m = 5...12 \\ I_m &= 0, \text{ for } m = 1...4 \quad . \end{aligned} \tag{1}$$

Brodziak and Rosenberg (1993), in their model of the inshore *Loligo pealei* fishery off Cape Cod in the NW Atlantic, estimated a similar parameter to I_m, denoting the flow in the number of squid into the fishing area over a certain period.

Overall then, the dynamics of the biomass on the spawning grounds (B) are described in this study in terms of a composite parameter (g) defined above, a second parameter (I) which reflects immigration to these grounds, and the catches taken (C). At the beginning of month m in year y the biomass on the spawning grounds is given by:

$$\begin{aligned} B_{y,m} &= B_{y,m-1}\, e^{-g/12} + I_m - C_{y,m-1} + \eta_{y,m} \\ B_{y+1,1} &= B_{y,12}\, e^{-g/12} + I_{12} - C_{y,12} + \eta_{y,12} \quad , \end{aligned} \tag{2}$$

where the process error term $\eta_{y,m}$ primarily reflects variation about the expected level of immigration indicated by Equation (1), both within and outside the "May–December" spawning season. It also subsumes the effect of monthly variability of g about its average value used in the model, and therefore $\eta_{y,m}$ is assumed to be constant for all months. The monthly catch per unit effort $(C/E)_{y,m}$ is assumed to be proportional to the biomass on the spawning grounds:

$$(C/E)_{y,m} = q\, B_{y,m} \quad , \tag{3}$$

where the constant of proportionality q is termed the catchability. Note that this equation omits an observation error term. This is because the analyses that follow rest on the assumption that the variability in the magnitude of the monthly chokka immigration swamps variability in the *cpue*-biomass relationship (i.e. process error dominates observation error), so that observation error can be ignored. This assumption is considered to be justified because squid are short-lived and hence recruitment (immigration) is a large component of the biomass on the spawning grounds (Pierce and Guerra 1994). Unlike the situation for longer-lived fish populations which include many cohorts, the resultant variability contributed to Equation (2) would be expected to be relatively large

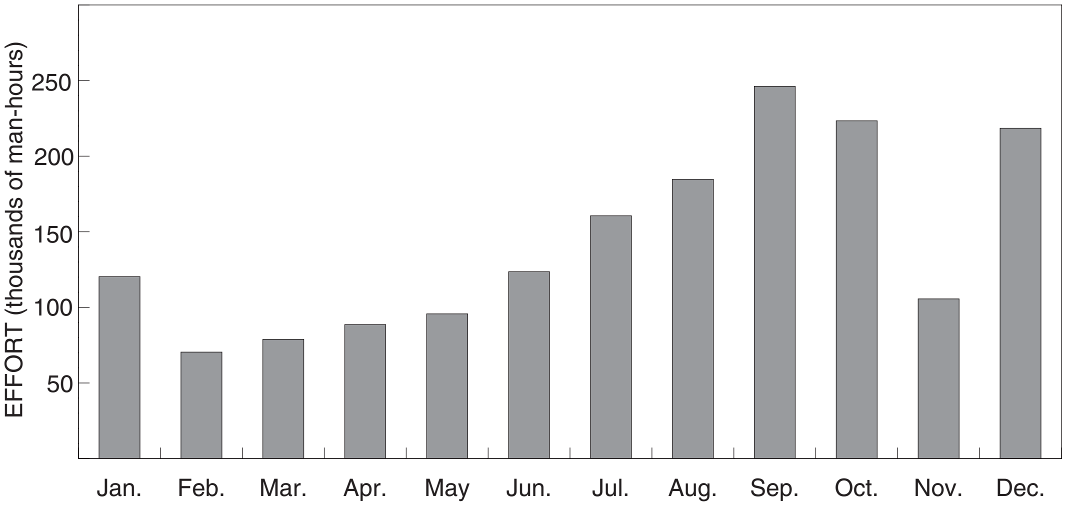

Fig. 3: Average monthly effort in the South African chokka jig fishery estimated from data from 1988 to 1995

in the case of squid.

Combining Equations (2) and (3) yields:

$$\begin{aligned}(\widehat{C/E})_{y,m} &= (C/E)_{y,m-1}\, e^{-g/12} + qI_m - q\, C_{y,m-1} \\ (C/E)_{y,m} &= (\widehat{C/E})_{y,m} + \eta'_{y,m} \quad ,\end{aligned} \tag{4}$$

where $(\widehat{C/E})_{y,m}$ is the monthly catch per unit effort predicted by the model, and

$$\eta'_{y,m} = q\ \eta_{y,m} \quad .$$

A process error estimator can then be constructed to estimate the three model parameters (g, I and q) by fitting to the monthly *cpue* data using a least squares criterion:

$$\begin{aligned}SS\,(g, I, q) &= \Sigma\ \{\eta'_{y,m}\}^2 \\ SS\,(g, I, q) &= \Sigma\ [(C/E)_{y,m} - (C/E)_{y,m-1}\, e^{-g/12} - qI_m + qC_{y,m-1}]^2 \,.\end{aligned} \tag{5}$$

However, experimentation on this basis showed that the data were not sufficiently informative to admit estimation of all three parameters. Accordingly the value for g was fixed externally, with results being evaluated for three different possibilities (g = 1, 1.5 and 2). Values less than 1 were not considered plausible given the short life of this species; values above 2 led to unrealistically high values for the biomass estimated. Taking partial derivatives of SS with respect to q and the composite parameter $I^* = I\,q$, and setting the results to zero, yields a pair of simultaneous linear equations in q and I^* which are readily solved to provide estimates for q and I for a given input value of g. Note that this process corresponds to maximum likelihood estimation if the assumption is made that the η' are normally distributed. Other forms could be argued for this distribution, but they would not have the convenience of closed form solution for q and I^*, as does the normality assumption.

The process error variance ($\hat{\sigma}^2$) was estimated from:

$$\hat{\sigma}^2 = {}^1\!/_n\ \Sigma\ (\eta'_{y,m})^2 \quad , \tag{6}$$

where n is the number of year-month combinations considered. Values for *cpue* can be unrepresentative in months with low fishing effort, which likely correspond to large sampling variability. The summation in Equation (6) therefore excluded all months for which the effort level was less than 5 000 h, which corresponds approximately to 2% of the effort deployed by the current fleet. The months excluded as a result of applying this criteria were: January–July 1985, and November of 1989 and 1990. This is in the spirit of the process error estimator approach used here, which assumes that observation error is zero. These exclusions effectively omit data for which the observation error might be high.

Sensitivity tests were undertaken on the assumption of a constant g throughout the year and on the value of the threshold in the stock-recruit relationship. The details and results of these tests are presented under the section Results and Discussion.

Bootstrap estimation of confidence intervals

Simulated time-series of *cpue* [$(C/E)^s_{y,m}$] were generated by parametric bootstrapping for the three values of $\hat{g}$ considered, given the associated best estimates of the model parameters: $\hat{I}$, $\hat{q}$ and $\hat{g}$. Each such new data set was generated by randomly sampling from the normal probability distribution estimated for the residuals and adding a "new" residual to each predicted data point:

$$(C/E)^s_{y,m} = (C/E)^s_{y,m-1}\, e^{-\hat{g}/12} + \hat{q}\,\hat{I}_m - \hat{q}\, C^s_{y,m-1} + \eta^{*s}_{y,m} \quad , \quad (7)$$

where η^* is drawn from a normal distribution $N(0, \sigma^2)$ and the first *cpue* value in the series was taken to be equal to that observed. Note that each $(C/E)^s_{y,m-1}$ is treated as the preceding "actual" data point when the $(C/E)^s_{y,m}$ value is generated. While such bootstrap resampling is generally straightforward for observation error estimators, some care has to be taken in a process error situation to preclude unrealistic outputs. Therefore, in order to reduce the possibility that Equation (7) generates negative *cpue* values, the simulations were conditioned on the observed effort values, so that the simulated catches used in that equation were

$$C^s_{y,m-1} = (C/E)^s_{y,m-1}\, E_{y,m-1} \quad . \quad (8)$$

Nevertheless, some negative *cpue* values arose. To overcome this problem, the error term η^* was regenerated whenever the *cpue* that would otherwise have followed under Equation (7) was less than 5% of the previous month's value. In spite of this constraint, a small number (less than 10% of the simulated time-series), resulted in negative parameter estimates that are not biologically realistic. This proportion was considered sufficiently small for them to be discarded, with inferences concerning precision being based on the remainder.

This process was used to provide 1 000 replicate sets of parameter estimates which, on ordering, provided estimates of confidence intervals directly.

Projections

After obtaining estimates of the parameters $\hat{I}$, $\hat{q}$ and $\hat{\sigma}$, and their confidence limits, these estimates were used to assess the impact of various levels of effort and of the closed season on the resource and fishery. Time-series of *cpue* were generated by projecting the biomass forward using the most recent observation $(C/E)_{1996,12}$ as a starting point, and a set of parameters estimated from one of the bootstrap replicates (I^s, q^s and σ^s). These projections covered a period of 10 years, during which the annual fishing effort level was kept constant, and followed the average monthly pattern observed in the fishery since 1988, when the closed season was first enforced (Fig. 3). Thus, the simulated *cpue* for a future year and month was given by:

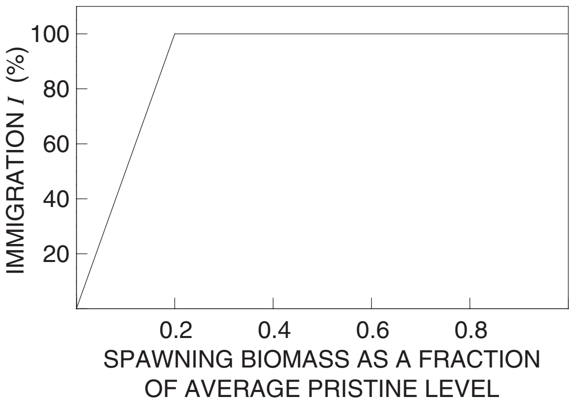

Fig. 4: Monthly immigration (I) in relation to previous year's spawning biomass of chokka squid

$$(C/E)^s_{y,m} = (C/E)^s_{y,m-1}\, e^{-g/12} + q^s I^s_m - q^s C^s_{y,m-1} + \eta^{*s}_{y,m} \quad , \quad (9)$$

where $\eta^{*s}_{y,m}$ was drawn from $N(0, (\sigma^s)^2)$.

The simulated catch $C^s_{y,m}$ was set by

$$C^s_{y,m} = \min\,\{(C/E)^s_{y,m}\, E_m;\ 0.95\, B^s_{y,m}\} \quad , \quad (10)$$

where $B^s_{y,m} = (C/E)^s_{y,m} / q^s$ and the effort E_m applied in a particular month is given by

$$E_m = E_{max}\lambda_m \quad , \quad (11)$$

where E_{max} is the maximum monthly effort applied in a year (in September, so that $\lambda_{September} = 1$ – see Fig. 3).

In the projections, E_{max} was increased in steps to a level where the resource was considered seriously depleted, in order to investigate the effects of different levels of effort, with and without the closed season. The closed season scenario was simulated by applying the past average monthly effort pattern, whereas that without a closed season had the maximum effort from September to November, i.e. $\lambda_m = 1$ for those three months. The "risk" associated with a particular effort level E_{max} was defined as the proportion of the 1 000 projections in which the average biomass between October and December fell below 20% of the average pristine, defined as completely unfished,

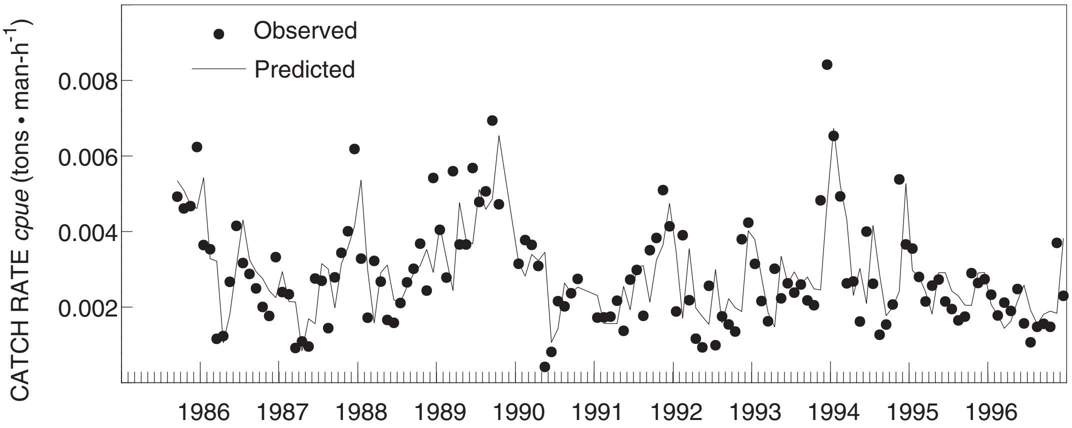

Fig. 5: Observed and model-predicted monthly catch rate according to the base case

spawning biomass for the parameters of that simulation, at least once within 10 years. The period October–December was chosen as representative of the effective spawning biomass based on the morphological studies of Augustyn (1989) and Sauer (1991), coupled with behavioural observations (Sauer *et al*. 1992) that indicate that the spawning intensity is at its maximum during these months.

In the absence of any information on the relationship between the size of the parental stock and subsequent immigration, the average immigration level, *I*, was assumed to be constant, as in Equation (1), provided the average biomass between October and December of the previous year was >20% of the average pristine biomass for the same three months. Below this threshold, *I* and the standard deviation of the associated process error, η^*, were reduced linearly in proportion to the spawning biomass in the previous year, as shown in Figure 4. This 20% threshold level was suggested in a paper by Clark *et al*. (1985) and has been used frequently since in fishery management evaluations (e.g. Butterworth *et al*. 1993 for the South African anchovy) as indicative of a level below which spawning success might be impaired. Basson and Beddington (1993) refer to a threshold level of 14% for the Falkland Islands *Illex argentinus* fishery, which they advance on the basis of the lowest estimated spawning biomass level that had led to viable recruitment in the following year. However, in light of the weak basis for their suggestion, they also investigated the sensitivity of their results to this assumption by considering two other levels, 7 and 27%. The standard choice of 20% was retained here, noting that it reflects a more conservative approach than would use of the 14% suggested by Basson and Beddington (1993).

RESULTS AND DISCUSSION

The parameter estimates, with their corresponding 95% confidence intervals represented by the 2.5th and 97.5th bootstrap percentiles, are given in Table I. The near invariance of the estimates of σ as *g* is varied reflects the earlier assertion above that there is insufficient information in the *cpue* data to estimate all three of the *q*, *I* and *g* parameters. The consequence of increasing *g* is an increase in the estimate of immigration *I* to compensate for the higher net losses.

The confidence intervals of the parameters are

Table I: Estimates of model parameters *I* (immigration), *q* (catchability) and σ (standard deviation of the residuals), together with 95% confidence invervals (*CI*), for three values of the composite parameter *g*

G	*q*	*CI*	*I* (tons)	*CI*	σ	*CI*
1.0	$0.465E^{-6}$	$0.14E^{-6}$; $1.10E^{-6}$	1 479	825; 3 940	$0.114E^{-2}$	$0.096E^{-2}$; $0.124E^{-2}$
1.5	$0.377E^{-6}$	$0.091E^{-6}$; $1.06E^{-6}$	1 984	988; 7 400	$0.114E^{-2}$	0.094^{-2}; $0.122E^{-2}$
2.0	$0.293E^{-6}$	$0.051E^{-6}$; $0.976E^{-6}$	2 752	1 108; 13 647	$0.113E^{-2}$	$0.094E^{-2}$;$0.122E^{-2}$
1.0*	$0.556E^{-6}$	$0.69E^{-6}$;$1.23E^{-6}$	1 121	1 108; 2 381	$0.116E^{-2}$	$0.11E^{-2}$; $0.124E^{-2}$

*g variable over the year (see text)

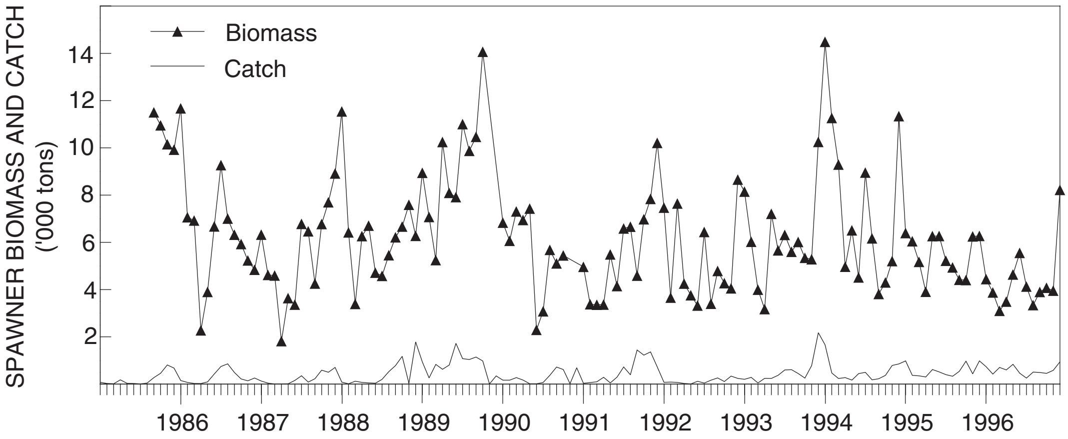

Fig. 6: Base case scenario estimates of spawning biomass and actual monthly catch data in the chokka squid jig fishery

wide and indicate skew distributions. For the moment, effort is concentrated on the *base case* with $g = 1$. As this is the case with the lowest biomass estimates, it is likely to be the one that leads to the greatest concerns in any "risk" context.

The observed and model-predicted *cpue* values for $g = 1.0$ are shown in Figure 5. The apparently good agreement is misleading in that it is to a large extent a consequence of the process error estimator approach which uses the observed *cpue* from one month to predict the *cpue* for the following month – see Equation (4). In fact, once this factor is discounted, the predictive ability of Equation (4) is seen to be quite weak – a reflection of the rather large value of the residual standard deviation, σ (see Table I), which in turn suggests that immigration varies considerably from month to month. Nevertheless, the model has allowed a first estimation of key parameters such as immigration to the spawning grounds (I), and of the underlying dynamics of the resource. The associated estimated biomass time-series is shown in Figure 6 together with the actual catches. Although, of the three values considered, $g = 1$ leads to the lowest estimated biomass levels, these still remain well above the actual catch at all times.

Evaluation of the effects of different effort levels and of the closed season

The effects of different levels of fishing effort, both with and without a closed season, on the resource biomass and the expected catches are shown in Figures 7 and 8. In both cases the effort shown on the horizontal axis corresponds to that in September, i.e. the month for which the effort is at its maximum over the year ($\lambda = 1$, see Equation 11).

The effective spawning biomass, calculated as the average of this biomass at the start of each of October, November and December, at the end of the 10-year projection period is represented in Figure 7 by the median over 1 000 simulations. This plot shows that the biomass is only marginally higher for the same maximum monthly effort when the closed season is in place. However, Figure 8 does indicate some gain in median annual catch given a closed season when the maximum monthly effort level is more than a million hours. Nevertheless, the improvement derived from the closed season is slight, which is not surprising given that it achieves

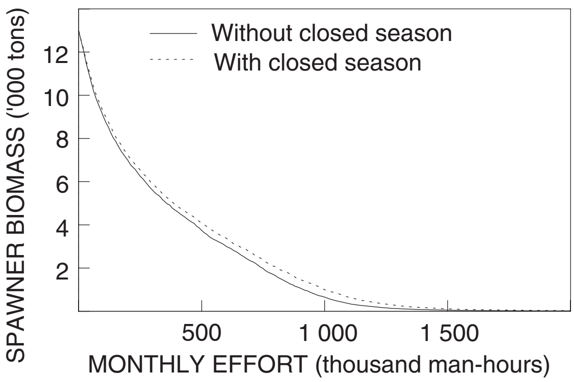

Fig. 7: Average spawning biomass of chokka squid at the end of 10-year projections with and without a closed season in place, according to the base case

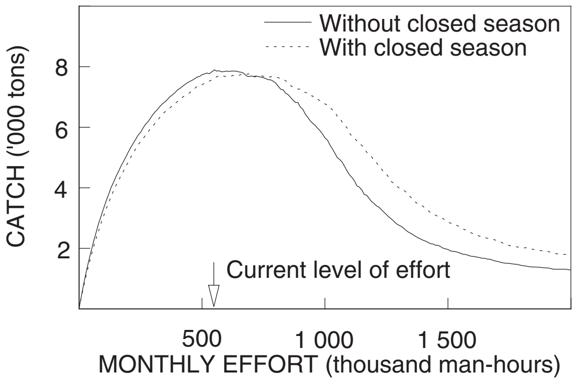

Fig. 8: Median annual catch of chokka squid over 10-year projections with and without a closed season in place, according to the base case

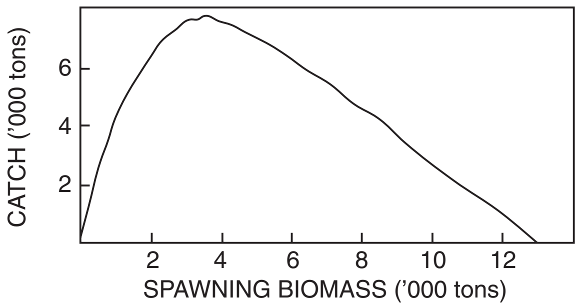

Fig. 9: Relationship between catch and spawning biomass of chokka squid over 10-year projections

only a 9% reduction of total annual effort. In reality, if the closed season results in a shift of some of the effort that would otherwise have been applied at that time to the rest of the fishing season, the conservation benefit would be even less.

The other primary question to be addressed is the appropriateness or otherwise of the current effort level in the light of these computations. An estimate of the annual effort currently exerted on the resource is 3.6 million hours, which corresponds to an effort level of 520 thousand hours in terms of a monthly maximum. Figure 7 shows that the spawning biomass would have been reduced to about one-third of its average pristine level under that level of fishing. Whether or not this indicates that the resource is being overexploited depends on the level of spawning biomass at which the maximum yield from the resource is attained. In order to determine that level, the median catch at the end of a 10-year projection at a constant level of effort was plotted against the corresponding spawning biomass at the end of that same period. The process was repeated at various levels of increased effort to generate the catch v. spawning biomass curve shown in Figure 9. The results indicate that, on average, the maximum sustainable yield is at biomass levels in the vicinity of 25% of pristine. The maximum yield that could be obtained from the resource as estimated in these simulations, and the annual effort that generates it, are shown in Table II for the various scenarios investigated. For the base case, current effort is well below the level generating maximum yield.

However, in addition to examining maximum average catch, in order to properly evaluate the long-term impact of such a level of effort, other performance statistics need to be examined. For example, the associated risk of falling below 20% of the average pristine spawning biomass level ("20% pristine") is estimated to be as high as 76%, a level much higher than the 30% over a 20-year period applied at present in managing the South African anchovy resource (Butterworth *et al*. 1993), also a short-lived species. The lowest spawning biomass levels attained are represented by the lower 5 percentiles of the distribution of lowest biomass values obtained in the 10-year projections. They are plotted in Figure 10. The graph shows that the 20% pristine level corresponds to relatively low levels of effort, again indicating very little benefit obtained from the current closed season.

In summary, there is no major biological or economic benefit to be derived from the existing closed season if the maximum monthly effort remains below 700 000 hours. Conversely, at effort levels greater than 800 000 hours, catches are better under a closed

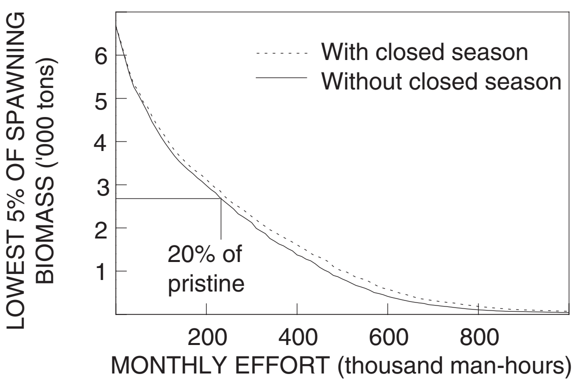

Fig. 10: Lowest 5% of spawning biomass distribution of chokka squid over 10-year projections with and without a closed season in place

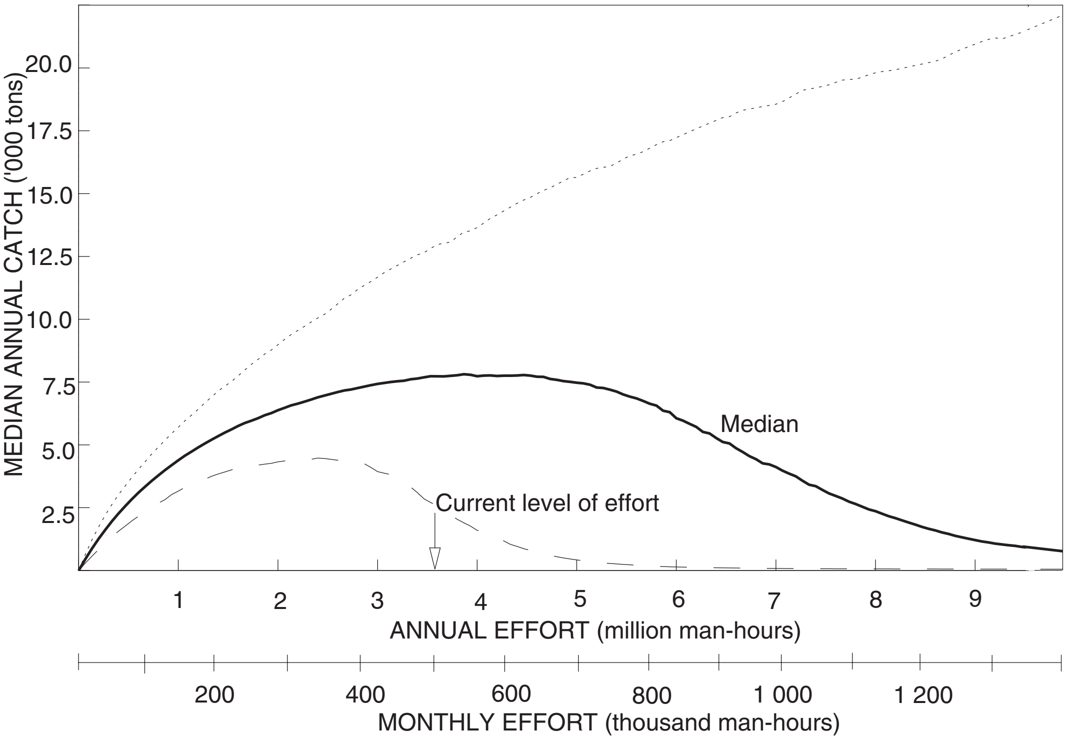

Fig. 11: Median annual catch of chokka squid over 10-year projections, and the corresponding 95% probability intervals at different levels of effort

season (see Fig. 8) because, in such circumstances, the long-term biomass level of the stock is improved. At present, with effort levels of about 520 000 hours (monthly maximum), these considerations alone suggest a case for allowing the effort to increase further. In addition, results from the projections indicate that there is a 72% probability that the current level of effort is below that corresponding to maximum catch. However, as shown by the wide distributions associated with the median catch v. effort plot in Figure 11, this statistic is poorly determined by the catch and effort data used for the present analysis.

Sensitivity to some of the most important model assumptions were tested. The base case assumes constant *g*, and this assumption could be challenged by observations which indicate that the chokka "disappears" from the fishing grounds in the first months of the year. To mimic this perception, calculations were repeated under a variable *g* pattern consisting of two levels of *g*: a low value prevailing during most of the year, including the spawning season, and a high value at the beginning of the year:

$$g \text{ low} = g * 0.5, \text{ from April to December} \quad ,$$

$$g \text{ high} = g * 2.5, \text{ from January to March} \quad .$$

The values of 0.5 and 2.5 are such that the cumulative *g* over the year would be the same as in the base case to ensure comparability of the results. The resulting parameter estimates and confidence intervals are included in Table I. The results regarding any benefit to be derived from the existing closed season are similar to those for the base case. However, the resource seems to be less productive under these conditions: note the lesser maximum yield in Table II.

Sensitivity to the threshold value of 0.2 used for the stock-recruit relationship (see Fig. 4) was also explored. The average annual catches over 10-year projections and the biomasses at the end of the 10 years are presented in Figures 12 and 13. The obvious effect of raising this threshold level is a decrease in the productivity of the resource. The spawning biomass declines very rapidly with effort level, as shown in Figure 12 (compared to the equiv-

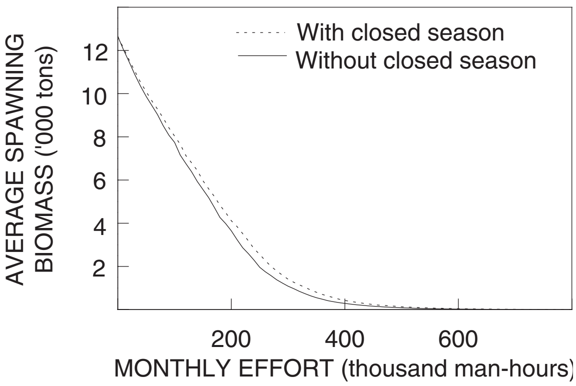

Fig. 12: Average spawning biomass of chokka squid at the end of 10-year projections with and without a closed season in place (stock-recruitment threshold = 0.5 – see text)

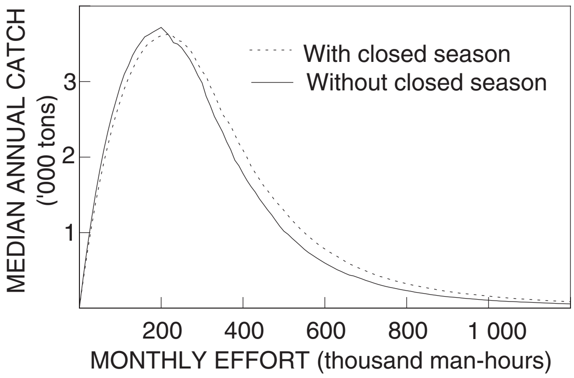

Fig. 13: Median annual catch of chokka squid over 10-year projections with and without a closed season in place (stock-recruitment threshold = 0.5 – see text)

alent plot for the base case in Fig. 7), and the maximum annual catch is reduced to just less than 4 000 tons (Table II), less than half of that for the base case. Therefore, the actual level of this threshold is crucial when it comes to inferences of whether or not the current effort level is less than would provide a maximum yield. Note, however, that these computations for the high threshold are likely to be negatively biased; they depend on parameters estimated from Equation (5), which ignores that threshold. This does not matter for calculation with a threshold of 0.2 because the spawning biomass is estimated not to drop below this level during the period 1988–1996 considered for the estimation, but this argument would not apply if the threshold level was 0.5.

CONCLUSIONS

This analysis has highlighted several important gaps in knowledge and data availability which have prevented a more comprehensive assessment of the status and dynamics of the stock under consideration. In particular, the following areas need further investigation in order to improve the reliability of the assessment.

- The relationship between *cpue* and spawning biomass should be investigated, especially considering the recent expansion of jigging operations into water deeper than the traditional fishing grounds. This is particulalrly important in view of the current dependence on *cpue* as an index of abundance. However, describing the relationship will not be easy, because there are currently no reliable fisheries-independent estimates of biomass. A comprehensive analysis of trends in *cpue* using, for example, generalized linear model-ling, could improve interpretation of these data and comparison with other fisheries indices, e.g. the demersal fishery, which takes squid as a bycatch (Cochrane *et al*. 1997). In addition, fisheries-independent surveys have been undertaken on the Agulhas Bank since the early 1980s. These do not cover the full area occupied by squid during the spawning season, because the ships utilized are too big to survey the shallow water where most spawning takes place. However, if a relationship between the survey estimates and the true stock biomass was found to be sufficiently precise, this index could be included in the model as an additional abundance measure.
- Biological research into determination of chokka squid lifespan would permit constraining the possible values of M (and hence g) and could also allow the development of an age-structured model if adequate data to estimate length composition of the catches became available.
- Research to determine more precisely the area where spawning takes place could result in an improved stock-recruit relationship or, at least, define better what constitutes the spawning stock.
- Similarly, an investigation into the sensitivity of the results to the choice of months used to estimate mean spawning biomass, coupled with improved knowledge of monthly spawning activity, could improve the precision of the model.

Notwithstanding the above reservations, the calculations in this paper indicate that the biological and

Table II: Performance statistics estimated in the 10-year projections, under different model scenarios

Scenario		Performance criteria			
g	Threshold	Maximum yield (tons)	Corresponding annual effort (million man-hours)	"Risk" * at current level of effort (%)	Depletion† at current level of effort (%)
1.0 (base case)	0.2	7 708	5.15	76	30
1.5	0.2	10 029	8.71	51	43
2.0	0.2	13 597	13.45	35	52
0.5; 2.5‡	0.2	6 646	4.18	79	24
1.0	0.5	3 696	1.53	99	1

* The probability that the spawning biomass falls below 20% of its average pristine level at least once during the 10-year projected period
† Depletion is the average spawning biomass at the end of the projection period expressed as a proportion of its average pristine level (i.e. average in the absence of fishing)
‡ *g* variable throughout the year

economic gains provided by the current closed season are small, consistent with the approximately 9% reduction in effort which they represent. While the benefits may be greater at higher effort levels than those currently being applied, such levels correspond to high risks of depleting the spawning biomass to levels at which the chance of successful recruitment might be impaired, and are therefore not feasible management options, even with a closed season. However, decisions on the desirability or otherwise of maintaining the closed season should not be taken without consideration of the effort level in the fishery as a whole.

Providing advice at this stage on an appropriate level of effort for the fishery is difficult for two reasons:

(i) Although point estimates indicate that the current level of effort is below that which would lead to a maximum yield, these estimates are not very precisely determined (Fig. 11) and therefore need to be interpreted with caution.

(ii) Risk-related statistics (indicating that risk is already very high at the current level of effort under the base-case assumptions of these analyses) are very sensitive to the assumptions made in the model, in particular to the assumed value and pattern of the composite parameter *g* and to specification of the spawning biomass level below which average recruitment is likely to fall. Further, there is both little information from squid fisheries elsewhere in the world upon which to base an informed opinion on this matter, and little prospect of immediate resolution on these points for this particular fishery.

Although, therefore, the closed season seems little more than a mechanism for effort reduction on the basis of the results above, it would seem prudent in view of the apparently high levels of risk associated with the current effort level, to maintain it and certainly not to allow it to increase until greater clarity on the matters raised in points (i) and (ii) above becomes available. This is consistent with the precautionary approach advocated as essential for responsible fisheries management. Above all, the precautionary approach calls for prudent foresight and priority to be given to conservation of the resource under circumstances where the impact of fisheries on the resource is uncertain (F. A. O. 1995), as is being recommended here. South Africa's recent White Paper on Marine Fisheries (Anon. 1997) also advocates application of the precautionary approach in such cases.

The risk levels estimated in this study suggest that some consideration needs to be given to reducing the current level of effort. However, in view of the existing sensitivities regarding access to the resource and the fact that reducing the number of participants in the fishery would be very difficult under existing socio-political circumstances, it is probably preferable to achieve the required reduction in effort by increasing the length of the existing closed season rather than by attempting to reduce the numbers currently having access to the fishery.

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