S. Afr. J. mar. Sci. 22: 121–135
2000

INVESTIGATION INTO THE DECLINING TREND IN CHOKKA SQUID *LOLIGO VULGARIS REYNAUDII* CATCHES MADE BY SOUTH AFRICAN TRAWLERS

B. A. ROEL, K. L. COCHRANE† and J. G. FIELD‡*

The trawl fishery, which targets Cape hake *Merluccius* spp. and Agulhas sole *Austroglossus pectoralis*, takes chokka squid *Loligo vulgaris reynaudii* as by-catch. Catch and effort data from the trawl fishery for the period 1978–1996 are used to obtain annual estimates of catch rate (catch per unit effort *cpue*) for that period. Examination of the *cpue* trend shows a sharp decline in the early 1980s and, in order to identify factors that could have influenced that decline, the distribution of fishing effort is investigated both temporally and spatially. There is a possible change in the incidence of squid-directed catches over time, but their overall scarcity could have had only a small impact on the annual *cpue* trend. Further, using distribution of fishing effort to evaluate the effects of possible changes in fishing patterns, rather than changes in resource abundance, on the trend in trawl *cpue*, it became clear that there had been a contraction of the trawling grounds and changes in fishing patterns in relation to depth over time. Finally, a general linear model (GLM) is developed to quantify the effect on *cpue* of factors such as vessel characteristic, depth and position of the drag, season and target species, so obtaining a standardized trawl *cpue* index of chokka abundance. Analysis of that trend reveals a mean 7.7% annual decline for the period investigated, which should be interpreted as a strong sign of resource decline.

The South African chokka squid *Loligo vulgaris reynaudii* is caught by a local jig fishery, which targets primarily spawning aggregations off the South Coast, and as by-catch in the bottom trawl fishery, which targets Cape hake (*Merluccius* spp.) and Agulhas sole (*Austroglossus pectoralis*). The bottom trawl fishery off South Africa started, around the turn of the century, for Agulhas sole, despite hake already being recognized as an abundant resource (Payne 1989). Presumably, squid were always caught by trawl, but it was only during the 1970s and early 1980s that official statistics started to reveal squid in the catches of both local and foreign trawlers. While the local fleet targeted mainly hake or, to a lesser extent, Agulhas sole, and squid was only a by-catch, chokka squid were eagerly targeted by the Japanese fleet from around 1974 to meet an increasing demand in that country for loliginid squid (Sato and Hatanaka 1983).

According to Augustyn (1989), the trawl industry operating in South African waters in the 1980s could be divided into three sectors:

- a South African offshore component fishing off both West and South coasts, in water deeper than 100 m and concentrating mainly on the two species of Cape hake (deep-water Cape hake *Merluccius paradoxus* and shallow-water Cape hake *M. capensis*);
- a South African inshore component, fishing exclusively on the South Coast in water up to 110 m deep, although in recent years this has extended to 150 m (P. F. Sims, Marine & Coastal Management, MCM, pers. comm.), largely for Agulhas sole and shallow-water Cape hake;
- a foreign fleet consisting of a small number of Japanese and Taiwanese vessels, operating in waters deeper than 110 m off the South Coast, catching hake, horse mackerel *Trachurus trachurus capensis*, panga *Pterogymnus laniarius* and chokka.

Currently, the first two sectors are still operative, but foreign permits were phased out by 1992.

The hake fishery expanded rapidly in the 1950s and, after a period of gradual increases in catches and a peak in 1972 (Payne 1989), the *cpue* dropped to very low levels by the mid 1970s. The first action to protect hake took place in 1975, when a minimum legal stretched-mesh size for hake fishing of 110 mm was implemented. However, this regulation did not apply to the entire South African coast, because a 75 mm mesh for mixed-species trawling was still legal for trawling east of Cape Hangklip (i.e. the South Coast, see Fig. 1 for geographical references). The effect of mesh size on catches of *L. v. reynaudii* was investigated by Hatanaka *et al.* (1983) and Uozumi *et al.* (1984) during a selectivity experiment using 90-, 105- and 120-mm mesh sizes. Augustyn *et al.* (1993) concluded from the re-

* Formerly Marine & Coastal Management, Private Bag X2, Rogge Bay 8012, South Africa, and University of Cape Town; now CEFAS, Pakefield Road, Lowestoft, Suffolk NR33 0HT, United Kingdom. E-mail: b.a.roel@cefas.co.uk
† Fisheries Department, F.A.O., Via delle Terme di Caracalla, 00100 Rome, Italy. E-mail: kevern.cochrane@fao.org
‡ Dept of Zoology, University of Cape Town, Private Bag, Rondebosch 7700, South Africa. E-mail: jgfield@pop.uct.ac.za

Manuscript received April 2000; accepted June 2000

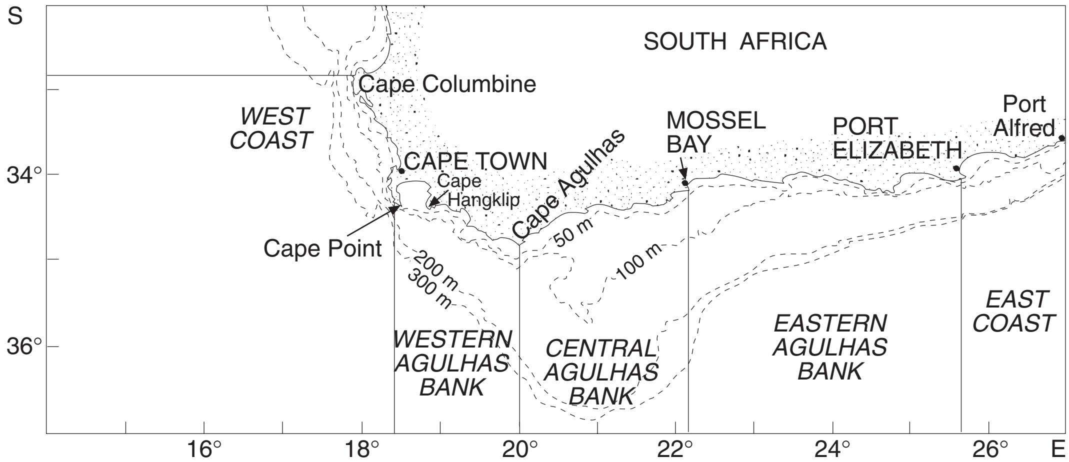

Fig. 1: Main area of distribution of chokka *Loligo vulgaris reynaudii*

sults of those experiments that escapement of squid, even small ones, from the net was poor, despite the rather large mesh sizes. A second major advance to protect hake was made on 1 November 1977, when a 200-mile exclusive fishing zone off South Africa was implemented (Payne 1989). This probably had more of an impact on squid catches than did the mesh size regulations, because the 200-mile area closed to foreign activity would have eliminated non South African trawlers (except the gradually reducing number allowed in terms of bilateral agreements) from the areas where chokka squid aggregate.

Closure of the inshore bays for trawling between 1985 and 1987, and the prohibition, for the offshore trawling component referred to above, on operating off the South Coast inshore of the 110 m contour since 1978, are both measures that excluded the trawlers from the inshore grounds where chokka aggregate to spawn. The closure could, therefore, have caused a decrease in the chokka by-catch. The impact on chokka catches of illegal net liners that reduce the effective mesh size of the nets is probably minimal, but in any case it cannot be evaluated because there is no information on the extent of use of such liners.

Catch statistics of chokka are available from trawlers since 1971. Annual catches made by foreign trawlers, South African trawlers and by jigging are shown in Figure 2. Foreign trawl catches decreased after peaking in 1974 and 1975. A difference in permit conditions between the South African deep-sea fleet and foreign vessels resulted in the creation of a large area on the central Agulhas Bank, the so-called "foreign triangle", where only foreign vessels could operate, and the foreign fleet harvested substantial quantities of chokka there from 1973 to 1978 (Japp *et al*. 1994). However, foreign catches declined rapidly after 1983, when increased restrictions were placed on the fleets of those countries that had retained a bilateral fishing agreement with South Africa after 1977.

Catches by local trawlers also declined from 1974, and jig catches increased rapidly after 1984. Although the declining trend in foreign trawl catches, especially those of Japan, which directly targeted chokka, can be explained by their gradual exclusion from South African waters, the reasons for the decline in local trawl catches are not obvious. Although some regulations (e.g. the closure of bays) could have precluded trawlers from operating in areas of high density of chokka, it is clear that other events, such as changes in fishing pattern or an overall decline in the resource, could well be manifest in the decline in the annual catch. It was therefore decided to undertake an analysis to detect possible changes over time in the distribution of fishing effort exerted by trawlers during that period in the history of chokka exploitation.

Results presented by Roel (1998) showed that trawl fishing effort was spread evenly throughout the year after 1978, except perhaps for the months April–June and to a lesser extent October–December, when the proportion of drags seemed smaller than during the rest of the year. However, seasonal trends remained similar throughout the period considered and no temporal trends were apparent as a result of the analysis. Changes in the depth ranges fished or seasonal changes in fishing operations may also have had an impact on chokka catches, so they too are investigated. Further, trends in

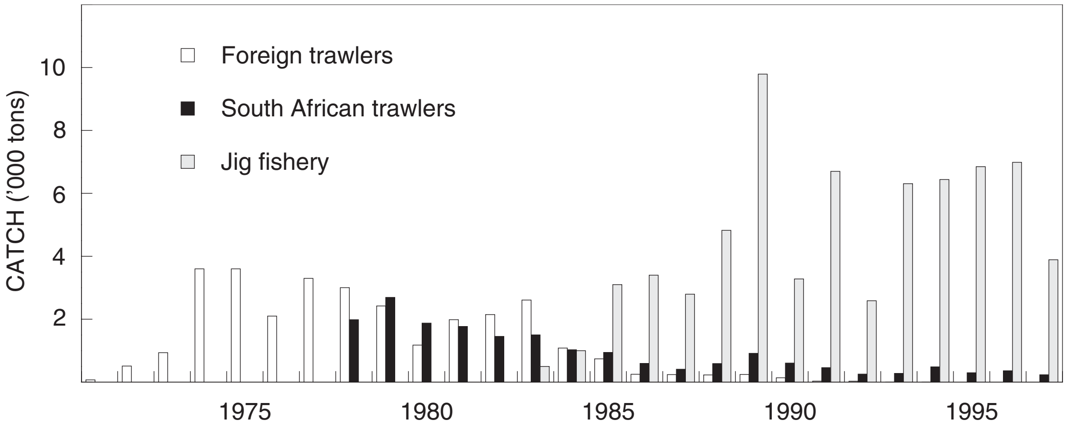

Fig. 2: Annual landings of *Loligo vulgaris reynaudii*, 1971–1997, by the trawl fishery, both South African and foreign, and by the jig fishery

trawl catch per unit effort (*cpue*), as a possible indicator of resource abundance, are analysed. Finally, a rigorous analysis of the factors influencing the trawl *cpue* is undertaken within the statistical framework of General Linear Modelling (GLM).

MATERIAL AND METHODS

Data

Detailed information from the trawl fishery on catch position, trawl duration and species composition of each trawl, as well as on vessel characteristics, is available only from 1978. Trawl data from 1978 to 1996 that coincide with the main area of chokka distribution were analysed to investigate possible changes in fishing patterns. Only hauls made south of Cape Columbine and shallower than 300 m were included in the analysis, to avoid including data from areas where chokka occur only rarely and which therefore would have a very high frequency of zero catches.

Catch and effort data extracted include information on landing date, drag date, drag duration (effort), latitude, longitude and average depth of the statistical grid number in which the drag was made, mesh size, target species and chokka catch. The data base contains catch returns reported at the drag level, which are referred to subsequently as *drag-by-drag* data, and catch returns for which the effort was reported by drag, but the catch was accumulated throughout the day and reported against the last drag of the day. Such data are referred to subsequently as *daily data*. Daily data can be used to compute an average daily *cpue* per vessel; information on position and depth can be averaged as well, resulting in a loss of detailed information. The advantage of using drag-by-drag data is, first, that there is no loss of information and, second, that potential outliers in the data can be identified at the drag level.

Data reported by drag and by day were identified at the time of extraction, and it was found that about 95% of the data from 1978 to 1994 were reported by drag. Consequently, only data by drag were extracted from 1978 to 1994. However, a large proportion of the 1995 and 1996 data was reported on a daily basis, so eliminating the daily data for those two years would have resulted in a substantial loss of information. It was therefore decided to use all the data for those two years and to compute an average daily *cpue* as the ratio of the daily catch to the corresponding total daily effort. The corresponding water depth was recorded as the average for the day. The latitude, longitude and statistical grid number of the last trawl were assigned to the data for that day. Owing to the different formats in which the catch and effort data were reported, the absolute numbers of observations are not directly comparable between the periods 1978–1994 and 1995–1996. To circumvent this problem in the analysis, relative proportions were used instead of absolute number of observations when the two sets of data were combined.

Identification of outliers

When the total catch in a day was more than 80 tons, an error was assumed and the observation omitted, because a single trawl in the fishery cannot realistically contain more than 25 tons, and a maximum of three trawls can be made per day when catch rates are so high (R. W. Leslie, MCM, pers. comm.). Finally, three observations in September 1989 corresponding to Boat Number 248 recorded unusually large catches of chokka. As an error in the data was suspected, that entry was eliminated. The combined data set contains 533 502 records between 1978 and 1994 (before accumulation per day) and close to 20 000 records for the period 1995–1996.

Most drags (98%) refer to three target species only: Cape hake, Agulhas sole and horse mackerel. Fewer than 1% were declared as having targeted chokka. However, some concern has been expressed about chokka-directed drags having been included in the data set and not having been reported as such. Therefore, a small proportion of drags containing >50% of chokka in the catch were identified; details regarding percentage incidence, location and temporal trend are reported in the results section for those drags. Given their geographical location, on traditional hake grounds of the South African trawl fishery (Japp *et al*. 1994), it is considered very unlikely that they were actually directed at chokka. As a result, they were not excluded from the analysis. However, given the years when most of them were made, late 1970s and early 1980s, they might be seen as having influenced the apparent sharp decline in trawl *cpue* after those years. Therefore, a test was made of the sensitivity of the results from the GLM to eliminating those drags from the data set. After identification and elimination of outliers, as described in the following section, *cpue* was recalculated for consistency as a daily average for the 1978–1994 data in the same manner as for the 1995 and 1996 data.

Brown (1996) identified several typographic errors and missing data when analysing hake *cpue*, and some of the criteria used in that study to detect those are also applicable to an analysis of chokka *cpue*. Records with the following characteristics were considered errors and were omitted:

- drags with positive effort, but zero catch (of any species);
- drags with effort values below the 1% quantile and above the 99% quantile (<60 or >390 minutes duration);
- drags with *cpue* values above the 99% quantiles computed per year from the distribution of the *cpue* per drag data;
- drags with missing data on date, mesh size, squid catch or total catch.

Drags of foreign vessels were eliminated from the data set because they may have been targeting on chokka.

Vessel attribute

Data on the attributes of the vessels operating in the hake and sole fisheries are available from MCM. The attributes considered for the analysis are:

- Vessel length
- Gross tonnage
- Propulsion capability/power (in hp and kW)
- Propeller (fixed or variable pitch)
- Kort nozzle (presence or absence)

A linear relationship between landings-per-hour-trawled and vessel horse-power class has been documented for Canadian trawlers landing Pacific cod *Gadus macrocephalus* (Westrheim and Foucher 1985). Glazer (1999) performed a GLM analysis of trawl data for the South African demersal fishery, to estimate an index of abundance for hake. She found a high level of correlation between a number of vessel characteristics, and initially selected vessel length for inclusion in the GLM standardization as an index of fishing power, because it was the most complete information concerning vessel power in the data base. For that reason, vessel length is also the variable chosen to indicate vessel fishing power for the GLM analyses herein.

Examination of the vessel attributes file revealed that 20% of the vessels had variable pitch propellers and, of those, only 12% had a kort nozzle. Further, all vessels with variable pitch propellers were longer than 42 m.

The GLM model

The basic assumption made was that *cpue* was proportional to squid abundance, but for this assumption to hold, effort from all the vessels should be standardized. The background on methods of effort standardization and the approach followed in this analysis can be found in Kimura (1981). The algorithm used to model the *cpue* is

$$cpue_{yij} = e^{(\ell n(cpue_{111})+\alpha_y+\beta_i+\gamma_j+\varepsilon_{yij})} - \delta \quad ,$$

where $cpue_{111}$ is the catch rate in year 1, location 1 and vessel attribute 1, α_y the abundance in year y relative to year 1, β_i the abundance in location i relative to location 1, γ_j the effect of a vessel having attribute j instead of attribute 1, δ the log-transformation constant, and ε_{yij} is the residual for year y, location i and vessel attribute j.

The factors considered were location factors, such as water depth, target species, season and area in which the trawl was made, and vessel attribute such as total length, presence or absence of a kort nozzle and type of propeller. The Greek letters are the regression coef-

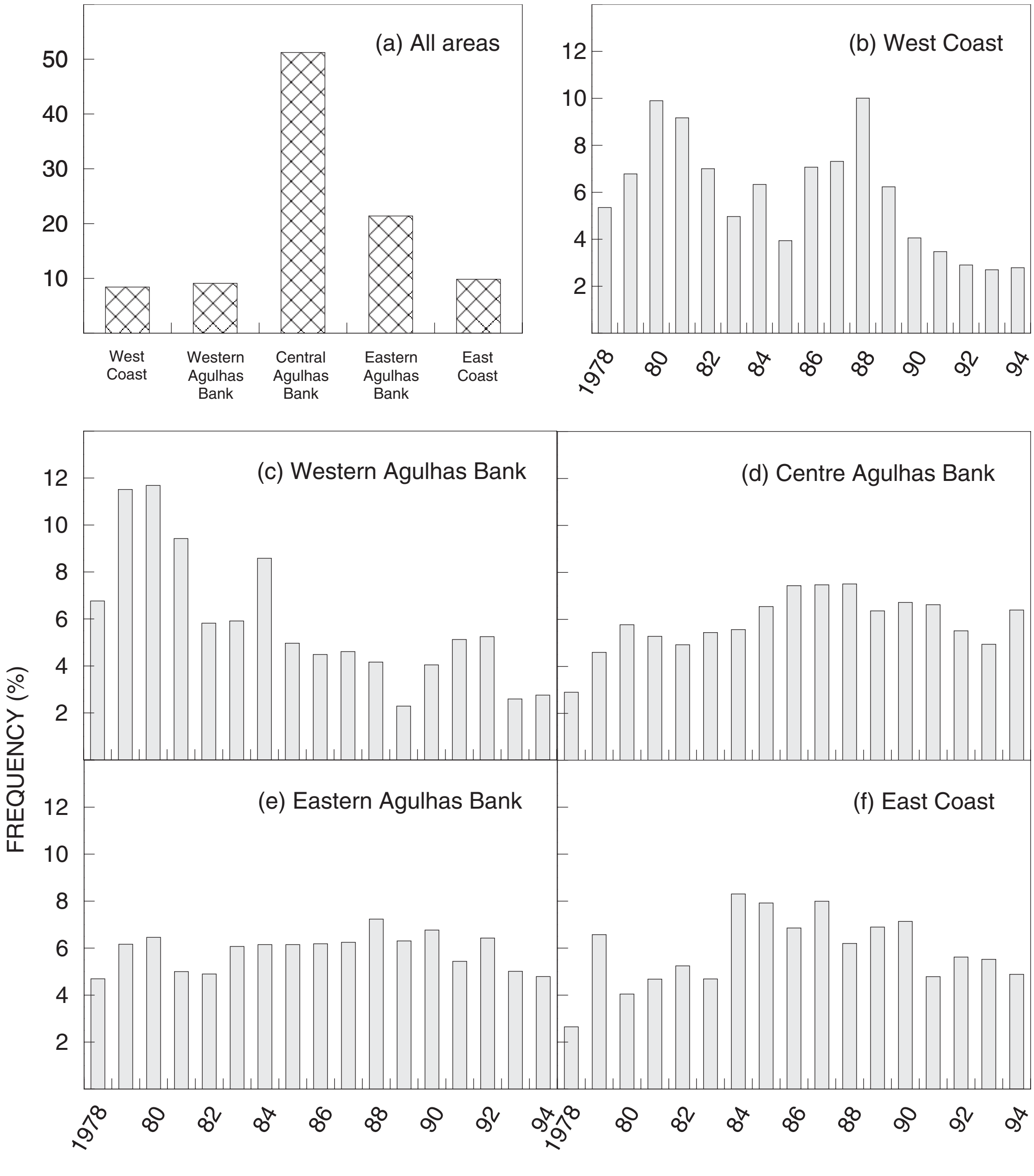

Fig. 3: Frequency distribution of the number of trawls (drags) per area, 1978–1994

ficients, except δ, which is the constant added to the *cpue* data to be able to deal with the zeros at the time of the log-transformation.

From the above equation, it is evident that *cpue* is assumed related to average abundance during the corresponding year (year-factor) as well as to factors that affect catchability (vessel characteristic, time and position of the trawl). By including such factors in the model, their relationship with *cpue* can be determined. This is done by taking logarithms of both sides of the equations and performing a multiple linear regression. Indices of year abundance similar to adjusted *cpues* can be estimated directly from the regression. The rationale for log-transformation is the assumption of log-normality of residuals, i.e. that the logs of the residuals are independent and normally distributed, and that they have constant variance. Gulland (1956) gives empirical evidence that logarithmic transformation normalizes *cpue* data and stabilizes its variance.

Variables such as vessel length and mean depth of the drag were initially treated as continuous. However, inspection of the associated residuals suggested that their treatment as discrete categorical variables may allow better fits, because there were no clear linear relationships between the continuous variables and the catch rate. The relationship between catch rate and vessel length was therefore modelled by estimating a separate factor for each 5 m length-class.

The Generalized Linear Models were fitted using the procedure REG, available in the SAS statistical package. REG uses the principle of least squares to produce estimates that are the best linear unbiased estimates under classical statistical assumptions (SAS/STAT User's guide, Release 6.03 Edition, 1988).

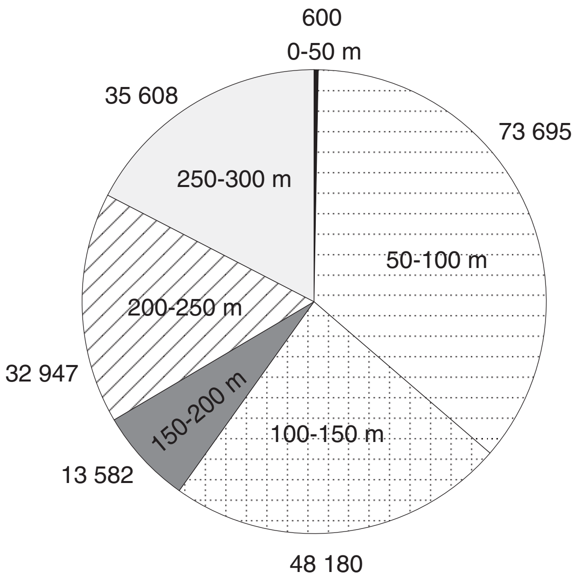

Fig. 4: Number of daily trawl records per depth interval in the study area, 1978–1996

RESULTS AND DISCUSSION

Spatial and temporal distribution of trawl fishing effort

The percentage distribution of drags between 1978 and 1996 by area and year was computed to investigate changes in the spatial distribution of trawling operations in the area of study. The study area was divided into five regions along the coast, taking into account the distribution of chokka and the main geographical reference points (see Fig. 1). These areas are the West Coast, between Cape Columbine and Cape Point, the Western Agulhas Bank, between Cape Point and Cape Agulhas, the Central Agulhas Bank, between Cape Agulhas and Mossel Bay, the Eastern Agulhas Bank, between Mossel Bay and Port Elizabeth, and the East Coast, east of Port Elizabeth.

Most drags in the data analysed (70–80%) were made east of Cape Agulhas, the area in which the main chokka spawning aggregations occur (Fig. 3a). Whereas there is some decline in the proportion of trawls over time on the West Coast and the Western Agulhas Bank (Figs 3b,c), there are no clear trends in the other areas. The proportion of drags made on the Western Agulhas Bank was relatively high between 1978 and 1981, and then declined gradually. The Central Agulhas Bank between Cape Agulhas and Mossel Bay is the area where most of South Africa's south coast trawling traditionally takes place (Japp *et al*. 1994).

The distribution of trawling operations in relation to water depth over the period 1978–1996 was also investigated. The results are plotted in Figure 4, each segment representing the number of drags that took place in a particular depth range during the whole period analysed. Most trawling took place between 50 and 100 m deep, and to a lesser extent between 100 and 150 m deep. There was little trawling activity close to the coast, i.e. in water shallower than 50 m, where good catches of adult chokka would have been expected, partly because the rocky nature of much of the sea bed inshore precludes safe trawling there.

Possible changes over time in catch position in relation to depth were investigated by computing the frequency of occurrence of drags per 50-m depth interval over the entire area of distribution of chokka. The percentage of drags that took place in a given year, less the average occurrence between 1978 and 1996, is plotted by depth interval in Figure 5. There is a clear decline in the proportion of drags after 1983 in the 0–50 m interval, likely the result of the closure of many of the bays to trawling at about that time. However, given the small percentage represented by these drags, the impact of this decline on the total chokka *cpue* would be expected to be negligible, unless inshore catches were extremely large compared

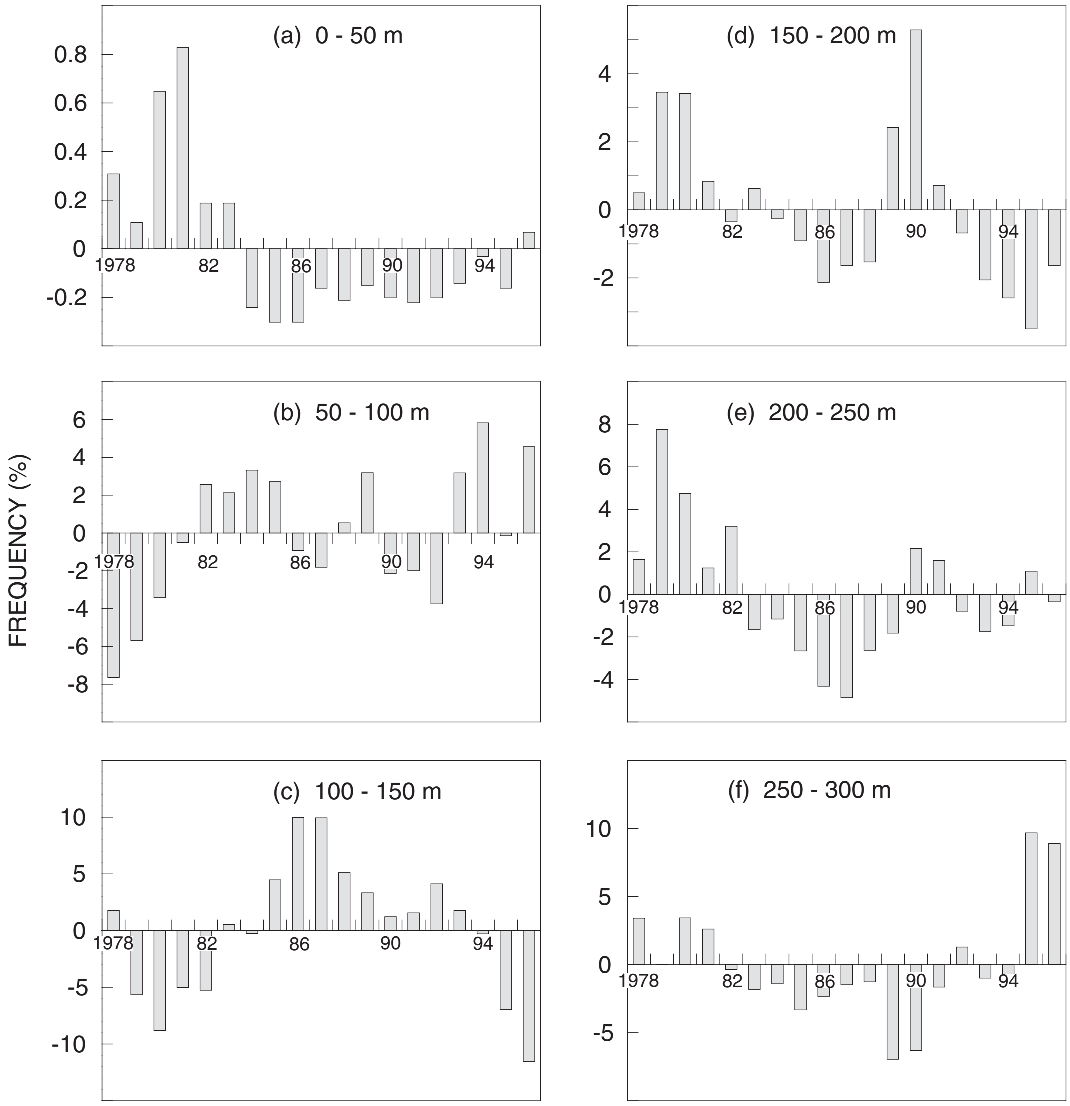

Fig. 5: Frequency distribution of the number of trawls per depth range over time. The Y-axis refers to the observed percentage less the mean (the mean percentages for each depth interval in ascending order are 0.3, 39.6, 25.0, 6.5, 15.4 and 13.3 respectively)

to those made in deeper water. There also seems to have been a larger proportion of drags deeper than 150 m prior to 1982. Differences over time in the distribution of the fishing fleet in relation to depth could be responsible, to some extent, for the declining trend in annual *cpue* (Fig. 6). The GLM analysis performed in this study (see later) discriminates these effects from real changes in resource abundance.

Exploratory analysis of the trawl *cpue* data

ANNUAL TREND IN TRAWLED CHOKKA CATCH RATE

The overall trend in mean annual trawl *cpue* of chokka, the nominal *cpue*, for the years 1978–1996 is negative and includes a particularly sharp decline

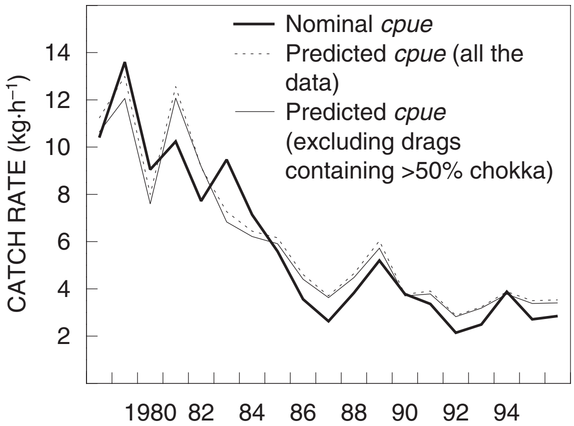

Fig. 6: Nominal and predicted *cpue* of chokka from the GLM analysis, 1978–1996. Nominal *cpue* computations are based on catch and effort data by boat and accumulated per day

after 1983, followed by a modest recovery in 1988 and 1989. Thereafter, *cpue* dropped again and then remained low but relatively stable (Fig. 6). This finding could be linked to the perception of trawlermen that the quantity of chokka available to trawlers decreased substantially after the onset of the jig fishery (C. A. Atkins, Irvin & Johnson Ltd, pers. comm.). However, the first records of jigging operations are dated 1983, whereas the decline in nominal *cpue* started in 1980. Therefore, the declining trend in trawled chokka *cpue* could be the result of a change in resource abundance, but it could as easily be due to a change in fishing strategy, including a decrease in the amount of directed fishing for the species over the period under consideration.

INFLUENCE ON THE DATA OF POSSIBLY DIRECTED TRAWL CATCHES OF CHOKKA

The drag-by-drag data between 1978 and 1994 were used to evaluate the impact of trawling operations targeting chokka directly on the annual estimate of *cpue*. Drags where the percentage of chokka in the total catch was more than 50% could be suspected of being chokka-directed. Although the percentages, both of occurrence and by mass, vary substantially between years, with maxima in 1979 and 1983, they are relatively small and cannot be expected to have made a major impact on the overall annual *cpue* (Fig. 7).

The average depth at which chokka-directed drags took place was investigated by Roel (1998), who found the annual average depth to lie between 100 and 150 m deep, with the exception of 1982, when chokka-directed trawling was generally deeper. This indicates that, if South African trawlers do target chokka, they would not necessarily target inshore spawning aggregations, but may well catch them in deeper water either before they spawn or when they are dispersing after spawning.

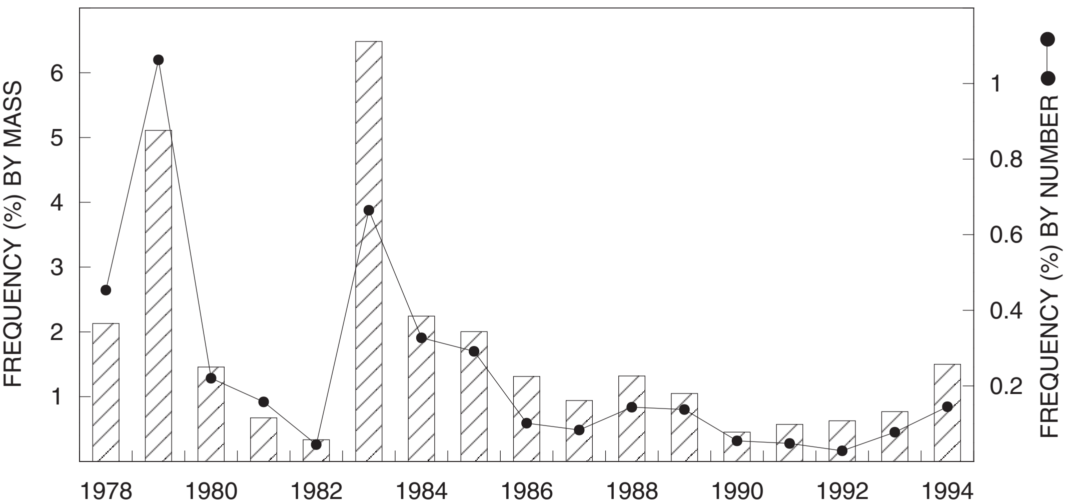

Fig. 7: Incidence of catches containing >50% chokka, 1978–1994

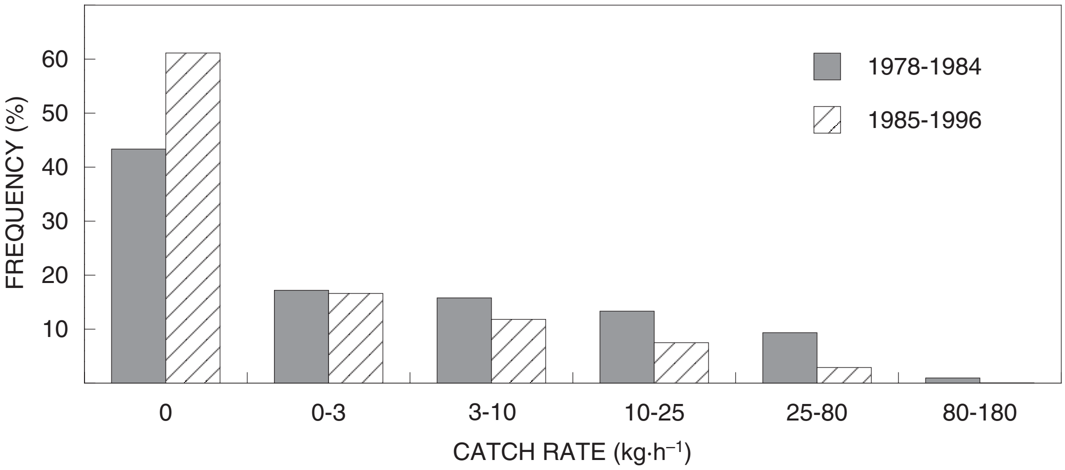

Fig. 8: Frequency distribution of trawled chokka *cpue* categories for the periods 1978–1984 and 1985–1996

TRAWLED CHOKKA CATCH RATE BY AREA AND DEPTH RANGE

To provide a more detailed description of the distribution of trawled chokka *cpue*, the period 1978–1996 was divided into two sub-periods: one of relatively high and the other of relatively low *cpue*, with the end of 1984 being taken as the cut-off point. The *cpue* values, calculated on a daily basis, were grouped into six intervals for descriptive purposes: zero, >0–3, 3–10, 10–25, 25–80 and >80 kg per hour trawling, where the class intervals were chosen taking into consideration the highly skewed nature of the distribution and the great frequency of low values of *cpue*. The results reveal clear differences between the percentages corresponding to the zero *cpue* interval, and to the intervals corresponding to *cpue* values of >3 $kg \cdot h^{-1}$ (Fig. 8). However, it is likely the difference in the number of zero *cpue* observations between the two periods, close to 20%, which would have had the larger impact on the annual estimate of *cpue*.

Plotting chokka *cpue* by area and for the two time-periods reveals that the percentage occurrence of zero *cpue* values rises to more than 80% on the West Coast for the most recent period, compared to less than 60% for the earlier (Fig. 9). The large proportion of high *cpue* values on the Western Agulhas Bank for the whole period (Roel 1998) is mainly the result of high values in the earlier period. An eastward shift of chokka, similar to that observed for the anchovy *Engraulis capensis* spawning area after the mid 1980s (Van der Lingen *et al.* in press), may have caused the observed shift in distribution of the *cpue*.

Figure 10 shows possible differences in the distribution of trawled chokka *cpue* grouped in six 50-m depth categories between the same two periods (1978–1984 and 1985–1996). The percentage occurrence of zero catches was lower in the early period than in the most recent one for the inshore interval and for intervals deeper than 150 m. The opposite trend prevails for the non-zero *cpue* categories, particularly in water deeper than 150 m, where the incidence of high *cpue* values was greater in the earlier period.

Index of abundance derived from the trawl by-catch fishery

VARIABLE SELECTION

Standard statistical model selection procedures include or exclude factors based on their statistical significance. However, in cases such as this with a very large data set, factors can be significant but of minimal effect, and the evaluation of significance itself rests on assumptions of independence of data which, in all likelihood, are correlated to some extent. To overcome the problem, the approach followed in this study was to add a group of categorical variables related to a particular feature one at a time and then to make a decision on whether to include the group or to exclude it from the model, depending on its effect on the coefficient of determination, R^2, i.e. only groups making a relatively large contribution to R^2 (>0.005) are retained.

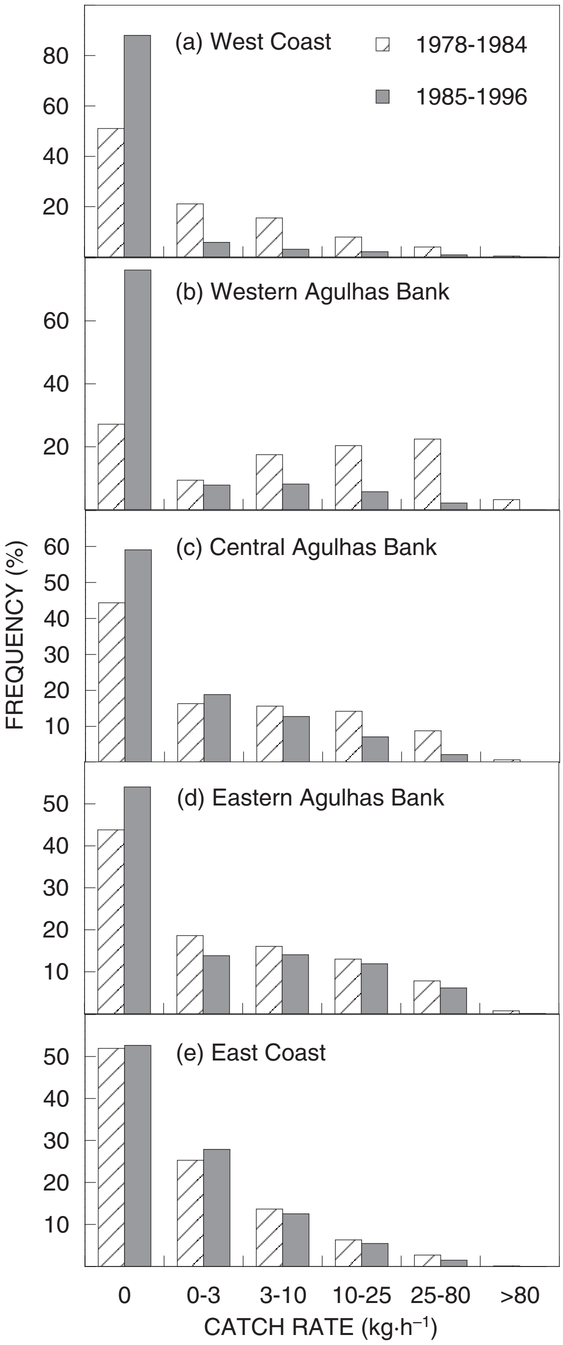

Fig. 9: Frequency distribution of trawled chokka *cpue* categories per area for the periods 1978–1984 and 1985–1996

Table I: Results from a stepwise procedure for variable selection

Model: $\ell n\ (cpue+\delta)$ ~	R^2
~ year + vessel length	0.1102
~ year + vessel length + propeller	0.1123
~ year + vessel length + kort nozzle	0.1120
~ year + vessel length + area	0.1397
~ year + vessel length + area + depth	0.1800
~ year + vessel length + area + depth + season	0.2046
~ year + vessel length + area + depth + season + offshore grid	0.2046
~ year + vessel length + area + depth + season + target species	0.2125

The categorical variables considered relate to the following features:

- vessel length – each variable corresponds to a 5-m length category, starting with <15 m;
- type of propeller (fixed or variable);
- presence or absence of a kort nozzle;
- area where the drag took place – West Coast, Western Agulhas Bank, Central Agulhas Bank, Eastern Agulhas Bank, East Coast;
- depth where the drag took place – the Boolean variables correspond to 50-m intervals between 0 and 300 m deep;
- season when the drag took place – i.e. the three-month periods January–March, April–June, July–September, October–December;
- target species declared by the skipper, i.e. hake, sole, horse mackerel or "other";
- offshore grid – a Boolean variable identifies the drags that took place in deep water off the Eastern Agulhas Bank during the early years of the period considered in this study (see previous section).

Results from the inclusion of different groups of variables in steps are presented in Table I.

Vessel attributes, such as the type of propeller or the presence or absence of a kort nozzle, had minimal or no effect on the R^2 and therefore were not retained in the final model; "offshore grid" was excluded for the same reason. Therefore, the variables retained in the model are vessel length, the area and depth where the drag took place, the season and the target species.

SPECIFYING THE PARAMETER δ

A constant δ is added to the *cpue* in order to be able to take the logarithm in those cases where the *cpue* is zero. In similar work carried out at ICCAT (the International Commission for the Conservation of Atlantic Tunas), a value of δ of 0.1 times the mean *cpue* has

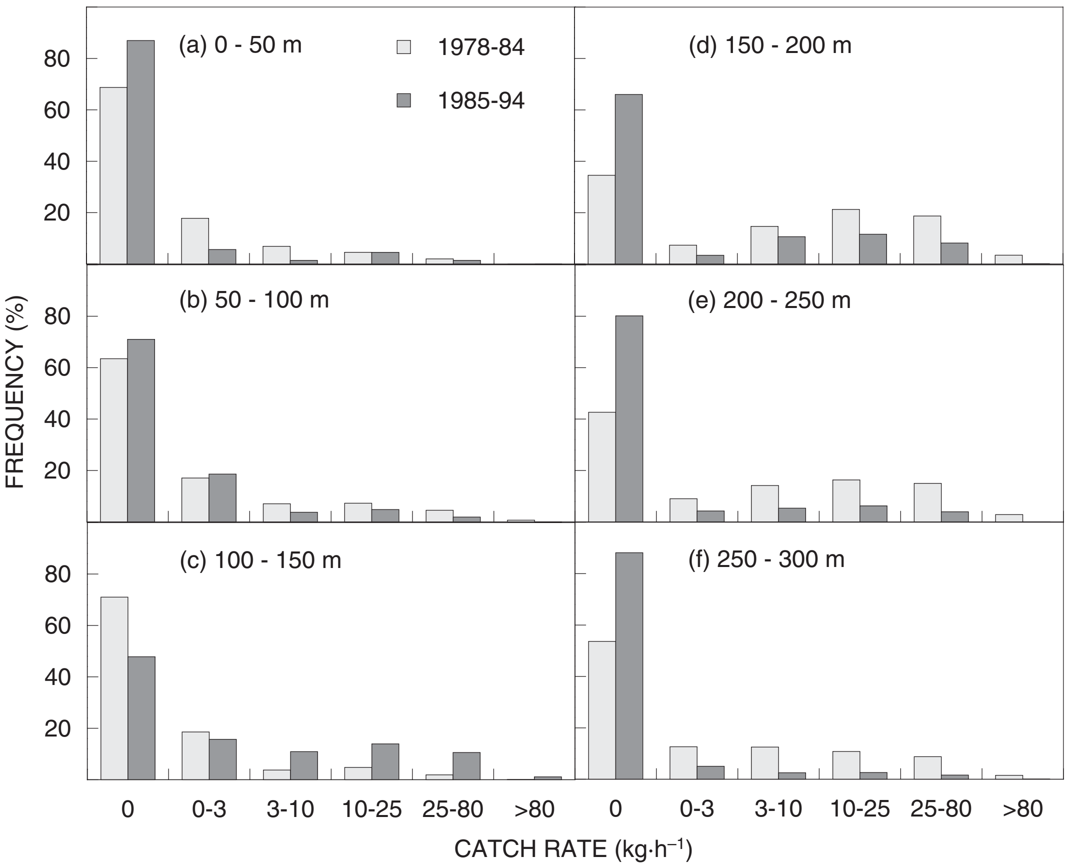

Fig. 10: Frequency distribution of trawled chokka *cpue* values per drag for six depth ranges and two periods, 1978–1984 and 1985–1994

been recommended. Glazer (1999), in applying a GLM to hake data, based her selection of δ on the normality of the residual distribution obtained from the model fit. In the current study, the regression was run for three values of δ to decide which provided a residual distribution closest to normal. A value of skewness, a measure of the tendency of residuals to be larger in one direction than in the other and defined as the expected value of the cubed deviations from the population mean, divided by σ^3, i.e.

$$Skw = E(x - \mu)^3 / \sigma^3 \quad ,$$

as well as of kurtosis, which assesses the shape of the distribution considering the fourth power of the deviations from the mean (Zar 1984), were calculated for each value of δ. The values are listed in Table II.

Table II: Skewness and kurtosis of the chokka population data

Parameter	δ as a factor of mean *cpue*		
	0.05	0.010	0.005
Skewness	0.506	0.315	0.261
Kurtosis	–0.50	–0.885	–0.99

In a perfectly normal distribution, the skewness and the kurtosis should equal zero. Despite none of the distributions of the residuals being completely normal, a value of δ of 0.05 times the average *cpue* (average *cpue* = 5.05) was considered to provide the best trade-off in relation to the two measures considered and to be closer to the criteria adopted by ICCAT. Therefore, that value was used in the analysis.

Table III: Parameter estimates and associated statistics from a GLM applied to the trawl *cpue* data

Variable	Parameter estimate	Standard error	T	Probability $> T$
Intercept	–0.7238	0.0880	–8.223	0.0001
1979	0.1338	0.0249	5.372	0.0001
1980	–0.3462	0.0242	–14.298	0.0001
1981	0.1048	0.0247	4.234	0.0001
1982	–0.1916	0.0254	–7.534	0.0001
1983	–0.4373	0.0252	–17.323	0.0001
1984	–0.5481	0.0247	–22.215	0.0001
1985	–0.5924	0.0249	–23.761	0.0001
1986	–0.8868	0.0245	–36.240	0.0001
1987	–1.0909	0.0245	–44.562	0.0001
1988	–0.8721	0.0245	–35.569	0.0001
1989	–0.6245	0.0255	–24.485	0.0001
1990	–1.0815	0.0252	–42.835	0.0001
1991	–1.0534	0.0256	–41.204	0.0001
1992	–1.3482	0.0256	–52.599	0.0001
1993	–1.2252	0.0269	–45.476	0.0001
1994	–1.0540	0.0265	–39.815	0.0001
1995	–1.1806	0.0274	–43.105	0.0001
1996	–1.1739	0.0282	–41.584	0.0001
Season:				
Apr.–Jun.	–0.5307	0.0106	–49.942	0.0001
Jul.–Sep.	–0.6175	0.0105	–58.882	0.0001
Oct.–Dec.	–0.0561	0.0105	–5.330	0.0001
Boat length (m):				
15–19	–0.1421	0.0825	–1.722	0.0851
20–24	0.0919	0.0822	1.118	0.2635
25–29	0.8851	0.0852	10.385	0.0001
30–34	0.1529	0.0847	1.805	0.0710
35–39	1.2257	0.0888	13.809	0.0001
40–44	0.9570	0.0849	11.277	0.0001
45–49	0.8366	0.0844	9.908	0.0001
50–54	1.1370	0.0920	12.354	0.0001
55–59	1.1044	0.0907	12.180	0.0001
60–64	0.6896	0.0847	8.139	0.0001
65–69	1.3787	0.0953	14.468	0.0001
70–74	1.1113	0.0899	12.366	0.0001
75–79	–0.4566	0.1098	–4.157	0.0001
80–84	0.3476	0.0887	3.918	0.0001
85–89	0.8884	0.1105	8.039	0.0001
90+	0.5388	0.1001	5.381	0.0001
Area:				
Western Agulhas Bank	0.8803	0.0185	47.485	0.0001
Central & Eastern Agulhas Bank	0.6315	0.0158	39.935	0.0001
East Coast	0.1974	0.0210	9.414	0.0001
Depth range (m):				
50–100	1.0100	0.0304	33.215	0.0001
100–150	1.4212	0.0288	49.374	0.0001
150–200	1.1283	0.0287	39.293	0.0001
200–250	0.5255	0.0256	20.549	0.0001
250–300	0.0576	0.0249	2.313	0.0207
Target species:				
Agulhas sole	–0.4732	0.0120	–39.594	0.0001
Horse mackerel	–0.1905	0.0188	–10.142	0.0001
Other	–1.1096	0.1044	–10.631	0.0001

RESULTS FROM THE GLM

The R^2 value associated with the full model was 0.2125. The F value used to test the null hypothesis (H_0) that all coefficients in the model, except the intercept, are equal to zero was 1 004.48. The probability of obtaining a value of $F \geq 1\,004.48$ by chance alone, if in fact H_0 were true, is 0.0001 (*df*: model = 47; total = 174 985). Therefore H_0 can be rejected.

The parameter estimates from the multiple regression and associated statistics are listed in Table III.

The intercept corresponds to boats between 10 and 15 m long, to West Coast operations shallower than 50 m and targeting on hake, from January to March 1978. The implication is that the predicted trawled chokka *cpue* for a boat operating under those circumstances is 0.23 kg·h^{-1} ($e^{\text{intercept}}$ –0.05). Alternatively, the predicted *cpue* of a 50 m vessel operating between 100 and 150 m, all other conditions remaining the same, is 6.01 kg·h^{-1}.

All parameter estimates are significantly different from zero at the 5% level, except for those related to three boat length-classes. Examination of the regression coefficients reveals that the 65–69 m vessel category is the most efficient, and that highest catch rates are obtained over the Western Agulhas Bank (i.e. between Cape Point and Cape Agulhas) during the first three months of the year and between 100 and 150 m deep when targeting Cape hake. The results confirm the indications presented in the exploratory analysis above. With the exception of vessels 25–29 m long, the coefficients for vessels <35 m seem to be not significantly different from the intercept, which relates to vessels 10–14 m long (see Table III). The fishing power of vessels longer than 35 m increases slowly up to the 65–69 m length-class (Fig. 11a). The 75–79 m boat length-class category contains data from only two trawlers, which operated in different periods. Most of the drags were made by one of them that operated towards the edge of the maximum abundance of chokka (deeper than 150 m), so realizing a relatively low vessel factor. Similar considerations, particularly in relation to the area of operation, may apply to several trawlers >70m long.

In addition, trawled chokka *cpue* falls rapidly for depths >200 m, beyond which the continental slope lies. This effect is illustrated in Figure 11b.

A time-series of predicted *cpue* under the most frequent conditions (a 50–55 m trawler operating 100–150 m deep) is shown on Figure 6 together with the time-series of nominal trawl *cpue*. The model predicts the same abundance in 1979 and 1981, unlike the nominal *cpue*, and shows slightly less pro-

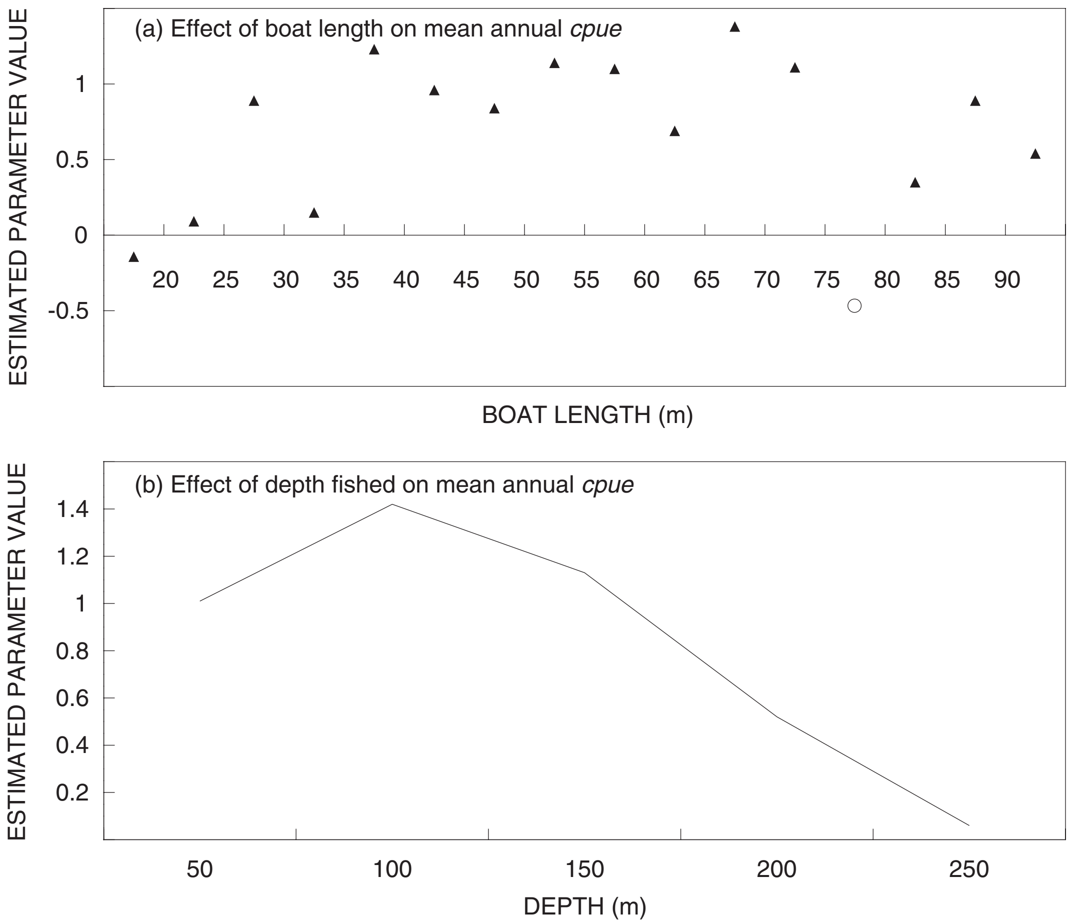

Fig. 11: Regression parameters for the factors boat length and depth of drag, estimated by the GLM

nounced fluctuations from 1983 onwards. As a sensitivity test, a GLM was also conducted, but eliminating from the data those drags with >50% chokka in the catch. The resulting time-series is also plotted on Figure 6. The trend is similar to that produced with all the data included. The average rate of decline in *cpue* derived from regressing the logarithm of the model prediction against time, is 7.7% per year.

CONCLUSIONS

Over the full period analysed, most trawling activity was in the area between Cape Agulhas and Port Elizabeth (i.e. the Central and Eastern Agulhas Bank). For the same period, about one-third of the drags were made between 50 and 150 m deep (more than in any of the other depth ranges). These ranges cover the main area of operation of the inshore trawl fishery and a notable portion of the fishing range of the offshore trawl fishery of the South African south coast.

There has, however, been a contraction of the trawling area over time as a result of trawlers withdrawing from some of the grounds farther offshore. Nevertheless, closer examination suggests that the effort expended on those grounds was traditionally small, possibly having little impact on overall *cpue*. In addition, examination of the frequency distribution of trawls per depth range shows differences in fishing patterns between the years prior to and after 1982. The influence on the *cpue* of those changes, both contraction of the fishing grounds over time and changes in fishing patterns in relation to depth, was evaluated by means of GLM.

Comparison of the *cpue* frequency distribution between the periods 1978–1984 and 1985–1996 reveals marked differences in the relative occurrence of zero catches of chokka, and in the relative frequency of high values of *cpue*. The proportion of zero catches was clearly higher in the more recent period, particularly off the West Coast and in water deeper than 150 m. This could, of course, be construed as an indication of a contraction in resource distribution that is itself often a sign of a general decline in abundance. Lluch-Belda *et al*. (1989) documented this scenario for various stocks of anchovy and sardine worldwide.

Values of *cpue* were high on the fishing grounds farther offshore, where there has been little trawling since the early 1980s. This situation could potentially have had a large impact on the overall trend in trawled chokka *cpue*, if those grounds were heavily fished at the time. However, it appears that only few trawls took place on those sites, consequently having little impact on overall stock size. The highest incidence of large values of *cpue* was in the early period on the fishing grounds between Cape Point and Cape Agulhas (Western Agulhas Bank), for water depths of 150–200 m. Although those two geographical and depth ranges display the largest contrast between the two periods analysed, the feature of higher frequency of zero catches and lower frequency of high catches in the most recent period compared to the situation in the earlier period prevails for all geographical and depth ranges studied. The regions with higher values of *cpue* are far from the grounds traditionally believed to be where chokka spawn, indicating that chokka squid tend to be caught by trawlers either during their migration towards the inshore spawning grounds or while dispersing after spawning (if indeed they do disperse). Augustyn (1990) concluded, after comparison of length/weight relationships, that squid caught in trawl surveys offshore were in better condition than those caught inshore by jigging. That finding suggests that trawlers catch the chokka on their way to the spawning grounds. However, clarifying those mechanisms is important if it is considered necessary to model the resource and the fishery dynamics in a more realistic manner.

Drags in which chokka contributed more than 50% of the catch seem to constitute only a small percentage of the total number made, most of those having taken place in 1979 and 1983. Such drags could be categorised as chokka-directed and there could be a case for eliminating them from the GLM analysis performed. Even so, given their overall infrequency of occurrence, it is obvious that changes in the incidence of directed catches over time have had only minimal impact on the standardised annual trend in *cpue.*

A quantitative assessment of the various effects examined is provided by the GLM analysis. Although the results indicate a correlation between *cpue* and the set of explanatory variables, much of the variability in the trawl *cpue* data (close to 80%) is not explained by the regression. This is to be expected in a data set of this nature, where the error associated with estimates of *cpue* is probably large. Further, *cpue* is likely to be influenced also by such factors as immediate ground topography, weather condition, current and skippers' skill, none of which are included in the present model.

The variables identified as most influential on trawl *cpue* were vessel length, area, depth, season and year when the drag took place, and target species. Examination of the regression coefficients indicates higher values of trawled chokka *cpue* in the first three months of the year, between 100 and 150 m deep and in the area offshore between Cape Point and Cape Agulhas. These results are consistent with those obtained from the exploratory analysis.

The estimated trawl *cpue* from the GLM analysis for the most frequent trawling conditions, i.e. the standardized trawl *cpue*, declines from 1982 in a slightly less pronounced manner than that indicated by the trend in nominal *cpue*. However, it still indicates a 7.7% annual decline over the period investigated. This trend should be interpreted by those responsible for managing the fishery as a strong indication of resource decline during the period considered. Such a decline needs to be reversed if sustainability of the resource is to be ensured.

ACKNOWLEDGEMENTS

This paper is based on a section of a Ph.D. thesis submitted to the University of Cape Town (UCT) in August 1998. We thank the MCM technicians and Dr R.W. Leslie (MCM), for their assistance in data collection and collating, Mrs J. P. Glazer (MCM), for useful discussions on the application of GLMs, Prof. D. S. Butterworth (UCT), for advice, and the reviewers (Dr. A. J. Booth, Rhodes University, Grahamstown; and Dr C. J. Augustyn, MCM), for their valuable suggestions on an earlier draft of the manuscript.

LITERATURE CITED

AUGUSTYN, C. J. 1989 — Systematics, life cycle and resource potential of the chokker squid *Loligo vulgaris reynaudii*. Ph.D. thesis, University of Port Elizabeth: xi + 378 pp.

AUGUSTYN, C. J. 1990 — Biological studies on the chokker squid *Loligo vulgaris reynaudii* (Cephalopoda; Myopsida) on spawning grounds off the south-east coast of South Africa. *S. Afr. J. mar. Sci*. **9**: 11–26.

AUGUSTYN, C. J., ROEL, B. A. and K. L. COCHRANE 1993 — Stock assessment in the chokka squid *Loligo vulgaris reynaudii* fishery off the coast of South Africa. In *Recent Advances in Cephalopod Fisheries Biology*. Okutani, T., O'Dor, R. K. and T. Kubodera (Eds). Tokyo; Tokai University Press: 3–14.

BROWN, J. P. 1996 — Results from further sensitivity analysis for the west coast hake. *Internal Report, Sea Fisheries Research Institute* **WG/10/96/D:H:35**: 4 pp.

GLAZER, J. P. 1999 — The application of general linear modelling methods to estimate trends in abundance of the hake and rock lobster stocks off southern Africa. M.Sc. thesis, University of Cape Town: 239 pp. (thesis reprint TR 99/02, Dept of Maths and Applied Maths, University of Cape Town, dated 1999).

GULLAND, J. A. 1956 — On the fishing effort in English demersal trawl fisheries. *Fishery Invest., Lond. (Ser. 2)* **20**: 41 pp.

HATANAKA, H., SATO, T., AUGUSTYN, C. [J.], PAYNE, A. [I. L.] and R. [W.] LESLIE 1983 — Report on the Japan/South Africa joint trawling survey on the Agulhas Bank in November/December 1980. *Spec. Publ. mar. Fish. Resource Cent*.: 73 pp.

JAPP, D. W., SIMS, P. [F.] and M. J. SMALE 1994 — A review of the fish resources of the Agulhas Bank. *S. Afr. J. Sci*. **90**(3): 123–134.

KIMURA, D. K. 1981 — Standardized measures of relative abundance based on modelling log (*cpue*), and their application to Pacific ocean perch (*Sebastes alatus*). *J. Cons. perm. int. Explor. Mer* **39**(3): 211–218.

LLUCH-BELDA, D., CRAWFORD, R. J. M., KAWASAKI, T., MacCALL, A. D., PARRISH, R. H., SCHWARTZLOSE, R. A. and P. E. SMITH 1989 — World-wide fluctuations of sardine and anchovy stocks: the regime problem. *S. Afr. J. mar. Sci*. **8**: 195–205.

PAYNE, A. I. L. 1989 — Cape hakes. In *Oceans of Life off Southern Africa*. Payne, A. I. L. and R. J. M. Crawford (Eds). Cape Town; Vlaeberg: 136–147.

ROEL, B. A. 1998 — Stock assessment of the chokka squid *Loligo vulgaris reynaudii*. Ph.D. thesis, University of Cape Town: 217 pp.

SATO, T. and H. HATANAKA 1983 — A review of assessment of Japanese distant-water fisheries for cephalopods. In *Advances in Assessment of World Cephalopod Resources*. Caddy, J. F. (Ed.). *F.A.O. Fish. tech. Pap*. **231**: 145–180.

UOZUMI, Y., HATANAKA, H., SATO, T., AUGUSTYN, C. [J.], PAYNE, A. [I. L.] and R. [W.] LESLIE 1984 — Report on the Japan/South Africa joint trawling survey on the Agulhas Bank in November/December 1981. *Publ. Far Seas Fish. Res. Lab., S Series* **11**: 91 pp.

VAN DER LINGEN, C. D., HUTCHINGS, L., MERKLE, D., VAN DER WESTHUIZEN, J. J. and J. NELSON (in press) — Comparative spawning habitats of anchovy (*Engraulis capensis*) and sardine (*Sardinops sagax*) in the southern Benguela upwelling ecosystem. In *Proceedings of the Symposium on Spatial Processes and the Management of Fish Populations*. University of Alaska Sea Grant.

WESTRHEIM, S. J. and R. P. FOUCHER 1985 — Relative fishing power for Canadian trawlers landing Pacific cod (*Gadus macrocephalus*) and important shelf cohabitants from major offshore areas of western Canada, 1960–81. *Can. J. Fish. aquat. Sci*. **42**(10): 1614–1626.

ZAR, J. H. 1984 — *Biostatistical Analysis*, 2nd ed. Englewood Cliffs, New Jersey; Prentice-Hall: xiv + 718 pp.