A study of trends in the chokka squid (*Loligo vulgaris reynaudii*) resource and fishery from commercial and survey data.

by

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Summary

This document contains the results of an investigation of three data sets relevant to the management of the squid jigging fishery in South Africa, viz. the trawl CPUE data, the jig CPUE data, and the demersal cruise data for the South Coast. The results update a number of analyses which have already been reported upon previously:

1) An update of estimates of the stratified survey biomass estimates of squid from the demersal cruises aimed at hake. We have updated these to 2004.

2) GLM standardised CPUE trends for the commercial trawl data. These are updated from the previously reported estimates up to and including 2003. (We did receive 2004 data but were advised not to use it as it was still in the process of being checked and validated).

3) GLM standardised CPUE trends for the commercial jig data. These are updated from the previously reported estimates up to and including 2004.

In addition we have explored a number of variants of standard GLM approaches for the commercial jig and trawl data. In particular we have explored the possibility of different trends in CPUE in different strata, and the possibility of effort saturation effects in the case of the commercial jig data.

The following key results are obtained:

1) The updated stratified survey biomass estimates for squid shows a stable or increasing trend over the period 1986 to 2005.

2) Although the nominal trawl CPUE shows a sharp decline from 2001 to 2003 not evident in the scientific stratified biomass estimates, GLM standardised trawl CPUE trends are more consistent with survey biomass estimates.

3) The commercial trawl CPUE shows a sharp decline between 1978 and 1986 which is either a result of a decline in the abundance of squid available to trawl gear or a change in fishing strategy by trawlers. The scale of catches by trawlers at the time (1978 to 1986) was small (1000 to 2000 tons) indicative that the decline in the trawler CPUE for squid is more likely to be a targeting effect (or a gear effect related to the phasing out of liners) than a resource depletion effect.

4) There is some indication that effort saturation effects play a role in the fishery, with implications for the GLM and effort controls, but subsequent analyses show that the impact of this on jig CPUE GLM results is very small. The inclusion of stratum*year interactions is however substantial, and bring the jig CPUE results more into line with the survey biomass estimates, i.e. a flatter trend in resource abundance from 1986 to 2004 than is proposed by either the nominal CPUE or GLMs incorporating standard main effects.

5) The GLM results including stratum*year interactions suggest that the deployment of effort in the fishing hotspot areas causes a depression of catch rate in the hotspot fishing areas which is not reflected in other areas which are fished much more lightly. There is thus some suggestion that the biomass in other areas act as a buffer against the impact of fishing. Thus, from a population modelling point of view there is a broader population to consider, and this is not reliably indexed by the resource located in the vicinity of fishing alone.

Based on the evidence of different trends in the squid resource from area to area and the fact that each dataset has a specific spatial bias, it may be sensible to introduce some spatial disaggregation in models used to explore management options for the resource. This would facilitate the use of all available data, and would also better reflect the dynamics of the resource.
1. Introduction.

There are three separate data sources which can be used to draw inferences about trends in the abundance of squid in South African waters. These are

- data from the commercial squid-directed jigging fishery,
- data from the offshore and inshore trawl fisheries (in which squid is taken as by-catch), and
- data collected by the RV Africana in its biannual demersal surveys.

Trends in the resource indicated by these three sources appear at face value to be in conflict. We endeavour in this study to explain differences by examining the dependence of squid density on spatial, temporal and other factors which may influence these trends.

There has also been concern about an increase in effort levels in the jigging fishery and MCM appointed scientists have pointed to a potential decline in abundance of the resource at current levels of effort. We thus examine the components of effort in this fishery and the relationship between effort and CPUE.

Section 2 describes the data sources. Section 3 presents empirical analyses which examine trends in catch and effort in the 2 commercial fisheries. Section 4 focuses on effort considerations in the jigging fishery. Section 5 presents analyses of the South Coast survey data. Sections 6 and 7 draws upon the results and considerations raised in Sections 3 to 5 in designing GLM-based analyses of the commercial data with a view to producing standardised indices of resource abundance. We conclude in Section 8 by presenting an overview impression of developments in the resource, based on the results of our analyses.

2. Description of the data used in this study.

2.1 Jig Data

This dataset contains the primary catch statistics on the fishery based on the use of hand operated jigs and are the data used to estimate the effort in the fishery, the primary means of control in the fishery. These data are captured in the so-called “blue books”.

The jig dataset contains 293581 records, each record representing 1 sea-day by 1 vessel and spanning years 1985 to 2004. It is provided to us by MCM as a series of 20 flat files, each file representing a calendar year and containing the following information for each sea-day: vessel code, vessel number, date, number of crew, hours fished, alongshore locality (distance in km along the coastline from the Ruvuma River in Northern Mozambique), distance from shore (km), target species (squid in all cases) and squid catch (kg). We have merged the 20 files into a single dataset.

85288 records have null entries in either the hours fished or number of crew columns, so that only the remaining 208293 may be used for analysis of effort or of catch per unit effort. This also necessitates some adjustment of annual effort totals, which we describe in Section 4.1

2.2 Trawl Data

This information is recorded in skipper log books in the offshore and inshore trawl fishery. The offshore and inshore data have been combined into a single database for the purpose of this study. Though these fisheries are in general directed at species other than squid (hake, horse mackerel, sole etc), squid are caught as a by-product and squid catches are recorded along with the target and other by-catch species. The inshore and offshore trawl fisheries are somewhat different, eliciting concern over the validity of combining their data. However most of the analyses we conduct on these data are stratified by depth, thus largely separating the two fisheries.
The trawl data set contains 1195771 records, each record representing 1 drag. The total squid catch represented by this dataset is 17 000 tons (compared to 116 000 tons in the jig dataset) so that this is a valuable additional source of information about trends in the squid population.

The dataset was supplied as a flat file containing the following information: company code, vessel code, landing date, drag, effort, ICSEAF division, grid number, depth, mesh size, latitude and longitude (to the nearest 20 minutes), target species, catch by species for 10 species (hake, horse mackerel, monk, kingklip, East Coast sole, West Coast sole, snoek, mackerel, red squid and white squid (squid)).

The data supplied by MCM excluded all records north of Cape Columbine on the West Coast and all records at depths greater than 450m, the rationale given to us being that squid are unlikely to be found in records of catches further north or at greater depths.

2.3 Survey Data

These comprise records of 2199 trawls from 25 surveys conducted with the RV Africana on the South Coast from September 1986 to May 2005. 11 of these surveys were conducted in spring (September/October) and 14 in autumn (April/May).

The data consist of (a) a flat file consisting of trawl by trawl records of latitude, longitude, depth, date, time, trawl speed, trawl duration, net width and the total catch (all species) for all trawls in the 25 surveys; (b) a file with records for each non-zero catch of squid trawl and category (the categories being large males, large females, juvenile males, juvenile females, males, females, unspecified sex and eggs), containing the catch weight for that trawl and category; (c) a file for each length frequency sample taken, containing the total sample weight, number of fish sampled, and the number in each 1cm length class.

Since the length frequency datafiles were not in a format readily extracted by standard software, it was necessary to develop custom built FORTRAN code which reads these files and restructures the information in a flat format.

Files (a), (b) and (c) are then merged in various formats depending on the nature of each investigation conducted on these data.

3. Nominal trends in the commercial data

3.1 Definitions of effort

Jig data: In the jigging dataset we define effort for any particular sea-day as number of crew times number of hours fished on that day, as per the definition used by Roel (1998) and by Glazer et al (2005), that is; man-hours.

Trawl data: In the trawl dataset we define effort for a particular drag as the number of minutes of trawl time. CPUE (catch per unit effort) for one drag or sea day is then calculated as the catch for that drag or sea-day (by mass, in kg) divided by the effort. CPUE for a period greater than one sea day or drag, e.g. for a particular year, is calculated as the total catch for that year divided by the total effort for that year.

The above definitions imply that catch is directly proportional to effort. This assumption is examined in a later section.

3.2 Comparison of jig and trawl CPUE trends by year.

The key goal of these analyses is to determine reliable historic trends in the resource abundance of squid in the period covered by the data. The basic assumption in fisheries science is that CPUE is directly proportional to fish density, and that fish density is proportional to resource abundance.
Because CPUE is influenced by factors other than abundance, where possible these other factors need be addressed in producing an unbiased and fair comparison of year to year changes in CPUE. Hence the need for the standardisation of CPUE trends by means of General Linear Models (GLMs) or similar techniques.

Fig. 1 shows the nominal CPUE in the jig and trawl fisheries by year. A key difference between the nominal jig and trawl CPUE trends is that the jig CPUE shows some recovery since 2001 while the trawl CPUE declines sharply after 2001.

3.3 Comparison of jig and trawl CPUE trends by month.

A potential source of bias in relating nominal CPUE trends to resource abundance is the failure to account for differential effort by month, in circumstances where CPUE differs over months. Fig. 2 compares the nominal mean CPUE by calendar month for the jig and trawl fisheries. Both datasets show a clear and smooth pattern of high CPUE in summer months and low CPUE in winter months. This pattern is more pronounced for the trawl data than for the jig data. Nevertheless on the basis of these results it is advisable to include a month effect in any GLM analyses aimed at standardising these data.

3.4 Comparison of total jig and trawl effort by month.

Fig. 3 shows the corresponding total effort deployed by month in each fishery. The trawl effort shows little within year pattern. The jig data shows a progressive decline in effort from December through February, an increase from February through October and low effort in November, corresponding to the closed season.

3.5 Effort and CPUE versus distance from shore in the jig fishery.

The spatial information in the jigging records is given by the position of the nearest land-based point (measured in km of coastline distance from the Ruvuma River on the Northern Mozambique border with Tanzania,) and the distance from shore, at a 1 km resolution.

Records appear in the dataset as far as 280 km offshore, but 98.2% of the recorded effort lies within 11km of the coastline, as is illustrated in Fig. 4. Fig. 5 shows the trend in mean CPUE with distance from shore. No clear pattern is evident in the first 11km, though there is evidence of exponential decay in CPUE with distances beyond 11km. It may be that this trend has more to do with gear limitations than with real abundance of squid, but it is nonetheless an important feature.

3.6 Effort and CPUE versus longshore location in the jig fishery.

Alongshore, records extend as far as St Lucia on the East Coast and Port Nolloth on the West Coast, but 99.9% of the recorded effort is between Cape Town and East London and of this, 95% is east of Knysna. Fig. 6 shows the distribution of effort binned at alongshore intervals of 50km. Fig. 7 shows the trends in CPUE. The first panel shows all positions, the second shows only positions in which at least 100 sea-days of effort have been recorded. Some very high points from the first panel which are lost in the second are at the following positions: 3750 (St Lucia), 4250 (Northern Transkei), 6000 (Eland’s Bay) and 5700 – 5800 (Hout Bay to Dassen Island). In the first three of these positions the effort is so low as to almost warrant total disregard (1,7 and 4 sea-days respectively.) The 3 consecutive divisions from Hout Bay to Dassen Island represent a total of 110 sea-days and so perhaps deserve some attention. Disregarding these anomalies, the CPUE in the second panel of Fig. 7 is roughly mirrored by the concentration of effort, as would be expected.

The fact that some pattern is evident suggests that alongshore factors may be important in GLM analysis of the CPUE, which we deal with in section 7.
3.7 Spatial patterns over time in trawl effort and CPUE.

Spatial information for the trawl records is given at the level of grid cells with dimension 20 minutes of latitude by 20 minutes of longitude, together with depth. The distribution of trawl effort and CPUE by depth (binned at 50m intervals) is illustrated in Fig. 8. The first panel shows the distribution over all years covered by the data (1977 to 2004.) The greatest concentration of effort is in the 51 to 100m depth zone while CPUE is highest in the 151 to 200m zone. The remaining panels show the distributions over 5-year intervals. Note that the CPUE mode appears to have shifted progressively into shallower waters, from 201-250m in the late 1970’s to 101-150m since 1995. The distribution of effort by depth appears to have been fairly stable, with the notable exception that since 2000, very little effort is recorded at depths shallower than 200m. The mismatch of effort and CPUE distributions is of course because this fishery is not squid-directed.

The apparent strong dependence of CPUE on depth from these plots suggest that depth should be included as a factor in GLM analysis of the CPUE data in section 6. What is less clear is whether a changing depth-CPUE relationship should be modelled by means of depth*year interactions.

3.8 Trends in space: comparison of the trawl and jig CPUE datasets.

In order to reconcile spatial information in the jig and trawl fisheries, we define 20 alongshore divisions common to both fisheries, whose definitions are given together with longitude, latitude, landmarks and coastal distances in Table 1, and which are illustrated in the map on Fig. 9.

Fig. 10 compares the jig and trawl effort and CPUE on the basis of these common divisions. This plot highlights in particular the difference in effort distributions and the potential value of each of the data sources as representative of perhaps different components of the resource (with some overlap of course).

4. Trends in effort over time and the relationship between effort and CPUE in the jig fishery

4.1 Adjustment of jig effort to account for incomplete records.

Of the 293581 sea-day records in the jig dataset, 85288 records have null entries in either the hours fished or number of crew columns, so that effort and CPUE may not be calculated for these records (though the catch is recorded), and aggregated annual effort is understated. We thus calculate an “adjusted effort” for each year by the formula:

\[
E_{\text{adj}}^{y} = E_{y}^{R} \times \frac{C_{y}^{T}}{C_{y}^{R}}
\]

where \( E_{y}^{R} \) is the recorded effort in year \( y \).

\( C_{y}^{T} \) is the total catch in year \( y \).

\( C_{y}^{R} \) is the catch in year \( y \) from records with complete effort information.

This is probably the method used by MCM in compiling annual effort aggregates.

4.2 Trends in jig effort and the components of effort in time.

Fig. 11 shows the year to year changes in recorded effort and adjusted effort in the jig fishery. Effort may be considered to be the product of 4 components: number of crew, number of hours fished per day, number of sea-days per vessel per year and the number of vessels operating in the fishery. Fig. 12
shows the year to year changes in each of these 4 components. We see from these plots, three periods of changing effort with different characteristics:

1) In the period 1986 to 1996, the increase of effort was driven by all four components: sea-days per vessel increased from about 40 to almost 100, number of vessels increased from 125 to 190, average crew increased from 7 to 12 and average fishing hours per day increased from 12 to 15.

2) In the period 1996 to 2001, the decrease in effort was driven by the number of vessels in the fleet which decreased from 190 to 130, with the other 3 components stabilising.

3) In the period 2001 to 2004, the increase in effort has been primarily driven by an increase in the number of sea-days per vessel per year from 100 to 140, while the other 3 components have shown very slight increases.

4.3 The relationship between effort and CPUE in the jig fishery.

The assumption underlying the definition of effort as man-hours is that the expected catch is directly proportional to the number of man-hours. Fig. 13(a) shows a plot of catch versus man-hours. Although catch increases as a function of man-hours, the rate of increase is not linear since there is apparently no benefit to catch for man-hours in excess of 400. This non-linearity is better viewed in the plot of catch/man-hours (CPUE) versus man-hours, Fig. 13(b). If catch were indeed directly proportional to man-hours, this plot would just be a constant equal to the overall proportionality coefficient. Fig. 13(b) shows that there is in fact a distinct fall off in CPUE as effort increases. Thus the assumption of direct proportionality between catch and effort seems on the face of it to be faulty. Of course the missing variable in all this is the resource abundance – consideration of changes in resource abundance normally dictates a negative relationship between CPUE and effort of the kind demonstrated in Fig. 13. Any speculation about the relationship between CPUE and effort is therefore best viewed in the context of a GLM in which changes in abundance are dealt with by the inclusion of a year effect. Therefore, the following points should be taking to be introductory remarks as a rough guide to consideration of certain effort effects in such a GLM analysis.

Is the fall off in CPUE with increased effort due to an increase in the number of fishing hours or due to an increase in the number of crew? Fig. 14 suggests that CPUE declines both with number of crew and with number of fishing hours per day independently.

Panel (a) of Fig. 14 shows anomalously low catch per crew corresponding with 24 hours of fishing. A possible explanation of this anomaly may be in the interpretation of the term “fishing hours”. Some skippers may interpret this to mean the number of hour at sea, and not solely fishing. In this case the “24 hour” records would typically overstate effort, and hence understate CPUE.

Panel (c) of Fig. 14 indicates that the “24 hour” category is not necessarily anomalous but is reasonably consistent with a systematic decline in CPUE as the number of hours is increased. In this plot it is the 1, 22 and 23 hour categories that represent deviations from this trend.

Panel (b) of Fig. 14 shows a non-linear increase in catch per hour with crew size up to a level of about 25 crew members. Beyond that number, the plot shows that additional crew yield no additional increase in catch. Roel (1998) suggests that this phenomenon might be due to boats with large crew comprising a crew component which is employed in non-fishing activities such as packing squid. Panel (d) shows that CPUE decreases consistently as crew size increases. Panels (e) and (f) are repeats of (c) and (d) respectively but on a log-scale and with exponential regression lines inserted. The purpose of these plots is to show that the relationship between CPUE and either of “hours” or “crew” is approximately log-linear, motivating the modelling approach taken in Section 7 later in this document.
Panel (c) of Fig. 14 also suggests an anomalous comparison between catch per crew member per hour for the 1 and 2 hour duration. That is, a sharp reduction (~40%) going from 1 to 2 hours. It seems that this anomaly could in some way be related to reporting practice, particularly the rounding off and truncation decisions required to reduce duration information to integer hours.

Based on the above, we speculate that:

1) Large crews experience greater competition between crew-members targeting the same group of fish than do small crews.

2) Boats fishing for shorter periods per day are likely to spend a greater portion of their fishing time in optimal conditions than those fishing for longer periods.

These results have implications for the GLM analysis of the jig CPUE data, and also for the relative merits of different methods of controlling effort in the fishery. For the GLM analysis these observations suggest that both the number of crew and number of hours fished should be included as covariates in the GLM analyses of the jig CPUE data. In Section 7 we present two variants of a GLM on the jig CPUE which includes first crew size alone and then crew size and fishing hours as covariates. Including these variables in this way assumes that effort is the “cause” variable, and CPUE is the “effect” variable in a cause and effect relationship. It is possible however that the direction of causation is in the other direction, i.e. lower CPUE causing higher effort, as fishing dynamically increases effort in order to compensate for lower CPUE levels. In the latter situation the inclusion of crew size and fishing hour covariates can lead to entirely spurious estimates of the year effect parameters assumed to index the resource biomass.

As regards effort controls, the foregoing suggests that, above a threshold amount, a reduction in either the number of crew and/or the number of hours fished per day will not have an impact on overall catches of the same degree (as the reduction).

5. Scientific survey data

Survey data play an important role in fisheries management and contain some inherent advantages over commercial data in that fishing methods are dictated by scientific goals and are not subject to economic pressures which may change commercial practice and thus exert non-biological influences over quantities such as CPUE. We have thus spent some time conducting analyses on the survey data provided by MCM.

5.1 Calculation of a stratified survey biomass from the demersal cruise data

As per the method used by MCM, a stratified survey biomass estimate can be obtained as follows:

1. The swept area for each trawl is calculated as the product of trawl speed, net width and trawl time.

2. 4 strata are defined by depth ranges 0 to 50 metres, 50 to 100m, 100 to 200m and 200 to 500m.

3. The swept area in each stratum is then the sum of swept areas for all trawls in that stratum.

4. The squid density is the total catch divided by total swept area.

5. The stratum biomass is the product of the stratum density and the stratum area.

6. Finally the total squid biomass is the sum of the stratum biomasses.

7. Since 6 of the 25 surveys did not trawl deeper than 200m, we include only the first three depth strata in this final sum. In those surveys where the 200m to 500m stratum was sampled, the biomass estimate in this stratum is on average less than 2% of the total, so that it makes a negligible contribution to the year to year trend.
The choice of strata for the survey are oriented to optimise the results for hake, not squid. Also, the demersal nature of the sampling gear may result in the survey missing a portion of the stock higher up in the water column.

Table 2 shows the biomass estimate in each stratum for each survey, and the 0 to 200m total. Table 3 shows the stratum areas, average density and average biomass over all surveys.

Fig. 15 shows the survey biomass estimates, first as a single time series and then as separate series for the autumn and spring surveys. The linear trend in the survey biomass is positive, but statistically not significantly different from zero (flat.)

Fig. 16 compares the survey index in Fig. 15 to the nominal jig and trawl CPUE trends. There is a sharp decline in the commercial trawl index since 2001, while the survey index shows an increase over the same time period. Explanation of this difference may lie in the spatial and temporal differences between survey and commercial effort. In particular: the surveys take place at a certain time of year, whereas the commercial trawl is year-round; the survey samples cover the entire South Coast whereas the commercial trawl effort is predominantly west of Knysna and the jig effort is concentrated within 10 km of shore in the area around Port Elizabeth. Also playing a role may be the differences in trend between large and small squid, with the smaller mesh size in the survey gear likely to catch a greater proportion of small fish. These points of difference are not addressed directly by the GLM analyses presented in Sections 6 and 7, but should be borne in mind and accounted for appropriately when using the GLM-standardised CPUE series within an assessment framework.

5.2 Scientific survey data: Spatial trends in the survey data.

Fig. 17 shows the survey density trends separated by the 4 depth divisions and also into areas west and east of 24 degrees, so that 8 strata in all are represented. Note the strata 0 to 50m in the east, 50 to 100m in the east and 100 to 200m in the west are characterised by unusually high density in the early 1990s.

Table 4 shows the survey-estimated density and biomass in each of these 8 new strata defined purely for the purpose of comparison, averaged over all 25 surveys. Note that the stratum 200 to 500m in the west, which shows the greatest decline since 1996, represents only 3% of the area and 3% of the biomass on average. The most abundant stratum (in biomass terms) is that between 100m and 200m in the west, representing 42% of the biomass and which shows, if anything, some increase in trend (3rd panel of Fig. 17.) suggesting that this stratum may be functioning as a de facto reserve for squid, providing a buffer against fishing in other areas.

5.3 Scientific survey data: Trends in mean size.

A possible explanation of the difference in trend between the survey biomass estimates and the commercial CPUE is that the survey represents the entire population, while the commercial data are subject to fishing selectivity and thus represent the larger fish.

Fig. 18 shows the distribution of length over all survey trawls and all surveys. The modal length is 7cm, the mean length is 12.13cm, and the maximum recorded length is 50cm, though 95% of sampled fish are 22cm in length or less. Note that by contrast mean length in the jig fishery in 1988 and 1999 ranged from 23 to 33 cm, depending on month (Roel 1998). Fig. 19 shows a distinct relationship between average length and depth, with the average length increasing from about 11cm at 30m of depth to about 25cm at depths greater than 300m.

Fig. 20 shows a systematic increase in average length moving alongshore from west to east. The average length at 26 degrees E (Jeffrey’s Bay) being about 3cm longer than that at 20 degrees E (Cape Agulhas.) This trend is borne out in Fig. 21 which shows also that the larger size-classes of squid tend
to reside at shallower depths in the east than in the west. Much of this feature is of course due to the
inshore spawning aggregations in the east.

The plots in Fig. 22 represent a stratified estimate of the total number of fish on the South Coast in each
of the 4 size classes. These estimates are obtained in the same way as the overall biomass estimate,
with the number in each stratum being up-weighted by the stratum area. These plots suggest some
decline in numbers of fish larger than 21cm and some increase in numbers of fish smaller than 20cm.

6. GLM standardisation of the commercial trawl CPUE data

As seen in the nominal CPUE plots of Section 3, CPUE for a particular drag in the trawl fishery is
affected not only by the abundance of the resource in general, but by numerous other factors specific to
that drag such as the depth of fishing, the location of fishing, the time of year, and other factors not yet
considered such as the vessel efficiency, so that the nominal average CPUE by year is likely to contain
some inherent biases. This is particularly likely considering that the trawl fishery is not directed at
squid. Thus some standardisation of CPUE with respect to these other factors is desirable. We consider
here two standardisations by means of General Linear Models (GLMs.)

6.1 GLM 1 – use of typical main effects.

The first GLM we apply is one similar to that used by Roel (1998), with the following form:

\[
\ln(CPUE + \delta) = \mu + \alpha_y + \beta_S + \phi_V + \chi_A + \eta_D + \psi_T + \varepsilon
\]

where

- \( \mu \) is the intercept
- \( \alpha_y \) is the year effect in year \( y \)
- \( \beta_S \) is the season effect in season \( S \) (summer, autumn, winter, spring)
- \( \phi_V \) is the vessel effect for vessel \( V \)
- \( \chi_A \) is the area effect for area \( A \) (West of 20 degrees, 20 to 24 degrees, 24 to 27 degrees,
  East of 27 degrees)
- \( \eta_D \) is the depth effect for depth category \( D \) (at 50m depth intervals)
- \( \psi_T \) is the target species effect for target species \( T \)
- \( \delta \) is a constant equal to 5% of the average CPUE
- \( \varepsilon \) is the residual

The standardised CPUE series resulting from this GLM is illustrated in Fig. 23, together with the
nominal CPUE trend. Notably the standardised CPUE indicates a sharper decline in abundance during
the period 1978 to 1986 than does the nominal. In the period 1986 to 2003, however, which
corresponds with the period covered by the surveys, notwithstanding the very low estimate for 1997,
the trend in the standardised series shows some stability by comparison with the decline in nominal
CPUE over the same period. The period 1999 to 2003 is one in which the standardised series (showing
an increase) contrasts sharply with the decreasing nominal CPUE.

The adjusted R^2 statistic for GLM 1 is 0.211.

6.2 GLM 2 – introduction of stratum*year, stratum*depth and stratum*season interactions

The disadvantage of the approach taken in GLM1 above is that no allowance is made for different
trends in different strata. The standard way of introducing this possibility is to include stratum*year
interactions in the model. If in addition, one includes stratum*depth and stratum*season interactions, then the relationship between CPUE and depth and the within year changes in density are also not constrained to be the same for all strata.

We define 16 spatial strata in the area covered by the trawl fishery. The strata consist of 4 alongshore divisions by 4 depth divisions as shown in Tables 5(a) to (c) so that the 8 central strata are those covered by the demersal survey on the South Coast and coincide with the survey stratification.

Tables 5(a) to (c) shows the trawl effort and the areas of these strata. Of the 16 strata shown, only 8 contain sufficient data to reasonably assess trends in the resource over an extended period. A ninth stratum, that shallower than 50m between 20 and 24 degrees E, shows strong evidence of decline in the period 1978 to 1983. However analyses not presented here show that this trend is mirrored in the 50 to 100m stratum at the same longitudes so that it is reasonable to combine these strata. Note too that the 8 strata containing sufficient data represent 99% of the trawl effort.

We thus redefine 8 strata of which the trawl data can be assumed to reasonably represent. These strata are named A to H and shown in Tables 6(a) to (c) which show the proportion of trawl effort and the proportion of area in each stratum.

This comparison of effort and areas enabled by Tables 6(b) and (c) shows the important feature that the relative effort in strata A,B,C and D is disproportionate to the areas of these strata. The effect of this mismatch between area and effort is that in a nominal CPUE series, and likewise in a non-stratified GLM-standardised series as provided by GLM1 above, strata B and C will be over-represented and strata A and D under-represented, thus resulting in bias if trends differ for these four strata.

The form of GLM2 is then:

\[
\ln(\text{CPUE} + \delta) = \mu + \alpha_{y,j} + \beta_{s,j} + \phi_V + \eta_{D,j} + \psi_T + \varepsilon
\]  

(3)

where

- \(\mu\) is the intercept
- \(\alpha_{y,j}\) is the effect in year \(y\) and stratum \(j\) (\(j = A,B,C,D,E,F,G\) or \(H\))
- \(\beta_{s,j}\) is the season effect in season \(S\) and stratum \(j\)
- \(\phi_V\) is the vessel effect for vessel \(V\)
- \(\eta_{D,j}\) is the depth effect for depth category \(D\) and stratum \(j\)
- \(\psi_T\) is the target species effect for target species \(T\)
- \(\delta\) is a constant equal to 5\% of the average CPUE
- \(\varepsilon\) is the residual

We include in the analysis only those trawls within strata A to H so that 2505 out of the 1.2 million trawls are excluded (i.e. about 0.25\%).

The GLM standardised series in each stratum are shown in Fig 24, together with the nominal series for comparison. Each series has been standardised to winter, with a median vessel efficiency, median depth and median target species effect and then scaled so that the standardised mean CPUE in each series is the same as the nominal mean in each series (over all years).

The area-weighted aggregated series emerging from GLM2 is plotted together with the nominal CPUE in Fig. 25 and again with the GLM1 series in Fig. 26. Note that the trend since 2000 is less optimistic for GLM2 than for GLM1, but more optimistic than the nominal CPUE. The general level of depletion
relative to 1978 is more optimistic from GLM2 than from either the nominal or the GLM1-standardised series.

Fig. 27 compares the GLM2 series with the survey-estimated biomass over the period 1986 to 2003. Recall that the survey index is representative of strata C to H only, so we produce here a commercial index which is an area-weighted average of these 6 strata alone, rather than the full 8 strata. Note that the two commercial indices in this plot do not differ greatly from each other. Both however are less optimistic than the survey trend, again – probably mainly due to the fact that the commercial index represents an “exploitable” component of the resource, which would tend to consist mainly of larger fish compared to the survey index which represents the population as a whole.

The adjusted $R^2$ statistic for GLM 2 is 0.231, compared with 0.211 from GLM 1, so that an additional 2% of the variance in the data is explained by the interactions of stratum with year, depth and season effects. The p-test for these interactions is 0.000, indicating that they are strongly statistically significant.

7. GLM standardisation of the jig CPUE data

We present 6 GLM analyses of the jig CPUE data, increasing in complexity.

GLMa is the simplest of the 6 and standardises the CPUE with respect to vessel and to month of fishing. The form of GLMa is:

$$\ln(\text{CPUE}) = \mu + \alpha_x + \beta_m + \phi_v + \varepsilon$$  \hspace{1cm} (4)

where $\mu$ is the intercept  
$\alpha_x$ is the year effect in year $y$ 
$\beta_m$ is the season effect in month $m$  
$\phi_v$ is the vessel effect for vessel $V$  
$\varepsilon$ is the residual

The series is standardised for a median vessel efficiency and median month effect.

GLMb models in addition to the effects of GLMa, a dependence on alongshore position. The alongshore positions are categorised as in Table 1 and Fig. 9. The form of GLMb is then:

$$\ln(\text{CPUE}) = \mu + \alpha_x + \beta_m + \phi_v + \chi_L + \varepsilon$$  \hspace{1cm} (5)

where $\chi_L$ is the effect for alongshore division $L$

The series is standardised at alongshore division 8 (Jeffrey’s Bay,.) which is the division with the highest concentration of effort.

GLMc models, in addition to the effects of GLMb, a dependence on offshore position. Three offshore positions categories are identified in view of the plot in Fig. 5, viz. 0 to 11km from shore; 12 to 60km from shore; and more than 60km from shore. The form of GLMc is then:

$$\ln(\text{CPUE}) = \mu + \alpha_x + \beta_m + \phi_v + \chi_L + \lambda_D + \varepsilon$$  \hspace{1cm} (6)

where $\lambda_D$ is the effect for offshore position $D$. 

12
GLMd takes a stratified approach similar to that of GLM2 in section 6, where we allow for the possibility of different trends in CPUE within 4 different alongshore strata. These strata are defined as: west of 20 degrees E, 20 to 24 degrees E, 24 to 27 degrees E and east of 27 degrees E.

The form of GLMd is then:
\[
\ln(CPUE) = \mu + \alpha_y + \beta_m + \phi_r + \chi_L + \lambda_D + \psi_{S,y} + \epsilon
\]

where \( \lambda_D \) is the year*stratum interaction effect in stratum S and year y.

GLMe and GLMf make provision for effort saturation effects as discussed in Section 4, i.e. that sea-days with large crews or those fishing for many hours in the day may experience saturation effects which depress CPUE. GLMe first considers only a dependence on number of crew, which is modelled as a covariate so that GLMe takes the form:
\[
\ln(CPUE) = \mu + \alpha_y + \beta_m + \phi_r + \chi_L + \lambda_D + \psi_{S,y} + \xi C + \epsilon
\]

where C is the number of crew

and \( \xi \) is the covariate coefficient for number of crew.

GLMf then considers hours fished as a covariate in addition to the number of crew, so that GLMf takes the form:
\[
\ln(CPUE) = \mu + \alpha_y + \beta_m + \phi_r + \chi_L + \lambda_D + \psi_{S,y} + \xi C + \zeta H + \epsilon
\]

where H is the number of hours fished

and \( \zeta \) is the covariate coefficient for hours fished.

7.2 Commercial jig CPUE: Results

A summary of the effects modelled in each of the above GLM’s and the associated R-squared statistics is provided in Table 7. Note that the R-squared increases markedly with each additional effect, and the p-test statistics are less than 0.001 for each effect type, indicating that all are statistically significant.

The standardised CPUE series generated by GLMs a, b and c are shown in Fig. 28. GLMs a and c are shown together with the nominal trend in Fig. 29, with each series normalised relative to the starting value. Note that neither the initial GLM standardisation nor the introduction of offshore and alongshore effects substantially change the trend. The size of the effect is however substantial. For example the standardised CPUE at longshore division 10 (just west of Knysna) is half of that at Jeffrey’s Bay while that at offshore positions greater than 60 km from shore is about 40% of that within 11 km of shore.

The stratified approach taken in GLMs d, e and f produce very different trends for the 4 strata as illustrated in Fig. 30, with strata in the east and the west showing an increase in CPUE, while the stratum between 24 and 27 degrees shows decline and that between 20 and 24 degrees is relatively stable.

The “crew” saturation effect introduced in GLMe compared to GLMd produces a slightly more optimistic trend, while the additional “hours” saturation effect does not make much extra difference. This is best seen in Figs 31 (a) and (b) which compare the standardised out put from these 3 GLMs firstly in the 24 to 27 degree stratum (Jeffrey’s Bay/Port Elizabeth, where most of the effort is concentrated) and then as a weighted average of the 4 strata using the 1:4:1:1 weighting discussed below.
7.3 Notes on the jig CPUE GLM analyses

Interpretation of the suite of trends generated by GLMs d, e and f rests on two key questions. The first relates to the validity of the effort saturation hypothesis. As discussed in Section 4, this issue must at this stage be considered unresolved and the topic of future study. The second is a question of which component of the resource these data are able to justifiably represent.

As discussed in Section 6 with regard to the trawl data, if the jig CPUE is to be used as an index of biomass for the entire population, then this should be done by means of an area-weighted average of the series from the 4 strata. In the depth range 0 to 200m, where the bulk of the population resides, the area between 20 and 24 degrees (19906 km$^2$) is roughly 4 times that between 24 and 27 degrees (5147 km$^2$). The planar surface area values east of 27 degrees were not available to the authors as of writing this document, nor were those west of 20 degrees and shallower than 100m. In the absence of this information, we assumed that the strata west of 20 degrees and east of 27 degrees are roughly the same as the 24 to 27 degree stratum. We provide thus a roughly area weighted CPUE series using the weighting ratio 1:4:1:1 for the 4 strata (from west to east.) This is the weighting adopted to produce Figs 31(b), 32 and 33. It must be said that this weighting regime is somewhat ad hoc, and that other weightings could produce a variety of aggregated trends. We note however, as shown by Fig. 33, that the area weighted series from GLMs d and f are in much better agreement with the survey index than is the nominal jig CPUE shown in Fig. 16.

An alternative approach is that no attempt should be made to aggregate the trends from the 4 strata, but rather that they should be taken as separate indices into a stratified assessment framework and each given an allotment of influence relative to other data sources (such as survey and commercial trawl indices) in relation to the quantity of data it represents.

8. Conclusions

The initial objective of this work was to analyse the jig and trawl CPUE data and the scientific survey data with a view to identifying whatever important implications emerge from a management point of view.

A key aim has been to isolate unbiased year to year indices for resource biomass from these three sources of data.

In this study we were able to update and improve on a number of analyses which have already been reported upon previously:

4) An update of estimates of the stratified survey biomass estimates of squid from the demersal cruises aimed at hake. We have updated these to 2004.

5) GLM standardised CPUE trends for the commercial trawl data. These are updated from the previously reported estimates up to and including 2003. (We did receive 2004 data but were advised not to use it as it was still in the process of being checked and validated).

6) GLM standardised CPUE trends for the commercial jig data. These are updated from the previously reported estimates up to and including 2004.

In addition we have explored a number of variants of standard GLM approaches for the commercial jig and trawl data. In particular we have explored the possibility of different trends in CPUE in different strata, and the possibility of effort saturation effects in the case of the commercial jig data.

We have also explored the data at a nominal level and have drawn a variety of conclusions from this level of analysis.
A key result from the update of the stratified biomass estimates for squid from the scientific survey data is Fig. 15. This suggests a stable or increasing trend in squid resource biomass over the period 1986 to 2005.

The nominal commercial trawl CPUE time series appears less optimistic than the survey biomass trends. In particular the nominal commercial trend shows a decline from 2001 to 2003 which is not evident in the scientific stratified biomass estimates. However, GLM analyses of the commercial trawl CPUE suggest a different trend, one which is more consistent with the survey biomass estimates (see Fig. 23). The explanation offered is that trawl effort has moved deeper, and the GLM resolves this adequately such that there is better agreement with the survey data.

For the period 1978 to 1986 there is only the commercial trawl CPUE data to provide any information about resource biomass trends, and this CPUE shows a sharp decline (see Fig. 23). This may be due to (a) a decline in the abundance of squid available to trawl gear or (b) a change in fishing strategy by trawlers. In regard to the latter we note that the period 1978 to 1986 spans the period where phasing out of the use of liners in trawl nets took place, and this may have had an impact on the catch of squid by trawlers. The scale of catches by trawlers at the time (1978 to 1986) was between 1000 and 2000 tons. This is not a very large amount and perhaps this is indicative that the decline in the trawler CPUE for squid is more likely to be a targeting effect (or a gear effect related to the phasing out of liners) rather than a resource depletion effect.

We argue that GLM2, which makes provision for stratum*year interactions and hence allows for differing trends in different strata, is superior to GLM1, which does not. GLM2 is also in better agreement with the stratified survey biomass (see Fig. 27) than GLM1.

Results are presented showing the impact on the jig GLM results from inclusion of effort saturation effects, and stratum*year interactions. The impact of effort saturation is summed up by GLMf (Fig. 31) compared to GLMd and GLMe – all of these contain stratum*year interactions (the effect of effort saturation is small). The results of including stratum*year interactions and effort saturation effects in the GLM are illustrated in Fig. 32, comparing GLMf to GLMc (GLMc does not contain stratum*year interactions and effort saturation effects). We have made some rough assumptions about planar surface areas for this calculation and a more detailed investigation would be useful. The implication is of a flatter trend in resource abundance from 1986 to 2004 than is proposed by either the nominal CPUE or GLMe.

The GLM results including stratum*year interactions suggest that the deployment of effort in the fishing hotspot areas causes a depression of catch rate in the hotspot fishing areas which is not reflected in other areas which are fished much more lightly. There is thus some suggestion that the biomass in other areas act as a buffer against the impact of fishing. This is implied by Fig. 10 which shows that although fishing is focussed in a particular area, good CPUE levels can be achieved over a much broader area. Thus, from a population modelling point of view there is a broader population to consider, and this is not reliably indexed by the resource located in the vicinity of fishing alone.

Based on the evidence of different trends in the squid resource from area to area and the fact that each dataset has a specific spatial bias, it may be sensible to introduce some spatial disaggregation in models used to explore management options for the resource. This would facilitate the use of all available data, and would also better reflect the dynamics of the resource.

9. References

Glazer, J.P. and Butterworth, D.S.  2005. Results obtained from projecting the squid resource *Loligo vulgaris reynaudii* 10 years into the future. MCM working group document WG/05/08/SQ1.

**10. Acknowledgements**

To MCM, and in particular to Darrel Anders, Jean Glazer, Marek Lipinski, Rob Leslie, Chris Wilkie and Farzana Brey for provision and clarification of the data.
Tables and Figures

Table 1. Longshore divisions used to reconcile spatial information in the jig dataset (coastal distance) with that in the trawl dataset (longitude and latitude). These divisions are illustrated in Fig. 13.

<table>
<thead>
<tr>
<th>Division</th>
<th>Longitude</th>
<th>Latitude</th>
<th>Division Boundary Landmarks</th>
<th>Coastal Distance from Ruvuma River</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>East of 27</td>
<td>North of 30</td>
<td>North of Isipingo</td>
<td>North of 3978</td>
</tr>
<tr>
<td>2</td>
<td>East of 27</td>
<td>30 to 31</td>
<td>Isipingo to Port Edward</td>
<td>3979 to 4121</td>
</tr>
<tr>
<td>3</td>
<td>East of 27</td>
<td>31 to 32</td>
<td>Port Edward to Stoney Point</td>
<td>4122 to 4368</td>
</tr>
<tr>
<td>4</td>
<td>East of 27</td>
<td>32 to 33</td>
<td>Stoney Point to Hamburg</td>
<td>4369 to 4505</td>
</tr>
<tr>
<td>5</td>
<td>East of 27</td>
<td>South of 33</td>
<td>Hamburg to Port Alfred</td>
<td>4506 to 4573</td>
</tr>
<tr>
<td>6</td>
<td>27 to 26</td>
<td>South of 33</td>
<td>Port Alfred to Sunday's River</td>
<td>4574 to 4674</td>
</tr>
<tr>
<td>7</td>
<td>26 to 25</td>
<td>South of 33</td>
<td>Sunday's River to Gamtoos River</td>
<td>4675 to 4783</td>
</tr>
<tr>
<td>8</td>
<td>25 to 24</td>
<td>South of 33</td>
<td>Gamtoos River to Storms River</td>
<td>4784 to 4913</td>
</tr>
<tr>
<td>9</td>
<td>24 to 23</td>
<td>South of 33</td>
<td>Storms River to Knysna</td>
<td>4914 to 5008</td>
</tr>
<tr>
<td>10</td>
<td>23 to 22</td>
<td>South of 33</td>
<td>Knysna to Dana Bay</td>
<td>5009 to 5125</td>
</tr>
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<td>11</td>
<td>22 to 21</td>
<td>South of 33</td>
<td>Dana Bay to Steenkoelfontein</td>
<td>5126 to 5247</td>
</tr>
<tr>
<td>12</td>
<td>21 to 20</td>
<td>South of 33</td>
<td>Steenkoelfontein to Cape Agulhas</td>
<td>5248 to 5373</td>
</tr>
<tr>
<td>13</td>
<td>20 to 19</td>
<td>South of 33</td>
<td>Cape Agulhas to Gansbaai</td>
<td>5374 to 5464</td>
</tr>
<tr>
<td>14</td>
<td>19 to 18</td>
<td>South of 33</td>
<td>Gansbaai to Cape Point</td>
<td>5465 to 5653</td>
</tr>
<tr>
<td>15</td>
<td>West of 18</td>
<td>South of 34</td>
<td>Cape Point to Cape Town Harbour</td>
<td>5654 to 5725</td>
</tr>
<tr>
<td>16</td>
<td>West of 18</td>
<td>34 to 33</td>
<td>Cape Town Harbour to Saldanha Bay</td>
<td>5726 to 5882</td>
</tr>
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<td>17</td>
<td>West of 18</td>
<td>33 to 32</td>
<td>Saldanha Bay to Eland's Bay</td>
<td>5883 to 6050</td>
</tr>
<tr>
<td>18</td>
<td>West of 18</td>
<td>32 to 31</td>
<td>Eland's Bay to Skaapvlei</td>
<td>6050 to 6149</td>
</tr>
<tr>
<td>19</td>
<td>West of 18</td>
<td>31 to 30</td>
<td>Skaapvlei to Skulpfontein Punt</td>
<td>6150 to 6340</td>
</tr>
<tr>
<td>20</td>
<td>West of 18</td>
<td>North of 30</td>
<td>North of Skulpfontein</td>
<td>North of 6341</td>
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</table>
Table 2. Scientific survey data: Survey biomass estimates by survey and depth stratum, in tons.

<table>
<thead>
<tr>
<th>season</th>
<th>year</th>
<th>0 to 50m</th>
<th>50 to 100m</th>
<th>100 to 200m</th>
<th>200 to 500m</th>
<th>total (0 to 200m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>spring</td>
<td>1986</td>
<td>2204</td>
<td>6785</td>
<td>4740</td>
<td>229</td>
<td>13959</td>
</tr>
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<td>spring</td>
<td>1987</td>
<td>1320</td>
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<td>61</td>
<td>11625</td>
</tr>
<tr>
<td>autumn</td>
<td>1988</td>
<td>893</td>
<td>3164</td>
<td>4532</td>
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</tr>
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<td>337</td>
<td>5443</td>
<td>13003</td>
<td></td>
<td>18784</td>
</tr>
<tr>
<td>autumn</td>
<td>1990</td>
<td>209</td>
<td>2187</td>
<td>6185</td>
<td>8582</td>
<td></td>
</tr>
<tr>
<td>spring</td>
<td>1990</td>
<td>1542</td>
<td>4157</td>
<td>6677</td>
<td>74</td>
<td>12450</td>
</tr>
<tr>
<td>autumn</td>
<td>1991</td>
<td>6240</td>
<td>2564</td>
<td>5000</td>
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<td>1991</td>
<td>2817</td>
<td>4342</td>
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<tr>
<td>autumn</td>
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<td>6069</td>
<td>4839</td>
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<td>2173</td>
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<tr>
<td>autumn</td>
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<td>5300</td>
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<td>4035</td>
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<td>21776</td>
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<td>405</td>
<td>2659</td>
<td>6361</td>
<td>398</td>
<td>9823</td>
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<tr>
<td>autumn</td>
<td>2003</td>
<td>1519</td>
<td>10690</td>
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<td>2003</td>
<td>674</td>
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<td>8083</td>
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<td>2005</td>
<td>1339</td>
<td>8894</td>
<td>6134</td>
<td>18</td>
<td>16385</td>
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Table 3. Scientific survey data: Stratum areas, average survey density and biomass estimates by depth stratum.

<table>
<thead>
<tr>
<th>Depth Range</th>
<th>0 to 50 meters</th>
<th>50 to 100m</th>
<th>100 to 200 m</th>
<th>200 to 500m</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area (km²)</td>
<td>1493</td>
<td>7596</td>
<td>15965</td>
<td>3828</td>
<td>28882</td>
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<tr>
<td>Average Density, all surveys (kg/km²)</td>
<td>1130</td>
<td>695</td>
<td>508</td>
<td>82</td>
<td></td>
</tr>
<tr>
<td>Average Biomass, all surveys (tons)</td>
<td>1690</td>
<td>5278</td>
<td>8131</td>
<td>301</td>
<td>15401</td>
</tr>
<tr>
<td>Proportion of Biomass</td>
<td>11%</td>
<td>34%</td>
<td>53%</td>
<td>2%</td>
<td></td>
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Table 4. Scientific survey data: Survey-estimated density and biomass for 8 spatial strata.

<table>
<thead>
<tr>
<th>Depth</th>
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<th>East of 24 degrees</th>
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<tr>
<td></td>
<td>0 to 50m</td>
<td>50 to 100m</td>
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<tr>
<td>Area (km²)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>772</td>
<td>6466</td>
<td>12668</td>
</tr>
<tr>
<td>Average Biomass (tons)</td>
<td>445</td>
<td>4099</td>
</tr>
<tr>
<td>Average Density (kg/km²)</td>
<td>576</td>
<td>634</td>
</tr>
<tr>
<td>% Area</td>
<td>3%</td>
<td>22%</td>
</tr>
<tr>
<td>% Biomass</td>
<td>3%</td>
<td>26%</td>
</tr>
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</table>
Table 5. Commercial trawl CPUE data: Trawl effort and Area in 16 spatial strata.

<table>
<thead>
<tr>
<th>(a) Effort (million minutes)</th>
<th>West of 20 deg</th>
<th>20 to 24 deg E</th>
<th>24 to 27 deg E</th>
<th>East of 27 deg E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 to 50 m</td>
<td>0.04</td>
<td>0.44</td>
<td>0.03</td>
<td>0</td>
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<tr>
<td>50 to 100 m</td>
<td>0.06</td>
<td>65.49</td>
<td>5.48</td>
<td>0.21</td>
</tr>
<tr>
<td>100 to 200 m</td>
<td>3.52</td>
<td>28.46</td>
<td>16.24</td>
<td>0.03</td>
</tr>
<tr>
<td>200 to 500 m</td>
<td>70.99</td>
<td>17.47</td>
<td>9.97</td>
<td>0.02</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>(b) Proportion of Total Trawl effort</th>
<th>West of 20 deg</th>
<th>20 to 24 deg E</th>
<th>24 to 27 deg E</th>
<th>East of 27 deg E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 to 50 m</td>
<td>0.02%</td>
<td>0.20%</td>
<td>0.01%</td>
<td>0.00%</td>
</tr>
<tr>
<td>50 to 100 m</td>
<td>0.03%</td>
<td>29.98%</td>
<td>2.51%</td>
<td>0.10%</td>
</tr>
<tr>
<td>100 to 200 m</td>
<td>1.61%</td>
<td>13.03%</td>
<td>7.44%</td>
<td>0.01%</td>
</tr>
<tr>
<td>200 to 500 m</td>
<td>32.50%</td>
<td>8.00%</td>
<td>4.56%</td>
<td>0.01%</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>(d) Area (km²)</th>
<th>West of 20 deg</th>
<th>20 to 24 deg E</th>
<th>24 to 27 deg E</th>
<th>East of 27 deg E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 to 50 m</td>
<td>unknown</td>
<td>772</td>
<td>721</td>
<td></td>
</tr>
<tr>
<td>50 to 100 m</td>
<td></td>
<td>6466</td>
<td>1130</td>
<td></td>
</tr>
<tr>
<td>100 to 200 m</td>
<td>4048</td>
<td>12668</td>
<td>3296</td>
<td></td>
</tr>
<tr>
<td>200 to 500 m</td>
<td>4527</td>
<td>3033</td>
<td>795</td>
<td></td>
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</table>

Table 6. Commercial trawl CPUE data: Proportion of Trawl effort and Area in Strata A to H.

<table>
<thead>
<tr>
<th>(a) Stratum Names</th>
<th>West of 20 deg</th>
<th>20 to 24 deg E</th>
<th>24 to 27 deg E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 to 100 m</td>
<td>C</td>
<td></td>
<td>F</td>
</tr>
<tr>
<td>100 to 200 m</td>
<td>A</td>
<td>D</td>
<td>G</td>
</tr>
<tr>
<td>200 to 500 m</td>
<td>B</td>
<td>E</td>
<td>H</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>(b) Proportion of area (A to J)</th>
<th>West of 20 deg</th>
<th>20 to 24 deg E</th>
<th>24 to 27 deg E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 to 100 m</td>
<td></td>
<td>19%</td>
<td>5%</td>
</tr>
<tr>
<td>100 to 200 m</td>
<td>11%</td>
<td>34%</td>
<td>9%</td>
</tr>
<tr>
<td>200 to 500 m</td>
<td>12%</td>
<td>8%</td>
<td>2%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>(c) Proportion of effort in strata A to J</th>
<th>West of 20 deg</th>
<th>20 to 24 deg E</th>
<th>24 to 27 deg E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 to 100 m</td>
<td></td>
<td>30%</td>
<td>3%</td>
</tr>
<tr>
<td>100 to 200 m</td>
<td>2%</td>
<td>13%</td>
<td>7%</td>
</tr>
<tr>
<td>200 to 500 m</td>
<td>33%</td>
<td>8%</td>
<td>5%</td>
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Table 7. Modelled effects and R-squared statistics for GLMs a-f on the jig CPUE data.

<table>
<thead>
<tr>
<th></th>
<th>GLMa</th>
<th>GLMb</th>
<th>GLMc</th>
<th>GLMd</th>
<th>GLMe</th>
<th>GLMf</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
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<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td>Year Effect</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td>Month Effect</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td>Vessel Effect</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td>Alngshore Effect</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
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<tr>
<td>Offshore Effect</td>
<td></td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td>Stratum*Year</td>
<td></td>
<td></td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td>Interaction</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crew Covariate</td>
<td></td>
<td></td>
<td></td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td>Hours Covariate</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>YES</td>
</tr>
<tr>
<td># parameters</td>
<td>439</td>
<td>457</td>
<td>459</td>
<td>515</td>
<td>516</td>
<td>517</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.240</td>
<td>0.272</td>
<td>0.273</td>
<td>0.283</td>
<td>0.296</td>
<td>0.300</td>
</tr>
</tbody>
</table>
Figure 1. Commercial jig CPUE data compared to commercial trawl CPUE data: Nominal mean CPUE by fishing year across all records.

Figure 2. Nominal mean commercial jig CPUE data compared to nominal mean commercial trawl CPUE data, on a month by month basis.

Figure 3. Mean jig effort (man-hours) to mean trawl effort (minutes trawled) by month.
Figure 4. Total jig effort versus distance from shore.

Figure 5. Nominal mean jigging CPUE by distance from shore. The first panel shows the full range of distances and the exponential trend. The second panel shows only distances up to 11 km (which covers 98% of the effort).
Figure 6. Jig effort: Alongshore distribution of effort in the jig dataset at intervals of 50km coastline distance.

Figure 7. Alongshore trends in CPUE in the jig dataset at intervals of 50km coastline distance. The first panel shows all positions with non-zero effort. The 2nd panel shows only those positions with at least 100 sea-days of effort.
Figure 8. Commercial trawl CPUE data: Distribution of effort and CPUE by 50m depth interval in the trawl dataset. The first panel shows the distributions for all years covered by the data (1977 to 2004), subsequent panels show the distributions over 5 year periods.
Figure 9. Map of the fishing area covered by the data, with lines of longitude and latitude. The large font numbers 1 to 20 indicate the long-shore divisions, the small font three digit numbers indicate the 20 minute grid square references.
Figure 10. Commercial jig CPUE data compared to commercial trawl CPUE data: Comparison of long-shore distribution of effort and CPUE in the jig and trawl datasets. Open squares on the CPUE plots indicate that these points are based on fewer than 100 sea-days (jig) or 100 drags (trawl.)
Figure 11. Annual change in total jigging effort (man-hours per year.) The lower line (square markers) shows the effort recorded. The upper line (diamond markers) shows the adjusted effort, which has been calculated by up-weighting the recorded effort by the ratio of the total catch to the catch corresponding to recorded effort.

Figure 12. Annual change in the components of jig effort. The first panel shows the number of vessels operating each year. The second panel shows the average number of sea-days per vessel together with the total number of sea-days per year. The third panel shows the mean crew size and the mean number of hours fished per vessel per day (where these quantities have been recorded.)
Figure 13. Commercial jig CPUE data: (a) Mean catch and (b) mean CPUE by total effort (hours x crew) per sea-day.
Figure 14. Commercial jig CPUE data: (a) Catch per crew number by number of fishing hours per day, (b) catch per hour by number of crew, (c) catch per crew member per hour by number of hours and (d) catch per crew member per hour by number of crew in the jig fishery (over all years.) Plots (e) and (f) are repeats of (c) and (d) respectively, but on a log scale, and with log-linear (exponential) regression lines shown.
Figure 15. Scientific survey data: Stratified survey biomass estimates on the South Coast. Stratification is by depth ranges 0 to 50m, 50 to 100m, 100 to 200m, 200 to 500m. The first panel shows the biomass estimates for all South Coast surveys and the linear trend. The second panel shows the estimates as separate series for spring and autumn surveys and linear trend lines for each series.
Figure 16. Scientific survey data: Survey biomass estimates 1986 to 2005 by comparison with nominal commercial jig and trawl CPUE indices. Each series has been normalised to its value in 1986.
Figure 17. Scientific survey data: Survey density trends by depth stratum, separated into regions west of 24 degrees E and those east of 24 degrees E.
Figure 18. Scientific survey data: Histogram of length frequencies for all samples over all trawls.

Figure 19. Scientific survey data: Scatter plot of mean length vs depth for survey trawls in which length frequency samples were taken.
Figure 20. Scientific survey data: Mean length by alongshore position. Each point on the plot represents the mean length of all sampled trawls by degree of longitude.

Figure 21. Scientific survey data: Mean length, alongshore position, and depth. The x-axis (long20min) represents the alongshore position divided into regions of width 20 minutes of longitude is, the y-axis (dep10) represents depth divided into 10m intervals. Sampled trawls are aggregated by these depth and alongshore divisions. The divisions have then been separated into 4 categories depending on the mean length of samples within that division.
Figure 22. Scientific survey data: Stratified survey estimates of the total number of squid by size classes 1 to 10 cm, 11 to 20 cm, 21 to 30 cm and 31 cm+. Also shown are the linear trends lines.
Figure 23. Commercial trawl CPUE data: GLM-standardised CPUE using GLM1, as described in Section 6.1 of the text, and nominal CPUE in the commercial trawl fishery, 1978 to 2003. Each series is normalised relative to its value in 1978.

Figure 24. Commercial trawl CPUE data: GLM standardised CPUE for strata A to H using stratified GLM2 described in Section 6.3 of the text. The dotted lines in each plot show the nominal CPUE as in figure 34a. Years shown are 1978 to 2003.
Figure 25. Commercial trawl CPUE data: GLM-standardised stratified mean CPUE using GLM2 compared to the nominal CPUE for the commercial trawl fishery.

Figure 26. Commercial trawl CPUE data: GLM-standardised stratified mean CPUE using GLM2, unstratified GLM-standardised CPUE using GLM1 and the nominal CPUE. Each series has been normalised relative to its value in 1978.
Figure 27. Commercial trawl CPUE data: GLM-standardised stratified mean CPUE using GLM2 in all areas (strata A to H) and in areas east of 20 degrees E (strata C to H) in years 1986 to 2003, compared to the South Coast survey biomass estimates. Each series has been expressed relative to its value in 1986.

Figure 28. Commercial jig CPUE data: GLM-standardised CPUE using GLMa (with year, month and vessel effects only), GLMb (including alongshore position effects) and GLMc (including alongshore and offshore position effects).
Figure 29. Commercial jig CPUE data: GLM-standardised CPUE using GLMa and GLMc compared to the nominal CPUE. Each series has been normalised relative to its value in 1985.

Figure 30. Commercial jig CPUE data: GLM-standardised CPUE in 4 alongshore strata using GLMd (with no saturation effect) GLMe with a saturation effect due to number of crew, and GLMf, with saturation effects due to number of crew and hours fished. The dotted line in each plot shows the nominal CPUE in that stratum.
Figure 31. Commercial jig CPUE data: GLM-standardised CPUE from GLMs d, e and f. Panel (a) shows the series for the Port Elizabeth stratum (24 to 27 degrees E), panel (b) shows the weighted average over the four alongshore strata.

![Figure 31](image)

Figure 32. Commercial jig CPUE data: GLM-standardised CPUE from GLMc, GLM-standardised CPUE from GLMf as a weighted average of the 4 strata and the nominal CPUE in the jigging fishery.

![Figure 32](image)
Figure 33. Commercial jig CPUE data: GLM-standardised weighted-average stratified CPUE from GLMd (without effort saturation) and GLMf (with effort saturation) by comparison with the stratified survey biomass estimates. Each series has been normalised relative to its value in 1986.