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## EXECUTIVE SUMMARY

**Coburn, R.P.; Doonan, I.J.; McMillan, P.J. (2002): CPUE analyses for the Southland black oreo and smooth oreo fisheries, 1977–78 to 1999–2000.**

*New Zealand Fisheries Assessment Report 2002/3.* **28 p.**

The feasibility of using both standardised and unstandardised analyses of commercial catch and effort data as relative abundance indices for black oreo and smooth oreo in the Southland area of OEO 1 and the major fisheries in OEO 6 was investigated. The fisheries produced on average about 1000 t of smooth oreo and 600 t of black oreo per year from 1990–91 to 1999–2000 and CPUE data were available from 1977–78 to 1999–2000. Data for the catch of either black oreo or smooth oreo were included when target species was any one of the three recorded oreo target species, e.g., all black oreo caught when target species was unspecified oreo, smooth oreo, or black oreo (to ensure that large amounts of data were not discarded). Data were divided into pre- and post-GPS series and consequently there were four CPUE series, black oreo pre-GPS, smooth oreo pre-GPS, black oreo post-GPS, and smooth oreo post-GPS. Standardised analyses used regression-based methods employed in previous Chatham Rise analyses. Unstandardised analyses were difficult to interpret because of the three target species options, but the two smooth oreo series showed flat mean annual catch per tow trends while the black oreo series both fluctuated but appeared to decline. Vessel continuity analysed for the standardised analyses showed there was substantial turnover at times, but that generally the changes occurred slowly enough to allow linkages between years to be maintained. The two post-GPS series were longer and were better linked than the pre-GPS series. The last year of the pre-GPS series was poorly linked to the rest of the series due to changes in the fleet composition. There were 5 years acceptable data for the black oreo and smooth oreo pre-GPS series but only four years of linked data. There were eight years of acceptable, linked data for the black oreo and smooth oreo post-GPS series analyses. Standardised analyses for both species were feasible and offered substantial advantages over unstandardised analyses as potential indices of abundance.

# 1. INTRODUCTION

## 1.1 Objective

Project OEO2000/02

Overall Objective: to carry out a stock assessment of black oreo and smooth oreo, including estimating biomass and sustainable yields.

Specific Objective 4: to determine the feasibility of using both standardised and unstandardised analyses of commercial catch and effort data as relative abundance indices for black oreo and smooth oreo in the Southland area of OEO 1 and the major fisheries in OEO 6.

This report analyses commercial catch and effort data for the black oreo and smooth oreo fisheries in the Southland area of OEO 1 only. A separate report analysed the data for the oreo fisheries in OEO 6.

## 1.2 General

There are no black oreo and smooth oreo abundance estimates available for stock assessments of most of the oreo fisheries away from the Chatham Rise. The Chatham Rise oreo fisheries are the largest in New Zealand waters, have an interaction with the important Chatham Rise orange roughy fishery, and have been the subject of a number of research surveys and CPUE studies (Annala et al. 2001). Absolute (acoustic survey) abundance estimates, plus relative abundance estimates from standardised CPUE analyses and research trawl surveys, are available for the Chatham Rise oreo fisheries and were used in past stock assessments (Annala et al. 2001). In contrast, no research surveys have been carried out on other oreo fisheries except for a trawl survey designed to sample orange roughy at Puysegur (Annala et al. 2001).

The aim of this work was to determine the feasibility of carrying out unstandardised and standardised CPUE analyses for oreo stocks that lack estimates of abundance. This study examined the Southland (QMA 3A and 1) black oreo and smooth oreo fisheries. The latter are amongst New Zealand's oldest deepwater fisheries with CPUE data starting in 1977–78 when 2747 t of unspecified oreo was reported caught (McMillan et al. 2001). There was little reported catch between 1978–79 and 1982–83' but from 1983–84 to 1989–90 mean annual catches were about 1200 t of smooth oreo and 700 t of black oreo: from 1990–91 to 1999–2000 mean annual catches were about 1000 t of smooth oreo and about 600 t of black oreo. The Southland and other (not Chatham Rise) oreo fisheries were subjected to descriptive CPUE analysis (McMillan et al. 2001), but no standardised CPUE analyses were carried out.

The approach adopted for this study was to first assemble all the CPUE data, then to examine the quantity and quality of the data to determine particularly if a standardised analysis was possible. The assessment of data focused on the continuity of participating vessels in the fishery. Standardised analyses were performed and the effect on the resulting index of removing the data from each vessel in turn from the analyses was examined. Coefficient of variation on the index were calculated using a modified jackknife technique that dropped one vessel's data at each iteration. R-square values from the standardised analyses provided a measure of the variability of the data and were compared with the equivalent values from the unstandardised analyses to decide if the standardised analyses were worthwhile.

## 2. METHODS

### 2.1 Definitions and abbreviations

All data were grouped by fishing year, i.e., 1 October to 30 September. Abbreviations are: SSO, smooth oreo; BOE, black oreo; OEO, unspecified oreo; ORH, orange roughy; FSU, Fisheries Statistics Unit; TAC, total allowable catch; CPUE, catch per unit effort; c.v., coefficient of variation; GPS, global positioning system; GLM, generalised linear model.

### 2.2 Data

Tow-by-tow data from trawl catch effort returns were used, including those derived from the FSU from 1977–78 and from the Ministry of Fisheries catch and effort database from 1988 on. These data were checked for systematic errors and gross outliers and for consistency over the time series. Initially data from all tows that targeted or caught oreo (SSO, BOE, or OEO) were considered. The data were restricted to a study area as defined below. The tow data included start position, catch by species, target species, depth, vessel, distance towed, time of day, and date. Nationality and tonnage were recorded for each vessel.

### 2.3 The study area

The area studied was the same as that defined for a study of descriptive catch and effort for the Southland oreo fishery by Hart et al. (2000) and McMillan et al. (2001). Figure 1 shows the study area and the location of all tows that targeted oreo within and around it. The Southland fishery forms a discrete spatial unit with its nearest neighbour fishery on the south Chatham Rise in OEO 3A. The study area straddles the southern boundary between OEO 1 and OEO 3A, reflecting the distribution of the fishery rather than the management areas and consequently the CPUE data used in analyses were subsets of those for the whole of OEO 1 and OEO 3A. The boundary of our study area is given by the vertices at 44° 41.3′ S, 170° 51.0′ E; 45° 17.1′ S, 172° 40.1′ E; 47° 24.2′ S, 171° 49.3′ E; 47° 38.1′ S, 170° 20.9′ E; 46° 22.6′ S, 169° 3.8′ E.

### 2.4 Choice of CPUE measure

Catch-per-tow (tonnes-per-tow) was chosen as the index of abundance rather than catch-per-kilometre and follows the Deepwater Working Group's preference in previous smooth oreo and black oreo standardised CPUE analysis (Doonan et al. 1995, Coburn et al. 1999).

### 2.5 Unstandardised CPUE

The descriptive analysis of CPUE data from the Southland fishery (McMillan et al. 2001) was used as a starting point in describing the fishery. This provided the fractions of data coverage, nationality and tonnage composition of the fleet, the target composition of the fishery, catches, and target catch rates and highlighted changes in these elements over time. Additional descriptive work included plots of the locations of tows in the study area, the bathymetry of the area, and the spatial pattern of catch by species and fishing year. Subsets of the data were identified as candidates for standardised CPUE analysis and summaries of these datasets including catches, mean catch per tow, and fraction of zero tows were compiled.

## 2.6 Standardised CPUE

For the candidate datasets the number of tows by fishing year and vessel provided patterns of effort by each vessel as they entered and left the fishery. These data were presented in a way (referred to as a year-cross table) that indicated the suitability of the dataset for standardised CPUE analysis. The year-cross analysis gave the number of vessels that 'linked' each pair of years in the candidate CPUE series. A link was established where a vessel made at least 10 tows in each of the paired years. The year-cross analysis also identified subsets within the series that were unlinked, i.e., there were fewer than 10 tows in each of the paired years. Poorly linked years in the series were arbitrarily defined as years when the mean of the number of vessels linking any year was less than one in the cross-year table. A poorly linked year is susceptible to influence by changes in the fishing power or ability of a single vessel. For example, if a year is linked to the rest of the series by only one vessel then changes in fishing power for that vessel between that year and the other years will determine that year's index (relative to the rest of the series). Changes in vessel fishing power can be caused by re-powering, change of skipper, or a host of other operational factors, which presumably have nothing to do with abundance. When several vessels link each pair of years the likelihood is high that such changes will be spread, presumably randomly, over the different vessels.

Unlinked or poorly linked parts of the series will occur if there was a rapid replacement of the fleet by a new set of vessels with little cross-over period. In the worst case there may be no vessels that fished early and late in the series and hence no way to disentangle the year effect from the vessel effect.

The standardised CPUE analyses performed were similar to that described by Doonan et al. (1995) and used a two part model which separately analysed the tows on which the species were caught using a log-linear regression (referred to as the positive catch regression) and a binomial part which used a Generalised Linear Model with a logit link for the proportion of successful tows (referred to as the zero catch regression). The binomial part used all the tows but considered only whether or not the species was caught and not the amount caught. The yearly indices from the two parts of the analysis (positive catch index and zero catch index) were multiplied together to give a combined index (Vignaux 1994).

Analyses of smooth oreo CPUE in OEO 4 (Coburn et al. 2001) showed that catch rates rose during the period that GPS was adopted. The data from this period (1989–90 to 1991–92, Coburn et al. 2001) were therefore dropped, splitting the analyses into pre- and post-GPS periods. The analyses for black oreo and smooth oreo were performed separately, allowing the selection of predictor variables to be optimal in each case. Therefore there were four candidate analyses: smooth oreo, pre-GPS; smooth oreo, post-GPS; black oreo, pre-GPS and black oreo, post-GPS.

The Southland fisheries were treated as mixed target fisheries, i.e., it was difficult to target one species exclusively (SSO or BOE). Just using data from target fishing a single species, e.g., only tows that targeted SSO for a smooth oreo index, greatly reduced the datasets and the number of years in which an index could be estimated, so this approach was rejected. Thus all the tows that targeted OEO or SSO or BOE and caught SSO or BOE were used for each analysis. Only small amounts of black oreo and smooth oreo were caught as bycatch during target fishing for other species (see table 1.7 in McMillan et al. 2001) so only a small amount of oreo CPUE data was not included in the analyses. The inclusion of target species as a candidate predictor in the regression models allowed the models to set different expectations for each target type.

Data were included in the analyses if there were at least three years with more than 50 catches of black oreo or smooth oreo. Data were excluded if only one vessel caught 80% or more of the black oreo or smooth oreo catch in a year.

Predictor variables in the regressions were all designated as categorical (Table 1). Numeric variables, e.g., depth, were converted into categorical variables by splitting the range into eight bins. Eight bins were chosen as sufficient to model any dependencies in the data (without prejudice as to the shape of any dependency) while ensuring that the resultant models were not over-parameterised. Bin widths were chosen to ensure that tow numbers in each bin were similar. Vessel entered as a categorical variable except that vessels with fewer than 50 tows over the whole time period were all lumped into the same category. Tow position was reduced to a single predictor variable by using the latitude only. This worked in this fishery as the tows lie approximately along a north to south axis (see Figure 2).

A forward stepwise selection of predictor variables was used with a cut off when the predictors (see Table 1) failed to account for at least 1% of the overall sum of squares (or for the GLM, 1% of the null deviance). Interaction terms were not used. In order to evaluate how sensitive the indices were to the inclusion of individual vessels, the selected regression models were refitted, dropping the data from each vessel one at a time. The resultant set of indices was plotted to show the variation.

Annual c.v.s for the combined indices were estimated using a jackknife technique (Doonan et al. 1995). Mean c.v. for the series was calculated as the square root of the mean of the squared non-reference c.v.s. divided by the square root of 2. A year from the middle of the time series that had a greater than average number of tows was chosen as the reference year.

The mathematical technique used for the standardised CPUE analysis is described in Appendix 1.

## 3. RESULTS

### 3.1 Unstandardised CPUE

#### 3.1.1 General description

A previous study of oreo catch and effort data was used to describe the general features of the Southland oreo fisheries (McMillan et al. 2001). The tow-by-tow data on which this study is based accounted for about 80% of the total OEO 1 declared catch and about 90% of the total OEO 3A catch (tables 1.1 & 1.2, McMillan et al. 2001). The difference between the tow-by-tow and declared catch totals is typical of other deepwater fisheries in New Zealand where close to the entire fishery is captured. Differences are mostly because CPUE data are estimated (sometimes by eye) while declared catch is often based on values calculated from factory product and conversion factors from product to whole (green) fish. Small amounts of oreo may also be reported as declared caught but not included as one of the first five estimated species caught in each tow. These data appear complete enough for satisfactory descriptive and standardised analyses of CPUE.

Initially Soviet vessels fished the Southland fishery, but by the mid 1980s they were replaced by Korean vessels and, increasingly, New Zealand vessels. The latter dominated the fishery in the 1990s (table 1.5, McMillan et al. 2001). The change in fleet led to a decrease in typical vessel tonnage (table 1.6, McMillan et al. 2001).

Most oreo in Southland was caught during target fishing for oreo (SSO, BOE, or OEO). The principal target species progressed from BOE to SSO to increasingly OEO in the later years (table 1.7 McMillan et al. 2001). Most catch was recorded by species, with the exception of 1977–78 to 1979–80 when OEO was the main recorded catch. More SSO than BOE has been reported except for the early years and in 1996–97 (table 1.8, McMillan et al. 2001).

Mean target catch-per-tow for smooth oreo was variable until 1992–93 then remained fairly steady at 1–2 t/tow (table 1.9, McMillan et al. 2001). Mean target catch-per-tow for black oreo should be considered only between 1983–84 and 1987–88, as the number of black oreo target tows was small outside that period. During that time catch rates declined steadily from about 5.7 to 2.4 t/tow.

### 3.1.2 Spatial distribution of catch

The fishery in Southland occurs off the edge of the continental shelf at depths between 700 and 1200 m. The region is rugged with some large canyons and multitudes of gullies and drop offs (Figure 2). Oreo aggregate over rugged bottom, but are also caught on flat ground typically in the shallow end of the fishery depth range. The Waitaki Canyon is a large canyon in the north (at about 45° 20′ S) and fishing was seen north and south of it (Figure 2). Fishing elsewhere is known to be associated with drop offs and other bottom features, but the detail of topography and inaccuracy of the tow positions makes the association difficult to identity.

Most catch came from a "main" southern region with about a quarter as much from a northern part and a smaller amount between these. This pattern holds when examined by species, although the northern area favours smooth oreo slightly (Figure 3).

Before 1991–92, nearly all catch came from the main region (Figure 4). In 1991–92 the northern Waitaki Canyon was discovered and catches from that area dominated Southland catches. Since then catches from the north have dropped and by the late 1990s the catch distribution was similar to the pre-Waitaki Canyon period.

## 3.2 Unstandardised CPUE data

Raw data for the smooth oreo pre-GPS, smooth oreo post-GPS, black oreo pre-GPS, and black oreo post-GPS CPUE datasets are provided in Tables 6 to 9. In discussing these data all years with fewer than 100 tows were ignored as those data are likely to be highly variable in an unstandardised form. Data from 1977–78 to 1979–80 were also not used because most catch was not recorded by species.

**Smooth oreo, pre-GPS (Table 2)**
From 1983–84 to 1987–88 effort was between 101 and 797 tows and fleet size between 7 and 16 vessels. Annual catch varied between 160 and 4240 t. The mean catch rates showed no trend.

**Smooth oreo, post-GPS (Table 3)**
From 1992–93 to 1999–2000 effort was between 163 and 531 tows and fleet size between 11 and 20 vessels. Annual catch varied between 450 and 1040 t. The mean catch rates showed no trend.

**Black oreo, pre-GPS (Table 4)**
From 1983–84 to 1987–88 effort was between 101 and 797 tows and fleet size between 7 and 16 vessels. Annual catch varied between 140 and 2100 t. The mean catch rates showed a downward trend.

**Black oreo, post-GPS (Table 5)**
From 1992–93 to 1999–2000 effort was between 163 and 531 tows and fleet size between 11 and 20 vessels. Annual catch varied between 220 and 1620 t. The mean catch rates showed no trend, but are variable.

## 3.3 Standardised CPUE

### 3.3.1 Fleet turnover

There was considerable turnover in the fleet for the pre-GPS years that had enough data to be used in a standardised analysis (1983–84 to 1987–88) (Table 6). Only 1 vessel fished in each of the five years, 1 fished four years, 6 fished 3 years, and 10 fished just two years (other vessels fishing in a single year are not shown in Table 6). The early and later years of the series are less well linked than the central years but the turnover was judged to be acceptable for all but the last year (1987–88) of the series which had a mean value of 0.8 and was poorly linked to the rest (Table 7).

There was also turnover for the post-GPS years that had enough data to be used in standardised analyses (1992–93 to 1999–2000) (Table 8), and again the central years are better linked than those at the start or finish of the series (Table 9). However, the effect is less pronounced and the mean linkage values are higher. As in the pre-GPS period, linkages are strongest between adjacent years (that is along the diagonal of the year-cross table).

### 3.3.2 Smooth oreo, pre-GPS

Catch and effort data from 1977–78 to 1988–89 were available for this analysis (see Table 2). Our selection criteria dropped the years before 1983–84 (only 10 t of smooth oreo was recorded caught in that period) and 1988–89. For the selected years, about 34% of the tows caught no smooth oreo.

Results of the positive catch regression and zero catch GLM are given in Table 10. The final model for positive catch used vessel, target, year, season, and depth (selected in that order) and that for zero catch used vessel, target, and season.

#### The indices

The abundance index results from each model (positive catch and zero catch) and the combined index are given in Table 11. The combined index from the final year was about a third the value of the first year.

#### Effects of individual vessels

The sensitivity of the combined index to the data contributed by each vessel was investigated by re-estimating the combined indices after removing the data from one vessel at a time (Figure 5). This showed that although there was some variation between vessels in the first year, the vessel variation was not large for the series overall, i.e., no vessel was highly influential on the series.

#### Confidence intervals

Mean c.v.s by year for the combined index calculated using a jack-knife technique are given in Table 11. The overall mean c.v. was 38%.

### 3.3.3 Smooth oreo, post-GPS

Catch and effort data from 1992–93 to 1999–2000 were available and all years were used for this analysis (see Table 3). About 22% of the tows caught no smooth oreo.

Results of the positive catch regression and zero catch GLM are given in Table 12. The final model for positive catch used vessel, latitude, year, season, and target, and that for zero catch used latitude, year, vessel, and season.

#### The indices

The abundance index results from each model (positive catch and zero catch) and the combined index are given in Table 13. The combined index from the final year was about the same as the value of the first year.

#### Effects of individual vessels

The sensitivity of the combined index to the data contributed by each vessel was investigated by re-estimating the combined indices after removing the data from one vessel at a time (Figure 6). This showed that, with the exception of one vessel that was influential on the last three years of the series, exclusion of individual vessels had little effect on the overall result.

#### Confidence intervals

Mean c.v.s by year for the combined index calculated using a jack-knife technique are given in Table 13. The overall mean c.v. was 49%.

### 3.3.4 Black oreo, pre-GPS

Catch and effort data from 1977–78 to 1988–89 were available for this analysis (see Table 4). Our selection criteria dropped the years before 1983–84 (180 t of black oreo was recorded caught in that period) and 1988–89. For the selected years, about 43% of the tows caught no black oreo.

Results of the positive catch regression and zero catch GLM are given in Table 14. The final model for positive catch used year, target, vessel, latitude, and season, and that for zero catch used vessel, year, season, and target.

#### The indices

The abundance index results from each model (positive catch and zero catch) and the combined index are given in Table 15. The combined index from the final year was about a tenth the value of the first year.

#### Effects of individual vessels

The sensitivity of the combined index to the data contributed by each vessel was investigated by re-estimating the combined indices after removing the data from one vessel at a time (Figure 7). This showed that although there was some variation between vessels in the first two years of the series, the exclusion of individual vessels had little effect on the overall result.

#### Confidence intervals

Mean c.v.s by year for the combined index calculated using a jack-knife technique are given in Table 15. The overall mean c.v. was 73%.

### 3.3.5 Black oreo, post-GPS

Catch and effort data from 1992–93 to 1999–2000 were available and were used for this analysis (see Table 5). About 39% of the tows caught no black oreo.

Results of the positive catch regressions and zero catch GLM are given in Table 16. The final model for positive catch used latitude, year, vessel, depth, and season, and that for zero catch used latitude, vessel, year, depth, target, and season.

#### The indices

The abundance index results from each model (positive catch and zero catch) and the combined index are given in Table 17. The combined index from the final year was about a third the value of the first year.

#### Effects of individual vessels

The sensitivity of the combined index to the data contributed by each vessel was investigated by re-estimating the combined indices after removing the data from one vessel at a time (Figure 8). This showed that no vessel or year was highly influential on the series. The series rose for the first two years but declined steadily since then.

### Confidence intervals

Mean c.v.s by year for the combined index calculated using a jack-knife technique are given in Table 17. The overall mean c.v. was 40%.

## 4. DISCUSSION

A standardised analysis of CPUE has advantages over unstandardised analyses because it removes biases and improves precision. Therefore this study focused on standardised CPUE in an attempt to get the most information from the Southland oreo fisheries data.

The study considered the feasibility of using CPUE analyses as indices of abundance for this fishery. The result suggested that standardised CPUE analyses of black oreo and smooth oreo, pre- and post-GPS are feasible, but the data and consequently the analyses for the two post-GPS fisheries are more reliable than the pre-GPS data sets and analyses.

The Southland fisheries have been going for about 20 years but are smaller than other oreo fisheries and consequently there were few data for some years. This was a mixed oreo fishery with black oreo and /or smooth oreo caught unpredictably when any of three "species" were listed as the target (OEO, SSO, or BOE), so target species was used as a predictor variable in the regressions rather than only using tows where target and catch were the same species, so that the data sets could be kept as large as possible. Vessel turnover in these data sets was substantial at times, but generally occurred slowly enough to allow linkages between years to be maintained. The two post-GPS series were longer (about 8 years) and were better linked than the pre-GPS series (about 5 years). The last year of the pre-GPS series was poorly linked to the rest of the series due to changes in the fleet composition. The post-GPS smooth oreo series was influenced by a single vessel over the last three years of the series. The area fished had a northern 'hotspot', the Waitaki area, which produced substantial catch for only a short time during the series while most of the catch came from south of about 46° S. The merit of including the Waitaki data in the Southland series is therefore debatable.

Standardised analyses are preferred over unstandardised CPUE mainly because there were substantial changes in the fleet and in the principal target species over the time series. Vessels had different fishing powers and so unstandardised catch rates were influenced by the turnover in the fleet. Standardising by vessel allows this to be corrected. The changing principal target species over time suggest that unstandardised CPUE should be restricted to target data only, but this restricts the time series. In particular, little could be known about black oreo CPUE in the post-GPS period. Standardised analyses allowed the use of data from the non-target tows in a reasonable way thus increasing the amount of data available and therefore increasing the period in which CPUE can be analysed.

Overall the standardised analyses probably reflected real trends in CPUE over the life of the fishery and these analyses could be incorporated into population modelling as indices of abundance to provide assessments of the stocks of black oreo and smooth oreo in the Southland fisheries.

## 5. ACKNOWLEDGMENTS

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**Table 1: Summary of non-year variables that could be selected in the regression models. All were categorical variables. df is the number of parameters to be estimated for that variable; –, not available: it depends on the dataset.**

| Variable | Df | Description |
|---|---|---|
| Target | 2 | Target species, SSO, BOE, or OEO. |
| Depth | 7 | Depth at start of a tow. Bins were defined to contain about the same number of tows. |
| Season | 7 | The fishing year divided into 8 periods. |
| Time | 7 | Time of day when a tow started, blocked into 8 periods. |
| Latitude | 7 | Latitude of start of tow, blocked into 8 cells. |
| Vessel | – | A parameter estimated for each vessel with at least 50 tows. Vessels with fewer than 50 tows were grouped together. |

**Table 2: Unstandardised smooth oreo pre-GPS CPUE for all tows in the study area that targeted OEO, SSO, or BOE. – data from less than four vessels.**

| Year | No. of tows | No. of vessels | Catch (t) | Mean catch per tow (t) | Zero catch tows (%) |
|---|---|---|---|---|---|
| 1977–78 | 314 | 6 | 0 | 0.0 | 100 |
| 1978–79 | – | – | 10 | – | – |
| 1979–80 | 85 | 5 | 0 | 0.0 | 99 |
| 1982–83 | – | – | 0 | – | – |
| 1983–84 | 498 | 9 | 1 260 | 2.5 | 50 |
| 1984–85 | 241 | 16 | 880 | 3.6 | 27 |
| 1985–86 | 797 | 15 | 4 240 | 5.3 | 19 |
| 1986–87 | 101 | 7 | 160 | 1.5 | 29 |
| 1987–88 | 220 | 12 | 910 | 4.1 | 37 |
| 1988–89 | 27 | 6 | 130 | 4.7 | 59 |

**Table 3: Unstandardised smooth oreo post-GPS CPUE for all tows in the study area that targeted OEO, SSO, or BOE.**

| Year | No. of tows | No. of vessels | Catch (t) | Mean catch per tow (t) | Zero catch tows (%) |
|---|---|---|---|---|---|
| 1992–93 | 336 | 19 | 770 | 2.3 | 32 |
| 1993–94 | 209 | 15 | 600 | 2.9 | 19 |
| 1994–95 | 163 | 11 | 450 | 2.8 | 29 |
| 1995–96 | 317 | 20 | 1 030 | 3.2 | 26 |
| 1996–97 | 531 | 16 | 610 | 1.1 | 27 |
| 1997–98 | 249 | 14 | 580 | 2.3 | 21 |
| 1998–99 | 404 | 16 | 1 040 | 2.6 | 11 |
| 1999–00 | 455 | 11 | 950 | 2.1 | 14 |

**Table 4: Unstandardised black oreo pre-GPS CPUE for all tows in the study area that targeted OEO, SSO, or BOE. – data from less than four vessels.**

| Year | No. of tows | No. of vessels | Catch (t) | Mean catch per tow (t) | Zero catch tows (%) |
|---|---|---|---|---|---|
| 1977–78 | 314 | 6 | 0 | 0.0 | 100 |
| 1978–79 | – | – | 110 | – | – |
| 1979–80 | 85 | 5 | 70 | 0.8 | 89 |
| 1982–83 | – | – | 0 | – | – |
| 1983–84 | 498 | 9 | 2 100 | 4.2 | 31 |
| 1984–85 | 241 | 16 | 1 000 | 4.2 | 30 |
| 1985–86 | 797 | 15 | 1 060 | 1.3 | 59 |
| 1986–87 | 101 | 7 | 150 | 1.5 | 39 |
| 1987–88 | 220 | 12 | 140 | 0.6 | 55 |
| 1988–89 | 27 | 6 | 70 | 2.6 | 37 |

**Table 5: Unstandardised black oreo post-GPS CPUE for all tows in the study area that targeted OEO, SSO, or BOE.**

| Year | No. of tows | No. of vessels | Catch (t) | Mean catch per tow (t) | Zero catch tows (%) |
|---|---|---|---|---|---|
| 1992–93 | 336 | 19 | 230 | 0.7 | 71 |
| 1993–94 | 209 | 15 | 220 | 1.1 | 45 |
| 1994–95 | 163 | 11 | 390 | 2.4 | 34 |
| 1995–96 | 317 | 20 | 720 | 2.3 | 32 |
| 1996–97 | 531 | 16 | 1 620 | 3.1 | 23 |
| 1997–98 | 249 | 14 | 240 | 1.0 | 41 |
| 1998–99 | 404 | 16 | 400 | 1.0 | 32 |
| 1999–00 | 455 | 11 | 400 | 0.9 | 37 |

**Table 6: Number of tows by fishing year for vessels in the pre-GPS period. Each row is a vessel; only vessels that fished in more than one year are shown. The vessels were sorted on their year of first and last appearance. – indicates zero tows.**

| 1983–84 | 1984–85 | 1985–86 | 1986–87 | 1987–88 |
|---|---|---|---|---|
| 195 | 2 | – | – | – |
| 56 | 4 | – | – | – |
| 15 | 6 | – | – | – |
| 6 | 1 | 134 | – | – |
| 42 | 60 | 103 | – | – |
| 45 | – | – | 1 | – |
| 55 | 65 | 136 | 28 | 1 |
| 14 | – | 7 | – | 127 |
| – | 14 | 7 | – | – |
| – | 2 | 3 | – | – |
| – | 5 | 14 | – | – |
| – | 16 | 49 | – | – |
| – | 19 | 55 | 12 | – |
| – | 1 | 69 | 7 | 6 |
| – | 14 | 37 | – | 10 |
| – | – | 57 | 18 | – |
| – | – | 30 | 16 | 2 |
| – | – | – | 19 | 2 |

Table 7: Year-cross table for the pre-GPS period. The symmetric part shows the number of vessels that 'link' each pair of years, e.g., 2 vessels link 1983–84 to 1984–85. A link was established when a vessel made at least 10 tows in each of the paired years. The rightmost column is the row means.

| | 1983–84 | 1984–85 | 1985–86 | 1986–87 | 1987–88 | Mean |
|---|---|---|---|---|---|---|
| 1983–84 | – | 2 | 2 | 1 | 1 | 1.5 |
| 1984–85 | 2 | – | 5 | 2 | 1 | 2.5 |
| 1985–86 | 2 | 5 | – | 4 | 1 | 3.0 |
| 1986–87 | 1 | 2 | 4 | – | 0 | 1.8 |
| 1987–88 | 1 | 1 | 1 | 0 | – | 0.8 |

Table 8: Number of tows by fishing year for vessels in the post-GPS period. Each row is a vessel; only vessels that fished in more than one year are shown. The vessels were sorted on their year of first and last appearance. – indicates zero tows.

| 1992–93 | 1993–94 | 1994–95 | 1995–96 | 1996–97 | 1997–98 | 1998–99 | 1999–00 |
|---|---|---|---|---|---|---|---|
| 9 | 3 | – | – | – | – | – | – |
| 3 | 2 | – | – | – | – | – | – |
| 45 | 18 | – | – | – | – | – | – |
| 3 | 37 | 6 | – | – | – | – | – |
| 17 | 5 | 1 | – | – | – | – | – |
| 3 | 28 | 4 | 8 | – | – | – | – |
| 118 | 23 | – | 21 | 103 | – | – | – |
| 8 | 18 | 10 | 4 | 18 | – | – | – |
| 10 | – | 2 | 3 | 35 | – | – | – |
| 3 | – | – | – | 1 | 2 | – | – |
| 34 | 3 | 68 | 37 | 2 | 87 | 126 | – |
| 1 | – | – | – | – | – | 13 | – |
| 33 | 30 | 19 | 65 | 47 | 25 | 16 | 15 |
| 3 | 2 | – | 11 | 13 | 8 | 1 | 100 |
| – | 24 | – | 4 | 16 | – | – | – |
| – | 13 | – | 4 | 8 | 21 | – | – |
| – | 2 | – | 14 | 14 | 7 | 12 | – |
| – | – | 35 | 12 | – | – | – | – |
| – | – | 9 | 4 | – | – | – | – |
| – | – | 8 | 20 | 11 | 6 | – | – |
| – | – | – | 22 | – | 2 | – | – |
| – | – | – | 24 | – | 2 | – | 3 |
| – | – | – | 7 | 17 | – | 43 | 32 |
| – | – | – | 51 | 11 | 31 | 31 | 39 |
| – | – | – | – | 17 | 5 | 1 | – |
| – | – | – | – | 215 | – | 1 | 5 |
| – | – | – | – | – | 12 | 47 | 26 |
| – | – | – | – | – | 33 | 7 | 17 |
| – | – | – | – | – | – | 16 | 193 |
| – | – | – | – | – | – | 44 | 2 |

Table 9: Year-cross table for the post-GPS period. The symmetric part shows the number of vessels that link each pair of years, e.g., 3 vessels link 1993–94 to 1992–93. A link was established where a vessel made at least ten tows in each of the paired years. The rightmost column is the row means.

| | 1992–93 | 1993–94 | 1994–95 | 1995–96 | 1996–97 | 1997–98 | 1998–99 | 1999–00 | Mean |
|---|---|---|---|---|---|---|---|---|---|
| 1992–93 | – | 3 | 2 | 3 | 3 | 2 | 2 | 1 | 2.3 |
| 1993–94 | 3 | – | 2 | 2 | 4 | 2 | 1 | 1 | 2.1 |
| 1994–95 | 2 | 2 | – | 3 | 2 | 2 | 2 | 1 | 2.0 |
| 1995–96 | 3 | 2 | 3 | – | 6 | 3 | 4 | 3 | 3.4 |
| 1996–97 | 3 | 4 | 2 | 6 | – | 2 | 4 | 4 | 3.6 |
| 1997–98 | 2 | 2 | 2 | 3 | 2 | – | 4 | 4 | 2.7 |
| 1998–99 | 2 | 1 | 2 | 4 | 4 | 4 | – | 5 | 3.1 |
| 1999–2000 | 1 | 1 | 1 | 3 | 4 | 4 | 5 | – | 2.7 |

Table 10: Smooth oreo pre-GPS. Stepwise selection of variables for the positive catch regression and the zero catch GLM for all tows in the study area that targeted smooth oreo, black oreo or unspecified oreo. New variables were added one at a time until $R^2$ (%) or its equivalent failed to increase by more than 1%. At each iteration the variable that increased $R^2$ the most was added. Variables considered for the positive and zero catch analyses are given in Table 1.

(a) Positive catch model $R^2$ values (%)

| | | | | | Iteration |
|---|---|---|---|---|---|
| Variable | 1 | 2 | 3 | 4 | 5 |
| Vessel | 26.0 | – | – | – | – |
| Target | 19.2 | 32.8 | – | – | – |
| Year | 5.6 | 30.3 | 37.2 | – | – |
| Season | 10.3 | 28.9 | 34.8 | 39.7 | – |
| Depth | 17.2 | 29.8 | 35.6 | 39.6 | 41.7 |
| Improvement in $R^2$ | 26.0 | 6.8 | 4.4 | 2.6 | 2.0 |

(b) Zero catch GLM $R^2$ values (% null deviance explained)

| | | | Iteration |
|---|---|---|---|
| Variable | 1 | 2 | 3 |
| Vessel | 14.7 | – | – |
| Target | 0.8 | 16.2 | – |
| Season | 4.4 | 16.1 | 17.3 |
| Improvement in $R^2$ | 14.7 | 1.5 | 1.1 |

Table 11: Smooth oreo pre-GPS positive catch, zero catch, combined index estimates by year, and jackknife c.v. estimates on the combined index from analysis of all tows in the study area that targeted smooth oreo, black oreo, or unspecified oreo.

| Year | Positive index | Zero index | Combined index | Jackknife c.v.(%) |
|---|---|---|---|---|
| 1983–84 | 1.69 | 1.03 | 1.74 | 13.4 |
| 1984–85 | 1.52 | 1.05 | 1.59 | 45.6 |
| 1985–86 | 1.00 | 1.00 | 1.00 | 0.0 |
| 1986–87 | 0.47 | 0.98 | 0.46 | 46.1 |
| 1987–88 | 0.55 | 0.85 | 0.47 | 86.4 |

Table 12: **Smooth oreo post-GPS. Stepwise selection of variables for the positive catch regression and the zero catch GLM for all tows in the study area that targeted smooth oreo, black oreo or unspecified oreo. New variables were added one at a time until $R^2$ (%) or its equivalent failed to increase by more than 1%. At each iteration the variable that increased $R^2$ the most was added. Variables considered for the positive and zero catch analyses are given in Table 1.**

(a) Positive catch model $R^2$ values (%)

| | Iteration | | | | |
|---|---|---|---|---|---|
| Variable | 1 | 2 | 3 | 4 | 5 |
| Vessel | 13.2 | – | – | – | – |
| Latitude | 6.2 | 16.2 | – | – | – |
| Year | 7.6 | 15.8 | 18.0 | – | – |
| Season | 5.3 | 15.6 | 17.9 | 19.4 | – |
| Target | 1.9 | 14.8 | 17.2 | 19.0 | 20.4 |
| Improvement in $R^2$ | 13.2 | 3.0 | 1.8 | 1.4 | 1.1 |

(b) Zero catch GLM $R^2$ values (% null deviance explained)

| | Iteration | | | |
|---|---|---|---|---|
| Variable | 1 | 2 | 3 | 4 |
| Latitude | 3.3 | – | – | – |
| Year | 2.4 | 5.6 | – | – |
| Vessel | 2.2 | 5.2 | 8.5 | – |
| Season | 1.5 | 4.1 | 7.1 | 9.7 |
| Improvement in $R^2$ | 3.3 | 2.3 | 2.9 | 1.2 |

**Table 13: Smooth oreo post-GPS positive catch, zero catch, combined index estimates by year, and jackknife c.v. estimates on the combined index from analysis of all tows in the study area that targeted smooth oreo, black oreo, or unspecified oreo.**

| Year | Positive index | Zero index | Combined index | Jackknife c.v.(%) |
|---|---|---|---|---|
| 1992–93 | 0.80 | 0.78 | 0.62 | 57.8 |
| 1993–94 | 0.63 | 1.01 | 0.64 | 53.3 |
| 1994–95 | 0.75 | 1.09 | 0.82 | 35.6 |
| 1995–96 | 1.00 | 1.00 | 1.00 | 0.0 |
| 1996–97 | 0.51 | 0.77 | 0.39 | 74.3 |
| 1997–98 | 0.73 | 1.08 | 0.78 | 86.6 |
| 1998–99 | 0.55 | 1.20 | 0.66 | 94.7 |
| 1999–2000 | 0.59 | 1.01 | 0.59 | 65.9 |

**Table 14: Black oreo pre-GPS. Stepwise selection of variables for the positive catch regression and the zero catch GLM for all tows in the study area that targeted smooth oreo, black oreo or unspecified oreo. New variables were added one at a time until $R^2$ (%) or its equivalent failed to increase by more than 1%. At each iteration the variable that increased $R^2$ the most was added. Variables considered for the positive and zero catch analyses are given in Table 1.**

(a) Positive catch model $R^2$ values (%)

| | | | | | Iteration |
|---|---|---|---|---|---|
| Variable | 1 | 2 | 3 | 4 | 5 |
| Year | 25.7 | – | – | – | – |
| Target | 11.0 | 33.4 | – | – | – |
| Vessel | 13.7 | 31.5 | 39.3 | – | – |
| Latitude | 4.2 | 28.3 | 35.4 | 41.5 | – |
| Season | 9.0 | 29.0 | 36.4 | 41.1 | 42.8 |
| Improvement in $R^2$ | 25.7 | 7.6 | 6.0 | 2.2 | 1.4 |

(b) Zero catch GLM $R^2$ values (% null deviance explained)

| | | | | Iteration |
|---|---|---|---|---|
| Variable | 1 | 2 | 3 | 4 |
| Vessel | 23.3 | – | – | – |
| Year | 5.2 | 27.3 | – | – |
| Season | 7.9 | 26.3 | 29.1 | – |
| Target | 11.0 | 26.2 | 28.6 | 30.1 |
| Improvement in $R^2$ | 23.3 | 4.0 | 1.8 | 1.0 |

**Table 15: Black oreo pre-GPS positive catch, zero catch, combined index estimates by year, and jackknife c.v. estimates on the combined index from analysis of all tows in the study area that targeted smooth oreo, black oreo, or unspecified oreo.**

| Year | Positive index | Zero index | Combined index | Jackknife c.v(%) |
|---|---|---|---|---|
| 1983–84 | 1.85 | 1.96 | 3.63 | 57.4 |
| 1984–85 | 1.64 | 1.57 | 2.57 | 29.7 |
| 1985–86 | 1.00 | 1.00 | 1.00 | 0.0 |
| 1986–87 | 0.37 | 1.52 | 0.57 | 40.2 |
| 1987–88 | 0.35 | 1.00 | 0.35 | 192.0 |

**Table 16: Black oreo post-GPS. Stepwise selection of variables for the positive catch regression and the zero catch GLM for all tows in the study area that targeted smooth oreo, black oreo or unspecified oreo. New variables were added one at a time until $R^2$ (%) or its equivalent failed to increase by more than 1%. At each iteration the variable that increased $R^2$ the most was added. Variables considered for the positive and zero catch analyses are given in Table 1.**

(a) Positive catch model $R^2$ values (%)

| | Iteration | | | | |
|---|---|---|---|---|---|
| Variable | 1 | 2 | 3 | 4 | 5 |
| Latitude | 21.9 | – | – | – | – |
| Year | 8.4 | 31.2 | – | – | – |
| Vessel | 9.2 | 25.0 | 33.9 | – | – |
| Depth | 6.0 | 23.9 | 32.8 | 35.5 | – |
| Season | 1.9 | 23.5 | 32.0 | 35.1 | 36.8 |
| Improvement in $R^2$ | 21.9 | 9.2 | 2.7 | 1.7 | 1.2 |

(b) Zero catch GLM $R^2$ values (% null deviance explained)

| | Iteration | | | | | |
|---|---|---|---|---|---|---|
| Variable | 1 | 2 | 3 | 4 | 5 | 6 |
| Latitude | 14.2 | – | – | – | – | – |
| Vessel | 5.3 | 18.6 | – | – | – | – |
| Year | 7.4 | 17.2 | 21.7 | – | – | – |
| Depth | 5.8 | 17.4 | 21.2 | 23.8 | – | – |
| Target | 3.1 | 16.2 | 21.1 | 23.2 | 25.3 | – |
| Season | 4.3 | 16.2 | 20.4 | 23.3 | 25.1 | 26.4 |
| Improvement in $R^2$ | 14.2 | 4.4 | 3.1 | 2.1 | 1.5 | 1.1 |

**Table 17: Black oreo post-GPS positive catch, zero catch, combined index estimates by year, and jackknife c.v. estimates on the combined index from analysis of all tows in the study area that targeted smooth oreo, black oreo, or unspecified oreo.**

| Year | Positive index | Zero index | Combined index | Jackknife c.v.(%) |
|---|---|---|---|---|
| 1992–93 | 1.23 | 0.57 | 0.70 | 57.6 |
| 1993–94 | 1.07 | 0.90 | 0.96 | 46.3 |
| 1994–95 | 1.72 | 0.99 | 1.71 | 33.2 |
| 1995–96 | 1.00 | 1.00 | 1.00 | 0.0 |
| 1996–97 | 0.78 | 1.03 | 0.81 | 101.0 |
| 1997–98 | 0.42 | 1.02 | 0.43 | 33.3 |
| 1998–99 | 0.28 | 1.12 | 0.31 | 52.1 |
| 1999–2000 | 0.21 | 1.18 | 0.24 | 47.3 |

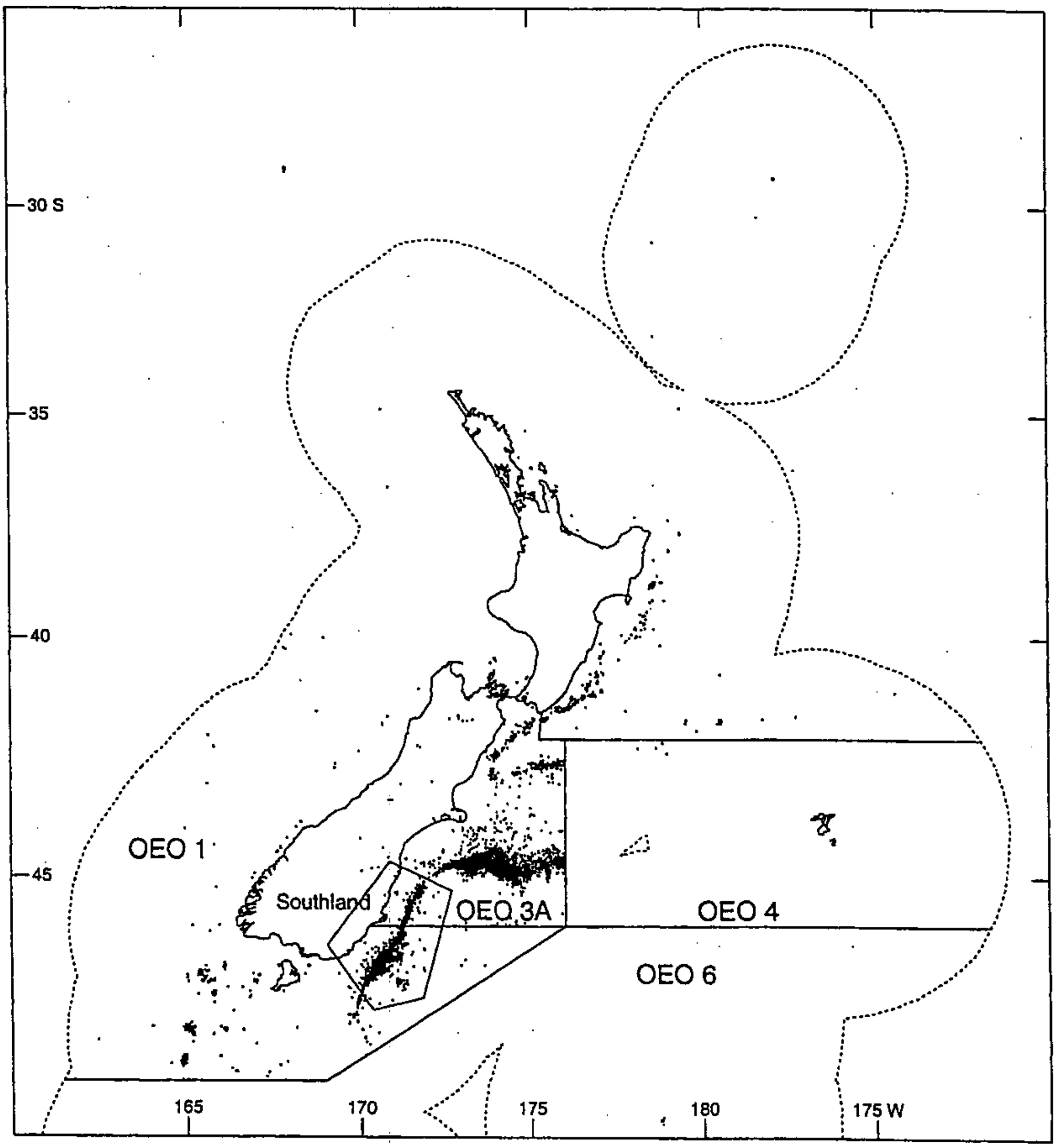


**Figure 1: Start positions of all tows targeting OEO, SSO, or BOE within OEO 1 and OEO 3A from 1977–78 to 1999–2000. The Southland study area is within the pentagon.**

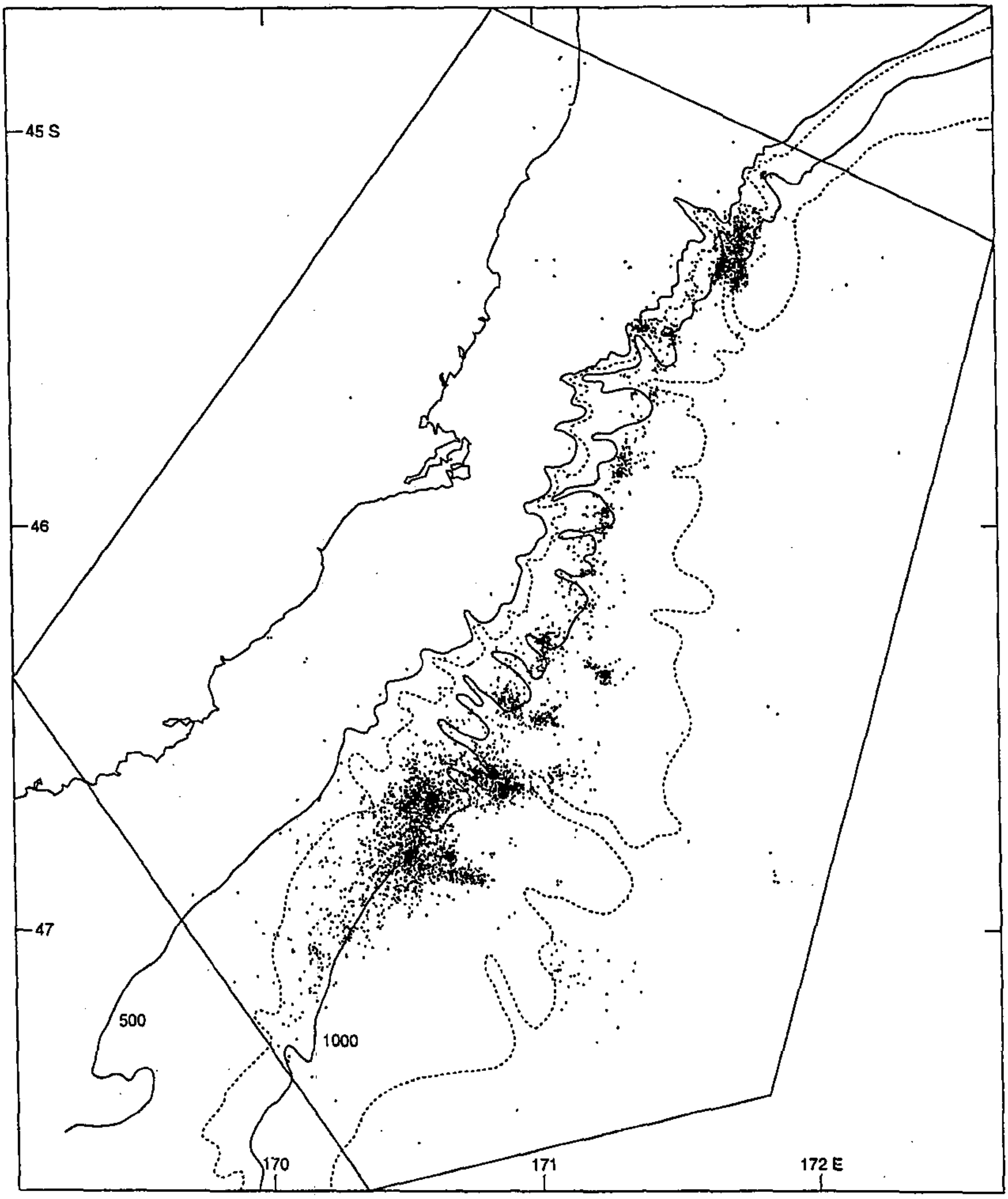


**Figure 2: The study area showing depth contours (m) and the start positions of all tows (dots) that targeted or caught OEO or SSO or BOE from 1977–78 to 1999–2000.**

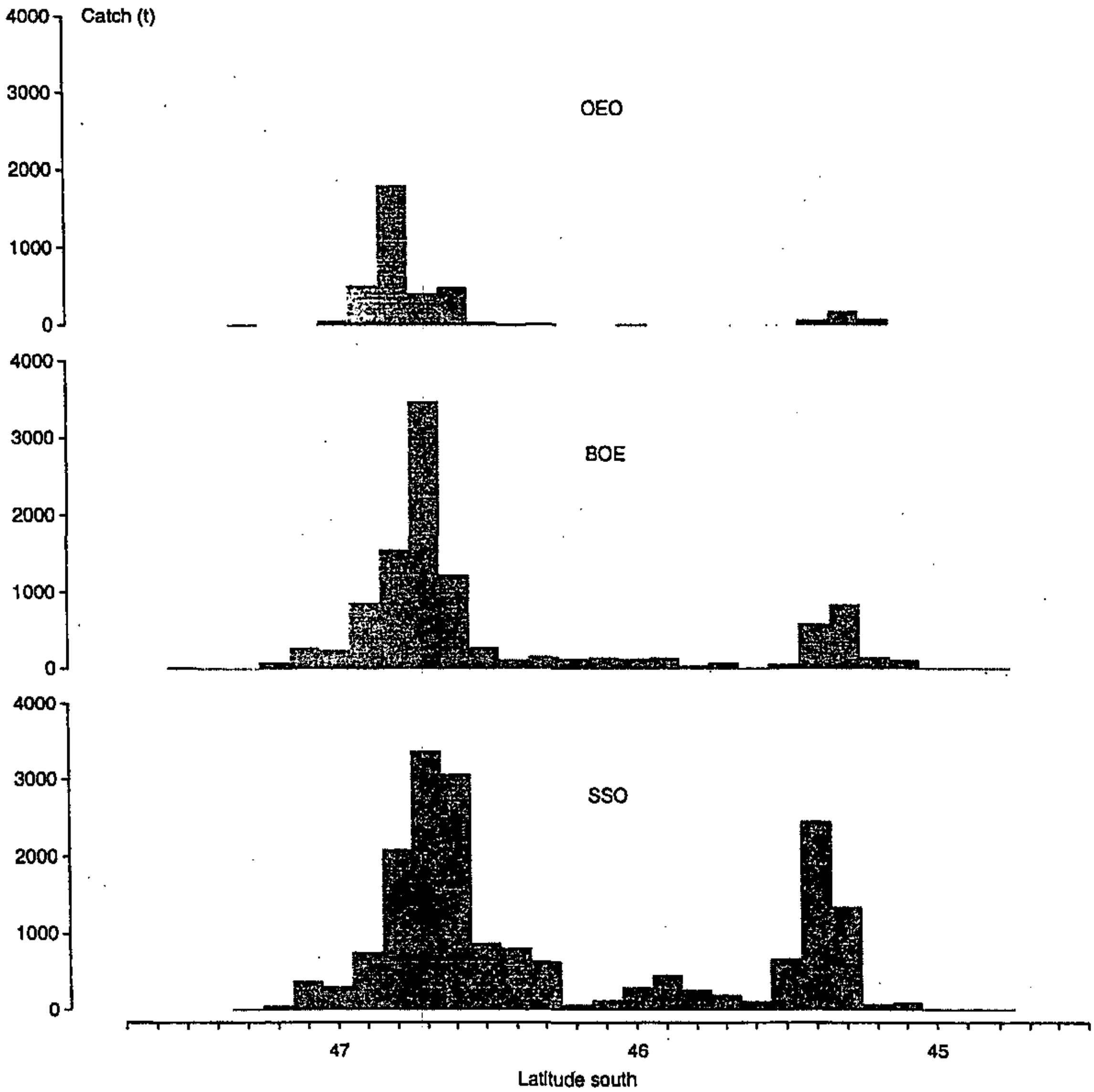


Figure 3: Catch of oreo species by 0.1 degree of latitude for 1977–78 to 1999–2000.

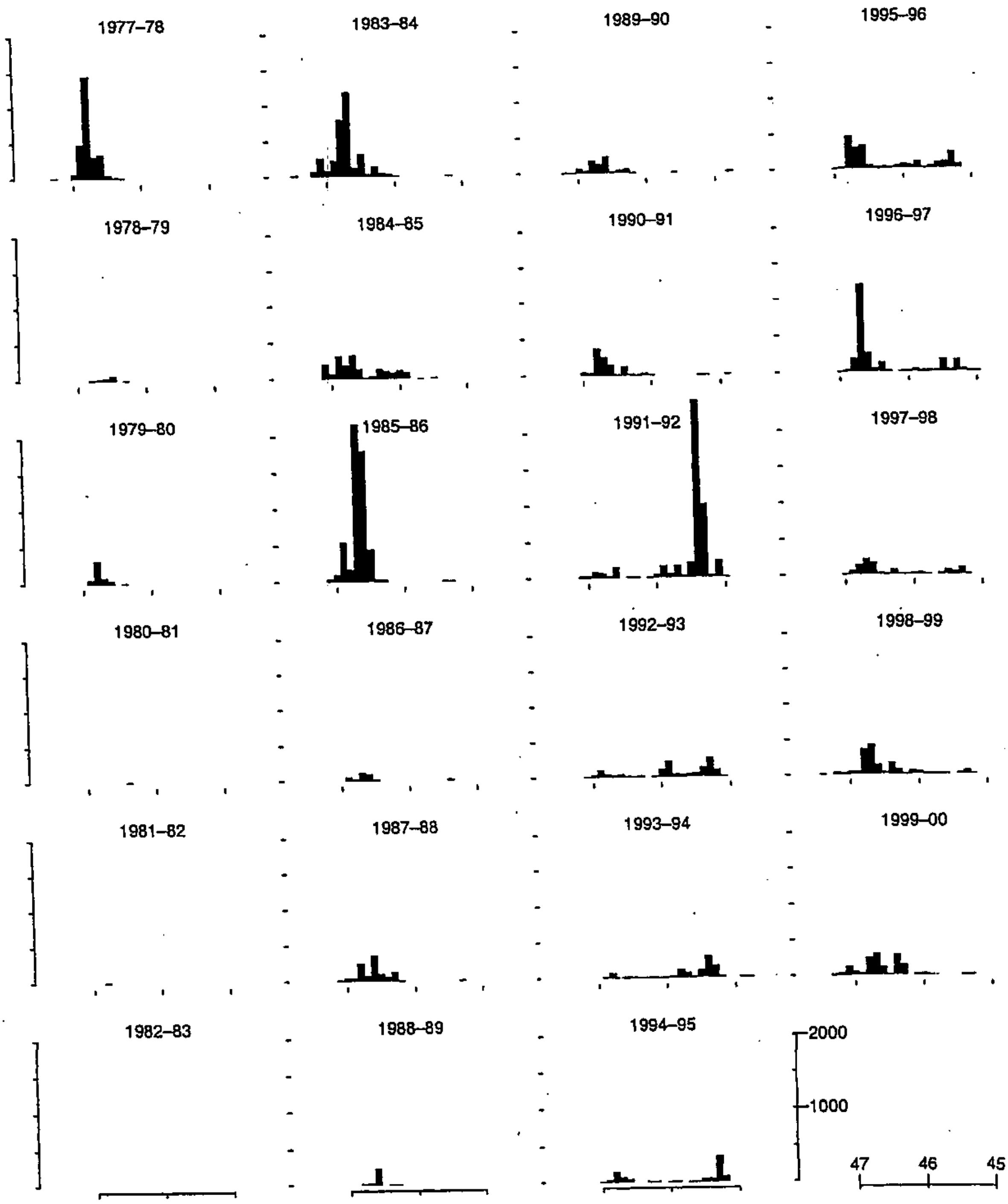


**Figure 4: Catch of all oreo (t), (SSO + BOE + OEO) by latitude for each fishing year from 1977–78 to 1999–2000. See bottom right of figure for scale axes.**


**Figure 5: Smooth oreo combined CPUE index plots for target smooth oreo, black oreo, or unspecified oreo pre-GPS showing the effect of removing one vessel at a time from the analysis. 1985–86 is the reference year.**

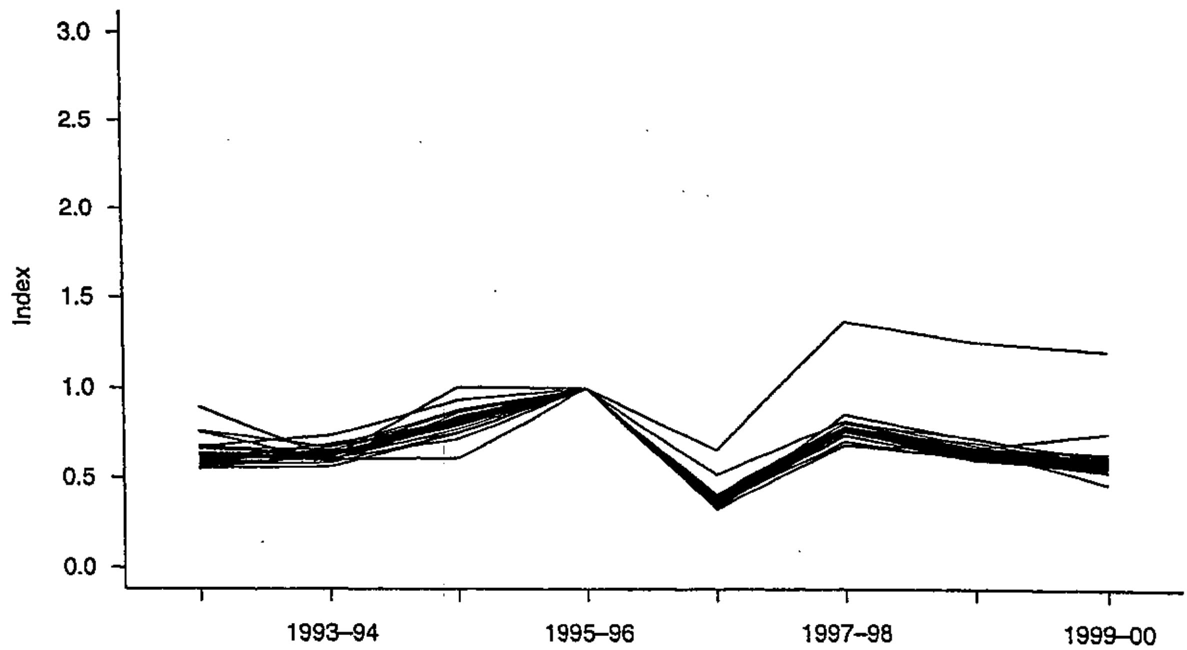


**Figure 6: Smooth oreo combined CPUE index plots for target smooth oreo, black oreo, or unspecified oreo post-GPS showing the effect of removing one vessel at a time from the analysis. 1995–96 is the reference year.**

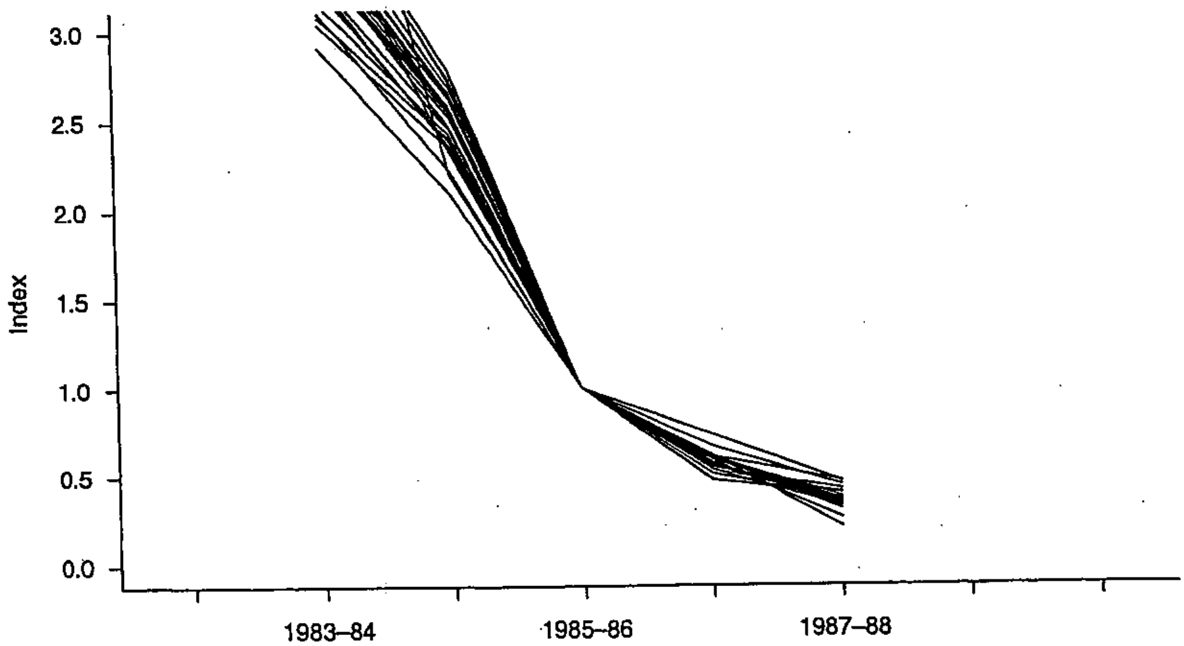


**Figure 7: Black oreo combined CPUE index plots for target smooth oreo, black oreo, or unspecified oreo pre-GPS showing the effect of removing one vessel at a time from the analysis. 1985–86 is the reference year.**

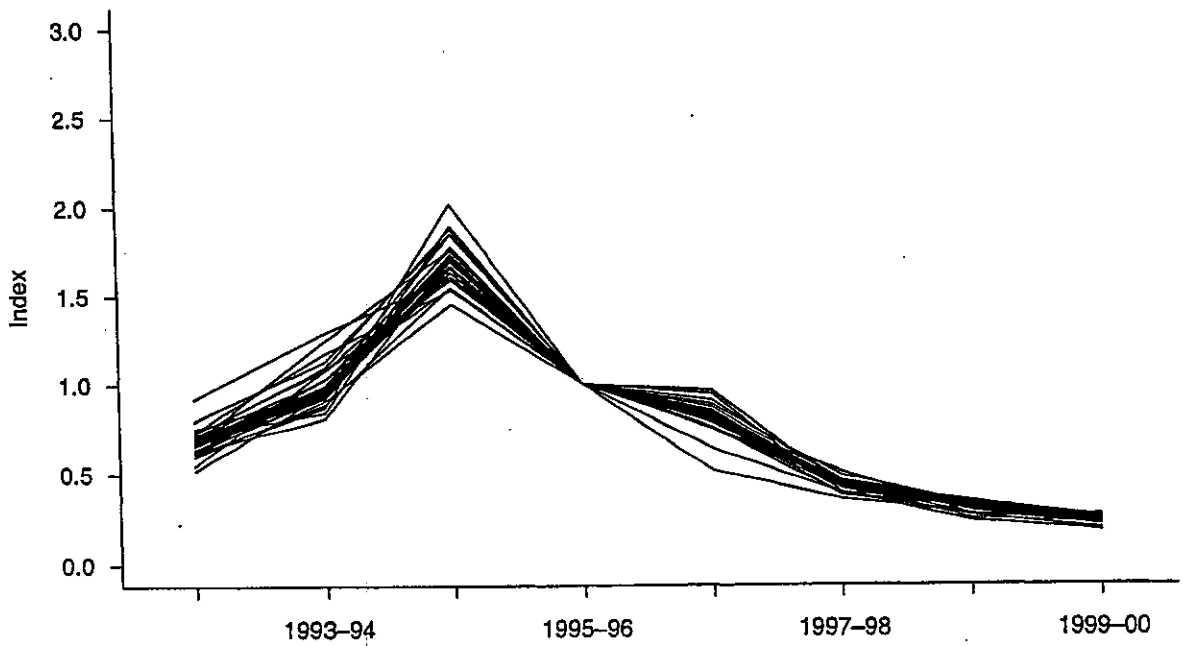


**Figure 8: Black oreo combined CPUE index plots for target smooth oreo, black oreo, or unspecified oreo post-GPS showing the effect of removing one vessel at a time from the analysis. 1995–96 is the reference year.**

## Appendix 1: Details of regression method

Abundance indices can be obtained from a log regression of catch rate on year and other variables (Doonan 1991). Zero catches are usually excluded or a constant is added to all catch rates. If the proportion of zero catches is small, then the results of the analysis are not affected much. If zero catches are more than 10% of the data, then a simple simulation[1] showed that the indices became distorted after the abundance had dropped to some level, even if the proportion of zeros was constant. The higher the proportion of zero catches, the more pronounced the distortion.

The proportion of zero catches each year varied from 5 to 47%, with a median of about 30% (see Tables 2 and 3). These levels of zero catch cause problems in the abundance index if a log regression analysis is employed. To resolve this, the analysis was initially separated into two regressions, one for the proportions of zero catches and another for the positive catches. The year effects estimated from the two regressions were then transformed and combined to form an abundance index for each year. Details were given by Vignaux (1994).

### Regression for positive catches

The regression for positive catches was based on:

$$\log(X_{ij}) = \mu + Y_i + \sum_k F_k(ij) + \varepsilon(ij)$$

where $X_{ij}$ is the catch for tow $j$ in year $i$, $\mu$ is the grand mean in the log scale, $Y_i$ is the year effect for year $i$, and $F_k(ij)$ is factor $k$ evaluated for the $(ij)$-th tow.

The variables considered for the regression (see Table 1) were included only if they lowered $R^2$ by more than 0.01 in a stepwise selection procedure, except for year which was always included.

The contribution to the abundance index for year $i$ relative to year $r$ was

$$e^{Y_i - Y_r}$$

1 For each year, the mean catch and proportion of zero catches were specified so that there was a decline of 90% over the series, i.e., year was the sole variable in the decline. Zero catches were binomially distributed, positive catches had a lognormal distribution. Simulated catches were analysed by regressing log(catch + constant) on year.

### Regression for zero catches

We used the Generalised Linear Model (GLM) with a binomial distribution and a logit link for the proportions, i.e.,

$$\log \frac{p_{ij}}{1 - p_{ij}} = \mu^{I} + Y_i^{I} + \sum_k F_k^{I}(i\ j)$$

where $p_{ij}$ is the expected proportion of zero catches for tow $j$ in year $i$, and the other terms correspond to those in the positive catch regression. Note that only the expected proportion of zero catches was transformed, not the data. In the positive catch regression, the data were transformed.

Non-year variables were included only if they lowered the deviance so that the GLM equivalent of $R^2$ (proportion of null deviance explained) increased by more than 1% in a stepwise selection procedure.

The contribution to the abundance index for year $i$ relative to year $r$ was

$$\frac{1}{1 - \pi_r(1 - e^{Y_i^I - Y_r^I})}$$

where $\pi_r$ is some reference proportion of zeros from year $r$.

### Combined abundance index

The combined abundance index was a product of the two parts

$$\left[\frac{1}{1 - \pi_r(1 - e^{Y_i^I - Y_r^I})}\right]\left[e^{Y_i - Y_r}\right]$$

### Estimate of the c.v. for the abundance index

The c.v. of the abundance index was calculated by a modified jackknife method, using vessel data as the subset, rather than carrying through the variances of the year effects from the regressions.

ear $i$, pseudo-abundance indices (suppressing the index $i$) were generated by

$$y^*_j = k * y_{all} - (k-1)\, y_j$$

e $y_j$ is the abundance index when the data for vessel $j$ were left out, $y_{all}$ is the abundance index all data included, and $k$ is the number of vessels in year $i$. In the usual application of the nife technique the number of data points left out would be the same for all vessels, but in our cation the size of the data subsets varied so much that we needed to weight each jackknife lo abundance index ($y^*_j$) in calculating the variance. The weights for $y^*_j$ were the number of vessel $j$ did in year $i$. Thus the variance of the index for year $i$ is $s^2/k$, where

$$s^2 = \sum_j \frac{n_j}{N} ( y^*_j - y_{all} )^2$$

he number of tows in year $i$ for vessel $j$ and

$$= \sum_j n_j$$

gnored the contributions from vessels that did not fish in year $i$, but which had an influence on timated effects of variables, e.g., depth, and through them an influence on the index for year $i$. urly, the effects of vessels that fished mainly in the reference year were not included as that year s had an index of 1, by definition.