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EXECUTIVE SUMMARY

Coburn, R.P.; Doonan, I.J.; McMillan, P.J. (2002): CPUE analyses for the major black oreo and smooth oreo fisheries in OEO 6, 1980–81 to 1999–2000.

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A feasibility study of unstandardised and standardised CPUE data for the major black oreo and smooth oreo fisheries in OEO 6 was carried out. The OEO 6 fisheries were exploited in the early 1980s, followed by a lull and then an increase in fishing from 1994 on. From 1995–96 to 1999–2000 annual catches averaged about 3600 t for smooth oreo and 1700 t for black oreo. CPUE data were available from 1980–81 to 1999–2000. Data for catch of either black oreo or smooth oreo were included in the analyses where target species was any one of four recorded target species, e.g., all black oreo caught when target was unspecified oreo, smooth oreo, black oreo, or orange roughy (to ensure that large amounts of data were not discarded). Standardised analyses used data divided into pre- and post-GPS series and employed regression-based methods used in previous Chatham Rise CPUE analyses. Five major fisheries were identified and included a black oreo post-GPS fishery on Pukaki Rise east that averaged about 1400 t per year from 1995–96 to 1999–2000, a smooth oreo post-GPS fishery on Pukaki Rise east that averaged 1200 t per year from 1995–96 to 1999–2000, a black oreo pre-GPS fishery on Pukaki Rise east that averaged 1200 t per year from 1980–81 to 1984–85, a smooth oreo post-GPS fishery on the Bounty Plateau that averaged 800 t per year from 1994–95 to 1999–2000, and a smooth oreo post-GPS fishery on the Auckland Island hills that averaged 500 t from 1994–95 to 1999–2000. Unstandardised analyses for the five fisheries were difficult to interpret because of the four target species options and showed flat or fluctuating CPUE trends except for the Pukaki Rise east black oreo pre- and post-GPS series which both appeared to decline. Vessel continuity analysed for the standardised studies of each of the five fisheries generally showed that changes occurred slowly enough to allow linkages across most years. The post-GPS series were better linked than the pre-GPS. The Pukaki Rise east black oreo pre-GPS had 5 years of acceptable data but these comprised two subsets of linked data (three plus two years). There were 6 years acceptable data for the Auckland Island hills smooth oreo post-GPS and Bounty Plateau smooth oreo post-GPS series, and these had 5 and 6 years of linked data respectively. The Pukaki Rise east black oreo post-GPS and smooth oreo post-GPS series had 5 years acceptable data and 5 years of linked data. Standardised analyses for these five fisheries 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 analysed commercial catch and effort data for the black oreo and smooth oreo fisheries in the major fisheries in OEO 6 only. A separate report analysed the data for the Southland oreo fisheries.

1.2 General

The deepwater trawl fisheries for black oreo and smooth oreo in OEO 6 first became important from 1981–82 to 1984–85 with a peak reported black oreo catch of 8500 t in 1981–82 and peak smooth oreo catch of 1300 t in 1983–84. There was a lull in fishing until the early 1990s when average annual catches of about 800 t for smooth oreo and 100 t for black oreo were reported in the 5 years from 1990–91 to 1994–95. The next 5 years (1995–96 to 1999–2000) saw increased fishing, principally targeted at orange roughy, and an increased TAC in 1996–97 (6000 t) resulting in average annual catches of about 3600 t of smooth oreo and 1700 t of black oreo.

Detailed tow-by-tow records of catch and effort data from 1980–81 onwards were examined to determine the feasibility of carrying out unstandardised and standardised CPUE analyses with potential for use as indices of abundance. There are no indices of abundance available for black oreo or smooth oreo from OEO 6. Previous oreo research has focused on the Chatham Rise (Annala et al. 2001).

The approach adopted for this study was to first assemble all the catch and effort data, then to examine the quantity and quality of the data to determine if a standardised analysis was possible. The continuity of the data series was investigated by examining the vessels participating throughout the time series. Standardised analyses were then performed and the effect on the resulting index of removing the data from each vessel in turn from the analyses was examined. Coefficients of variation (c.v.s) for the index were calculated using a modified jackknife technique that dropped one vessel's data at each iteration.

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 of 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 before 1988 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. It was thought that any remaining errors were essentially random. Initially data from all tows that targeted or caught oreo (SSO or BOE or OEO) were considered. The data were restricted to the study areas as defined in Section 2.3. 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 Study areas

The study areas were those defined by Hart et al. (2000) and McMillan et al. (2001) for each of the major oreo fisheries in OEO 6 and included Pukaki Rise east, the Bounty Plateau, and the Auckland Island hills (Figure 1). The Pukaki Rise west fishery was excluded because it was considered too small, i.e., there were only 2 years when there were more than 50 tows that caught oreos.

2.4 Choice of CPUE measure

Catch-per-tow (tonnes-per-tow) was chosen as the standard CPUE measure rather than catch-per-kilometre and followed 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 from the OEO 6 fisheries (McMillan et al. 2001) was used as a starting point in describing the fishery. This provided the fractions of data, nationality, tonnage composition of the fleet, target composition of the fishery, catches, target catch rates, and highlighted changes in these elements over time. 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 (tows with no catch of the target species) 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. That 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 where the mean of the number of vessels linking any year was less than one in the cross-year table. A poorly linked year was susceptible to influence by changes in the fishing power or ability of a single vessel. For example, if a year was 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 would determine that year's index (relative to the rest of the series). Changes in vessel 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 those 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, see Appendix 2) were therefore dropped, splitting the analyses into pre- and post-GPS periods. Black oreo and smooth oreo were analysed separately allowing the selection of predictor variables to be optimal in each case. Therefore there were four potential analyses for each fishery: smooth oreo, pre-GPS; smooth oreo, post-GPS; black oreo, pre-GPS, and black oreo, post-GPS.

The OEO 6 fisheries were all treated as mixed target fisheries, i.e., it was difficult to target one species exclusively (SSO or BOE or ORH). Just using data from target fishing a single species, e.g., 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 or ORH were used for each analysis. Only small amounts of black oreo and smooth oreo were caught as bycatch during target fishing for species other than those listed above (see tables 1.27, 1.32 & 1.37 in McMillan et al. 2001) so only a small amount of oreo CPUE data were not included in the analyses from that source. 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. Years were excluded if only one vessel caught 80% or more of the black oreo (black oreo analysis) or smooth oreo (smooth oreo analysis) 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 of the analysis were all lumped into the same category.

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 were 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. For the reference year we chose a year from the middle of the time series that had a greater than average number of tows.

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

3. RESULTS

3.1 Unstandardised CPUE

A previous study of oreo catch and effort data was used to describe the general features of the major oreo fisheries in OEO 6 (McMillan et al. 2001). Catches of oreo were declared from OEO 6 since 1978–79 (table 1.1, McMillan et al. 2001). The tow-by-tow data on which this study is based accounted for about 90% of the declared catch (table 1.1, 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) catch but 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. As OEO 6 is distant from secure serviced ports and subject to bad weather it is unlikely that small vessels (which are not required to provide tow-by-tow reports) fished in OEO 6. These data appear complete enough for satisfactory descriptive and standardised analyses of CPUE.

General descriptions of the major oreo fisheries are given below.

Auckland Island hills

The Auckland Island hills had a total of less than 100 t of oreo reported caught before 1992–93. Since then annual catch was almost entirely smooth oreo and usually exceeded 300 t, with a peak catch of 658 t in 1998–99 (table 1.28, McMillan et al. 2001). The fleet was entirely New Zealand vessels (table 1.25, McMillan et al. 2001), typically 1000–2000 grt. A maximum of six vessels fished in a single year (table 1.26, McMillan et al. 2001). Most of the fishing targeted ORH, but this declined recently and in 1999–2000 as many tows targeted OEO as ORH (table 1.27, McMillan et al. 2001). Unstandardised catch rates (table 1.29, McMillan et al. 2001) appeared stable. Because BOE was not caught, OEO target tows were treated as SSO target tows when examining catch rates.

Bounty Plateau

Before 1990 the Bounty Plateau had a single large annual catch of about 1150 t (525 t SSO and 628 t BOE) in 1983–84. In the 1990s, annual catch increased to a peak of about 1300 t SSO (1994–95) with negligible amounts of BOE reported. In 1996–97 most catch was recorded as OEO, but it is probable that the target was SSO (table 1.33, McMillan et al. 2001). The 1983–84 catch was taken by two Soviet vessels. In the 1990s the fleet was almost entirely New Zealand vessels, typically of 1000–2000 grt (tables 1.30 & 1.31, McMillan et al. 2001). In the 1990s fishing targeted OEO, SSO, and ORH (table 1.32, McMillan et al. 2001). Unstandardised catch rates appear stable (table 1.34, McMillan et al. 2001). Because BOE was not caught, OEO target tows were treated as SSO target tows when examining catch rates.

Pukaki Rise east

There was a period of fishing during the early 1980s with catches mainly of BOE and a peak catch of over 3118 t BOE in 1980–81 (table 1.38, McMillan et al. 2001). Fishing ceased about 1985–86 and began again in 1994–95. Since then catch was recorded by species and has averaged about 1100 t of SSO and about 1200 t of BOE. Soviet vessels fished in the 1980s and were typically over 2000 grt (tables 1.35 and 1.36, McMillan et al. 2001). New Zealand vessels fished in the 1990s and were generally under 2000 grt. There was a maximum Soviet fleet of eight in 1980–81 and maximum New Zealand fleet of seven in 1998–99 (table 1.36, McMillan et al. 2001). The Soviet fleet primarily targeted BOE but the New Zealand fleet initially targeted ORH, but increasingly this was displaced by oreo (usually unspecified) target tows (table 1.37, McMillan et al. 2001). The Soviet target catch rates for BOE dropped to about half the initial value between 1980–81 and 1984–85 whereas the New Zealand target catch rates are considered here only for OEO and declined from high initial values but appear stable in the last few years (table 1.39, McMillan et al. 2001).

Unstandardised CPUE for the candidate datasets used in the standardised analyses are provided below. Years with fewer than 100 tows should be ignored when interpreting mean catch rate and fractions of zero catch tows because those data are likely to be highly variable in an unstandardised form.

Auckland Island hills, smooth oreo, post-GPS (Table 2)
From 1992–93 to 1999–2000 effort was between 66 and 260 tows and fleet size from two to eight vessels. Annual catch varied from 270 to 660 t. Mean catch per tow and the fraction of zero catch tows showed no trend.

Bounty Plateau, smooth oreo, post-GPS (Table 3)
From 1992–93 to 1999–2000 effort and fleet size increased. Catch exceeded 1000 t in two years and was usually over 500 t. Mean catch per tow and the fraction of zero catch tows showed no clear trend.

Pukaki Rise east, smooth oreo, post-GPS (Table 4)
Effort increased from 1992–93 to 1999–2000 with peak effort of 606 tows in 1996–97. Fleet size increased to a maximum of 11 in 1998–99. Catches increased to a peak of 1570 t in 1999–2000. Mean catch per tow and the fraction of zero catch tows showed no clear trend.

Pukaki Rise east, black oreo, pre-GPS (Table 5)
From 1980–81 to 1987–88 effort declined from a maximum of 564 tows to less than 10 in 1985–86. Fleet size was a maximum of 10 in 1980–81 and dropped steadily after that. Catch fell from a peak of 3070 t in 1980–81. Mean catch per tow fell while the fraction of zero catch tows increased.

Pukaki Rise east, black oreo, post-GPS (Table 6)
Effort and fleet size are as given for smooth oreo above (Table 4). Catches exceeded 1000 t from 1995–96 to 1998–99. Mean catch per tow declined while the fraction of zero catch tows showed no trend.

3.2 Standardised CPUE

3.2.1 Fleet turnover

The results given below detail the fleet continuity for the candidate CPUE datasets. The Pukaki Rise east post-GPS SSO and BOE analyses used the same data and shared the same characteristics, i.e., all tows targeting OEO or SSO or BOE or ORH in the area and period.

Auckland Island hills, post-GPS
There was moderate turnover in the series. Three vessels fished just two years, one fished three years, two fished four, one fished five, and one also fished the entire six years (Table 7). Mean vessel linkages between years were mainly 1–2, but the 1999–2000 year was poorly linked to other years (mean 0.8) (Table 8).

Bounty Plateau, post-GPS
There was moderate turnover with five vessels that fished just two years, two fished three, and two each fished five and the full six years (Table 9). Mean linkages were a little better than for the Auckland Island hills series, generally better than two, and no individual year was poorly linked (Table 10).

Pukaki Rise east, pre-GPS

Vessels involved in the first three years of the series (1980–81 to 1982–83) were barely represented in the last two years (Table 11). Only one vessel fished in more than two years. This led to low mean linkages between years and the last two years had no link to the first three years (Table 12), i.e., the data formed two unlinked subsets.

Pukaki Rise east, post-GPS

There was moderate turnover with three vessels that fished just two years, one fished three, and two each fished four and the entire five years of the series (Table 13). One vessel (top row) accounted for most of the effort. Mean linkages between years on average were greater than two (Table 14) but the first year was less well linked than the others.

3.2.2 Auckland Island hills, smooth oreo, post-GPS

Catch and effort data from 1992–93 to 1999–2000 were available for this analysis (see Table 2). Data from before 1994–95 were dropped because they were dominated by catches from one vessel. For the selected years, 12% of the tows caught no smooth oreo.

Results of the positive catch regressions and zero catch GLM are given in Table 15. The final model for positive catch used season, vessel, longitude, and year (selected in that order) and that for zero catch used target, season, longitude, year, vessel, time, latitude, and depth.

The indices

The abundance index results from each model (positive catch and zero catch) and the combined index are given in Table 16. The combined index from the final year was about a quarter that 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 2). The series is sensitive to the choice of vessels especially in the first two years.

Confidence intervals

Mean c.v. by year for the combined indices calculated using a jack-knife technique is given in Table 16. The overall mean c.v. was 72%.

3.2.3 Bounty Plateau, smooth oreo, post-GPS

Catch and effort data from 1992–93 to 1999–2000 were available for this analysis (see Table 3). The years before 1994–95 were dropped because there were fewer than 50 catches per year. For the selected years, 13% of the tows caught no smooth oreo.

Results of the positive catch regressions and zero catch GLM are given in Table17. The final model for positive catch used vessel, target, longitude, season, and depth (selected in that order) and that for zero catch used target, longitude, season, year, latitude, vessel and depth.

The indices

The abundance index results from each model (positive catch and zero catch) and the combined index are given in Table 18. The combined index from the final year was about 60% that 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 3). This showed that one vessel was influential on the first two years of the series.

Confidence intervals

Mean c.v. by year for the combined indices calculated using a jack-knife technique are given in Table 18. The overall mean c.v. was 75%.

3.2.4 Pukaki Rise east, smooth oreo, post-GPS

Catch and effort data from 1992–93 to 1999–2000 were available for this analysis (see Table 4). Our selection criteria dropped the years before 1995–96 because there fewer than 50 catches per year. For the selected years, 31% of the tows caught no smooth oreo.

Results of the positive catch regressions and zero catch GLM are given in Table 19. The final model for positive catch used vessel, year, season, and target (selected in that order) and that for zero catch used vessel, season, and latitude.

The indices

The abundance index results from each model (positive catch and zero catch) and the combined index are given in Table 20. The combined index from the final year was about a fifth that 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 4). This showed that while there was some variation between vessels in the first two years the overall trend was clear. No vessel or year was highly influential on the series.

Confidence intervals

Mean c.v. by year for the combined indices calculated using a jack-knife technique is given in Table 20. The overall mean c.v. was 36%.

3.2.5 Pukaki Rise east, black oreo, pre-GPS

Catch and effort data from 1980–81 to 1987–88 were available for this analysis (see Table 5). Our selection criteria dropped the years after 1984–85 because there were fewer than 50 catches per year. For the selected years, 28% of the tows caught no black oreo.

Results of the positive catch regressions and zero catch GLM are given in Table 21. The final model for positive catch used vessel, season, depth, target and latitude (selected in that order) and that for zero catch used vessel, season, depth and year.

The indices

The abundance index results from each model (positive catch and zero catch) and the combined index are given in Table 22. The combined index from the final year was about the same as that 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 there is much variation in the index for the last two years depending on the vessels admitted.

Confidence intervals

Mean c.v. by year for the combined indices calculated using a jack-knife technique are given in Table 22. The overall mean c.v. was 12%.

3.2.6 Pukaki Rise east, black oreo, post-GPS

Catch and effort data from 1992–93 to 1999–2000 were available for this analysis (see Table 6). Our selection criteria dropped the years before 1995–96 because there were fewer than 50 catches per year. For the selected years, 23% of the tows caught no black oreo.

Results of the positive catch regressions and zero catch GLM are given in Table 23. The final model for positive catch used latitude, season, year, and longitude (selected in that order) and that for zero catch used vessel, longitude, season, year and latitude.

The indices

The abundance index results from each model (positive catch and zero catch) and the combined index are given in Table 24. The combined index from the final year was about a third that 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 two vessels were influential on the first two years but for the rest of the series the difference between vessels was slight.

Confidence intervals

Mean c.v. by year for the combined indices calculated using a jack-knife technique is given in Table 24. The overall mean c.v. was 14%.

4. DISCUSSION

There was only one pre-GPS series (black oreo from Pukaki Rise east) with enough data to meet the selection criteria for an acceptable standardised CPUE study, but that series comprised two unlinked subsets with three and two years of linked data. There were four post-GPS series that had 5–6 years of acceptable data and 5–6 years of linked data (Table 25). Additional years of data will be added to each post-GPS series, but the pre-GPS series is complete.

The OEO 6 oreo fisheries were smaller than those analysed for other CPUE studies, e.g., the Chatham Rise fisheries analysed by Doonan et al. (1995) and Coburn et al. (1999, 2001), and consequently there was less data available for each analysis. This suggests that the results of these analyses probably have more uncertainties than studies using larger datasets. Ideally the standardised CPUE analyses should have been for target species data only but these were mostly mixed fisheries where the target varied between unspecified oreo, smooth oreo, black oreo or orange roughy. To overcome this problem, target species was used as a predictor variable in the regression analyses to increase the size of the available datasets.

Another approach to this problem could be to use data from all the OEO 6 oreo fisheries combined and to incorporate an area-year interaction term in the regression model so that indices from each individual fishery could be produced. This would have the advantage of probably producing better estimates of the vessel effects and therefore better annual estimates. The disadvantages include the requirement to assume that effects other than year, e.g., depth, season, target species, were the same across all the OEO 6 oreo fisheries.

There have been oreo fisheries in OEO 6 since the early 1980s and some of these have become important during the last six or so years. There are no indices of abundance available for these fisheries. Because of their small individual relative size and distant location they are unlikely to be the subject of research abundance surveys in the immediate future. Therefore it seems sensible to consider the possibility of using standardised CPUE analyses to provide abundance indices. The present study suggests that such analyses are feasible for Pukaki Rise east pre-GPS black oreo (although there are only two short subsets of linked (three and two years) data), Pukaki Rise east post-GPS black oreo, Pukaki Rise east post-GPS smooth oreo, Bounty Plateau post-GPS smooth oreo, and Auckland Island hills post-GPS smooth oreo.

5. ACKNOWLEDGMENTS

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Table 1: Summary of non-year variables that could be selected in the regression models. All are 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	3	Target species, SSO, BOE, OEO, or ORH.
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 periods.
Longitude	7	Longitude of start of tow, blocked into 8 periods.
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 post-GPS CPUE for all tows in the Auckland Island hills area that targeted OEO, SSO, BOE, or ORH. – data from fewer than four vessels.

Year	No of tows	No of vessels	Catch (t)	Mean catch per tow (t)	Zero catch tows (%)
1992–93	–	–	290	–	–
1993–94	103	4	270	2.7	12
1994–95	260	5	560	2.1	17
1995–96	177	6	510	2.9	7
1996–97	109	7	270	2.5	13
1997–98	153	6	320	2.1	7
1998–99	217	8	660	3.0	10
1999–00	–	–	550	–	–

Table 3: Unstandardised smooth oreo post-GPS CPUE for all tows in the Bounty Plateau area that targeted OEO, SSO, BOE, or ORH. Catches of OEO have been included as SSO. – data from fewer than four vessels.

Year	No of tows	No of vessels	Catch (t)	Mean catch per tow (t)	Zero catch tows (%)
1992–93	–	–	80	–	–
1993–94	–	–	430	–	–
1994–95	162	8	1 280	7.9	11
1995–96	153	5	780	5.1	9
1996–97	170	6	560	3.3	18
1997–98	203	6	590	2.9	21
1998–99	338	13	1 060	3.1	11
1999–00	137	8	750	5.5	7

Table 4: Unstandardised smooth oreo post-GPS CPUE for all tows in the Pukaki Rise east area that targeted OEO, SSO, BOE, or ORH. – data from fewer than four vessels.

Year	No of tows	No of vessels	Catch (t)	Mean catch per tow (t)	Zero catch tows (%)
1992–93	–	–	0	–	–
1994–95	–	–	120	–	–
1995–96	317	4	1 110	3.5	20
1996–97	606	8	1 470	2.4	35
1997–98	582	9	1 070	1.8	44
1998–99	429	11	960	2.2	28
1999–00	588	7	1 570	2.7	21

Table 5: Unstandardised black oreo pre-GPS CPUE for all tows in the Pukaki Rise east area that targeted OEO, SSO, BOE, or ORH. – data from fewer than four vessels.

Year	No of tows	No of vessels	Catch (t)	Mean catch per tow (t)	Zero catch tows (%)
1980–81	564	10	3 070	5.4	15
1981–82	476	7	1 830	3.8	28
1982–83	106	7	400	3.8	47
1983–84	84	6	210	2.5	20
1984–85	169	5	360	2.2	65
1985–86	–	–	20	–	–
1987–88	–	–	0	–	–

Table 6: Unstandardised black oreo post-GPS CPUE for all tows in the Pukaki Rise east area that targeted OEO, SSO, BOE, or ORH. – data from fewer than four vessels.

Year	No of tows	No of vessels	Catch (t)	Mean catch per tow (t)	Zero catch tows (%)
1992–93	–	–	0	–	–
1994–95	–	–	210	–	–
1995–96	317	4	1 140	3.6	27
1996–97	606	8	1 900	3.1	13
1997–98	582	9	1 900	3.3	20
1998–99	429	11	1 050	2.5	19
1999–00	588	7	950	1.6	37

Table 7: Number of tows by fishing year for vessels in the Auckland Island hills smooth oreo post-GPS analysis. Each row is a vessel; only vessels that fished in more than one year are shown. The vessels have been sorted on their year of first and last appearance. –, indicates zero tows.

1994–95	1995–96	1996–97	1997–98	1998–99	1999–00
139	63	–	–	–	–
11	65	53	20	–	–
49	–	2	68	113	68
60	10	3	10	1	7
–	33	10	46	45	–
–	3	–	–	6	–
–	–	20	6	1	–
–	–	–	–	41	91

Table 8: Year-cross table for the Auckland Island hills smooth oreo post-GPS analysis. The symmetric part shows the number of vessels that 'link' each pair of years, e.g., 3 vessels link 1994–95 to 1995–96. There is a minimum of ten tows in each year by a vessel to create a link. "+" mark the diagonal. the rightmost column is the mean link value for each year.

	1994–95	1995–96	1996–97	1997–98	1998–99	1999–00	Mean
1994–95	+	3	1	3	1	1	1.8
1995–96	3	+	2	3	1	0	1.8
1996–97	1	2	+	2	1	0	1.2
1997–98	3	3	2	+	2	1	2.2
1998–99	1	1	1	2	+	2	1.4
1999–00	1	0	0	1	2	+	0.8

Table 9: Number of tows by fishing year for vessels in the Bounty Plateau smooth oreo post-GPS analysis. Each row is a vessel; only vessels that fished in more than one year are shown. The vessels have been sorted on their year of first and last appearance. –, indicates zero tows.

1994–95	1995–96	1996–97	1997–98	1998–99	1999–00
30	13	–	–	–	–
40	–	66	–	–	–
20	13	1	41	34	–
1	–	–	31	1	–
52	7	4	22	46	48
14	60	90	47	26	14
2	60	8	–	6	18
–	–	1	59	–	–
–	–	–	3	5	2
–	–	–	–	10	2
–	–	–	–	29	9

Table 10: Year-cross table for the Bounty Plateau smooth oreo post-GPS analysis. The symmetric part shows the number of vessels that 'link' each pair of years, e.g., 3 vessels link 1994–95 to 1995–96. There is a minimum of ten tows in each year by a vessel to create a link. "+" mark the diagonal. The rightmost column is the mean link value for each year.

	1994–95	1995–96	1996–97	1997–98	1998–99	1999–00	Mean
1994–95	+	3	2	3	3	2	2.6
1995–96	3	+	1	2	2	2	2
1996–97	2	1	+	1	1	1	1.2
1997–98	3	2	1	+	3	2	2.2
1998–99	3	2	1	3	+	2	2.2
1999–00	2	2	1	2	2	+	1.8

Table 11: Number of tows by fishing year for vessels in the Pukaki Rise east black oreo pre-GPS analysis. Each row is a vessel; only vessels that fished in more than one year are shown. The vessels have been sorted on their year of first and last appearance. –, indicates zero tows.

1980–81	1981–82	1982–83	1983–84	1984–85
22	59	–	–	–
58	94	–	–	–
114	28	27	–	–
–	108	24	–	–
–	170	36	–	–
–	–	4	8	–
–	–	–	8	11
–	–	–	21	28

Table 12: ***Year-cross table for the Pukaki Rise east black oreo pre-GPS analysis.*** **The symmetric part shows the number of vessels that 'link' each pair of years, e.g., 3 vessels link 1980–81 to 1981–82. There is a minimum of ten tows in each year by a vessel to create a link. "+" mark the diagonal. The rightmost column is the mean link value for each year.**

	1980–81	1981–82	1982–83	1983–84	1984–85	Mean
1980–81	+	3	1	0	0	1.0
1981–82	3	+	3	0	0	1.5
1982–83	1	3	+	0	0	1.0
1983–84	0	0	0	+	1	0.3
1984–85	0	0	0	1	+	0.3

Table 13: Number of tows by fishing year for vessels in the Pukaki Rise east black oreo and smooth oreo post-GPS analyses. Each row is a vessel; only vessels that fished in more than one year are shown. The vessels have been sorted on their year of first and last appearance. –, indicates zero tows.

1995–96	1996–97	1997–98	1998–99	1999–00
230	336	379	240	187
1	1	1	35	219
22	26	–	6	50
–	58	71	–	–
–	116	10	–	–
–	46	58	27	–
–	20	44	49	5
–	–	–	10	104

Table 14: Year-cross table for the Pukaki Rise east black oreo and smooth oreo, post-GPS analysis. The symmetric part shows the number of vessels that 'link' each pair of years, e.g., 2 vessels link 1995–96 to 1996–97. There is a minimum of ten tows in each year by a vessel to create a link. "+" mark the diagonal. The rightmost column is the mean link value for each year.

	1995–96	1996–97	1997–98	1998–99	1999–00	Mean
1995–96	+	2	1	1	2	1.5
1996–97	2	+	5	3	2	3.0
1997–98	1	5	+	3	1	2.5
1998–99	1	3	3	+	3	2.5
1999–00	2	2	1	3	+	2.0

Table 15: Auckland Island hills smooth oreo post-GPS. Stepwise selection of variables for the positive catch regression and the zero catch GLM for all tows that targeted smooth oreo, black oreo, unspecified oreo, or orange roughy. 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
Season	8.5	–	–	–
Vessel	2.6	11.0	–	–
Longitude	2.4	10.6	14.0	–
Year	2.4	10.0	13.0	16.2
Improvement in R^2	8.5	2.5	3.0	2.1

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

	Iteration							
Variable	1	2	3	4	5	6	7	8
Target	31.8	–	–	–	–	–	–	–
Season	5.1	35.2	–	–	–	–	–	–
Longitude	2.6	34.8	38.3	–	–	–	–	–
Year	2.2	33.4	37.0	40.5	–	–	–	–
Vessel	6.6	32.9	36.1	39.8	42.9	–	–	–
Time	0.4	33.2	37.1	40.1	42.4	45.0	–	–
Latitude	0.9	32.4	36.1	39.5	42.0	44.3	46.3	–
Depth	2.6	34.0	37.2	39.3	41.9	43.8	45.9	47.9
Improvement in R^2	31.8	3.4	3.1	2.2	2.4	2.1	1.3	1.6

Table 16: Auckland Island hills smooth oreo post-GPS. Positive catch, zero catch, combined index estimates by year, and jack-knife *c.v.* estimates on the combined index from analysis of all tows that targeted smooth oreo, black oreo, unspecified oreo or orange roughy.

Year	Positive index	Zero index	Combined index	Jackknife c.v.(%)
1994–95	2.55	1.07	2.72	70
1995–96	1.59	1.00	1.60	168
1996–97	1.25	0.89	1.11	81
1997–98	1.00	1.00	1.00	0
1998–99	1.92	1.06	2.05	102
1999–00	0.57	1.06	0.61	49

Table 17: Bounty Plateau smooth oreo post-GPS. Stepwise selection of variables for the positive catch regression and the zero catch GLM for all tows that targeted smooth oreo, black oreo, unspecified oreo, or orange roughy. 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	16.8	–	–	–	–
Target	9.7	23.7	–	–	–
Longitude	12.9	21.5	26.6	–	–
Season	9.7	21.2	26.2	28.7	–
Depth	8.1	20.8	25.4	28.0	30.0
Improvement in R^2	16.8	6.9	2.9	2.1	1.4

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

	Iteration						
Variable	1	2	3	4	5	6	7
Target	7.6	–	–	–	–	–	–
Longitude	2.3	11.5	–	–	–	–	–
Season	3.3	10.7	15.2	–	–	–	–
Year	2.2	11.5	15.1	17.8	–	–	–
Latitude	1.5	10.0	13.3	16.8	20.0	–	–
Vessel	5.5	10.4	14.6	17.2	19.1	21.6	–
Depth	2.6	10.6	13.5	17.0	19.3	21.1	22.7
Improvement in R^2	7.6	3.9	3.7	2.5	2.2	1.6	1.1

Table 18: Bounty Plateau smooth oreo post-GPS. Positive catch, zero catch, combined index estimates by year, and jack-knife *c.v.* estimates on the combined index from analysis of all tows that targeted smooth oreo, black oreo, unspecified oreo or orange roughy.

Year	Positive index	Zero index	Combined index	Jackknife c.v.(%)
1994–95	1.08	0.98	1.07	92
1995–96	0.76	1.09	0.83	74
1996–97	1.00	1.00	1.00	0
1997–98	0.75	0.73	0.55	46
1998–99	0.60	0.91	0.55	56
1999–00	0.56	1.07	0.60	193

Table 19: Pukaki Rise east smooth oreo post-GPS. Stepwise selection of variables for the positive catch regression and the zero catch GLM for all tows that targeted smooth oreo, black oreo, unspecified oreo, or orange roughy. 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
Vessel	7.5	–	–	–
Year	3.8	10.6	–	–
Season	1.9	9.6	15.8	–
Target	2.3	8.7	12.3	17.1
Improvement in R^2	7.5	3.0	5.2	1.3

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

	Iteration		
Variable	1	2	3
Vessel	7.2	–	–
Season	3.1	10.7	–
Latitude	4.2	10.4	14.2
Improvement in R^2	7.2	3.5	3.5

Table 20: Pukaki Rise east smooth oreo post-GPS. Positive catch, zero catch, combined index estimates by year, and jack-knife *c.v.* estimates on the combined index from analysis of all tows that targeted smooth oreo, black oreo, unspecified oreo or orange roughy.

Year	Positive index	Zero index	Combined index	Jack-knife c.v.(%)
1995–96	2.95	1.15	3.41	25
1996–97	1.78	1.18	2.10	43
1997–98	1.00	1.00	1.00	0
1998–99	0.78	1.25	0.98	71
1999–00	0.59	1.27	0.74	52

Table 21: Pukaki Rise east black oreo pre-GPS. Stepwise selection of variables for the positive catch regression and the zero catch GLM for all tows targeted smooth oreo, black oreo, unspecified oreo, or orange roughy. 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	16.1	–	–	–	–
Season	11.5	23.2	–	–	–
Depth	3.5	17.3	24.2	–	–
Target	5.8	16.5	24.0	25.4	–
Latitude	4.7	17.0	24.1	24.9	26.6
Improvement in R^2	16.1	7.1	1.1	1.2	1.2

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

				Iteration
Variable	1	2	3	4
Vessel	13.0	–	–	–
Season	8.5	17.3	–	–
Depth	5.5	17.0	21.0	–
Year	10.6	15.1	20.6	24.0
improvement in R^2	13.0	4.3	3.7	3.0

Table 22: Pukaki Rise east black oreo pre-GPS. Positive catch, zero catch, combined index estimates by year, and non-jack-knife *c.v.* estimates on the combined index from analysis of all tows that targeted smooth oreo, black oreo, unspecified oreo or orange roughy.

Year	Positive index	Zero index	Combined index	Drop.one.vessel c.v.(%)
1980–81	0.96	1.32	1.28	13
1981–82	1.00	1.00	1.00	0
1982–83	1.24	0.94	1.16	10
1983–84	1.08	1.29	1.39	24
1984–85	0.95	1.30	1.24	20

Table 23: Pukaki Rise east black oreo post-GPS. Stepwise selection of variables for the positive catch regression and the zero catch *GLM for all tows that targeted smooth* oreo, black oreo, unspecified oreo, or orange roughy. 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
Latitude	10.6	–	–	–
Season	10.1	17.0	–	–
Year	3.7	16.7	22.3	–
Longitude	10.4	12.7	19.0	24.4
Improvement in R^2	10.6	6.5	5.2	2.1

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

					Iteration
Variable	1	2	3	4	5
Vessel	14.9	–	–	–	–
Longitude	9.0	21.0	–	–	–
Season	3.1	19.1	24.1	–	–
Year	1.4	17.2	22.8	25.8	–
Latitude	4.5	19.3	22.0	25.1	26.9
Improvement in R^2	14.9	6.1	3.1	1.6	1.1

Table 24: Pukaki Rise east black oreo post-GPS. Positive catch, zero catch, combined index estimates by year, and jack-knife *c.v.* estimates on the combined index from analysis of all tows that targeted smooth oreo, black oreo, unspecified *oreo or orange roughy*.

Year	Positive index	Zero index	Combined index	Jackknife c.v.(%)
1995–96	1.87	0.95	1.77	3
1996–97	1.35	1.11	1.50	35
1997–98	1.00	1.00	1.00	0
1998–99	0.60	1.14	0.68	10
1999–00	0.45	1.05	0.47	16

Table 25: Summary of the feasibility and yearly data continuity for standardised CPUE analyses of major oreo fisheries in OEO 6. Acceptable feasibility criteria were at least three years with at least 50 catches of oreos per year. Data where 80% or more of the annual catch was taken by only one vessel were excluded. Links were where the mean of the number of vessels fishing in adjacent years across all years was at least 1. –, not available

	Species	Feasibility		Years of selected and linked ( ) data	
OEO 6 fishery		Pre-GPS	Post-GPS	Pre-GPS	Post-GPS
Pukaki Rise east	BOE	Yes	Yes	5 (3+2)	5 (5)
	SSO	No	Yes	–	5 (5)
Bounty Plateau	BOE	No	No	–	–
	SSO	No	Yes	–	6 (6)
Auckland Island hills	BOE	No	No	–	–
	SSO	No	Yes	–	6 (5)

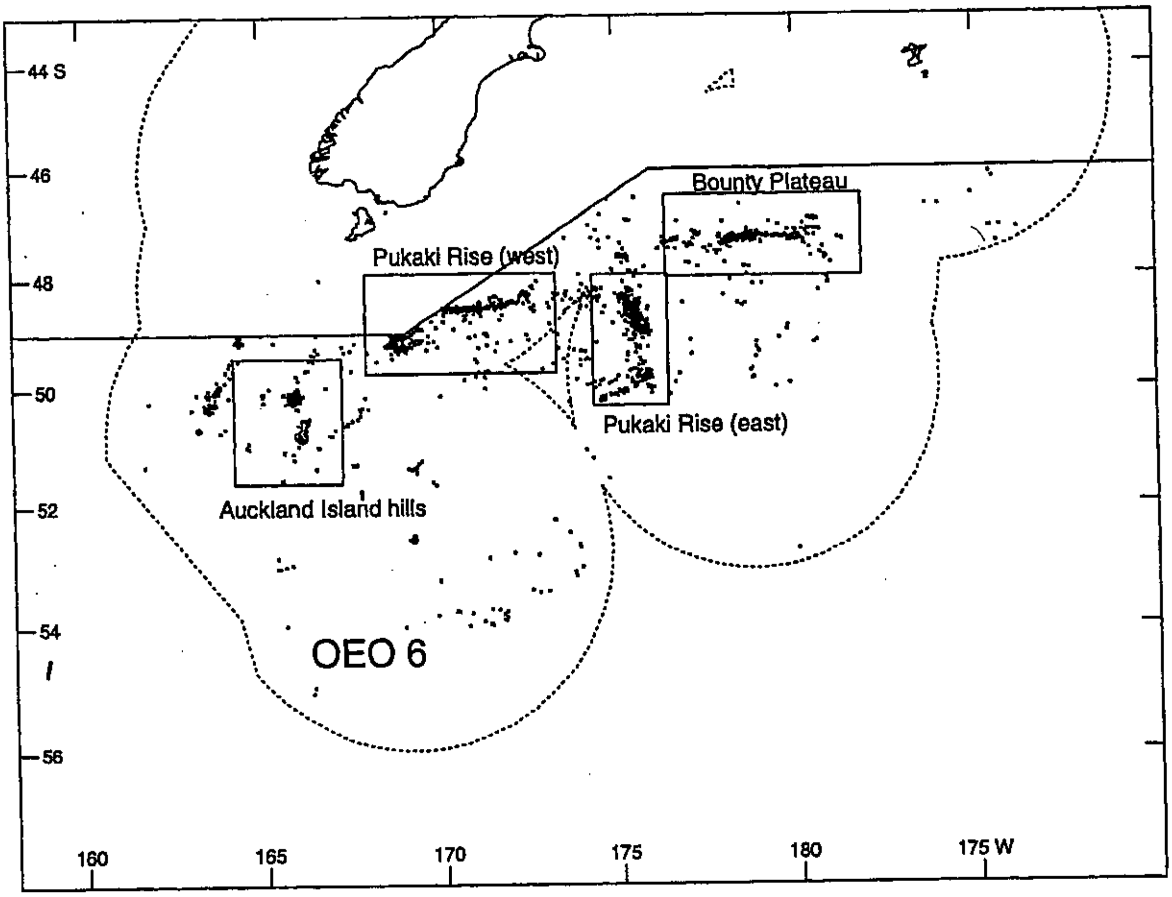

Figure 1: Start positions of all tows that targeted or caught oreos (OEO, SSO, or BOE) within OEO 6 from 1977–78 to 1999–2000. Pukaki Rise west was not a major fishery and was not analysed.

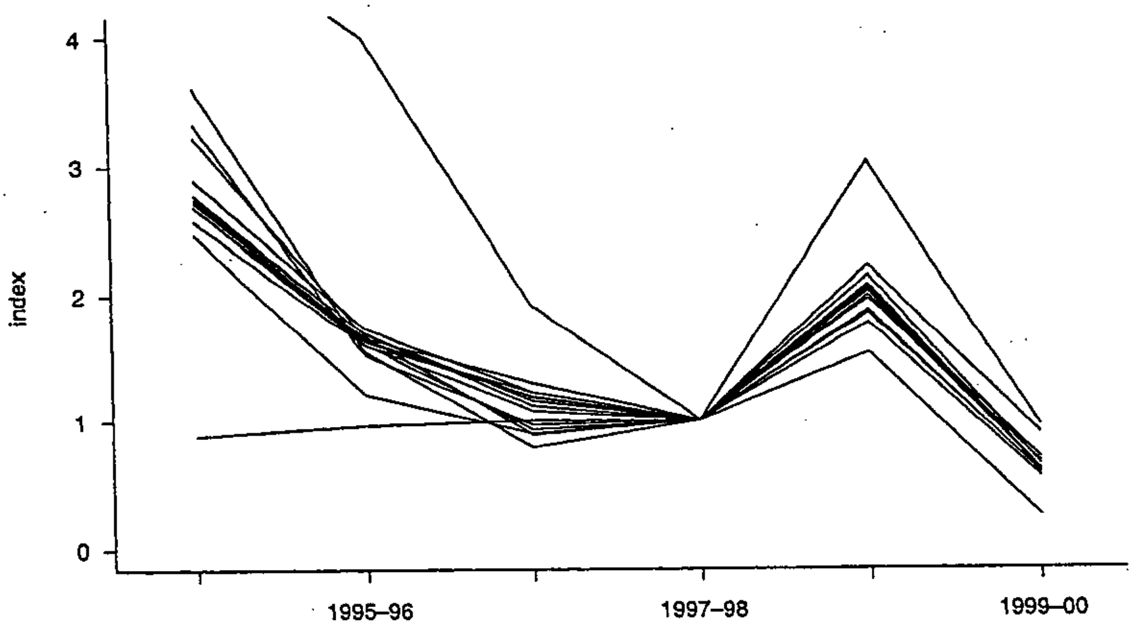

Figure 2: Smooth oreo combined CPUE index plots from the Auckland Island hills for target smooth oreo, black oreo, unspecified oreo, or orange roughy, post-GPS showing the effect of removing one vessel at a time from the analysis. 1997–98 is the reference year.

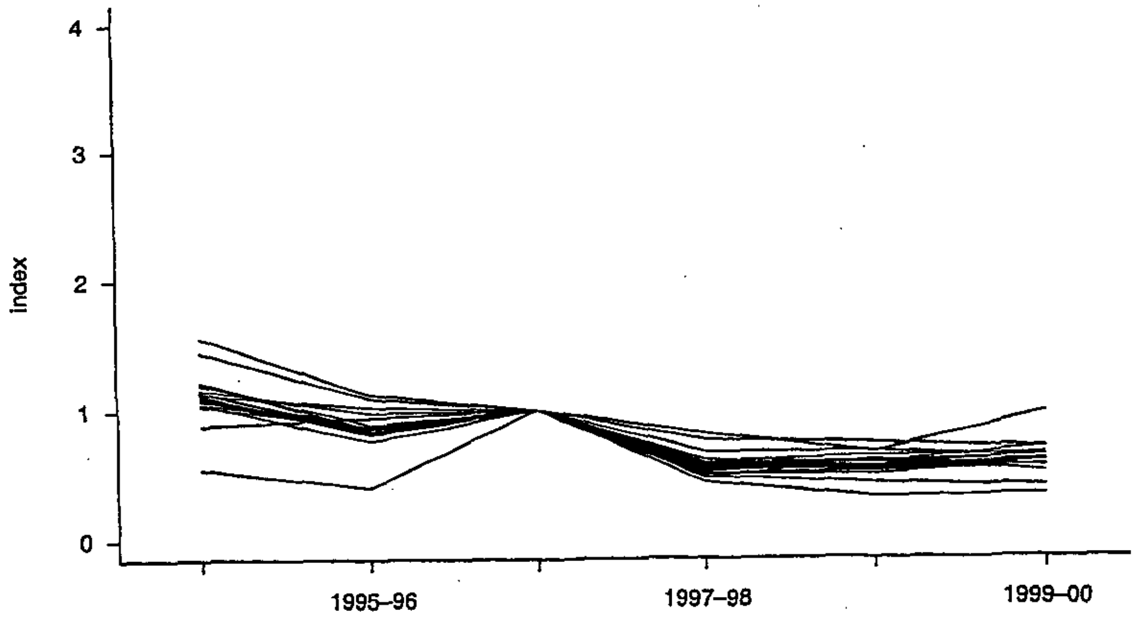

Figure 3: Smooth oreo combined CPUE index plots from the Bounty Plateau for target smooth oreo, black oreo, unspecified oreo, or orange roughy, post-GPS showing the effect of removing one vessel at a time from the analysis. 1996–97 is the reference year.

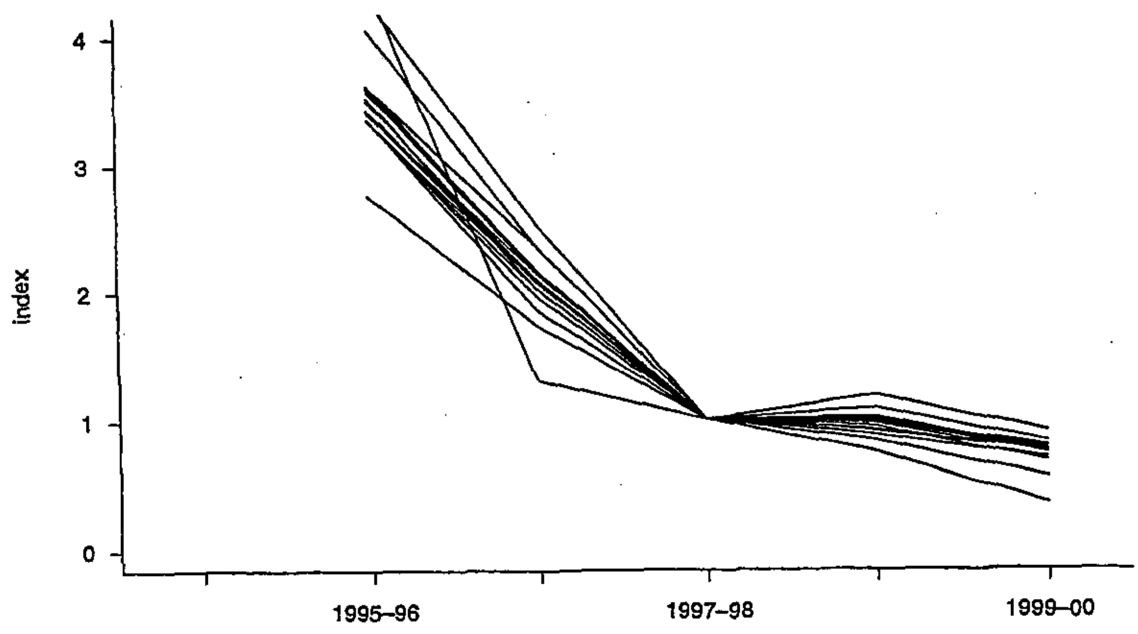

Figure 4: Smooth oreo combined CPUE index plots from the Pukaki Rise east for target smooth oreo, black oreo, unspecified oreo, or orange roughy post-GPS showing the effect of removing one vessel at a time from the analysis. 1997–98 is the reference year.

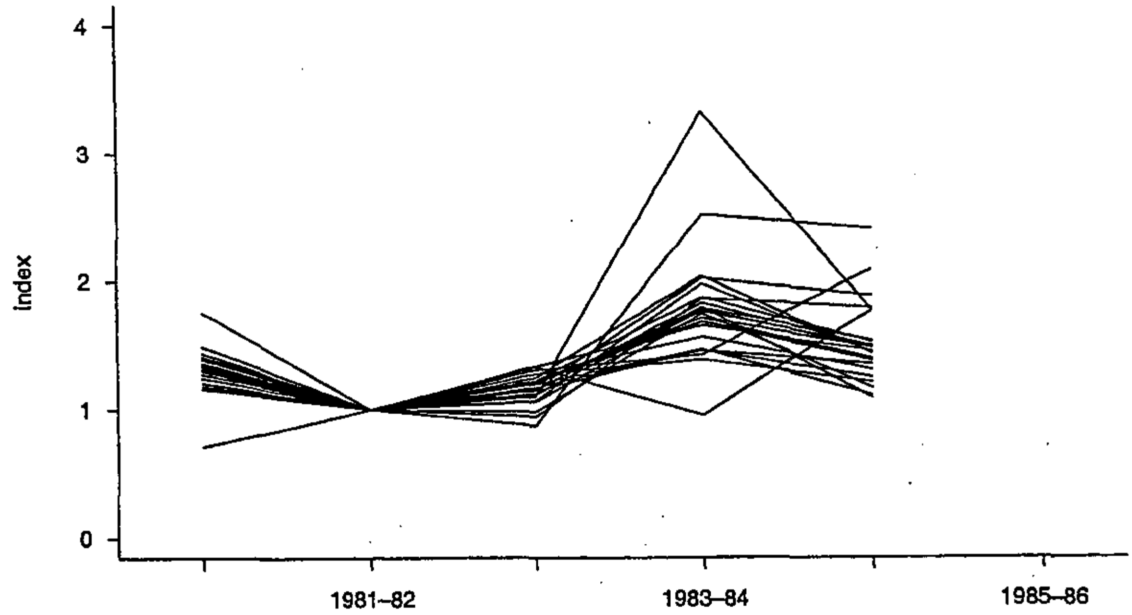

Figure 5: Black oreo combined CPUE index plots from the Pukaki Rise east for target smooth oreo, black oreo, unspecified oreo, or orange roughy pre-GPS showing the effect of removing one vessel at a time from the analysis. 1981–82 is the reference year.

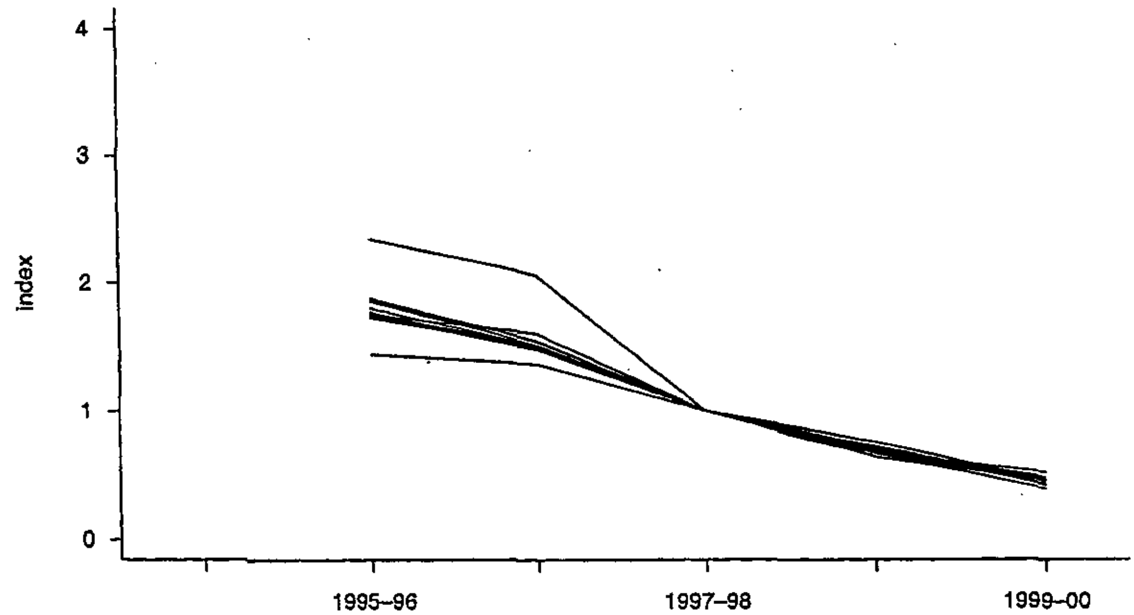

Figure 6: Black oreo combined CPUE index plots from the Pukaki Rise east for target smooth oreo, black oreo, unspecified oreo, or orange roughy post-GPS showing the effect of removing one vessel at a time from the analysis. 1997–98 is the reference year.

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, μ 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.,

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

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

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

where π_r is some reference proportion of zeros from year r.

Combined abundance index

The combined abundance index was a product of the two parts

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

Estimate of the c.v. for the abundance index

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

For year *i*, pseudo-abundance indices (suppressing the index *i*) were generated by

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

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

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

n_j is the number of tows in year *i* for vessel *j* and

$$N = \sum_j n_j$$

This ignored the contributions from vessels that did not fish in year *i*, but which had an influence on the estimated effects of variables, e.g., depth, and through them an influence on the index for year *i*. Similarly, the effects of vessels that fished mainly in the reference year were not included as that year always had an index of 1, by definition.

Appendix 2: Timing and coverage of GPS in N.Z. waters from 1985 onwards

Information from Trevor McDonald, Pacific Microsystems, GPS servicer to *Tangaroa*.

GPS was first used by New Zealand fishing vessels in 1985 by one Sealord vessel. Not all vessels installed GPS at the same time and there was variation in the coverage vessels enjoyed when they had it, depending on hardware.

Year	GPS coverage per day (h)	Equipment
1985	8	1 vessel only
1986	8+	
1987	8+	
1988	~12	3 vessels with Magnavox clock which needed only 2 satellites to give GPS accuracy
1989	12	
1990	12+	
1991	12+	
1992	~24	24 h for vessels with receiver able to receive low declination satellites. Late 1992 24 h most vessels
1993	24	