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EXECUTIVE SUMMARY

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New standardised CPUE analyses for smooth oreo in OEO 4 provided abundance indices for stock assessment in 2000. The analyses were split into two series for the periods before and after GPS was phased in (pre- and post-GPS) by excluding the years 1989–90 to 1991–92. Separate indices are presented for target smooth oreo CPUE and where smooth oreo was caught as bycatch of orange roughy fishing. Zero catch and positive catch data were initially analysed separately and their abundance indices then combined into one index series. For the bycatch analyses we discarded the zero catch component and used only positive catches for the final indices. Coefficients of variation (c.v.) for the indices were estimated using a jackknife technique. Target CPUE declined pre-GPS, but remained steady post-GPS (mean c.v.s 29% and 38%). Bycatch CPUE declined both pre- and post-GPS (mean c.v.s 28% and 25%).

1. INTRODUCTION

A standardised analysis of smooth oreo CPUE provided abundance estimates for the stock assessment for OEO 3A from 1995 to 1998. We present the first standardised CPUE analysis for smooth oreo in OEO 4. This is a large fishery both in catch (of about 6000 t a year) and area (about 360 000 km^2) with more than 20 years of detailed tow-by-tow data. The fishery is complicated by the close relationship between smooth oreo, black oreo, and orange roughy which are caught together. The complex nature of the fishery led us to break the data in several ways. Primarily we split the analyses into one using data from the target smooth oreo fishery (target) and another using data from the fishery that caught smooth oreo as a bycatch while target fishing for orange roughy (bycatch). We also split the analyses into two time series based on the data collected from the fishery before the introduction of Global Positioning System or GPS (pre-GPS) and the data from the fishery after GPS was phased in (post-GPS). Data from the phase-in years for GPS were dropped (1989–90 to 1991–92). This led to four basic indices of pre/post-GPS and target/bycatch. Additionally, we split the target post-GPS analysis by area with an west/east split. Hence six final indices are presented.

1.1 Literature review

This analysis closely follows that of Doonan et al. (1995). The method of Vignaux (1994) was used to provide a technique to analyse the zero catch component of the data. Hart et al. (2000) provided a basic catch and effort summary for oreos in OEO 4, including nationality, vessel tonnages, target species, catch, and unstandardised target catch per unit effort.

2. METHODS

2.1 Definitions and abbreviations

All data were grouped by the current fishing year, i.e., 1 October to 30 September. The following abbreviations are used in the text: 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 is thought that any remaining errors are essentially random. Initial data comprised all tow-by-tow records in OEO 4 where smooth oreo was targeted or caught, but the standardised analyses were restricted to data from a study area defined on the south Chatham Rise. However, when we embarked on bycatch analysis (because most of the SSO catch was a bycatch of ORH target fishing), we investigated using all tows in the study area that targeted orange roughy, regardless of whether smooth oreo was caught. For the final bycatch abundance indices, however, we ignored the tows that caught zero SSO and used only those tows that caught some SSO, i.e., trawls that targeted ORH and caught some SSO. 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.

Data were not used in the standardised analyses from any year when there were less than 50 tows or where a single vessel dominated the year's tows (greater than 80% of tows).

2.3 The study area

The bulk of the smooth oreo catch, and nearly all of the target smooth oreo catch, came from the south Chatham Rise part of OEO 4 (i.e., south of 43° 30′ S). We restricted our study to the area of the south Chatham Rise west of 174° 50′ W (between Big Chief and the Andes) because that coincided with the survey area used for the acoustic abundance index. The western boundary of OEO 4 at 176° E was also the western end of the study area (Figure 1).

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 standardised CPUE analysis (Doonan et al. 1995).

2.5 Unstandardised CPUE

Descriptive CPUE trends in the fishery were determined from Hart et al. (2000)

Additional analyses of unstandardised data included:

- plot of all tows that targeted SSO in OEO 4.
- plot of all tows that caught SSO in OEO 4.
- plot of SSO catch along the south, east, and north slope of OEO 4 Chatham Rise.
- proportion of SSO catch taken by target versus bycatch.
- the distribution of target and bycatch SSO within the study area caught west and east of 178° 12.6′ W by year.
- the proportions of zero catch tows in the data.
- unstandardised target and bycatch CPUE trends.

2.6 Standardised CPUE

The standardised CPUE analysis was similar to that described by Doonan et al. (1995) and used a two part model which separately analysed the tows on which smooth oreo 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 smooth oreo was caught and not the amount caught. The yearly indices from the two parts of the analysis were multiplied to give a combined index (Vignaux 1994).

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 with the modification that vessels with less than 50 tows over the whole time period were all lumped into the same category. Tow position was reduced to a single predictor variable, axis-position, by projection onto an axis drawn (by eye) through the middle of the fished band around the Chatham Rise from west to east (see Figure 1). The predictor 'hill' was a two-way categorical variable determined by the criterion that the tow be within 5 km of a known hill position.

A 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). This procedure selected models with first order terms.

In order to evaluate how sensitive the indices were to the vessels involved we repeated the selected regression models, 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 two. 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.

2.6.1 Model development

Initial standardised models for both target and bycatch CPUE showed large increases in CPUE in the early 1990s. For the target CPUE analysis this was approximately a four-fold increase and for bycatch approximately a three-fold increase in CPUE. Given the biology and population dynamics of smooth oreo this appeared to represent an unrealistic jump in biomass. If the increases in CPUE were due to increased abundance for a long lived and slow growing species like smooth oreo (Doonan et al. 1997b) then there must have been either substantial recruitment or immigration. Substantial recruitment should have been picked up in length frequency samples collected over time, but there is no evidence of this (see Doonan et al. 1997a, figure 4). Substantial immigration of adult fish seems unlikely as the closest neighbouring fishery and possible source of fish, OEO 3A, is thought to be at a population level well below virgin biomass (Doonan et al. 1999).

To investigate this we conducted standardised analyses on some of the main fishing patches identified in the unstandardised analysis (see Figure 1). Six patches were examined spanning most of the study area. The four westmost had sufficient data for target analysis and the four eastmost enough for bycatch analysis (two overlapped). For these analyses we dropped the requirement of at least 50 tows and admitted all year's data.

The positive catch regression year effects for these analyses are shown in Figure 2 (target) and Figure 3 (bycatch). We found that an increase in CPUE during the early 1990s was a persistent feature in each area for both the target and bycatch analyses. 1991 seemed an approximate mid-point for the increase, although exact timing varied between locations and target/bycatch. Two particular examples, Bobbin target (Figure 2) and Amaltal bycatch (Figure 3) starkly showed this change at 1991 with the index breaking cleanly into two trajectories. Other sub-areas differed, but most showed change at around the same time. GPS was introduced over the period in question (see Appendix 2) and we believe it to be the most likely principal cause of the change in CPUE.

We therefore decided to remove data from the transition period over which GPS was introduced from further analysis (1989–90 to 1991–92), providing two CPUE time series (pre- and post-GPS). This was done after consultation with the working group. Fortunately we were working with a long time series and the loss of three year's data was tenable.

The analysis of target CPUE initially used all trawls in which target species was SSO. The post-GPS target analysis was extended to include trawls in which target species was SSO or OEO on the grounds that there was little recorded targeting of BOE for this period (almost none that targeted BOE and caught SSO), so presumably OEO tows were in reality targeting SSO (Table 2). This approach was advantageous as it increased the data available and lead to improved c.v.s on the index. Without this extension there would have been only a bycatch index for the post-GPS period with reasonable c.v.s. It is believed that some fishers thought it was not permissible to use SSO or BOE as target codes and used OEO instead because oreos are managed as a species group and OEO is the formal quota code.

Finally the post-GPS target analysis was split geographically into west and east analyses at 178° 12.6′ W (see Figure 1) as this reflected other structure in the data and allowed different possible stock structures to be evaluated by stock assessment modeling. The structure is described in section 3.1, but briefly involved an east/west separation based on the development of the fisheries in time and in nature, with target SSO fishing in the west which started in the late 1970s and ORH fishing in the east developing in the mid 1980s.

The above data combinations led to six final models.

1. Target SSO, pre-GPS
2. Target SSO or OEO, post-GPS
3. Bycatch (target ORH), pre-GPS
4. Bycatch (target ORH), post-GPS
5. Target SSO or OEO, post-GPS, WEST
6. Target SSO or OEO, post-GPS, EAST

3. RESULTS

3.1 Unstandardised CPUE

Since the early 1980s, the TAC for oreos (SSO, BOE, OEO) has been about 7000 t and annual catches have been at about that level since the late 1970s (Hart et al. 2000, table 44). Since 1981–82 most catch was SSO, typically out-weighing BOE by about five to one. Before 1981–82 catch was probably mostly BOE although the large fraction of unspecified catch makes this uncertain (Hart et al. 2000, table 52).

Soviet vessels dominated the early catches, but by 1982–83 were declining as both New Zealand and Japanese vessels began fishing. By 1986–87 New Zealand vessels took more than half the oreo catch and the Soviets were about to disappear, while the Japanese were also on the way out having reached a maximum of about 30% of the catch in 1985–86. Since 1986–87, New Zealand vessels dominated the fishery (Hart et al. 2000, table 46).

Early fishing targeted mostly unspecified oreo (OEO). From the early 1980s an ORH fishery developed in the area and oreos became a major bycatch fishery, but target fishing for SSO occurred through the 1980s and to a lesser extent the 1990s (Hart et al. 2000, table 50).

Raw target CPUE for SSO fell during the 1980s, but increased in the 1990s with considerable inter-annual variation (Hart et al. 2000, table 54).

The locations of all tows targeting SSO in OEO 4 are shown in Figure 1. Most occured on the south Chatham Rise. There are several areas where there has been heavy target fishing some of which have been named (see Figure 1). Plots of tows where SSO was caught (regardless of target) show many other tows, particularly along the north Chatham Rise resulting in a fished band around the north, east, and south slopes of the Chatham Rise. We used a line drawn through this data (by eye) to project tow positions onto a single dimension, termed the axis-position, and Figure 4 plots catch along the fished band broken into four roughly even periods. Most of the catch came from the south Chatham Rise (south of 43° 30′ S, appoximate axis-position 900 km.) and most was inside our defined study area. A progression of high catch over time from west to east can be seen. Patches seen in Figure 1 can be identified and some show considerable persistence over the time series, e.g., Bobbin, Trevs.

Most SSO catch was taken during either target fishing for SSO or as bycatch of ORH target fishing (Table 2). The pre-GPS data (except for the last two years) mostly indexes the western side of the study area (Table 3). The post-GPS target data indexes both west and east sides. The post-GPS bycatch data mostly indexes the eastern side.

The unstandardised CPUE for each of the six final models have high fractions of zero catch tows in both the target and bycatch data which led us to use two part models (Tables 4–9).

Unstandardised target CPUE fell in the first few years, but was steady over most of the pre-GPS period. Post-GPS CPUE was usually higher than pre-GPS (Tables 4 and 5).

Unstandardised bycatch CPUE was fairly steady pre-GPS, with the exception of 1980–81. Post-GPS CPUE was generally higher than pre-GPS. The percentage of zero catch bycatch tows dropped from more than 50% to about 20% over the time series (Tables 6 and 7).

3.2 Standardised CPUE – final model results

3.2.1 Target SSO, pre-GPS

Catch and effort data from 1979–80 to 1988–89 were available for this analysis (Table 4). Our selection criteria dropped the 1979–80 and 1980–81 years (less than 50 tows). For the selected years, about 20% of the tows caught no SSO.

Results of the positive catch regressions and zero catch GLM are given in Table 10. The final model for positive catch used vessel, season, and axis-position (selected in that order) and that for zero catch used vessel, axis-position, and season.

The indices

The abundance index results from each model (positive catch and zero catch) and the combined index are given in Figure 5 and Table 11. The combined index from the final year was approximately half 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 no vessel or year was highly influential on the series.

Confidence intervals

Mean c.v. by year for the combined indices calculated using a jackknife technique are given in Figure 7 and Table 11. The overall mean c.v. (applied across the series including the reference year) was 29%.

3.2.2 Target SSO or OEO, post-GPS

Catch and effort data from 1992–93 to 1998–99 were available for this analysis (Table 5). Our selection criteria dropped the 1993–94 year. About 10% of the tows caught no SSO.

Results of the positive catch regressions and zero catch GLM are given in Table 12. The final model for positive catch used season, depth, vessel, and axis-position and that for zero catch used vessel, axis-position, year, depth, and season.

The indices

The abundance index results from each model (positive catch and zero catch) and the combined index are given in Figure 8 and Table 13. The combined index changed little over time especially considering the confidence intervals of Figure 10.

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 9). This showed some influential vessels, particularly in the earlier part of the series.

Confidence intervals

Mean c.v. by year for the combined indices calculated using a jackknife technique are given in Figure 10 and Table 13. The overall mean c.v. (applied across the series including the reference year) was 38%.

3.2.3 Bycatch (target ORH), pre-GPS

Catch and effort data from 1978–79 to 1988–89 were available for this analysis (Table 6). Our selection criteria dropped the first four years because the years 1978–79 to 1981–82 had less than 50 tows and the 1980–81 year was dominated by a single vessel. About 40% of the tows from the selected years caught no SSO.

Results of the positive catch regressions and zero catch GLM are given in Table 14. The final model for positive catch used year, depth, vessel, axis-position, and season and that for zero catch used vessel, year, and season.

The indices

The abundance index results from each model (positive catch and zero catch) and the combined index are given in Figure 11 and Table 15. The positive catch index decreased to less than half its orginal value over time, but the zero catch index increased.

Effects of individual vessels

The sensitivity of the positive catch index to the data contributed by each vessel was investigated by re-estimating the positive catch indices after removing the data from one vessel at a time (Figure 12). This showed that no vessels were highly influential in the series.

Confidence intervals

Mean c.v. by year for the positive catch indices calculated using a jackknife technique are given in Figure 13 and Table 15. The overall mean c.v. (applied across the series including the reference year) was 28%.

3.2.4 Bycatch (target ORH), post-GPS

Catch and effort data from 1992–93 to 1998–99 were available for this analysis (Table 7). Our selection criteria retained all years. About 35% of the tows caught no SSO.

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

The indices

The abundance index results from each model (positive catch and zero catch) and the combined index are given in Figure 14 and Table 17. The positive catch index in the last year was about two-thirds that of the first year. The zero catch index shows an increasing trend.

Effects of individual vessels

The sensitivity of the positive catch index to the data contributed by each vessel was investigated by re-estimating the positive catch indices after removing the data from one vessel at a time (Figure 15). This showed that one vessel was influential, particularly on the 1995–96 index.

Confidence intervals

Mean c.v. by year for the positive catch indices calculated using a jackknife technique are given in Figure 16 and Table 17. The overall mean c.v. (applied across the series including the reference year) was 25%.

3.2.5 Target SSO or OEO, post-GPS, WEST

Catch and effort data from 1992–93 to 1998–99 were available for this analysis (Table 8). Our selection criteria dropped the 1993–94 and 1994–95 years. About 10% of the tows caught no SSO.

Results of the positive catch regressions and zero catch GLM are given in Table 18. The final model for positive catch used depth, season, axis-position, vessel, and year and that for zero catch used axis-position, vessel, year, time, depth, and season.

The indices

The abundance index results from each model (positive catch and zero catch) and the combined index are given in Figure 17 and Table 19. The combined index in the final year was approximately twice 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 18). This showed some influential vessels for the 1995–96 and 1998–99 indices.

Confidence intervals

Mean c.v. by year for the combined indices calculated using a jackknife technique are given in Figure 19 and Table 19. The overall mean c.v. (applied across the series including the reference year) was 60%.

3.2.6 Target SSO or OEO, post-GPS, EAST

Catch and effort data from 1992–93 to 1998–99 were available for this analysis (Table 9). Our selection criteria dropped the 1992–93, 1993–94 and 1995–96 year. About 10% of the tows caught no SSO.

Results of the positive catch regressions and zero catch GLM are given in Table 20. The final model for positive catch used season, depth, and vessel and that for zero catch used vessel, season, axis-position, time, and depth.

The indices

The abundance index results from each model (positive catch and zero catch) and the combined index are given in Figure 20 and Table 21. The combined index changed little over time, the positive catch and zero catch indices changed in opposite directions with the positive catch index falling and the zero catch index rising.

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 21). This showed that the index was influenced by various vessels except 1998–99.

Confidence intervals
Mean c.v. by year for the combined indices calculated using a jackknife technique are given in Figure 22 and Table 21. The overall mean c.v. (applied across the series including reference year) was 103%.

4. DISCUSSION

This study was conducted to provide, if possible, an index of abundance for smooth oreo in OEO 4. Previously, trawl survey data had been used, but they are now thought unreliable (McMillan et al. 1996). Abundance indices are important because smooth oreo have proven vulnerable to over-fishing elsewhere (Doonan et al. 1999). Furthermore, this is a large fishery, valuable in its own right, which interacts with a high value orange roughy fishery. Two features of the study are of interest for other CPUE studies in New Zealand, the GPS effect and the analysis of bycatch data.

The GPS effect

We attributed a period of increasing standardised CPUE to the introduction of GPS. We dealt with this by removing the data from the introduction period and splitting the data into two time series.

In an ideal world data on the use of GPS by each vessel would have been collected along with the tow-by-tow data. This would have allowed these data to have been incorporated in the models directly and hence we could both measure the effect and use the data from the introduction period. However, GPS data were not collected and it is not possible to reconstruct the data as they depend on vessel hardware, location, time of day, etc.

GPS allows vessels to reliably find precise underwater features and improves vessels' ability to fish on them. Smooth oreo frequent certain locations and hence GPS provides a great advantage. Adoption of the technology has been rapid and complete.

Bycatch CPUE

The CPUE analyses were complicated by the interaction between smooth oreo and orange roughy because these species are frequently caught together. Orange roughy is considerably more valuable and so fishing strategy tends to be driven by that species. We believe the distribution of orange roughy on the south Chatham Rise has changed over the period and has been progressively restricted to the eastern end. The proportion of smooth oreo caught as a bycatch has progressively increased as the distribution of orange roughy diminished.

Bycatch CPUE is not favoured in CPUE analyses as its interpretation is generally thought more difficult than that for target CPUE, perhaps because most CPUE analyses in New Zealand to date have been on target fisheries. Another possible reason is that a target fishery is likely to centre on the distribution of the species we wish to assess, whereas a bycatch fishery is prone to being incidental to the distribution of the species of interest. Bycatch CPUE have rarely been committed (quantitatively) to stock assessment in New Zealand.

Notwithstanding these reasons, because most smooth oreo in OEO 4 since 1984–85 has been caught as bycatch (see Table 2) we embarked on a bycatch analysis in addition to a target analysis. There is an argument for using all tows targeting ORH (within the study area) for the bycatch analysis, this being that the tows targeting ORH are not targeting SSO and so (given independence of the SSO and ORH distributions) could be random with respect to the SSO distribution. Hence they could provide an unbiased abundance index (i.e., like a random trawl survey). Under these conditions ignoring the zero catch tows could introduce bias. This argument provoked us to consider all trawls targeting ORH for the bycatch analyses. The two part model employed allows us to examine the positive catch and zero catch indices separately, and the target analysis performed in the same time periods gave an opportunity to compare the bycatch indices with a 'preferred' target index.

We compared the bycatch results against the target results for the pre-GPS analysis (the post-GPS target analysis had high c.v.s). We found that the bycatch positive index was similar (trend and scale) to the target index while the bycatch zero catch index went the other way (increased rather than fell). So we rejected the bycatch zero catch indices and used the positive bycatch index as our index of abundance. This rejection makes sense in the context of the previous argument because there is evidence that the distributions of SSO and ORH are not independent. We know that these species share a similar depth range, that both aggregate on underwater features (drop-offs and seamounts), and that they are commonly caught together. We think the increasing trend in the zero catch index of the bycatch analyses (i.e., clean catches of ORH have become less common over time) reflects declining ORH abundance in the study area rather than telling us about SSO abundance.

The effects

Vessel was frequently the most important explanatory variable in the final regressions (6/12) and was selected in all of them. Additionally, the annual index depends on the vessels admitted to the model. This is consistent with other oreo CPUE studies (Coburn et al. 1999, Doonan et al. 1995) and motivated us to use the vessel jackknife technique to estimate the c.v. of CPUE indices.

Other important explanatory variables were season (selected in 11/12 final regressions), axis-position (10/12), and depth (8/12). These effects were examined among the sub-area models (where they were also consistently selected). We found that the season effect was consistent among the sub-areas and for both the target and bycatch analyses. This effect is an annual cycle where the lowest catch rates occur from January to March. The axis-position and depth effects were not consistent over the areas or between target and bycatch models.

Of the six final indices only target SSO, post-GPS, west increased over time (mean c.v. 60%). Target SSO, post-GPS (mean c.v. 38%) and target SSO, post-GPS, east (mean c.v. 103%) neither rose or fell. However, these indices were the poorest estimated. The better estimated indices, target SSO, pre-GPS (mean c.v. 29%), bycatch, pre-GPS (mean c.v. 28%), and bycatch, post-GPS (mean c.v. 25%) all declined, some to less than a half of initial values. To give some indication of the variability of the overall slope of the better estimated abundance indices we used a simple bootstrap where the indices are assumed to be lognormal with c.v. as given by the jackknife method and assuming that each annual index is independent of the others. For target SSO, pre-GPS there was a 10% chance that the index series increases. For bycatch, pre-GPS there was a 1% chance of an increase and for bycatch, post-GPS there was a 16% chance that the index series increases. We conclude that there is little evidence that CPUE is increasing in this fishery, but given the improvements in fishing technology over time (e.g., sounders, nets, more stable vessels) we might reasonably expect increased catch rates if abundance had been maintained.

Conclusion

This first study of standardised CPUE of smooth oreo in OEO 4 has provided indices of abundance for stock assessment and increased our understanding of this fishery. Doonan conducted separate stock assessments for the whole study area and also for the western and eastern parts. For the whole area and the western part he used the target pre-GPS and target post-GPS indices. For the eastern area he used just the ORH bycatch post-GPS indices. This is a complex fishery and much is still uncertain. The large area has a complexity of species, ground type, and environment, and stock structure within the area is not established. Further study might focus on a patch by patch analysis because we suspect there are spatial aspects of the data that have not been resolved and if orange roughy catch rates in the study area continue to decline we may be dealing with a mainly smooth oreo target fishery which could make analysis and interpretation simpler.

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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
Axis-position	8	Position of start of tow along the fished band.
Depth	8	Depth at start of a tow. Bins were defined to contain about the same number of tows.
Season	8	The fishing year divided into 8 periods.
Time	8	Time of day when a tow started, blocked into 8 periods.
Hill	2	Indicates if a tow starts within 5 km of a known hill.
Vessel	–	A parameter estimated for each vessel with at least 50 tows. Vessels with less than 50 tows were grouped together.

Table 2: Catch (t) of smooth oreo in OEO 4 by main target species. NA, unknown target species; OTH, other species; BOE, black oreo; OEO, unspecified oreo; ORH, orange roughy; SSO, smooth oreo.

	NA/OTH	BOE	OEO	ORH	SSO
1978–79	0	96	0	10	0
1979–80	1	0	0	0	625
1980–81	3	380	105	84	327
1981–82	2	659	1 097	107	1 759
1982–83	6	334	0	1 957	1 567
1983–84	221	696	0	1 263	2 682
1984–85	3	194	0	2 288	2 273
1985–86	20	143	21	2 396	2 267
1986–87	12	107	3	2 600	2 938
1987–88	322	225	3	3 501	3 594
1988–89	97	12	46	4 807	1 468
1989–90	26	0	74	3 296	1 943
1990–91	2	5	561	3 265	1 423
1991–92	0	11	258	3 366	1 154
1992–93	2	2	308	2 680	852
1993–94	5	2	84	4 577	97
1994–95	52	0	299	4 632	776
1995–96	50	0	518	3 449	1 410
1996–97	65	3	991	2 851	1 693
1997–98	276	0	1 198	2 787	1 018

Table 3: Catch (t) of smooth oreo from the study area split into west/east, at 178° 12.6′ W and by target/bycatch.

	Target west	Target east	Bycatch west	Bycatch east
1979–80	625	0	0	0
1980–81	305	0	62	0
1981–82	1 759	0	29	0
1982–83	1 555	0	1 838	1
1983–84	2 675	0	1 160	17
1984–85	2 244	19	2 193	57
1985–86	2 176	60	2 071	187
1986–87	2 557	372	1 572	935
1987–88	959	2 554	1 257	2 130
1988–89	305	1 161	1 771	2 828
1989–90	439	1 394	416	2 770
1990–91	839	579	412	1 878
1991–92	479	661	455	1 220
1992–93	582	269	209	1 876
1993–94	52	43	616	2 956
1994–95	367	409	556	3 333
1995–96	570	837	751	2 106
1996–97	508	1 173	410	1 619
1997–98	470	687	220	1 884
1998–99	906	1 362	157	978

Table 4: Unstandardised CPUE for smooth oreo from all tows in the study area that targeted smooth oreo pre-GPS.

Year	No. of tows	No. of vessels	Catch (t)	Mean catch per tow (t)	Zero catch tows (%)
1979–80	44	2	625	14.2	6.8
1980–81	36	3	305	8.5	0
1981–82	314	9	1 758	5.6	18.8
1982–83	389	10	1 555	4	29
1983–84	553	14	2 675	4.8	17.9
1984–85	594	20	2 262	3.8	24.9
1985–86	520	14	2 236	4.3	15.4
1986–87	705	17	2 928	4.2	13.6
1987–88	754	17	3 513	4.7	10.5
1988–89	312	8	1 465	4.7	7.7

Table 5: Unstandardised CPUE for smooth oreo from all tows in the study area that targeted smooth oreo or unspecified oreo post-GPS.

Year	No. of tows	No. of vessels	Catch (t)	Mean catch per tow (t)	Zero catch tows (%)
1992–93	162	8	1 155	7.1	10.5
1993–94	44	9	178	4.1	6.8
1994–95	131	6	1 071	8.2	7.6
1995–96	220	9	1 922	8.7	8.6
1996–97	439	9	2 671	6.1	14.1
1997–98	397	9	2 434	6.1	6
1998–99	565	16	3 454	6.1	5.1

Table 6: Unstandardised CPUE of smooth oreo from all tows in the study area that targeted orange roughy pre-GPS.

Year	No. of tows	No. of vessels	Catch (t)	Mean catch per tow (t)	Zero catch tows (%)
1978–79	1	1	0	0	100
1979–80	13	7	0	0	100
1980–81	248	4	61	0.2	91.1
1981–82	35	4	29	0.8	91.4
1982–83	885	17	1 839	2.1	53
1983–84	579	13	1 176	2	55.8
1984–85	1 103	16	2 250	2	38.6
1985–86	1 033	14	2 257	2.2	29.1
1986–87	1 014	18	2 506	2.5	29.2
1987–88	1 550	16	3 386	2.2	33.5
1988–89	2 374	14	4 599	1.9	17

Table 7: Unstandardised CPUE of smooth oreo from all tows in the study area that targeted orange roughy post-GPS.

Year	No. of tows	No. of vessels	Catch (t)	Mean catch per tow (t)	Zero catch tows (%)
1992–93	1 126	9	2 084	1.9	45.1
1993–94	1 831	13	3 571	2	41.9
1994–95	1 182	13	3 889	3.3	25.5
1995–96	741	9	2 857	3.9	26.6
1996–97	549	7	2 029	3.7	16
1997–98	825	10	2 103	2.5	22.2
1998–99	480	12	1 135	2.4	25.2

Table 8: Unstandardised CPUE of smooth oreo from all tows in the study area west of 178° 12.6′ W that targeted smooth oreo or unspecified oreo post-GPS.

Year	No. of tows	No .of vessels	Catch (t)	Mean catch per tow (t)	Zero catch tows (%)
1992–93	109	8	642	5.9	9.2
1993–94	26	8	124	4.8	11.5
1994–95	48	5	481	10	10.4
1995–96	137	8	1 032	7.5	10.9
1996–97	162	9	951	5.9	16
1997–98	224	8	1 225	5.5	4.5
1998–99	228	11	1 193	5.2	4.4

Table 9: Unstandardised CPUE of smooth oreo from all tows in the study area east of 178° 12.6′ W that targeted smooth oreo or unspecified oreo post-GPS.

Year	No. of tows	No. of vessels	Catch (t)	Mean catch per tow (t)	Zero catch tows (%)
1992–93	53	3	513	9.7	13.2
1993–94	18	5	54	3	0
1994–95	83	4	589	7.1	6
1995–96	83	3	889	10.7	4.8
1996–97	277	6	1 720	6.2	13
1997–98	173	7	1 209	7	8.1
1998–99	337	12	2 261	6.7	5.6

Table 10: Stepwise selection of variables for the smooth oreo positive catch regression and the zero catch GLM for all tows in the study area that targeted smooth oreo pre-GPS. 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
Vessel	13.23		
Season	6.83	17.89	
Axis-position	5.44	16.88	20.73
Improvement in R^2	13.23	4.66	2.84

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

	Iteration		
Variable	1	2	3
Vessel	8.86		
Axis-position	3.59	10.68	
Season	1.48	10.45	11.82
Improvement in R^2	8.86	1.81	1.14

Table 11: Smooth oreo 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 pre-GPS.

Year	Positive index	Zero index	Combined index	Jackknife c.v. (%)
1981–82	1.45	1.15	1.66	27.4
1982–83	1.61	1.01	1.61	22.9
1983–84	1.18	1.05	1.24	40
1984–85	1	1	1	0
1985–86	1.09	1.09	1.19	34.8
1986–87	1.01	1.16	1.17	55.2
1987–88	0.86	1.22	1.05	59.8
1988–89	0.69	1.16	0.81	28.5

Table 12: Stepwise selection of variables for the smooth oreo positive catch regression and the zero catch GLM for all tows in the study area that targeted smooth oreo or unspecified oreo post-GPS. 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	3.87			
Depth	2.09	7.18		
Vessel	3	6.26	9.14	
Axis-position	1.08	5.18	9.01	11.46
Improvement in R^2	3.87	3.31	1.96	2.32

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

	Iteration				
Variable	1	2	3	4	5
Vessel	8.80				
Axis-position	3.23	11.26			
Year	2.62	10.81	12.67		
Depth	2.84	9.88	12.54	14.42	
Season	1.59	10	12.51	14.03	15.64
Improvement in R^2	8.80	2.46	1.41	1.75	1.22

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

Year	Positive index	Zero index	Combined index	Jackknife c.v. (%)
1993–94	1.07	0.77	0.82	37.1
1994–95	1.34	0.84	1.12	45.5
1995–96	0.72	0.92	0.66	80.3
1996–97	1	1	1	0
1997–98	0.80	1	0.80	59.6
1998–99	0.76	1.06	0.80	28.4

Table 14: Stepwise selection of variables for the smooth oreo positive catch regression and the zero catch GLM for all tows in the study area that targeted orange roughy pre-GPS. 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	5.15				
Depth	2.76	9.28			
Vessel	4.73	8.51	13.22		
Axis-position	4.56	8.85	11.73	15.56	
Season	2.62	7.21	11.11	15.54	17.43
Improvement in R^2	5.15	4.13	3.93	2.35	1.87

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

			Iteration
Variable	1	2	3
Vessel	11.73		
Year	5.71	15.29	
Season	3.52	13.10	16.4
Improvement in R^2	11.73	3.56	1.12

Table 15: Smooth oreo positive catch, zero catch, combined index estimates by year and jackknife c.v. on the positive catch index for analysis of all tows in the study area that targeted orange roughy pre-GPS.

Year	Positive index	Zero index	Combined index	Jackknife c.v. (%)
1982–83	2.03	0.77	1.57	49.6
1983–84	2.08	0.82	1.70	48.4
1984–85	1.33	0.98	1.30	45.2
1985–86	1	1	1	0
1986–87	0.87	1.06	0.92	21
1987–88	1.03	1.09	1.11	39.5
1988–89	0.63	1.26	0.79	28.2

Table 16: Stepwise selection of variables for the smooth oreo positive catch regression and the zero catch GLM for all tows in the study area that targeted orange roughy post-GPS. 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
Axis-position	7.72			
Vessel	5.67	12.23		
Season	3.05	11.08	15.12	
Depth	3.17	9.17	13.44	16.3
Improvement in R^2	7.72	4.52	2.88	1.2

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

	Iteration		
Variable	1	2	3
Vessel	5.55		
Axis-position	3.82	9.59	
Year	3.78	8.59	11.87
Improvement in R^2	5.55	4.03	2.28

Table 17: Smooth oreo positive catch, zero catch, combined index estimates by year and jackknife c.v. on the positive catch index for analysis of all trawls in the study area that targeted orange roughy post-GPS.

Year	Positive index	Zero index	Combined index	Jackknife c.v. (%)
1992–93	1.22	0.82	0.99	35.9
1993–94	1.01	0.84	0.85	15.2
1994–95	1	1	1	0
1995–96	0.83	0.97	0.81	68.0
1996–97	1.28	1.12	1.44	12.4
1997–98	0.82	1.12	0.92	18.1
1998–99	0.81	1.14	0.92	26.1

Table 18: Stepwise selection of variables for the smooth oreo positive catch regression and the zero catch GLM for all tows in the study area that targeted smooth oreo or unspecified oreo post-GPS and are west of 178 12.6 W. 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
Depth	4.70				
Season	3.43	8.02			
Axis-position	2.20	6.58	9.83		
Vessel	1.40	5.74	9.21	11.29	
Year	0.81	6.12	8.88	10.82	12.51
Improvement in R^2	4.70	3.31	1.82	1.45	1.23

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

						Iteration
Variable	1	2	3	4	5	6
Axis-position	10.71					
Vessel	9.92	17.80				
Year	4.52	13.90	20.87			
Time	2.36	13.00	20.08	23.26		
Depth	6.52	13.10	19.55	22.8	25.30	
Season	3.64	14.20	19.58	22.09	24.43	26.44
Improvement in R^2	10.71	7.10	3.06	2.39	2.04	1.14

Table 19: Smooth oreo positive catch, zero catch, combined index estimates by year and jackknife c.v. on the combined index for analysis of all trawls in the study area that targeted smooth oreo or unspecified oreo post-GPS and are west of 178° 12.6′ W.

Year	Positive index	Zero index	Combined index	Jackknife c.v. (%)
1992–93	0.55	0.73	0.41	144
1995–96	0.58	0.96	0.56	67.6
1996–97	1	1	1	0
1997–98	0.77	1.05	0.81	26.7
1998–99	0.78	1.10	0.86	52.4

Table 20: Stepwise selection of variables for the smooth oreo positive catch regression and the zero catch GLM for all tows in the study area that targeted smooth oreo or unspecified oreo post-GPS and are east of 178 12.6 W. 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
Season	6.09		
Depth	2.82	11.02	
Vessel	4.97	10.63	14.55
Improvement in R^2	6.09	4.93	3.54

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

	Iteration				
Variable	1	2	3	4	5
Vessel	7.73				
Season	7.55	13.10			
Axis-position	4.35	12.80	17.10		
Time	3.08	10.80	16.10	19.91	
Depth	3.83	10.10	15.60	18.49	21.47
Improvement in R^2	7.73	5.40	4.00	2.79	1.55

Table 21: Positive catch, zero catch, combined index estimates by year and jackknife c.v. on the combined index for analysis of all tows in the study area that targeted smooth oreo or unspecified oreo post-GPS and are east of 178° 12.6′ W.

Year	Positive index	Zero index	Combined index	Jackknife c.v. (%)
1994–95	1.39	0.60	0.83	86.4
1996–97	1	1	1	0
1997–98	0.82	0.93	0.77	236
1998–99	0.83	1	0.83	21.8

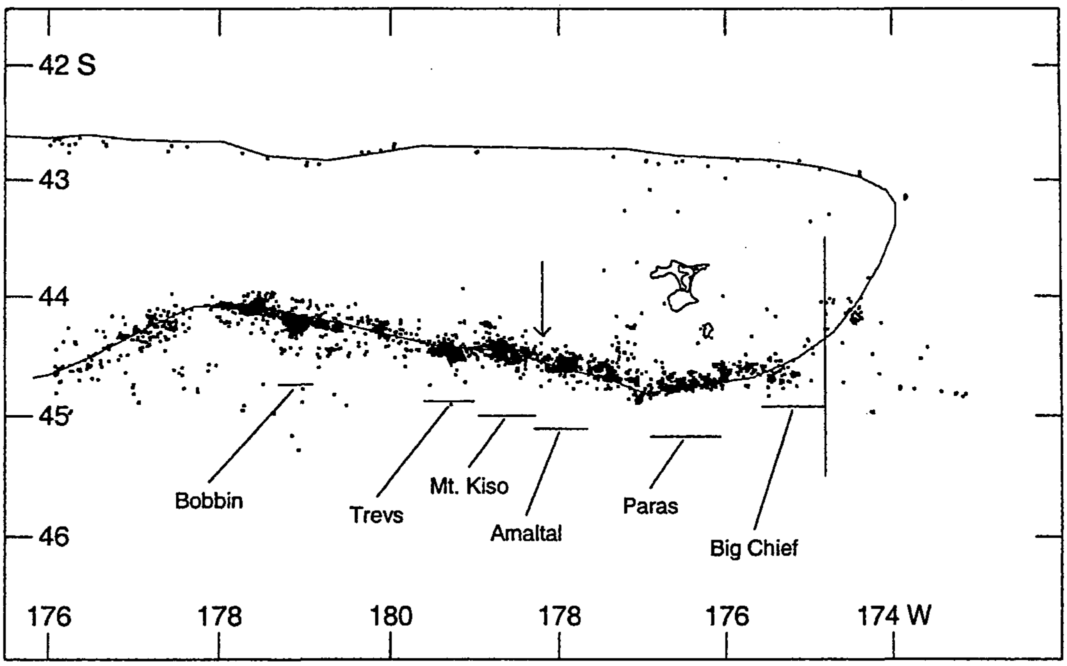

Figure 1: Start position (dots) of all trawls targeting smooth oreo in OEO 4 from 1978–79 to 1998–99. The western end of the study area is the boundary of OEO 4 at 176° E. The eastern boundary of 174° 50′ W is shown with a vertical line. An arrow shows the position of the west/east split at 178° 12.6′ W. Some main fishing patches are also indicated with horizontal bars. The axis-line (curved line) onto which positions were projected is also shown.

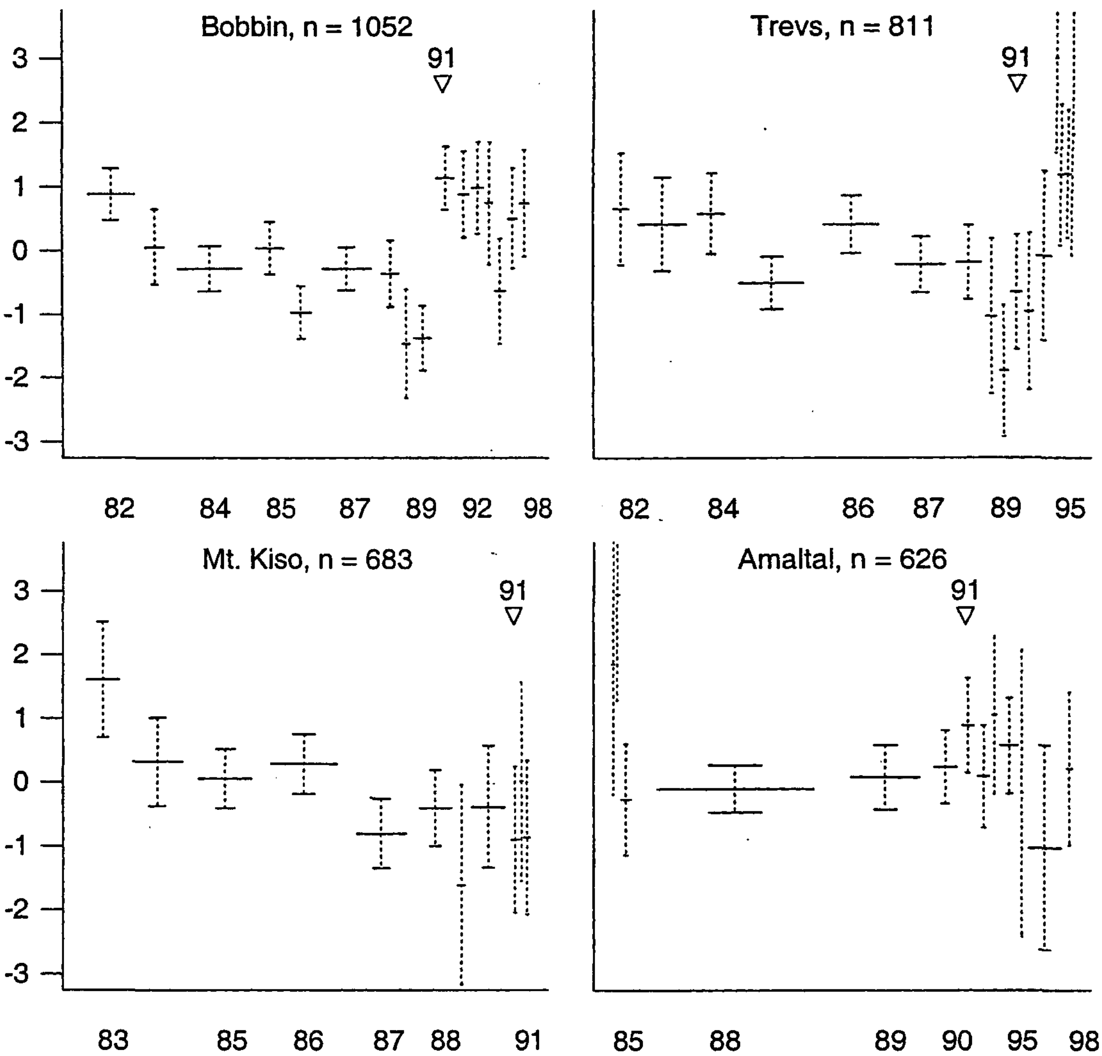

Figure 2: Non-zero year effect from the sub-area target models. Sub-areas are: Bobbin, 178° 41.5′ E to 179° 4.4′ E; Trevs, 179° 36.1′ W to 179° 1.3′ W; Mt. Kiso, 178° 57.9′ to 178° 17.8′ W and Amaltal, 178° 18.2′ W to 177° 39.6′ W. The y-axis is in log base two scale hence each y-unit corresponds to a doubling/halving of catch rate. Years are shown on the x-axis, 82 = 1981–82, etc. N is the number of tows in the regression. The width of the horizontal bars is proportional to the number of tows in each year. Confidence intervals of +/- 2 s.e. are also shown (dotted lines). The 1990–91 year is indicated as a common reference point.

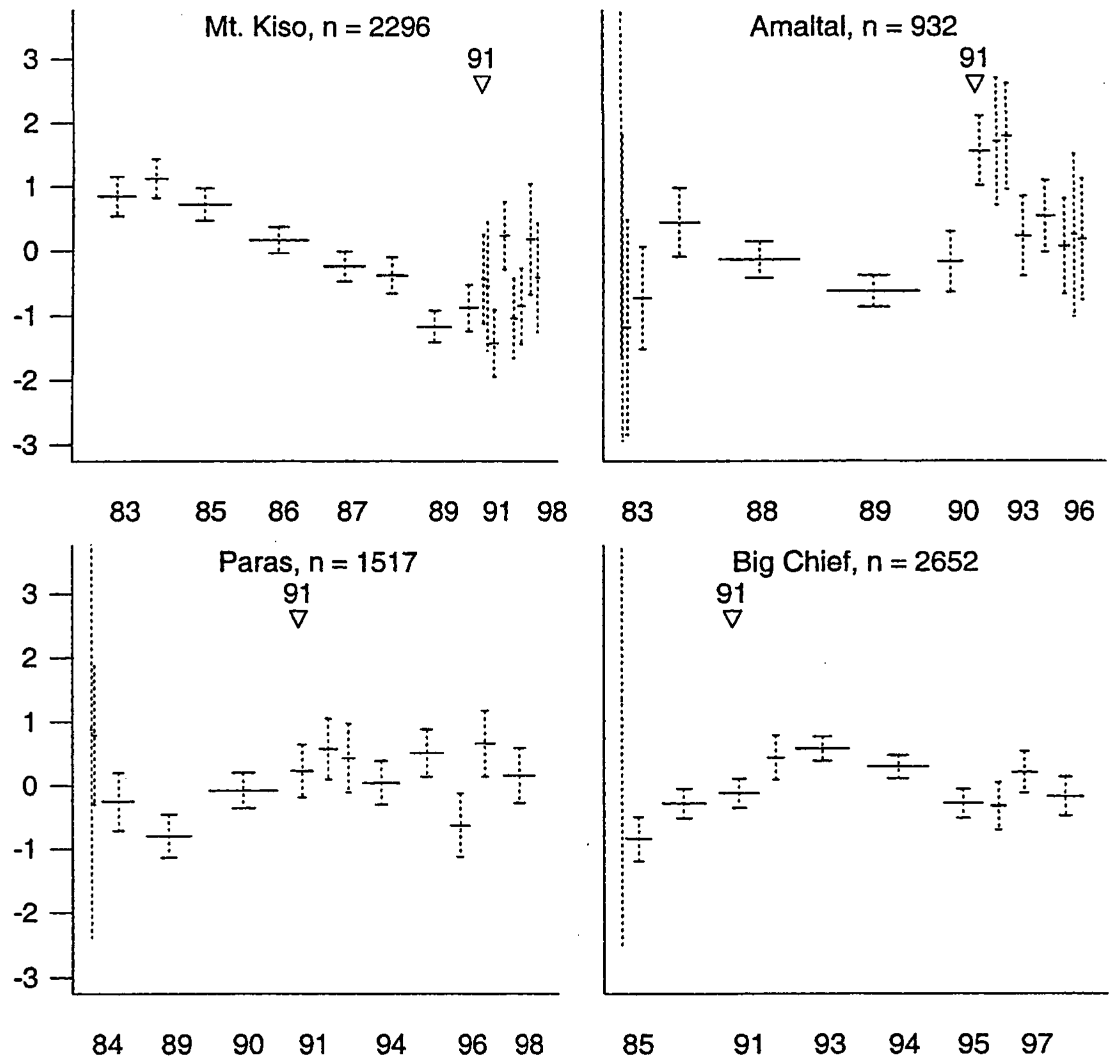

Figure 3: Non-zero year effect from the sub-area bycatch models. Sub-areas are: Mt. Kiso, 178° 57.9′ to 178° 17.8′ W; Amaltal, 178° 18.2′ W to 177° 39.6′ W; Paras, 176° 53.5′ W to 176° 4.7′ W and Big Chief, 175° 35′ W to 174° 50′ W. The y-axis is in log base two scale hence each y-unit corresponds to a doubling/halving of catch rate. Years are shown on the x-axis, 83 = 1982–83, etc. N is the number of tows in the regression. The width of the horizontal bars is proportional to the number of tows in each year. Confidence intervals of +/- 2 s.e. are also shown (dotted lines). The 1990–91 year is indicated as a common reference point.

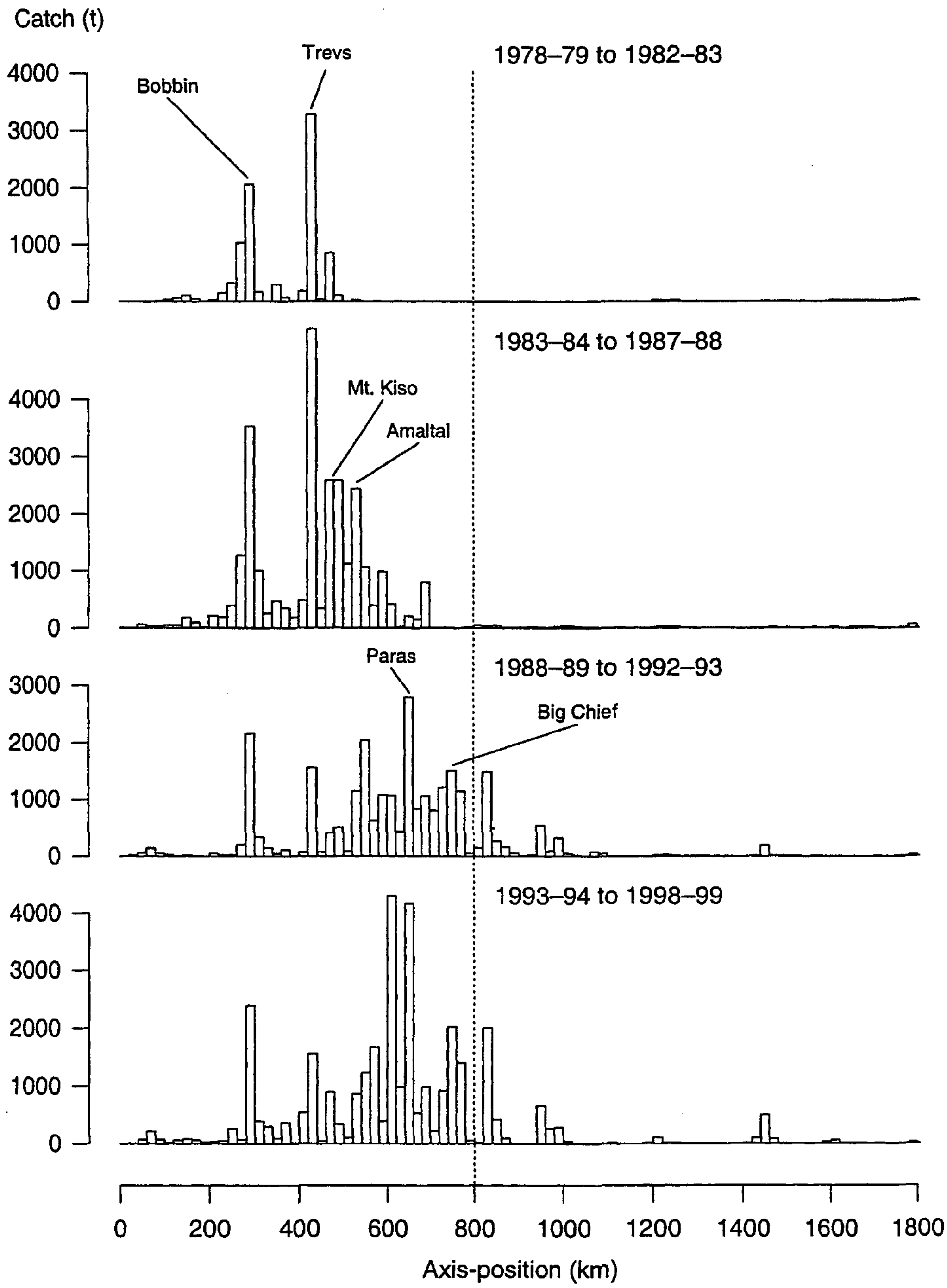

Figure 4: Catch (t) of smooth oreo by 20 km bars on the fished band drawn along the Chatham Rise from the southwest, east, north, then west slope (axis-position). The data were broken into four time periods indicated by the titles. The vertical dotted line is the eastern boundary of the study area. Some main fishing patches are also shown (see Figure 1).

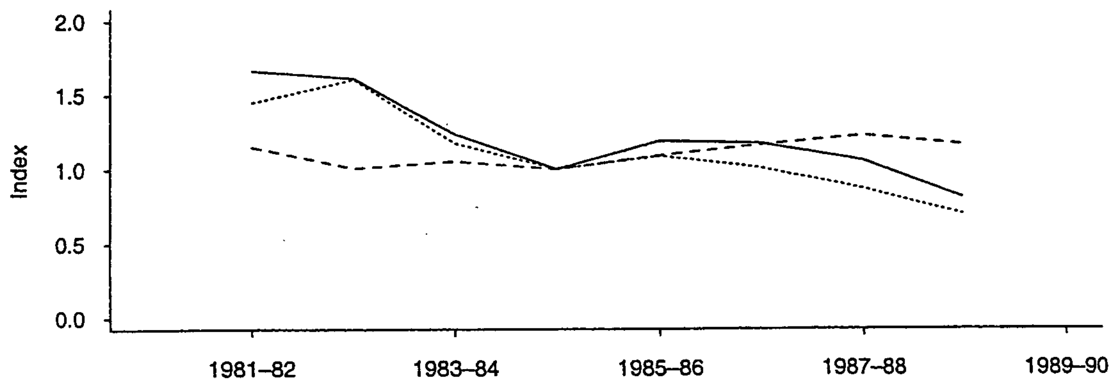

Figure 5: Smooth oreo combined CPUE indices (solid line) for target smooth oreo, pre-GPS with the zero catch regression index (large dashes) and the positive catch regression index (dots).

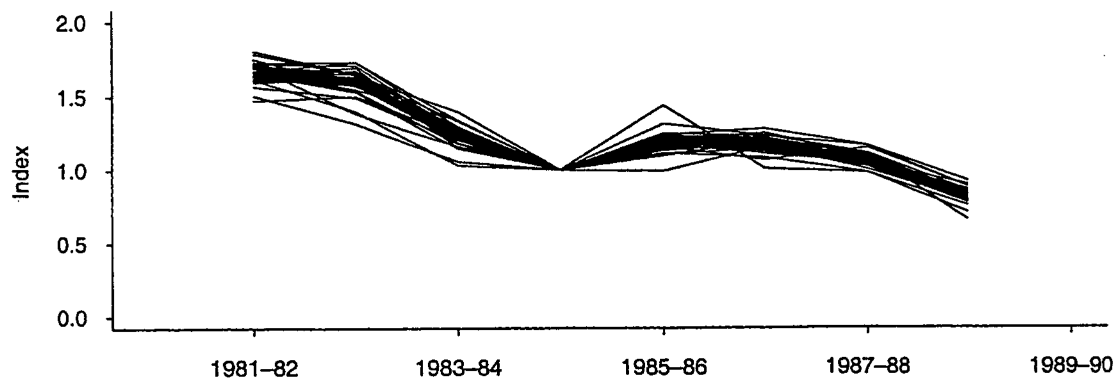

Figure 6: Smooth oreo combined CPUE index plots for target smooth oreo, pre-GPS showing the effect of removing one vessel at a time from the analysis. 1984–85 is the reference year.

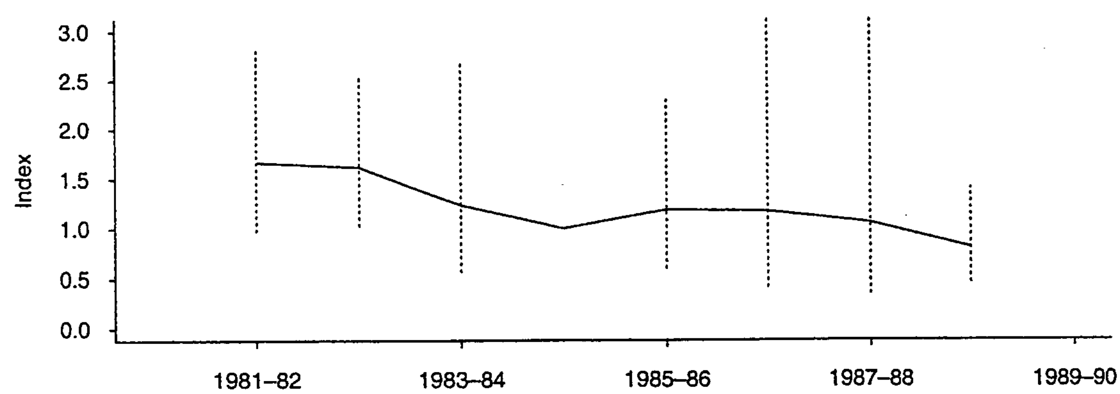

Figure 7: Smooth oreo combined CPUE index for target smooth oreo, pre-GPS. Each years estimate has a confidence interval of ± 2 s.d. calculated using a jackknife technique. The confidence interval for 1986–87 and 1987–88 exceeds the y-scale shown.

Figure 8: Smooth oreo combined CPUE indices (solid line) for target smooth oreo or unspecified oreo, post-GPS with the zero catch regression index (large dashes) and the positive catch regression index (dots). No index was calculated for 1993–94.

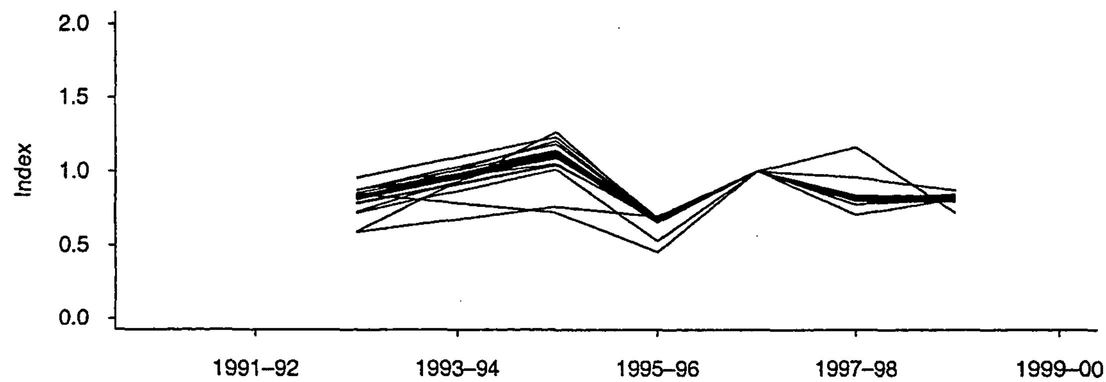

Figure 9: Smooth oreo combined CPUE index plots for target smooth oreo or unspecified oreo, post-GPS showing the effect of removing one vessel at a time from the analysis. 1996–97 is the reference year.

Figure 10: Smooth oreo combined CPUE index for target smooth oreo or unspecified oreo, post-GPS. Each years estimate has a confidence interval of ± 2 s.d. calculated using a jackknife technique.

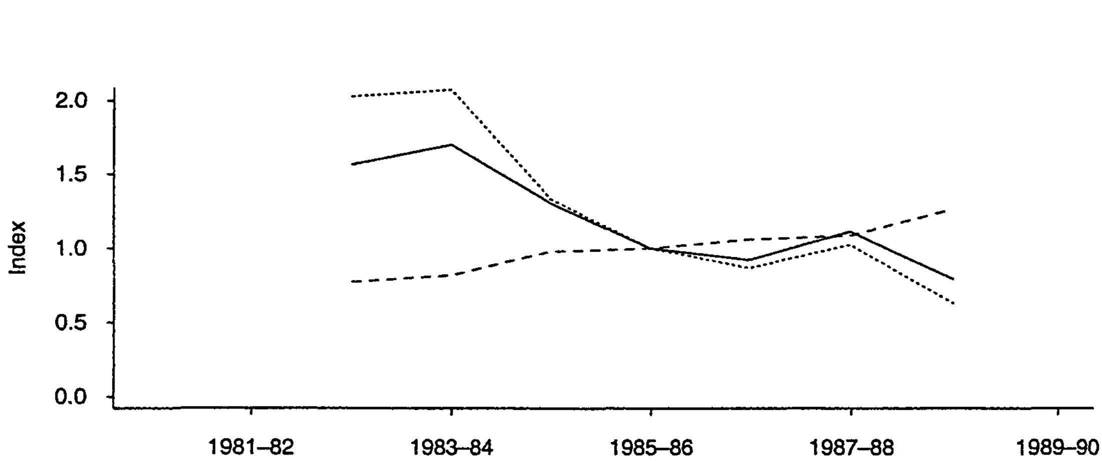

Figure 11: Smooth oreo combined CPUE indices (solid line) for target orange roughy, pre-GPS with the zero catch regression index (large dashes) and the positive catch regression index (dots).

Figure 12: Smooth oreo positive catch CPUE index plots for target orange roughy, pre-GPS showing the effect of removing one vessel at a time from the analysis. 1985–86 is the reference year.

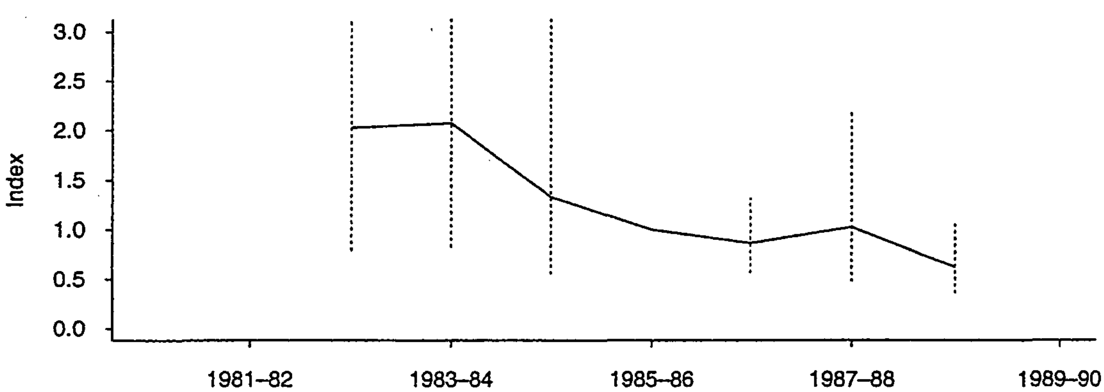

Figure 13: Smooth oreo positive catch CPUE index for target orange roughy, pre-GPS. Each years estimate has a confidence interval of ± 2 s.d. calculated using a jackknife technique. The confidence intervals for 1982–83 to 1984–85 exceed the y-scale shown.

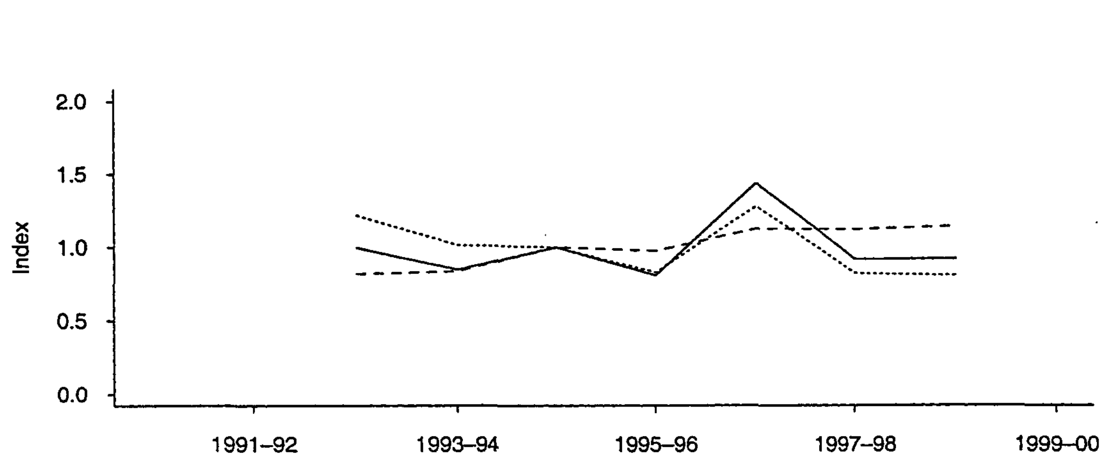

Figure 14: Smooth oreo combined CPUE indices (solid line) for target orange roughy, post-GPS with the zero catch regression index (large dashes) and the positive catch regression index (dots).

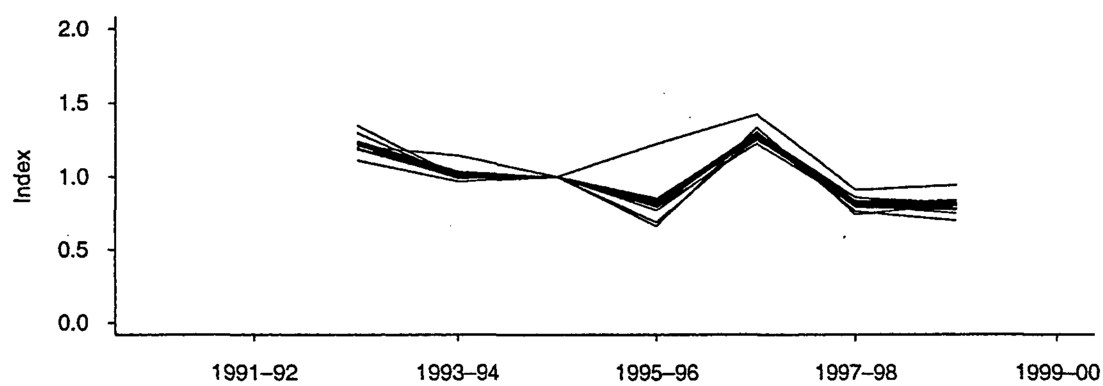

Figure 15: Smooth oreo positive catch CPUE index plots for target orange roughy, post-GPS showing the effect of removing one vessel at a time from the analysis. 1994–95 is the reference year.

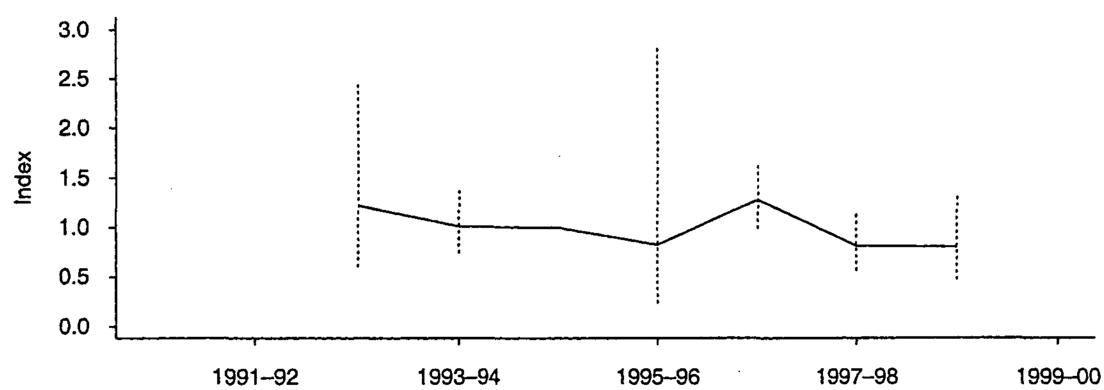

Figure 16: Smooth oreo positive catch CPUE index for target orange roughy, post-GPS. Each years estimate has a confidence interval of ± 2 s.d. calculated using a jackknife technique.

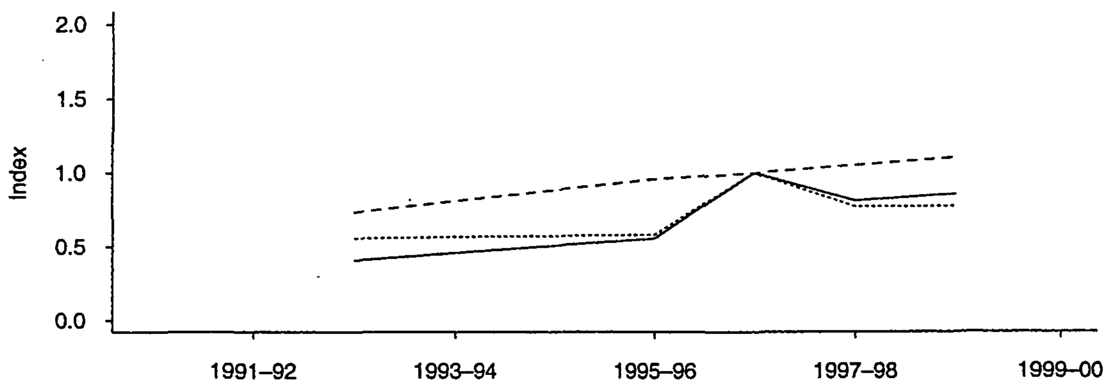

Figure 17: Smooth oreo combined CPUE indices (solid line) for target smooth oreo or unspecified oreo, post-GPS, west of 178° 12.6′ W with the zero catch regression index (large dashes) and the positive catch regression index (dots). No index was calculated for 1993–94 or 1994–95.

Figure 18: Smooth oreo combined CPUE index plots for target smooth oreo or unspecified oreo, post GPS, west of 178° 12.6′ W showing the effect of removing one vessel at a time from the analysis. 1996–97 is the reference year.

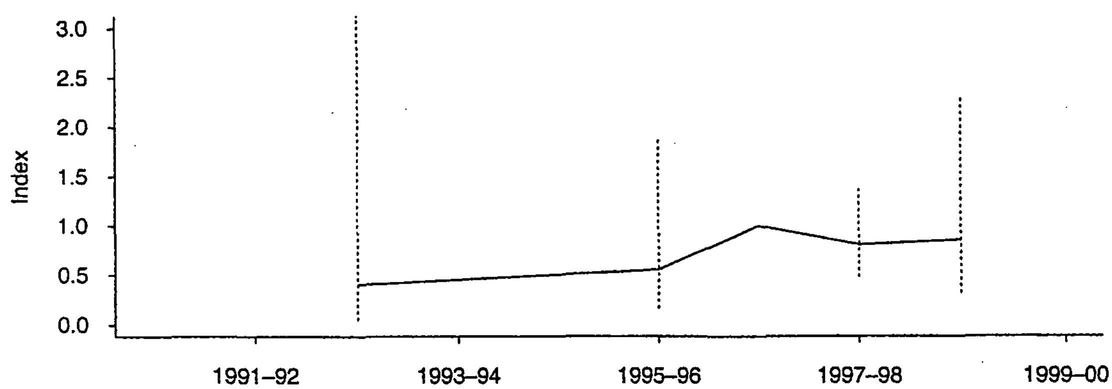

Figure 19: Smooth oreo combined CPUE index for target smooth oreo or unspecified oreo, post-GPS, west of 178° 12.6′ W. Each years estimate has a confidence interval of ± 2 s.d. calculated using a jackknife technique. The confidence interval for 1992–93 exceeds the y-scale shown.

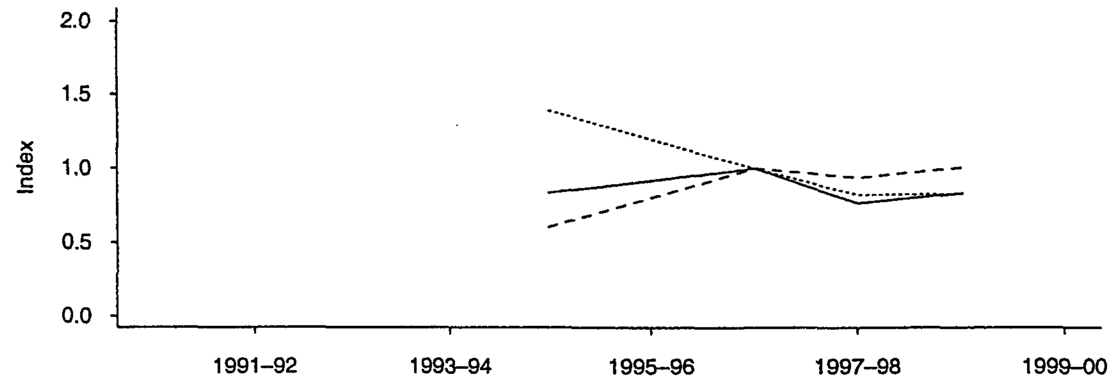

Figure 20: Smooth oreo combined CPUE indices (solid line) for target smooth oreo or unspecified oreo, post-GPS, east of 178° 12.6′ W with the zero catch regression index (large dashes) and the positive catch regression index (dots). No index was calculated for 1995–96.

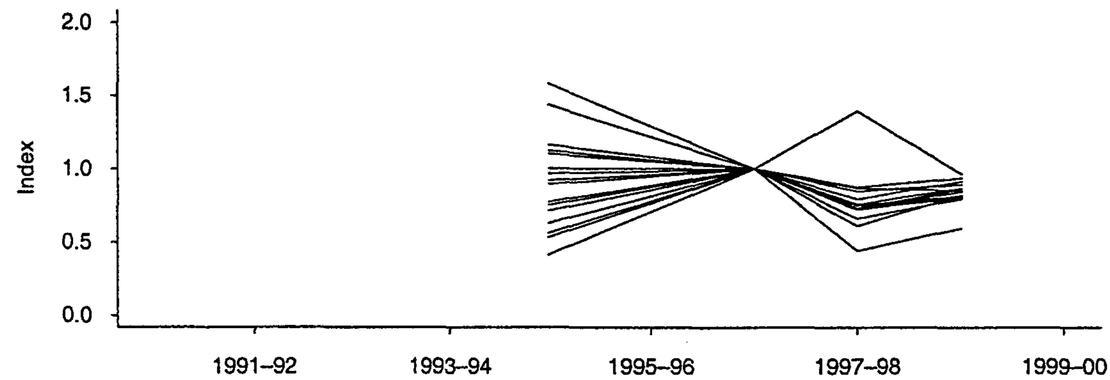

Figure 21: Smooth oreo combined CPUE index plots for target smooth oreo or unspecified oreo, post-GPS, east of 178° 12.6′ W showing the effect of removing one vessel at a time from the analysis. 1996–97 is the reference year.

Figure 22: Smooth oreo combined CPUE index for target smooth oreo or unspecified oreo, post-GPS, east of 178° 12.6′ W. Each years estimate has a confidence interval of ± 2 s.d. calculated using a jackknife technique. The confidence interval for 1994–95 and 1997–98 exceed the y-scale shown.

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 jackknife 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 jackknife 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 jackknife 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 NZ waters from 1985 onwards

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

GPS was first used by NZ fishing vessels in 1985 by one Sealord vessel. Trevor said that not all vessels got GPS at the same time and that 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 only needs 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	