MINISTRY OF FISHERIES

Te Tautiaki i nga tini a Tangaroa

ISSN 1175-1584

Black oreo abundance indices from standardised catch per unit effort data for OEO 4

R. P. Coburn
I. J. Doonan
P. J. McMillan

New Zealand Fisheries Assessment Report 2001/39
July 2001

Black oreo abundance indices from standardised catch per unit effort data for OEO 4

R. P. Coburn
I. J. Doonan
P. J. McMillan

NIWA
PO Box 14 901
Wellington

New Zealand Fisheries Assessment Report 2001/39
July 2001

Published by Ministry of Fisheries
Wellington
2001

ISSN 1175-1584

Citation:
Coburn, R.P.; Doonan, I.J.; McMillan, P.J. (2001).
Black oreo abundance indices from standardised catch per unit effort data for OEO 4.
New Zealand Fisheries Assessment Report 2001/39. 24 p.

This series continues the informal
New Zealand Fisheries Assessment Research Document series
which ceased at the end of 1999.

EXECUTIVE SUMMARY

Coburn, R.P.; Doonan, I.J.; McMillan, P.J. (2001). Black oreo abundance indices from standardised catch per unit effort data for OEO 4.

New Zealand Fisheries Assessment Report 2001/39. **24 p.**

New standardised CPUE analyses for black oreo in OEO 4 were developed as abundance indices for stock assessment. Indices were estimated using a log-linear regression part (positive catch regression) and a binomial part which used a Generalised Linear Model with a logit link for the proportion of successful tows (zero catch regression). Coefficients of variation (c.v.) for the indices were estimated using a jackknife technique. The binomial part used all the tows but considered only whether or not black oreo was caught and not the amount caught. The yearly indices from the two parts of the analysis were multiplied together to give a combined index for analyses of target black oreo CPUE. Only the positive catch regression was used from analyses of tows where black oreo was caught as bycatch of orange roughy fishing. Data from 1978–79 to 1998–99 were considered. The analyses were split into two series for the periods before and after GPS was phased in (pre- and post-) by excluding the years 1989–90 to 1991–92 because analysis of smooth oreo standardised CPUE showed that catch rates increased when GPS was introduced. There were four potential indices: target pre-GPS; target post-GPS; bycatch pre-GPS; and bycatch post-GPS.

A lack of data for target post-GPS meant that no index was available. The other three final CPUE indices were successfully developed and all showed declining trends. Over six years for target pre-GPS, CPUE declined to about 16% of its original value (mean c.v. 66%); for bycatch pre-GPS, CPUE declined to about 14% of its original value (mean c.v. 90%); and for bycatch post-GPS, CPUE declined to about 28% of its original value (mean c.v. 104%).

1. INTRODUCTION

1.1 Overview

This work contributed to the following objectives in MFish project "Oreo stock assessment" (OEO1999/02).

Overall objective

1. To carry out a stock assessment of black oreo (*Allocyttus niger*) and smooth oreo (*Pseudocyttus maculatus*), including estimating biomass and sustainable yields.

Specific objective

3. To conduct a stock assessment for black oreo and smooth oreo in OEO 4, including estimating biomass and sustainable yields.

A new OEO 4 black oreo standardised CPUE analysis was developed that aimed to provide relative abundance indices for stock assessment. The analysis used regression based methods, and was very similar to a standardised CPUE analysis of OEO 4 smooth oreo (Coburn et al. 2001). The same methods were used for standardised CPUE analyses of smooth oreo (Doonan et al. 1995, 1996, 1997, 1999) and black oreo in OEO 3A (Coburn et al. 1999). The abundance estimates for black oreo made here were evaluated and used for stock assessment in a separate report.

2. METHODS

2.1 Definitions and abbreviations

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

2.2 Data

Tow by tow data from trawl catch effort returns from 1978–79 to 1998–99 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 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 checked for systematic errors and gross outliers and for consistency over the time series. It was thought that any remaining errors are essentially random. Initial data comprised all tow-by-tow records in OEO 4 where black oreo was targeted or caught. However when we embarked on bycatch analysis (i.e., bycatch of orange roughy fishing) we included all tows in the study area that targeted orange roughy, regardless of whether black oreo was caught. The argument behind doing this is that trawls that target orange roughy are not targeting black oreo and as such are essentially random with respect to the black oreo distribution. Thus they could provide an unbiased estimate of abundance (like a random trawl survey). However, this argument does not seem to hold and there is evidence that the orange roughy and black oreo distributions are not independent. Therefore, for the final bycatch abundance indices we ignored the tows that caught zero black oreo and used only those tows that caught some black oreo, i.e., trawls that targeted orange roughy and caught some black oreo.

Data were not used in the standardised analyses where there were less than 50 tows per year or where a single vessel dominated the tows (more than 80% of tows) in any year.

The OEO 4 smooth oreo CPUE analysis (Coburn et al. 2001) demonstrated that standardised catch rates of smooth oreo increased when GPS was introduced and consequently CPUE data were split into two series, pre- (1978–79 to 1988–89) and post-GPS (1992–93 to 1998–99). Data from the intervening years (1989–90 to 1991–92) were dropped. The same procedure, i.e., splitting data into pre- and post-GPS series, was used for the black oreo analyses.

For the standardised analysis of target pre-GPS data only, we additionally limited the data to those from vessels with at least three years involvement in the fishery, because the early and late years of the series consisted of vessels without other major involvement in the data series. These years caused problems in the analysis of the jackknife c.v.s because they contained data from vessels which had little or inconsistent involvement in the rest of the fishery. Restricting analysis to vessels with three years involvement removed the inconsistent data.

A similar situation occurred for the bycatch pre-GPS analysis where the jackknife c.v. could not be determined for the initial year. Here we included that year's data for the calculation of the index but no jackknife c.v. was calculated or reported.

2.3 Area

The bulk of the black oreo catch, and nearly all of the target black 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 index. The western boundary of OEO 4 at 176° E was also the western end of the study area (Figures. 1 and 2).

2.4 Choice of CPUE measure

Catch-per-tow (tonnes-per-tow) was chosen as the index of density rather than catch-per-kilometre and follows the Deepwater Stock Assessment Working Group preference in previous black oreo standardised CPUE analyses (Coburn et al. 1999). Catch-per-tow is favoured because most black oreo is caught in aggregations and on underwater features where the recorded tow duration tells us little about the effective fishing time.

2.5 Unstandardised CPUE

Hart et al. (2000) reported descriptive unstandardised CPUE trends in the fishery. Further analyses of unstandardised CPUE were carried out here to provide information for developing the standardised CPUE analysis, i.e., determining the quality and quantity of CPUE data available. These analyses included: comparing the number of tows and the catches from tows that targeted and that caught black oreo over time; the proportions of zero-catch tows in the data; trends in unstandardised target and bycatch CPUE; the distribution of target and bycatch black oreo catches along the south Chatham Rise.

The OEO 4 smooth oreo CPUE analysis (Coburn et al. 2001) showed a pattern of systematic change in the fishery with catches from OEO 4 mainly taken on the flat or dropoffs at the west end in early years with a progressive change to most of the catch being taken from seamounts at the east end in the later years. Consequently the distribution of black oreo catches within the study area caught west and east of 178° 12.6′ W by year was examined to see if there was a similar systematic change in the pattern of fishing in the area.

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 black 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 black oreo was caught and not the amount caught. The yearly indices from the two parts of the analysis were multiplied together 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. Bin widths were chosen to ensure that tow numbers in each bin were similar. Eight bins were chosen to model any dependencies in the data while ensuring that the resultant models were not over parameterised. Vessel entered as a categorical variable with the modification that vessels with fewer than 50 tows over the whole time period were all lumped into the same category. Tow position was reduced to a single predictor variable, 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. The predictor 'hill' was a two-way categorical variable determined by the criterion that the tow be within 5 km of a known seamount position.

A forward stepwise selection of predictor variables was used with a cut off when the predictors (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.

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.s for the series were calculated as the square root of the mean of the squared non reference c.v.s. divided by the square root of two.

Details of the mathematical technique used for the standardised CPUE analysis are provided in Appendix 1.

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. Since 1981–82 most catch was smooth oreo, typically out-weighing black oreo by about five to one. Catch before 1981–82 was probably mostly black oreo, although the large fraction of unspecified catches makes this assumption uncertain. Catch of black oreo in the last 10 years was about 900 t per year.

Soviet vessels dominated the early catches, but by 1982–83 their catches were declining as both New Zealand and Japanese vessels began fishing. By 1986–87 New Zealand vessels took more than half the oreo and the Soviet catch was about to reduce to zero while the Japanese catch was also declining having reached a maximum of about 30% of the catch in 1985–86. Since 1986–87, New Zealand vessels have dominated the fishery.

Early fishing targeted mostly unspecified oreo (OEO). From the early 1980s an orange roughy fishery developed in the area and oreos became a major bycatch. Target fishing for black oreo occurred through the 1980s, but ceased in the 1990s. Raw target CPUE for black oreo fell during the 1980s.

The locations of all tows targeting black oreo in OEO 4 are shown in Figure 2. Most are on the south Chatham Rise to the west of 178° W. There are several areas (some named) where there was heavy target fishing (Figure 2). Plots of tows where black oreo was caught (regardless of target) show many other trawls on the south, east, and north Chatham Rise resulting in a fished band around the slopes of the Chatham Rise (see Figure 1). The amount of black oreo catch distributed along the Chatham Rise is shown in Figure 3. The vast majority of catch came from the south Chatham Rise (south of 43° 30′ S) and most was taken inside the defined study area. A progression of high catch over time from west to east can be seen. The high catches on Bobbin, Trevs, and Mt. Kiso were not sustained over the time series.

Most black oreo catch was taken during target fishing for black oreo (first half of the series) or as bycatch of orange roughy target fishing (second half of the series) (Table 2). The pre-GPS CPUE data mostly indexed the west side of the study area. For the target data, this identification was very strong except for the last year. The post-GPS CPUE data (all bycatch) principally indexed catch from the east side (Table 3).

Tables 4 to 7 show unstandardised CPUE for each of the four possible final models. Notable are high fractions of zero-catch tows in both the target and bycatch data which led us to use two part models. Unstandardised target CPUE fell over the pre-GPS period, except in the first and last years. Little can be said about target catch rates in the post-GPS period as the number of tows is tiny. Unstandardised bycatch CPUE fell both pre- and post-GPS. However, during the period in which GPS was introduced, i.e., 1989–90 to 1991–92, catch rates increased three to four times. The fraction of zero tows showed no clear trend for the target fishing, but for the bycatch pre-GPS data series it declined slightly. For the bycatch post-GPS data no trend in the fraction of zero tows was evident.

3.2 Standardised CPUE – final model results

3.2.1 Pre-GPS, target BOE

Catch and effort data from 1978–79 to 1988–89 were available for this analysis (see Table 4). Our selection criteria dropped the 1978–79, 1979–80, 1987–88, and 1988–89 fishing years. About 30% of the tows caught no black oreo.

Results of the positive catch regressions and zero-catch GLM are given in Table 8. The final model for positive catch used vessel, year, season, and depth and that for zero catch used vessel, season, year, depth, and axis-position.

The indices

The abundance index results from each model (positive catch and zero catch) and the combined index are given in Figure 4 and Table 9. The combined index from the final year was about a fifth that of the first year, with most of the decline occurring in the first three years.

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). The index was sensitive to most vessels, particularly so in the first two years.

Confidence intervals
Mean c.v. by year for the combined indices calculated using a jackknife technique is given in Figure 6 and Table 9. The overall mean c.v. (to be applied across the series including the reference year) was 66%.

3.2.2 Pre-GPS, target ORH

Catch and effort data from 1978–79 to 1988–89 were available for this analysis (see Table 6). Our selection criteria dropped the 1978–79, 1979–80, and 1981–82 years. About 70% of the tows caught no black oreo.

Results of the positive catch regressions and zero-catch GLM are given in Table 10. The final model for positive catch used year, vessel, and depth and that for zero catch used vessel, depth, season, and year.

The indices
The abundance index results from each model (positive catch and zero catch) and the combined index are given in Figure 7 and Table 11. The positive catch index decreased consistently over the series.

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 8). This showed that one vessel influenced the 1983–84 index. However, only two vessels contributed to the 1980–81 index and one of these never fished again, therefore the regression became singular when one of the vessels was dropped. In the preparation of the figure, we did not show the effect of removing that vessel. This may give a false impression of the variability on the 1980–81 year.

Confidence intervals
Mean c.v. by year for the positive catch indices calculated using a jackknife technique is given in Figure 9 and Table 11. The overall mean c.v. (to be applied across the series including the reference year) was 90%. No c.v. could be calculated for the 1980–81 year (see above and section 2.2). The 1980–81 index was very poorly determined.

3.2.3 Post-GPS, target ORH

Catch and effort data from 1992–93 to 1998–99 were available for this analysis (see Table 7). Our selection criteria retained all years. About 70% of the tows caught no black oreo.

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

The indices
The abundance index results from each model (positive catch and zero catch) and the combined index are given in Figure 10 and Table 13. The positive catch index fell to about a third over the period.

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 11). Several years index were influenced by one or two vessels, but the overall declining trend is clear.

Confidence intervals

Mean c.v. by year for the positive catch indices calculated using a jackknife technique are given in Figure 12 and Table 13. The overall mean c.v. (to be applied across the series including the reference year) was 104%. The 1998–99 index was poorly determined.

4. DISCUSSION

This study was conducted to provide, if possible, indices of abundance for stock assessment of black oreo in OEO 4. Other estimates available include an absolute abundance made from acoustic survey data (Doonan et al. 2000) and relative abundance from a series of trawl surveys. The trawl survey estimates are now thought to be unreliable (McMillan et al. 1996). In addition to providing abundance estimates, we hoped to determine the main explanatory predictors on which CPUE depends and to improve our understanding of the fishery. Two features of this study are of interest for other CPUE analyses in New Zealand, the GPS effect and the analysis of bycatch data.

We broke the data into two time series before and after the introduction of GPS (see Appendix 2) because the analysis of smooth oreo (Coburn et al. 2001) had demonstrated a GPS effect that could not be disentangled from the year effect. It is reasonable to assume that the effect will also apply to black oreo as the two species are caught together in the same way (in the same tows). The unstandardised CPUE for the bycatch data show that a GPS effect also exists for black oreo.

For the bycatch analysis we chose to use the positive catch regression as the index of abundance as this was consistent with our treatment of smooth oreo (Coburn et al. 2001). The bycatch zero-catch indices increased over time (both pre- and post-gps) for black oreo as they did for smooth oreo. In contrast, the target and the bycatch positive-catch indices both declined over time. We consider that the increasing zero-catch indices indicate declining orange roughy catch rates rather than increasing black oreo abundance, that is, as orange roughy abundance declines that species becomes more difficult to catch without some black oreo bycatch.

Vessel was the most important explanatory variable in half the final regressions and was selected in all of them. Additionally, the year index depended on the vessels admitted to the model. This result was consistent with other oreo standardised CPUE studies (see Coburn et al. 1999 and Doonan et al. 1995) and motivated the development of the vessel jackknife technique used to estimate the c.v. of these CPUE indices. Other important explanatory variables were year (selected in 5/6 final regressions), depth (5/6), season (4/6), and axis-position (3/6).

All three indices of abundance declined. In addition, the pattern of catches (see Figure 3) suggests serial depletion and may partly mask a decline in abundance. If abundance had remained the same we might expect CPUE to increase, given the improvement in fishing technology (as well as the introduction of GPS) over the period. However, the interpretation of bycatch CPUE is uncertain and the absence of target fishing in the 1990s reduced our certainty of what has happened to black oreo abundance over the last 10 years. This is a complex fishery with interaction of the three main species, ground type and environment and much remains to be learnt. Further study might involve analysis of particular fishing grounds and seamounts to investigate CPUE trends, but interpretation of the indices will probably remain uncertain because this is mainly a bycatch fishery.

5. ACKNOWLEDGMENTS

This research was carried out for the Ministry of Fisheries under Project OEO199902. Thanks to Alistair Dunn for reviewing the manuscript and the Deepwater Working Group for their appraisal and suggestions.

6. REFERENCES

Coburn, R.P.; Doonan, I.J.; McMillan, P.J. (1999). Black oreo abundance indices from standardised catch per unit of effort data for OEO 3A. New Zealand Fisheries Assessment Research Document 99/32. 18 p. (Unpublished report held in NIWA library, Wellington.)

Coburn, R.P.; Doonan, I.J.; McMillan, P.J. (2001). Smooth oreo abundance indices from standardised catch per unit of effort data for OEO 4. *New Zealand Fisheries Assessment Report 2001/11*. 39 p.

Doonan, I. (1991). Orange roughy fishery assessment, CPUE analysis - linear regression, NE Chatham Rise. New Zealand Fisheries Assessment Research Document 95/12. 31 p. (Unpublished report held in NIWA library, Wellington.)

Doonan, I.J.; Hart, A.C.; McMillan, P.J.; Coombs, R.F. (2000). Oreo abundance estimates from the October 1998 survey of the south Chatham Rise (OEO 4). *New Zealand Fisheries Assessment Report 2000/52*. 26 p.

Doonan, I.J.; McMillan, P.J.; Coburn, R.P.; Hart, A.C. (1995). Assessment of smooth oreo for 1995. New Zealand Fisheries Assessment Research Document 95/12. 31 p. (Unpublished report held in NIWA library, Wellington.)

Doonan, I.J.; McMillan, P.J.; Coburn, R.P.; Hart, A.C. (1996). Assessment of Chatham Rise smooth oreo (OEO 3A and OEO 4) for 1996. New Zealand Fisheries Assessment Research Document 96/17. 21 p. (Unpublished report held in NIWA library, Wellington.)

Doonan, I.J.; McMillan, P.J.; Coburn, R.P.; Hart, A.C. (1997). Assessment of Chatham Rise smooth oreo (OEO 3A and OEO 4) for 1997. New Zealand Fisheries Assessment Research Document 97/21. 26 p. (Unpublished report held in NIWA library, Wellington.)

Doonan, I.J.; McMillan, P.J.; Coburn, R.P.; Hart, A.C. (1999). Assessment of Chatham Rise OEO 3A black oreo for 1999. New Zealand Fisheries Assessment Research Document 99/52. 30 p. (Unpublished report held in NIWA library, Wellington.)

Hart, A.C.; Coburn, R.P.; McMillan, P.J.; Doonan, I.J. (2000). Descriptions of black oreo and smooth oreo fisheries in OEO 1, OEO 3A, OEO 4 and OEO 6 from 1977–78 to the 1997–98 fishing year. *New Zealand Fisheries Assessment Report 2000/23*. 43 p.

McMillan, P.J.; Doonan, I.J.; Coburn, R.P.; Hart, A.C. (1996). Is the south Chatham Rise trawl survey providing an index of smooth oreo abundance in OEO 4? New Zealand Fisheries Assessment Research Document 96/16. 18 p. (Unpublished report held in NIWA library, Wellington.)

Vignaux, M. (1994). Catch per unit effort (CPUE) analysis of west coast South Island and Cook Strait spawning hoki fisheries, 1987–93. New Zealand Fisheries Assessment Research Document 94/11. 29 p. (Unpublished report held in NIWA library, Wellington.)

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.

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 seamount.
Vessel	–	A parameter estimated for each vessel with at least 50 tows. Vessels with fewer than 50 tows were grouped together.

Table 2: Catch of black oreo (t) for 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	97	335	115	0	0
1979–80	1 272	199	1 406	5	0
1980–81	356	1 509	1 897	1 179	76
1981–82	21	2 975	253	27	318
1982–83	32	1 030	0	646	410
1983–84	67	826	0	199	188
1984–85	13	475	0	842	324
1985–86	36	483	54	139	269
1986–87	15	647	4	295	192
1987–88	37	356	0	254	249
1988–89	2	535	257	274	26
1989–90	25	0	3	323	88
1990–91	31	11	131	540	80
1991–92	41	16	48	1 559	32
1992–93	1	0	72	1 249	23
1993–94	3	8	28	1 504	12
1994–95	29	0	4	585	2
1995–96	21	0	30	301	12
1996–97	58	14	110	337	13
1997–98	79	0	248	349	17
1998–99	151	97	149	324	120

Table 3: Catch of black 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
1978–79	335	0	0	0
1979–80	195	4	0	0
1980–81	1 488	0	1 023	0
1981–82	2 971	0	1	0
1982–83	990	0	589	0
1983–84	790	16	175	5
1984–85	473	2	744	67
1985–86	483	0	79	53
1986–87	647	0	120	174
1987–88	351	2	120	131
1988–89	312	223	163	94
1989–90	0	0	65	253
1990–91	0	11	37	462
1991–92	16	0	26	161
1992–93	0	0	49	692
1993–94	7	1	93	914
1994–95	0	0	87	239
1995–96	0	0	67	110
1996–97	14	0	120	119
1997–98	0	0	70	180
1998–99	93	0	34	176

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

Year	No. of tows	No. of vessels	Catch (t)	Mean catch per tow (t)	Zero catch tows (%)
1978–79	116	5	334	2.9	6.9
1979–80	26	3	199	7.7	34.6
1980–81	298	6	1 487	5.0	5.0
1981–82	700	11	2 971	4.2	27.4
1982–83	257	10	989	3.9	37.0
1983–84	284	8	806	2.8	43.7
1984–85	255	11	475	1.9	43.1
1985–86	191	10	483	2.5	16.8
1986–87	280	5	646	2.3	21.8
1987–88	149	12	353	2.4	39.6
1988–89	75	8	534	7.1	4.0

Table 5: Unstandardised CPUE of black oreo from all tows in the study area that targeted black oreo post-GPS.

Year	No. of tows	No. of vessels	Catch (t)	Mean catch per tow (t)	Zero catch tows (%)
1992–93	1	1	0	0	100
1993–94	3	3	8	2.7	0
1995–96	1	1	0	0	100
1996–97	1	1	14	13.6	0
1997–99	15	2	93	6.2	0

Table 6: Unstandardised CPUE of black 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	1 023	4.1	24.2
1981–82	35	4	1	0	97.1
1982–83	885	17	589	0.7	74.7
1983–84	579	13	180	0.3	87.9
1984–85	1 103	16	811	0.7	52.3
1985–86	1 033	14	132	0.1	75.6
1986–87	1 014	18	294	0.3	69.2
1987–88	1 550	16	251	0.2	73.4
1988–89	2 374	14	258	0.1	65.5

Table 7: Unstandardised CPUE of black 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	740	0.7	69.4
1993–94	1 831	13	1 007	0.6	74.2
1994–95	1 182	13	326	0.3	77.9
1995–96	741	9	178	0.2	74.0
1996–97	549	7	239	0.4	60.5
1997–98	825	10	250	0.3	73.2
1998–99	480	12	210	0.4	65.8

Table 8: Stepwise selection of variables for the black oreo positive catch regression and the zero-catch GLM for all tows in the study area by vessel with at least three years involvement that targeted black 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	4
Vessel	12.0			
Year	7.1	24.6		
Season	9.2	17.0	32.0	
Depth	4.2	16.4	26.3	33.1
Improvement in R^2	12.0	12.6	7.4	1.1

(b) Zero-catch GLM R^2 values (%) (GLM equivalent)

					Iteration
Variable	1	2	3	4	5
Vessel	7.1				
Season	4.6	13.4			
Year	5.1	11.9	18.6		
Depth	3.5	10.4	15.2	21.3	
Axis-position	2.3	8.8	15.0	20.0	22.5
Improvement in R^2	7.1	6.3	5.2	2.7	1.2

Table 9: Black 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 by vessels with at least three years involvement that targeted black oreo pre-GPS.

Year	Positive index	Zero index	Combined index	Jackknife c.v. (%)
1980–81	1.52	1.84	2.80	122.0
1981–82	1.70	1.60	2.72	94.8
1982–83	0.86	1.18	1.02	68.1
1983–84	1	1	1	0
1984–85	0.59	1.09	0.64	60.8
1985–86	0.44	1.06	0.46	127.0
1986–87	0.35	1.17	0.41	63.4

Table 10: Stepwise selection of variables for the black 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
Year	35.6		
Vessel	34.1	46.3	
Depth	11.1	38.6	48.9
Improvement in R^2	35.6	10.7	2.5

(b) Zero-catch GLM R^2 values (%) (GLM equilavent)

	Iteration			
Variable	1	2	3	4
Vessel	16.6			
Depth	3.0	18.1		
Season	2.1	18.1	19.6	
Year	4.7	17.8	19.6	20.9
Improvement in R^2	16.6	1.5	1.5	1.3

Table 11: Black 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. NA, could not be estimated because of poor data quality.

Year	Positive index	Zero index	Combined index	Jackknife c.v. (%)
1980–81	4.54	0.57	2.56	NA
1982–83	1.19	0.85	1.01	40.6
1983–84	1.31	0.54	0.70	123.0
1984–85	1	1	1	0
1985–86	0.47	0.91	0.43	36.7
1986–87	0.60	0.96	0.58	55.3
1987–88	0.32	0.88	0.28	176.0
1988–89	0.13	1.23	0.16	211.0

Table 12: Stepwise selection of variables for the black 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 3.

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

					Iteration
Variable	1	2	3	4	5
Axis-position	9.3				
Vessel	8.1	15.7			
Year	7.9	14.6	20.1		
Depth	1.3	11.4	17.6	22.3	
Season	3.0	11.3	17.7	21.3	23.4
Improvement in R^2	9.3	6.4	4.5	2.2	1.1

(b) Zero-catch GLM R^2 values (%) (GLM equilavent)

			Iteration
Variable	1	2	3
Axis-position	8.6		
Vessel	6.9	13.1	
Year	0.9	9.5	14.1
Improvement in R^2	8.6	4.4	1.0

Table 13: Black 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	1.32	1.02	1.34	39.2
1993–94	1.31	1.08	1.42	75.4
1994–95	1	1	1	0
1995–96	0.63	1.06	0.66	88.1
1996–97	0.95	1.86	1.76	45.9
1997–98	0.63	1.52	0.95	39.2
1998–99	0.37	1.91	0.70	332.0

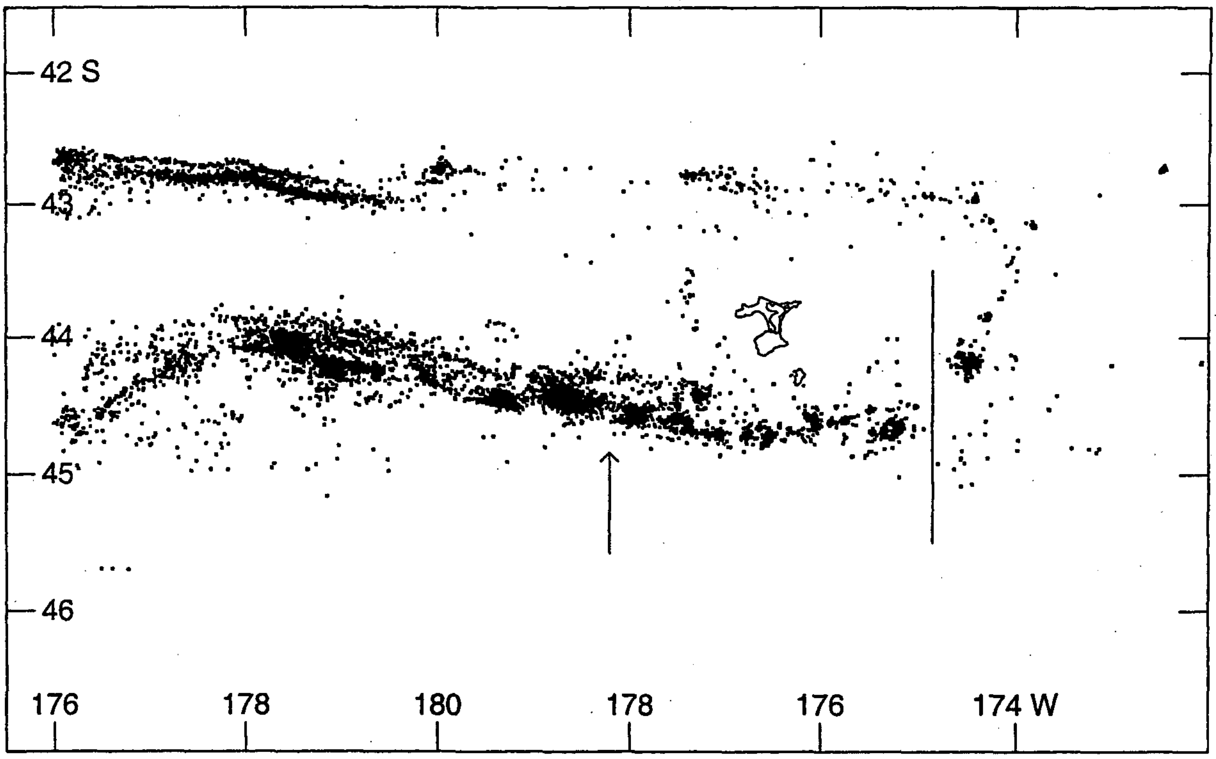

Figure 1: Start position (dots) of all trawls that caught black oreo in OEO 4 from 1978–79 to 1998–99. The western end of the study area is the boundary of OEO 4 at 176° E. The eastern boundary of 174° 50′ W is shown with a vertical line. An arrow shows the position of the west/east split at 178° 12.6 W.

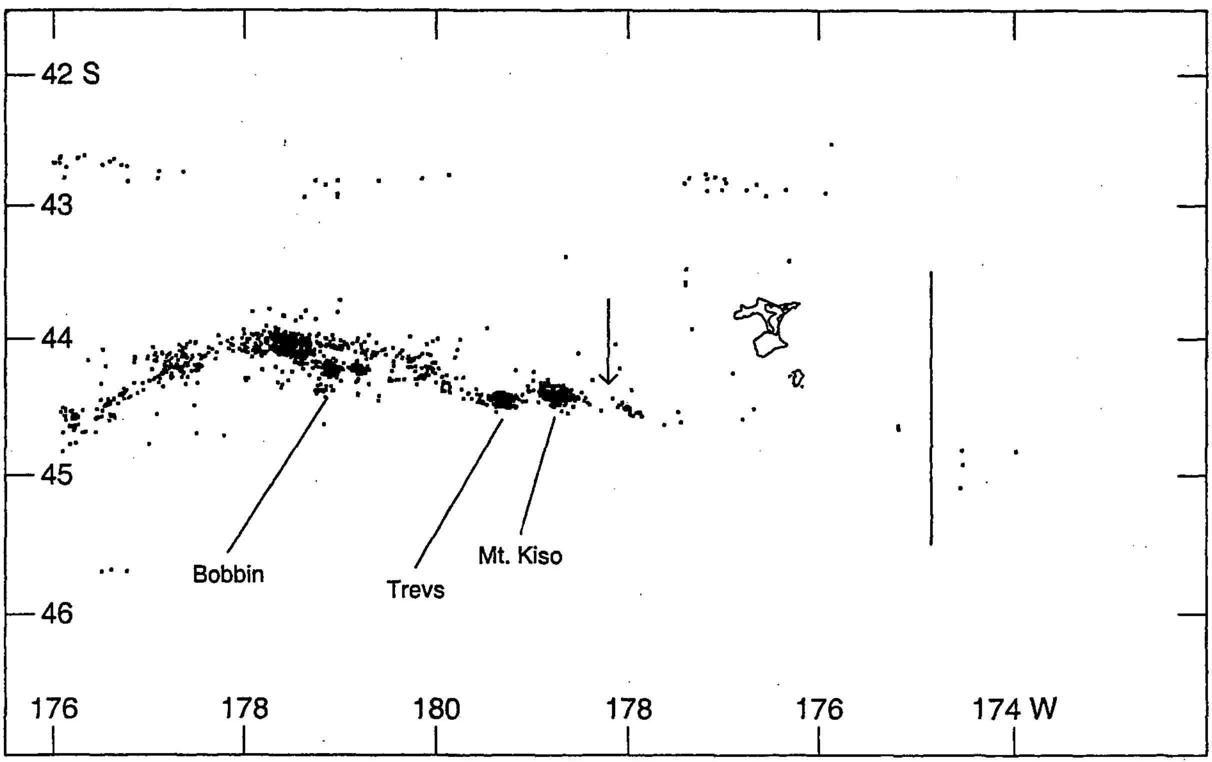

Figure 2: Start position (dots) of all trawls targeting black oreo in OEO 4 from 1978–79 to 1998–99. The western end of the study area is the boundary of OEO 4 at 176° E. The eastern boundary of 174° 50′ W is shown with a vertical line. An arrow shows the position of the west/east split at 178° 12.6′ W. Three main fishing locations are named.

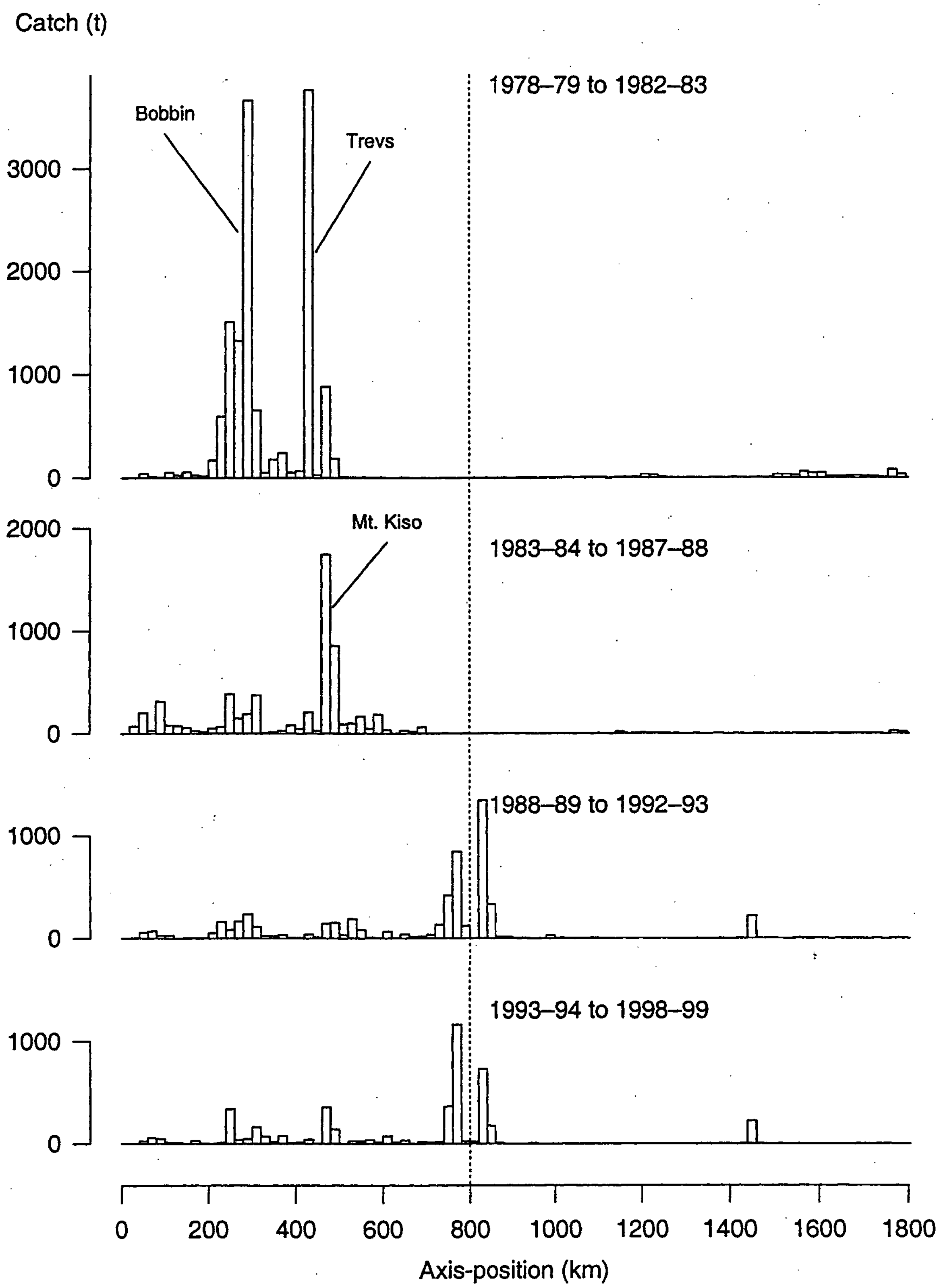

Figure 3: **Catch of black oreo (t) by 20 km bars along the axis. The data were broken into four time periods indicated by the titles. The vertical dotted line is the eastern boundary of the study area. Three main fishing locations are named (see also figure 2).**

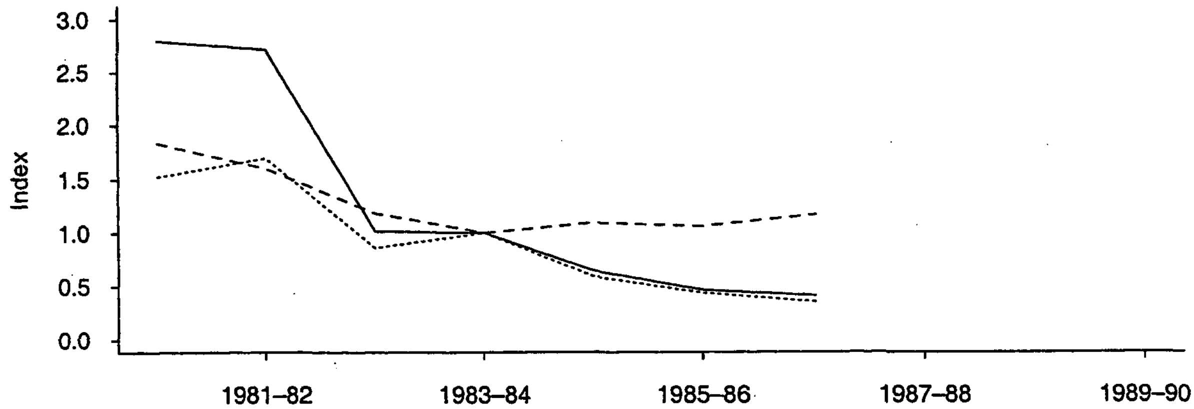

Figure 4: Black oreo combined CPUE indices (solid line) for target black oreo, pre-GPS, vessels with at least three years involvement, with the zero catch regression index (large dashes) and the positive catch regression index (dots).

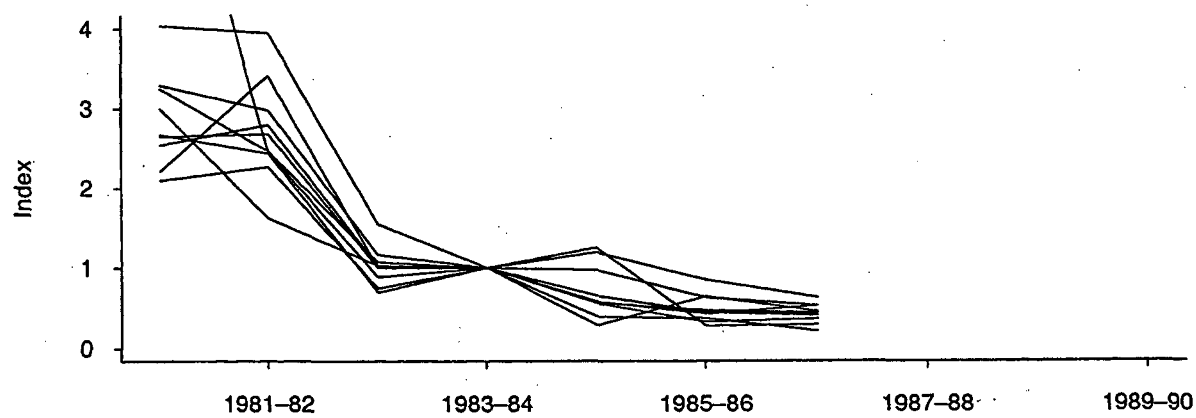

Figure 5: Black oreo combined CPUE index plots for target black oreo, pre-GPS, vessels with at least three years involvement, showing the effect of removing one vessel at a time from the analysis. 1983–84 is the reference year.

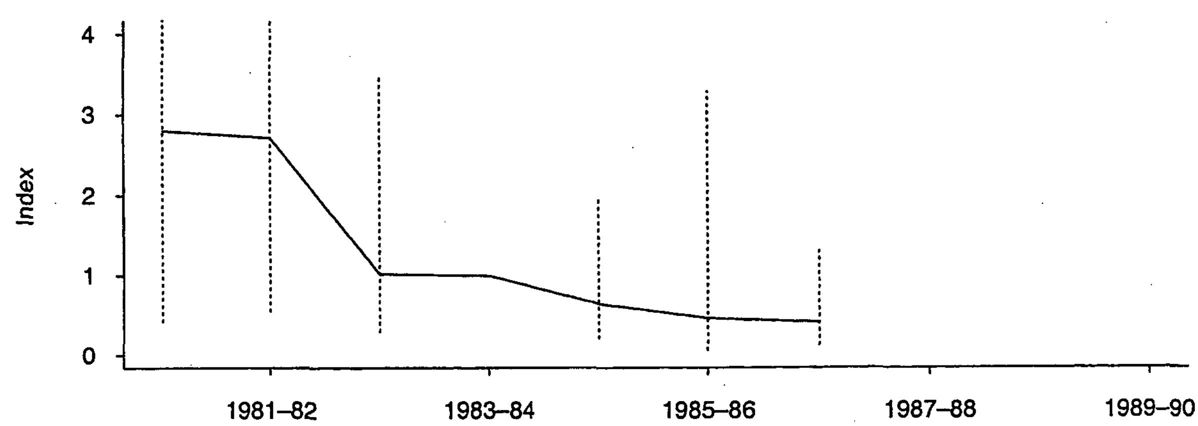

Figure 6: Black oreo combined CPUE index for target black oreo, pre-GPS, vessels with at least three years involvement. Each year's estimate has a confidence interval of ± 2 s.d. calculated using a jackknife technique. The confidence interval for 1980–81 and 1981–82 exceeds the y-scale shown.

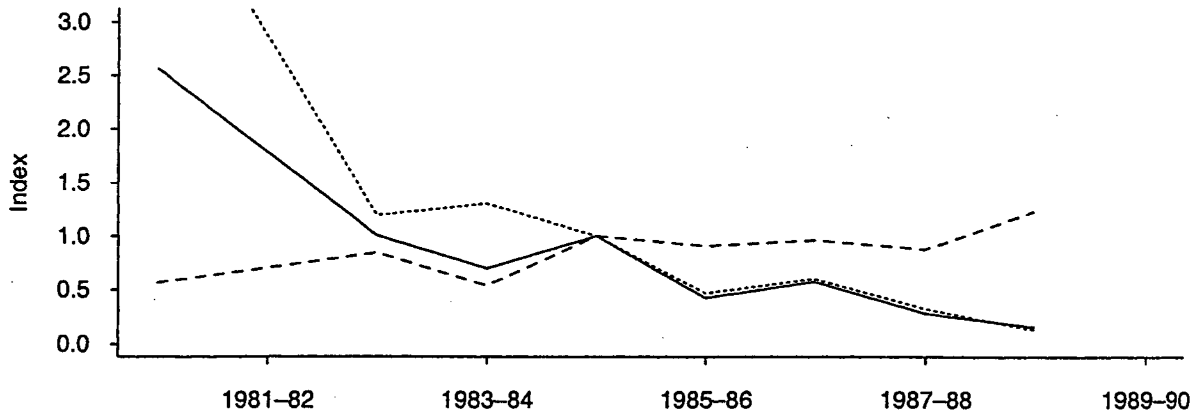

Figure 7: Black oreo combined CPUE indices (solid line) for target orange roughy, pre-GPS, with the zero catch regression index (large dashes) and the positive catch regression index (dots). No index was calculated for 1981–82.

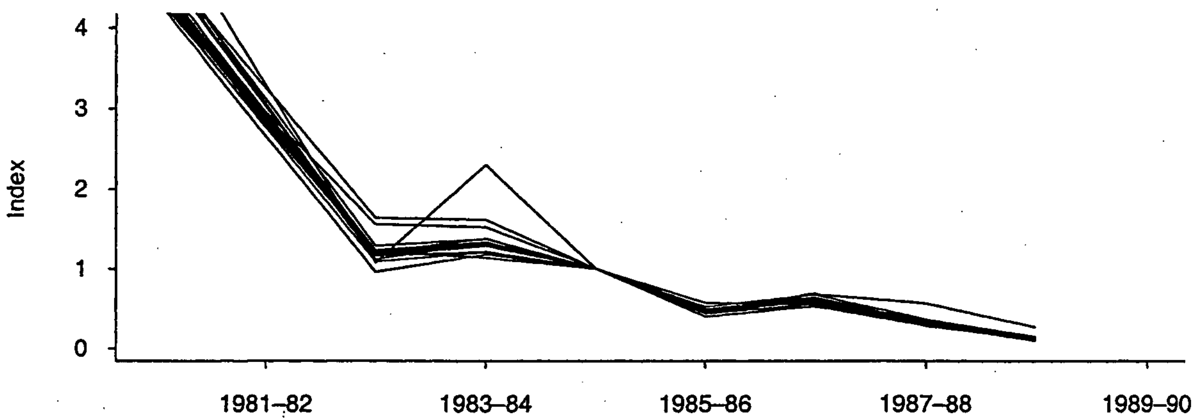

Figure 8: Black oreo positive catch CPUE index plots for target orange roughy, pre-GPS showing the effect of removing one vessel at a time from the analysis. 1984–85 is the reference year.

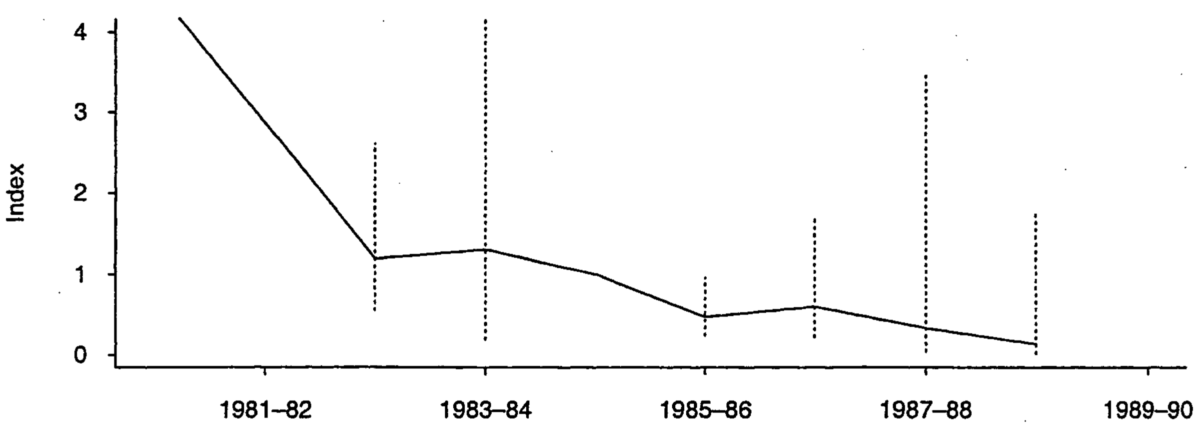

Figure 9: Black oreo positive catch CPUE index for target orange roughy, pre-GPS. Each year's estimate has a confidence interval of ± 2 s.d. calculated using a jackknife technique. The confidence interval for 1980–81 was not calculated. The confinence interval for 1983–84 exceeds the y-scale shown.

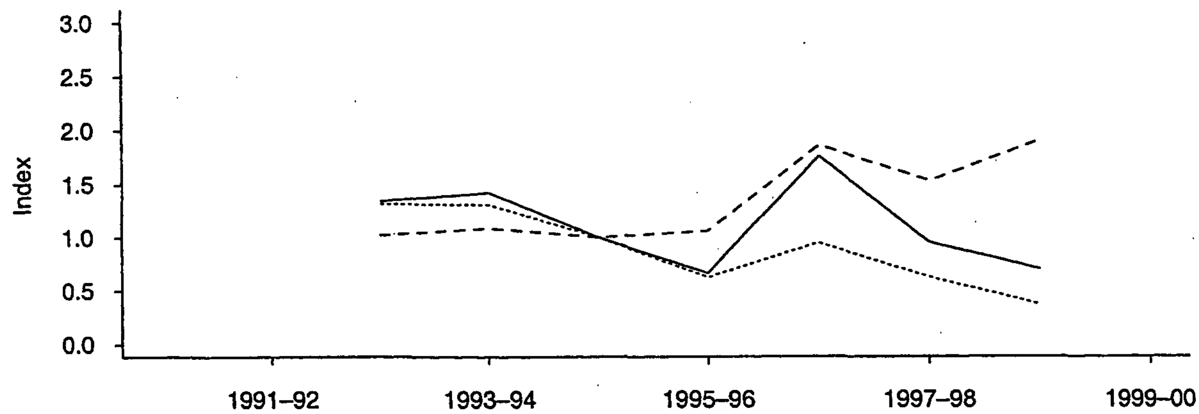

Figure 10: Black oreo combined CPUE indices (solid line) for target orange roughy, post-GPS, with the zero catch regression index (large dashes) and the positive catch regression index (dots).

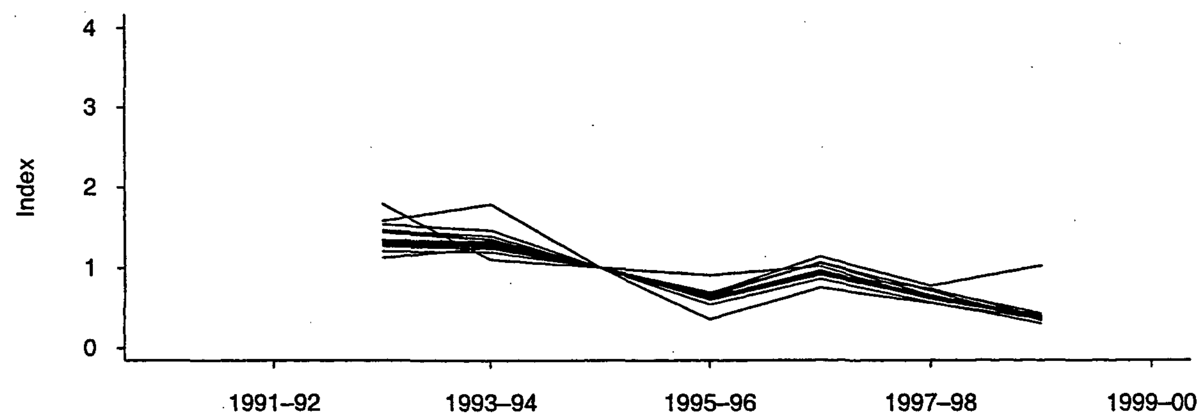

Figure 11: Black oreo positive catch CPUE index plots for target orange roughy, post-GPS, showing the effect of removing one vessel at a time from the analysis. 1994–95 is the reference year.

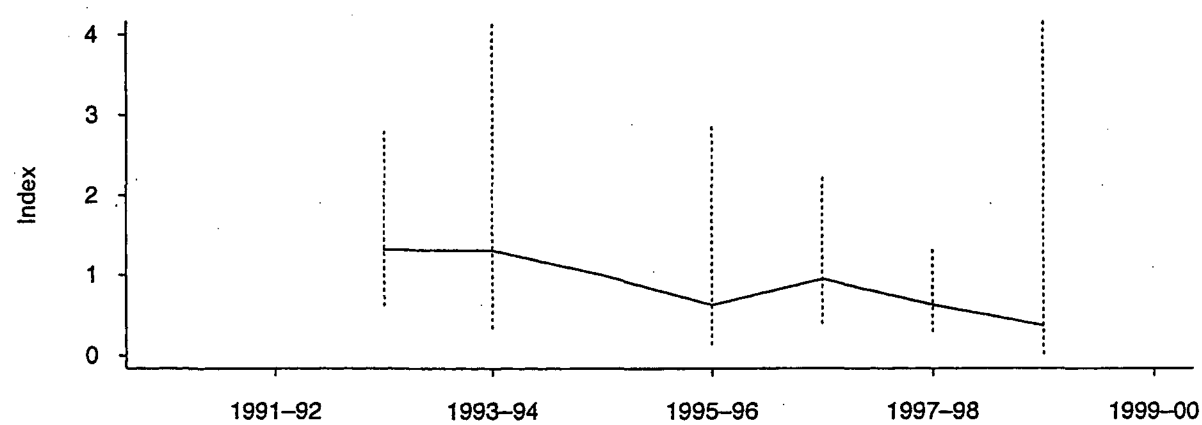

Figure 12: Black oreo positive catch CPUE index for target orange roughy, post-GPS. Each year's estimate has a confidence interval of ± 2 s.d. calculated using a jackknife technique. The confidence interval for 1993–94 and 1998–99 exceed the y-scale shown.

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, 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 (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 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 N.Z. waters from 1985 onwards

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

GPS was first used on N.Z. fishing vessels by one Sealord vessel in 1985. Trevor McDonald said that not all vessels got GPS at the same time and that there was variation in the coverage vessels enjoyed depending on the hardware installed.

Year	GPS coverage per day (h)	Equipment
1985	8	1 vessel only
1986	8+	
1987	8+	
1988	~12	3 vessels with Magnavox clock which needs 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	