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Development of an abundance index for Bounty Plateau smooth oreo using commercial CPUE data from 1994–95 to 2011–12: comparison of standard (GLM) procedures and preliminary spatial CPUE analyses.

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EXECUTIVE SUMMARY

Roux, M.-J.; Doonan, I.J. (2015). Development of an abundance index for Bounty Plateau smooth oreo using commercial CPUE data from 1994–95 to 2011–12: comparison of standard (GLM) procedures and preliminary spatial CPUE analyses.
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Catch per unit effort (CPUE) abundance indices were developed for smooth oreo *Pseudocyttus maculatus* from the Bounty Plateau (part of OEO 6) using GLM-standardisation procedures and preliminary spatial CPUE analyses. All indices indicated a reduction in the relative abundance of smooth oreo over the period of targeted fishing, 1995–2012. The magnitude of reduction varied from 49% to 60% among spatial indices, to over 80% in the standardised (GLM) index. An investigation of potential changes in search time (i.e., time spent on the fishing grounds) was performed on the main core vessels. Anecdotal information was collected through informal discussions with members of the fleet. Differences in economic considerations determined vessel-specific changes in search time, which were consistent with the observed reduction in CPUE. Spatial CPUE analyses accounted for bias in the year effect (initial hyper depletion) resulting from non-random changes in the spatial distribution of fishing effort over time. Full quantitative assessment of the stock was not undertaken as the Deepwater Fisheries Assessment Working Group had concerns about use of these CPUE analyses as indices of abundance. Commercial CPUE data are the only information source available to evaluate stock status of oreo species in OEO 6. A voluntary (industry) closure of the fishery was in place in 2012–13 and 2013–14.

1. INTRODUCTION

The Bounty Plateau (part of OEO 6) supports a demersal trawl fishery for smooth oreo *Pseudocyttus maculatus* (SSO). Fishing activities targeting smooth oreo mainly occur on the slope, between 800 m and 1200 m depth. A small number of underwater topographic features (UTFs) are also fished for smooth oreo and orange roughy *Hoplostethus atlanticus* within the Bounty fishing grounds. Bounty Plateau is essentially a smooth oreo fishery, in contrast to the Pukaki Rise (also OEO 6), which supports a mixed species fishery for smooth oreo, black oreo *Allocyttus niger* (BOE) and unspecific oreo species (OEO) (Anderson & Doonan 2013)

A first CPUE abundance index and a stock assessment of Bounty smooth oreo were developed by McKenzie & Coburn (2009) using data from 1994–95 to 2007–08. Biomass estimates from the stock assessment were deemed uncertain for a number of reasons, including: 1) uncertainty around the use of commercial CPUE data as a valid index of abundance; 2) the use of biological parameter estimates from oreo stocks from other areas; and 3) contrasting biomass signals resulting from the use of different CPUE indices for stock assessment (either single or split index to account for temporal changes in fleet composition).

The objectives of the present work (as specified under project DEE201002OEOC - stock assessment of oreo) were:

- Overall objective

To carry out a stock assessment of oreo (black oreo and smooth oreo) in OEO 6, including estimating biomass and sustainable yields.

- Specific objective

To update standardised catch per unit effort analyses and stock assessments of oreo, including estimates of biomass, risk and yields for Bounty smooth oreo in 2013–14.

- Additional objectives (as per Deepwater Fisheries Assessment Working Group requests)

To investigate potential changes in time spent on the fishing grounds (or ‘search time’) in the main core vessels that targeted or caught smooth oreo on the Bounty Plateau, 2000–2012.
To analytically account for non-random changes in spatial effort distribution over the Bounty Plateau fishing grounds, 1995–2012.

This document presents a partial assessment of smooth oreo stock status on the Bounty Plateau. An updated standardised catch per unit effort (CPUE) abundance index and preliminary spatial CPUE analyses and abundance indices are presented as potential inputs to a full stock assessment. Full assessment of the stock was not carried out because of concerns within the Deepwater Fisheries Assessment Working Group regarding the use of commercial CPUE data as an index of abundance.

2. METHODS

2.1 Assessment area

For the purpose of assessment, the Bounty Plateau fishery is defined by a polygon with vertices at:
46°26'S, 174°59'E; 48°31'S, 177°E; 48°31'S, 177°W; 46°S, 177°W; 46°S, 176°E (Figure 1).

2.2 Data sources and grooming

Commercial catch and effort (tow by tow TCEPR) data from bottom trawling activities that targeted or caught OEO (unspecified oreo species), SSO (smooth oreo), BOE (black oreo) or ORH (orange roughy) within the assessment area between 1 October 1980 and 30 September 2013 were extracted from the fishery statistics database managed by the Ministry for Primary Industries (MPI) and used for analyses. Standard error checking and grooming procedures were applied (see Anderson & Doonan 2013 for details). Catches reported as 'OEO' were re-assigned to SSO and BOE based on their proportional contributions to total catch in the dataset (as averaged over all tows).

2.3 Data selection

Data from all tows that targeted or caught SSO were considered for analyses. For the purpose of estimating relative abundance indices, the fishery was split into two time periods: exploratory (1981–1994) and targeted (1995–2012) (Table 1). Only data from the targeted fishery (annual effort at least 49 tows) were used in CPUE analyses.

2.4 Standardised CPUE analyses

Commercial CPUE abundance indices were developed following CPUE standardisation methods described in Coburn et al. (2002) and Anderson & Doonan (2013).

Core vessel selection was performed. Data from vessels that were in the fishery for at least two consecutive years and contributed a minimum of 10 tows per year were retained for CPUE standardisation.

Estimates of relative year effects were obtained from a stepwise multiple regression method, where the data were fitted using a lognormal model on log-transformed, non-zero catch-effort data. A delta lognormal model (including a binomial model for the occurrence of zero tows) was fitted during preliminary analyses (Roux, 2014a), but not considered any further.

A forward stepwise Generalised Linear Model (Chambers & Hastie 1991) implemented in R code (R Development Core Team 2014) was used to select among explanatory variables offered in the saturated model (Table 2). *Fishing year* was included as the first term and the algorithm added variables based on changes in residual deviance. The explanatory power of a particular model is described by the reduction in residual deviance relative to the null deviance defined by a simple intercept model (R^2). Variables were added to the model up to a 1% improvement in explained residual deviance.

The standardised indices were calculated using GLM, with associated standard errors. Indices are presented using the canonical form (Francis 1999) so that the year effects were standardised to have a geometric mean of 1. The coefficients of variation (CV) represent the ratio of the standard error to the index. The 95% confidence intervals were calculated for each index. Unstandardised CPUE were derived for each year from the available catch-effort data. The annual indices were calculated as the mean catch (t) per tow.

Model fits were investigated using standard residuals diagnostics (i.e., plots of residuals against fitted values; plots of fitted versus observed values; plots of residuals against quantiles of the standard normal distribution; and residual density plots) were produced to check for departures from the regression assumptions of homoscedasticity and normality of errors in log-space (i.e., log-normal errors).

The influence of each explanatory variable in the final model was quantified and described using the 'overall influence' statistic and coefficient-distribution-influence (CDI) plots (Bentley et al. 2012). 'Overall influence' measures the extent to which a variable changes CPUE from year to year and is expressed as a percentage. Influence plots depict the combined effects of (a) the expected log catch for each level of the variable (model coefficients) and (b) the distribution of the levels of the variable in each year (distributional changes), thereby describing the influence that the variable has on the unstandardised CPUE which is accounted for by the standardisation.

The sensitivity of the CPUE index was tested by fitting a number of different models to alternative sets of input data and using different explanatory variables. Alternative scenarios included an all target and a SSO/OEO target model fitted on the 1995–2012 and post-2000 time series, respectively.

2.5 Changes in search time

Changes in search time were investigated for the main core vessels. Fishing trips were distinguished based on the time difference (in days) from one tow to the next. A threshold of three or more days without fishing corresponded to a different trip. Five search time indicators were characterised and compared: 1) counts of fishing days per year and trip; 2) counts of trips per year; 3) counts of daily tows within a trip; 4) daily occurrence of zero tows within a trip; and 5) catch per trip. Median values and uncertainties (25th and 75th percentiles) were compared for all indicators among fishing years using box-and-whisker plots.

2.6 Spatial CPUE analyses

Spatial analyses of catch and effort data assume that overall population abundance is contributed from several spatial cells or areas a within the fishing grounds, which can be weighted to reflect their respective contributions to total abundance (Walters 2003).

Thus for a given species in year y:

$$CPUE_y = \sum_{a}^{areas} \bar{cr}_{a,y} w_a$$

In this context, annual abundance indices ($CPUE_y$) are the weighted averages (w_a = area weight) of area-specific catch rates (cr). This approach requires that all areas or spatial cells are small enough to allow for random fishing within individual area boundaries (Walters 2003). Relative abundance is related to catch rates via a population catchability parameter, and w_a is assumed to be proportional to area-specific catchability q_a:

$$w_a \propto \frac{n_{a,y}}{N_y} \propto \frac{1}{q_a}$$

Preliminary spatial CPUE analyses were conducted on the complete (1995–2012) time series. Hierarchical cluster analysis (with adjustments) was used to define spatial cells within the Bounty fishing grounds. Average distance between tows was calculated and distance clustering was performed using the Ward algorithm, which is a minimum variance method that aims at finding compact, spherical clusters (Ward 1963). The resulting cells were adjusted to ensure a minimum number of tows (at least 50) per cell. Further adjustments were made to ensure that individual cells corresponded to either slope or UTF effort/tows.

A space-time table of nominal catch rates (t per tow) was constructed, which has a row for every year and a column for each area. A minimum effort threshold (at least 10 tows per year) was applied, meaning that for a given area, fishing years with less than 10 tows were not considered to be representative of local abundance and were included in the table as missing data.

Missing year/area data were populated according to Walters (2003) using the following imputation criteria:

- Backward imputation (prior to the start of the fishery) was carried out by assigning the maximum catch rate recorded during the first three years of fishing to earlier years.
- Forward imputation (following the cessation of fishing) was carried out by assigning the mean catch rate from the last three years of data to subsequent years.
- Linear interpolation was used to populate missing data in-between adjacent years.

For each area, the re-constructed CPUE time series were normalised to the first fishing year (1995). For preliminary analyses, a simple set of four area weighting criteria was considered:

1. $w_a - 1$: same catchability across all areas.
2. w_a =orh.adj : catchability is 0.5 ($w_a = 2$) in ORH areas and 1 in all other areas.
3. w_a= cc : catchability is proportional to area-specific cumulative catch (cc).
4. w_a =cc.orh.adj: catchability is proportional to cumulative catch (cc) and adjusted for ORH.

Area weights were kept independent from the number of observations (i.e., total effort) made within each area (Walters 2003). Catches of orange roughy were plotted by area to determine 'ORH areas'.

The spatial approach was validated by contrasting spatial CPUE indices against previous and current standardised indices generated using the standard (glm) procedure.

3. RESULTS

3.1 Standardised CPUE indices

Four standardised abundance indices were developed, including an all-target model and an SSO/OEO target model for each of the 1995–2012 and 2000–2012 time series (Figure 2).

The four models had limited explanatory power (R^2 values of 0.08–0.14). Higher R^2 values were achieved for the all-target models in both time-series. These models were retained as the final models. Residuals diagnostics and influence plots for the final models are presented in Figures 3 and 4, respectively. Selected explanatory variables included target species, depth (as 100 m depth strata), and vessel (Table 3). Vessel had the most influence in the overall (1995–2012) model, followed by target species and depth strata. Target species had the most influence in the recent period (2000–2012) model, followed by vessel and depth strata.

Influence plots demonstrated a transition from lower-coefficient to higher-coefficient vessels before/after 2000 in the overall (1995–2012) model (Figure 4). In contrast, vessel effects were variable and showed no temporal trend in the post-2000 model. Influence plots for target species showed that effort targeting orange roughy decreased over time, while a transition from 'OEO' to 'SSO' target occurred in recent years. This was linked to an increasingly positive influence of target species on CPUE between 2000 and 2010. The influence of depth was not independent from vessel or target species, as indicated by influence patterns similar to vessel (1995–2012 model) and target species (post-2000 model). Lower and higher coefficients corresponded to the 500 m and 1100 m depth strata, respectively (Figure 4).

The standardised indices indicated a reduction in CPUE of over 80% from 1995–97 to 2010–12 in the 1995–2012 model, and a reduction of 60% from 2000–2002 to 2010–2012 in the post-2000 model (Table 4). The scale of the initial (pre-2000) depletion in the 1995–2012 model was deemed unlikely to represent changes in relative abundance by the Deepwater Fisheries Assessment Working Group. Likewise, concerns over potential changes in search time by the main core vessels, which may have contributed to the reduction in CPUE, were expressed by the Deepwater Fisheries Assessment Working Group and a fishing search time investigation was requested and undertaken.

3.2 Changes in search time

Changes in search time were investigated and characterised for a vessel that consistently fished during the post-2000 fishery period and another that remained in the fishery from 2000 to 2010 (Figure 5).

Results of search time investigations were consistent with the observed reduction in the CPUE index of Bounty SSO in recent years. Different patterns were observed between the two vessels. One vessel increasingly spent more time and effort on the fishing grounds in order to maintain catches in the late 2000s, despite an increasing occurrence of zero tows (Figure 5A). Another vessel spent less time and effort on the fishing grounds as catches diminished (i.e. in 2007–2012 compared to earlier years) (Figure 5B). Anecdotal information revealed that differences in economic considerations determined vessel-specific changes in search time (i.e. one vessel had economic incentives to try and maintain catches on the fishing grounds, while the other vessel didn't).

Search time investigations also demonstrated temporal changes in search patterns (as spatial distribution of tow tracks) in the core vessels (Roux & Doonan 2014a). This corroborated both factual and anecdotal evidence for temporal changes in the spatial distribution of catch and effort in the Bounty SSO fishery (Roux 2014a, Roux 2014b, Appendix 1). Preliminary spatial CPUE analyses were thus undertaken to account for obvious biases resulting from non-random changes in spatial effort distribution over time.

3.3 Spatial CPUE indices

Fourteen areas were identified within the Bounty fishing grounds and considered for spatial CPUE analyses (Figure 6). These areas were validated against anecdotal information provided by members of the fleet. Areas C, D and E corresponded to UTF effort/tows. All other areas corresponded to slope effort/tows.

The raw and populated space-time tables of nominal catch rates are presented in Tables 5A and 5B, respectively. The raw table clearly identified the core area of the fishery (i.e., areas fished in all years), which comprised areas B, C, X, D and E (Table 5A). Fishing for orange roughy only occurred within core areas, namely in areas B and C and to a lesser extent in areas X and D (Roux & Doonan 2014b). Those areas were classified as ORH areas for weighting procedures.

Limited contrast in spatial CPUE indices was achieved among the four area weighting scenarios considered for preliminary analyses (Table 6, Figure 7). Spatial indices however clearly dampened the scale of the initial (1995–2000) depletion in comparison with the previous (McKenzie & Coburn 2009) and current (all target, 1995–2012) standardised indices. The reduction in average CPUE in 2010–2012 relative to 1995–97 ranged from 49% to 60% among spatial indices (Table 6).

4. DISCUSSION

Trends in relative abundance of Bounty Plateau smooth oreo were investigated using standard GLM procedures and a spatial approach applied to commercial CPUE data. The resulting indices all indicated a reduction in relative abundance of smooth oreo over time. The magnitude of this reduction differed among CPUE indices. Reductions of 49% to 60% in 2010–2012 relative to 1995–1997 were observed among spatial scenarios, compared to a more than 80% reduction in the standard, all-target GLM model for 1995–2012. Results from search time investigations were consistent with the pattern of decreasing abundance of smooth oreo and lower abundance in recent years (i.e., 2005–2012).

Spatial CPUE analyses were undertaken to deal with bias resulting from non-random temporal changes in the spatial distribution of fishing effort. The approach accounts for missing year-area data by imputing CPUE data for spatial areas that were not fished in some years. Where non-random spatial patterns in fishing occur, ignoring missing year-area data (which equates to assuming that data from areas that are actually fished are representative of changes in abundance in areas that have not been fished) can lead to important bias in the abundance trend or year effect (Walters 2003, Carruthers et al. 2011).

Our results indicated that the omission of missing year-area data in the standard GLM for Bounty smooth oreo, was linked to hyper depletion during the initial years of the fishery (1995–2000). The same missing data problem will persist in a spatial GLM, because year-area interaction effects cannot be estimated for those year-area strata without observations (Carruthers et al. 2011). Our preliminary analyses used the Walters (2003) imputation approach to account for missing year-area data. This approach was demonstrated during simulation exercises to reduce bias by up to 25% early in the time series of tropical tuna indices (Carruthers et al. 2010).

Spatial CPUE analyses were similarly undertaken for orange roughy and smooth oreo from the south-east Chatham Rise (ORH3B and OEO4) (Doonan et al. 2009, Doonan 2009). In both cases, more sophisticated (De Lury (or Leslie) depletion) methods were used with varying success to estimate area-specific catchability (or area weightings). The approach was successful in accounting for non-random spatial changes in orange roughy target fishing on the south-east Chatham Rise over time (Doonan et al. 2009).

Results of preliminary spatial CPUE analyses of Bounty smooth oreo confirm the usefulness and validity of the approach in deepwater fish/fisheries, where the assumption of limited dispersal or slow mixing/re-distribution of the target fish species between areas seem appropriate. Development options exist, including the use of standardised catch rates in the construction of space-time tables, the fine-tuning of alternative area weighting techniques (i.e., depletion and other q estimation methods and considerations of tow duration thresholds, specific catchabilities for the different types of terrain that are fished (i.e., slope, dropoff, UTF), time-varying area weighting, etc.), and the testing of an integrated spatial approach combining the imputation theory of Walters (2003) with conventional GLM standardisation techniques developed by Carruthers et al. (2011).

Spatial CPUE analyses hold promises in mixed species deepwater fisheries in which non-random fishing patterns occur, and commercial CPUE data are the only information source available for stock assessment.

No fishing activities that targeted or caught smooth oreo have occurred on the Bounty Plateau since 1 August 2012. A voluntary closure of the fishery was in place in 2012–13 and 2013–14.

5. ACKNOWLEDGMENTS

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Table 1: Catch and effort information by fishing year for bottom trawling activities that targeted or caught smooth oreo (SSO) on the Bounty Plateau from 1 October 1980 (1980–81 fishing year) to 30 September 2012 (2011–12 fishing year). % target = percentage of tows that targeted smooth oreo (SSO), unspecified oreo species (OEO), black oreo (BOE) and orange roughy (ORH), respectively.

Fishing year	No. tows	No. vessel	SSO catch (t)	SSO CPUE (t/tow)	% zero tows	% SSO target	% OEO target	%BOE target	%ORH target	
1980–81	8	2	0	0.1	75	62	38	0	0	Exploratory fishery (1981–1994)
1983–84	34	5	530	15.7	12	76	0	24	0	
1985–86	1	1	0	0	100	100	0	0	0	
1987–88	2	1	20	8.8	0	100	0	0	0	
1990–91	6	1	20	3.3	50	100	0	0	0	
1992–93	10	1	80	8.1	20	0	100	0	0	
1993–94	24	2	430	18.1	4	96	4	0	0	
1994–95	161	7	1 250	7.8	12	54	42	0	4	Targeted fishery (1995–2012)
1995 96	154	6	730	4.8	19	5	77	0	17	
1996–97	170	5	100	0.6	92	0	95	0	5	
1997–98	187	6	540	2.9	36	24	45	0	30	
1998–99	338	11	1 060	3.1	11	54	20	0	26	
1999–00	147	8	790	5.4	7	32	42	0	26	
2000–01	135	6	490	3.6	13	37	33	0	30	
2001–02	150	5	930	6.2	5	75	11	0	13	
2002–03	277	6	1 370	4.9	15	22	62	0	16	
2003–04	269	6	1 240	4.6	19	15	76	0	9	
2004–05	428	8	2 080	4.9	14	38	58	0	4	
2005–06	360	4	1 640	4.6	21	36	57	0	7	
2006–07	218	5	600	2.7	16	57	39	0	4	
2007–08	96	2	320	3.4	19	64	34	1	1	
2008–09	240	2	1 260	5.2	22	99	0	1	0	
2009–10	282	3	1 480	5.3	21	97	0	1	2	
2010–11	221	2	740	3.4	16	90	0	6	4	
2011–12	49	2	170	3.5	20	94	0	4	2	

Table 2: Summary of the variables offered in CPUE models for Bounty Plateau smooth oreo (SSO). All continuous variables were offered as third order polynomials.

Variable	Type	Description
Year	Factor	Fishing year (Oct 1–Sep 30)
Target	Factor	Target species as reported on a tow by tow basis
Vessel	Factor	Unique vessel identifier
Features	Factor	Distinction between features and slope effort*
Subarea	Factor	Subareas distinction within the fishing grounds**
Longitude	Continuous	Longitude at tow start position
Month	Factor	Calendar month
OSeason	Factor	Austral seasons delayed by a month (i.e. Spring = Oct–Dec, Fall=Apr–Jun, etc.)
Time of day	Factor	Distinction between day/night tows
Depth	Continuous	Average trawl depth (m)
fDepth	Factor	Average trawl depth split into 100 m depth strata
Duration	Continuous	Trawl duration (in hour)
fDuration	Factor	Distinction between short (≤0.5 hr) and long (>0.5 hr) tows
Trawl speed	Continuous	Average trawl speed (in knots)
Distance	Continuous	Distance (in km) as estimated from Lat/Lon data

* Criteria for feature tows = tows located within 1 n. mile distance from summit position.
** Three subareas were distinguished based on longitude within the Bounty Plateau boundaries: <178ºE = subarea A; 178º–179ºE = subarea B; and 179ºE–179ºW =subarea C.

Table 3: Summary of lognormal, all-target models for the Bounty SSO trawl fishery, 1995–2012 (top) and 2000–2012 (bottom) time series. Retained variables are in order of decreasing explanatory value, with the corresponding degrees of freedom (df), residual deviance (Res. Deviance), percent total deviance explained (R-squared) and overall influence (percent contribution to inter-annual variations in CPUE).

1995–2012 time series

	Res.df	Res.Deviance
NULL model	2985	11 850

Predictors	df	R^2	Res. Deviance	Influence (%)
Year	17	3.43	11 850	
fDepth	5	9.57	10 716	12.9
Target	3	11.72	10 461	16.3
Vessel	11	13.74	10 222	27.0

2000– 2012 time series

	Res.df	Res.Deviance
NULL model	2322	9 493

Predictors	df	R^2	Res. Deviance	Influence (%)
Year	12	2.7	9 233	
Target	3	8.3	8 708	12.4
fDepth	4	10.3	8 511	5.2
Vessel	6	11.5	8 405	6.4

Table 4: Lognormal CPUE standardized indices for the Bounty SSO trawl fishery (all target models for 1995–2012 and post-2000 time series), including 95% confidence intervals (lower and upper CI) and coefficients of variation (CV).

	1995–2012 time series				**2000–2012 time series**			
Year	Index	lower.CI	upper.CI	CV	Index	lower.CI	upper.CI	CV
1994–95	4.29	3.49	5.27	0.10				
1995–96	2.60	2.05	3.30	0.12				
1996–97	2.63	2.03	3.42	0.13				
1997–98	2.84	2.21	3.67	0.13				
1998–99	1.64	1.35	1.98	0.10				
1999–00	1.50	1.26	1.79	0.09	1.78	1.46	2.18	0.10
2000–01	0.70	0.57	0.85	0.10	1.04	0.85	1.27	0.10
2001–02	1.32	1.09	1.59	0.09	1.94	1.63	2.32	0.09
2002–03	0.72	0.63	0.83	0.07	0.99	0.86	1.14	0.07
2003–04	0.82	0.71	0.96	0.08	1.12	0.96	1.30	0.08
2004–05	0.89	0.79	1.01	0.06	1.31	1.16	1.48	0.06
2005–06	0.82	0.72	0.94	0.07	1.18	1.04	1.35	0.07
2006–07	0.56	0.47	0.65	0.08	0.83	0.71	0.97	0.08
2007–08	0.41	0.33	0.52	0.12	0.65	0.52	0.81	0.11
2008–09	0.80	0.67	0.96	0.09	1.31	1.10	1.57	0.09
2009–10	0.57	0.48	0.67	0.08	0.87	0.75	1.01	0.08
2010–11	0.26	0.22	0.31	0.09	0.39	0.33	0.47	0.08
2011–12	0.44	0.31	0.62	0.17	0.67	0.48	0.93	0.17

Table 5A: Raw data space-time table of nominal catch rates (t per tow) of Bounty smooth oreo, 1995–2012. Columns are areas (as depicted in Figure 6) and rows are fishing years (1 October to 30 September). NF= not fished.

	A	B	C	X	D	E	X2	F	G	H	I	J	K	L
1994–95	4.18	5.40	8.72	0	8.71	9.41	NF	NF	NF	NF	NF	0.10	0.08	NF
1995–96	18.45	2.04	2.67	5.50	8.35	7.64	0	NF	1.06	NF	NF	NF	NF	NF
1996–97	0.08	2.40	2.99	0	3.64	7.16	NF	NF	NF	NF	NF	1.21	NF	NF
1997–98	6.25	0.90	2.17	0.60	6.41	5.13	0	6	0.10	NF	NF	NF	NF	0.61
1998–99	19.25	1.21	2.27	0.82	9.02	7.17	6.75	NF	2.25	NF	0	0.10	NF	0.10
1999–00	6.72	1.28	2.07	0.50	2.55	4.99	5.66	15.40	1.17	NF	NF	11.90	7.07	0.58
2000–01	NF	3.02	2.55	5.50	6.20	4.33	1.00	4.24	NF	NF	NF	0.05	0.05	0.70
2001–02	3.44	2.83	6.95	4.04	5.28	4.03	13.46	6.60	0.02	1.96	0.04	NF	0.10	2.73
2002–03	0.16	1.64	4.38	0.53	0.84	0.50	6.00	10.41	NF	10.66	1.10	2.97	NF	2.05
2003–04	0	1.77	3.44	7.13	2.03	6.98	8.88	6.61	1.73	7.05	0	1.72	NF	0.04
2004–05	0.10	1.45	2.63	3.30	2.03	1.71	3.54	6.71	4.85	9.04	7.18	3.28	5.59	4.28
2005–06	3.34	2.77	2.46	3.56	6.48	4.67	3.95	0.91	2.29	6.24	5.56	6.87	1.13	4.47
2006–07	0.02	0.27	3.74	3.32	4.33	1.67	3.23	2.37	3.23	3.42	1.42	1.69	0.46	2.31
2007–08	NF	0.10	10.04	0.16	2.46	2.86	2.71	0	3.56	0	0.24	2.97	NF	1.46
2008–09	0	6.93	10.87	1.85	5.70	1.07	5.67	5.31	2.54	6.14	0.02	0.71	0.26	5.66
2009–10	1.50	0.69	5.10	3.06	5.35	2.56	5.84	12.01	2.37	9.40	0.47	1.78	0.03	1.42
2010–11	NF	0.71	4.19	0.20	1.84	3.81	7.87	2.84	2.58	4.98	0.10	0.07	0.03	0.54
2011–12	NF	1.04	1.96	0	0.53	0.05	13.75	6.89	4.24	1.03	0	1.28	NF	NF

Table 5B: Populated and normalised space-time table of nominal catch rates of Bounty smooth oreo, 1995–2012.

	A	B	C	X	D	E	X2	F	G	H	I	J	K	L
1994–95	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1995–96	1.00	0.38	0.31	1.00	0.96	0.81	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1996–97	0.59	0.44	0.34	1.00	0.42	0.76	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1997–98	0.59	0.17	0.25	1.00	0.74	0.55	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1998–99	0.59	0.22	0.26	0.11	1.03	0.76	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1999–00	0.59	0.24	0.24	0.56	0.29	0.53	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2000–01	0.59	0.56	0.29	0.56	0.71	0.46	1.00	0.28	1.00	1.00	1.00	1.00	0.90	1.00
2001–02	0.19	0.52	0.80	0.56	0.61	0.43	1.00	0.43	1.00	1.00	1.00	1.00	0.90	0.64
2002–03	0.18	0.30	0.50	0.56	0.10	0.59	0.45	0.68	1.00	1.00	1.00	0.91	0.90	0.82
2003–04	0.18	0.33	0.39	1.00	0.23	0.74	0.66	0.43	0.36	0.66	1.00	0.52	0.90	0.82
2004–05	0.18	0.27	0.30	0.75	0.49	0.18	0.26	0.44	1.00	0.85	1.00	1.00	0.79	1.00
2005–06	0.18	0.51	0.28	0.50	0.74	0.50	0.29	0.06	0.47	0.59	0.77	2.09	0.90	0.77
2006–07	0.18	0.90	0.43	0.47	0.50	0.31	0.36	0.42	0.67	0.32	0.20	0.52	0.90	0.54
2007–08	0.18	0.90	0.84	0.45	0.28	0.31	0.36	0.42	0.73	0.45	0.13	0.91	0.90	0.93
2008–09	0.18	1.29	1.25	0.45	0.65	0.11	0.36	0.42	0.52	0.58	0.13	0.22	0.90	1.32
2009–10	0.18	0.13	0.58	0.43	0.61	0.27	0.43	0.78	0.49	0.88	0.07	0.54	0.90	0.93
2010–11	0.18	0.13	0.48	0.45	0.21	0.41	0.58	0.18	0.53	0.47	0.13	0.02	0.90	0.93
2011–12	0.18	0.13	0.53	0.45	0.41	0.34	0.51	0.48	0.87	0.67	0.13	0.28	0.90	0.93

Table 6: Spatial CPUE indices for Bounty smooth oreo, as estimated from preliminary spatial CPUE analyses and four different area-weighting scenarios.

Fishing	w_a=1	w_a=orh.adj	w_a=cc	w_a=cc.orh.adj
1994–95	1.60	1.67	1.61	1.90
1995–96	1.45	1.38	1.33	1.44
1996–97	1.30	1.25	1.19	1.22
1997–98	1.28	1.22	1.18	1.23
1998–99	1.26	1.23	1.26	1.37
1999–00	1.19	1.07	1.06	0.98
2000–01	1.10	1.10	1.07	1.04
2001–02	1.05	1.12	1.16	1.21
2002–03	0.92	0.96	0.93	0.93
2003–04	0.87	0.88	0.83	0.82
2004–05	0.82	0.89	0.84	0.81
2005–06	0.76	0.93	0.86	0.85
2006–07	0.67	0.79	0.73	0.81
2007–08	0.75	0.76	0.83	0.71
2008–09	0.84	0.82	1.01	0.86
2009–10	0.80	0.71	0.83	0.71
2010–11	0.60	0.55	0.56	0.48
2011–12	0.73	0.67	0.73	0.63

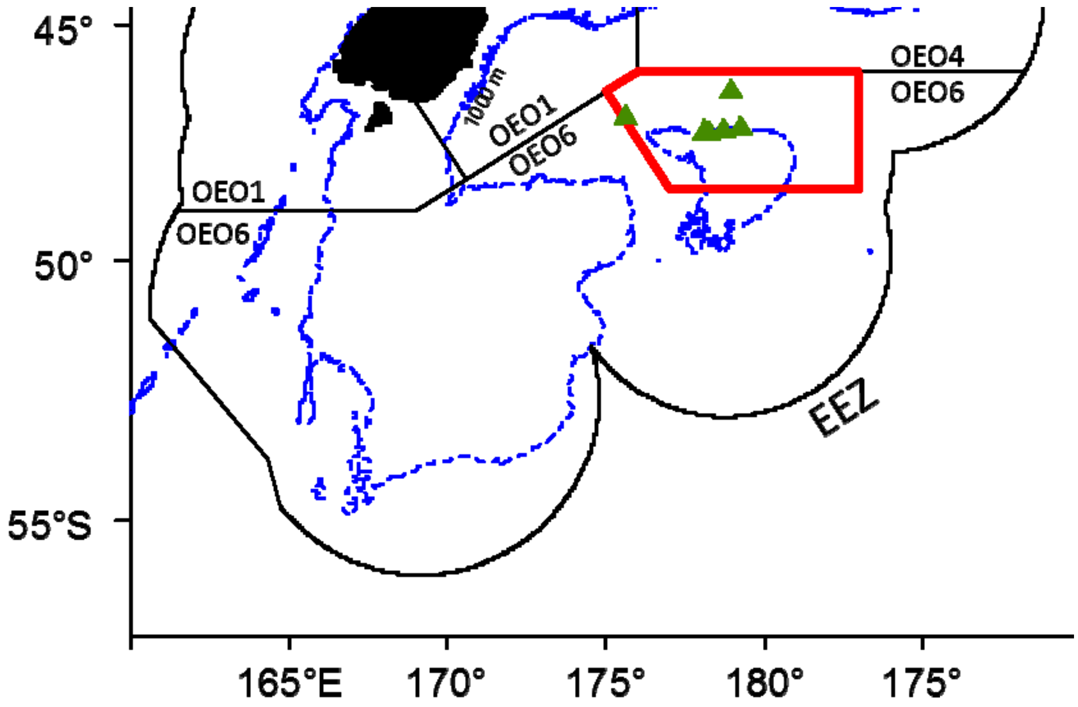


Figure 1: Southern portion of the New Zealand EEZ showing OEO management areas boundaries and the Bounty Plateau fishery within OEO 6 (in red). Green triangles correspond to recognised hills within the Bounty Plateau fishing grounds.

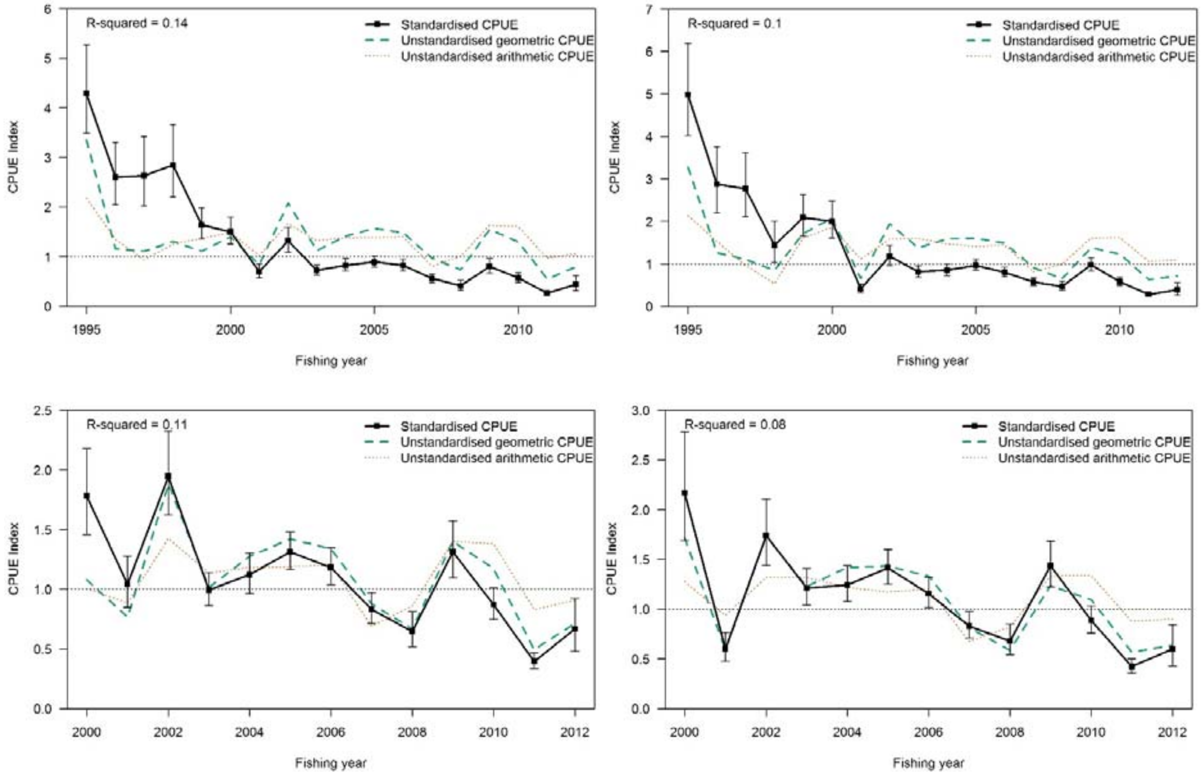


Figure 2: Standardized CPUE indices for Bounty smooth oreo (SSO). All target (left) and SSO/OEO target models (right) are shown for the 1995–2012 time series (top) and post-2000 time series (bottom), respectively. The final model is the all target, post-2000 (bottom left). Indices are presented using the canonical form (Francis 1999) so that the year effects were standardised to have a geometric mean of 1, shown by the dotted horizontal line.

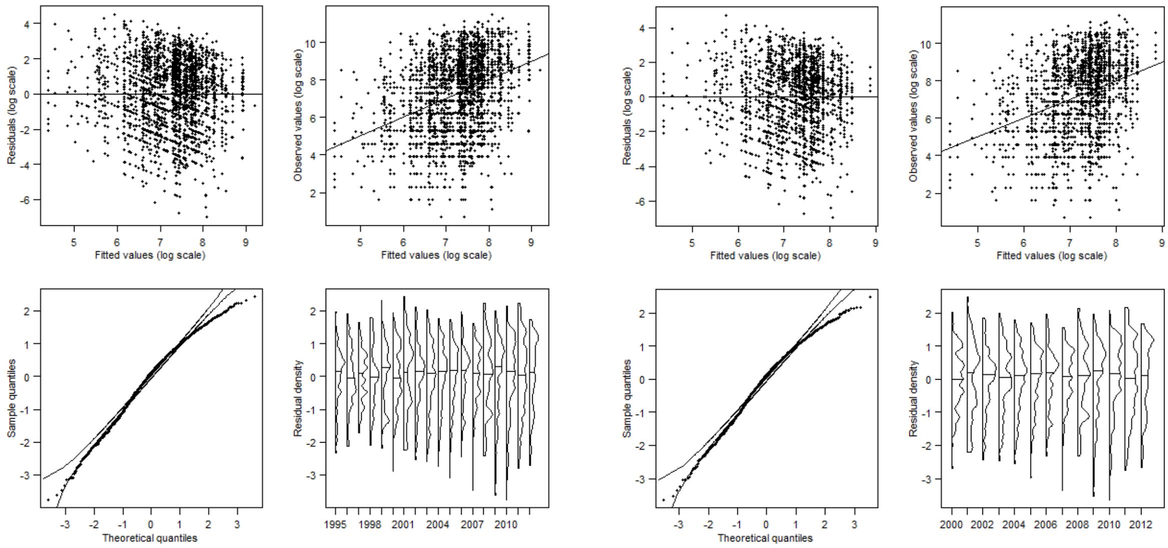


Figure 3: Residuals diagnostics plots for the all-target, lognormal CPUE models for Bounty SSO. (Left = model fitted on 1995–2012 time series data; Right = model fitted on post-2000 data only).

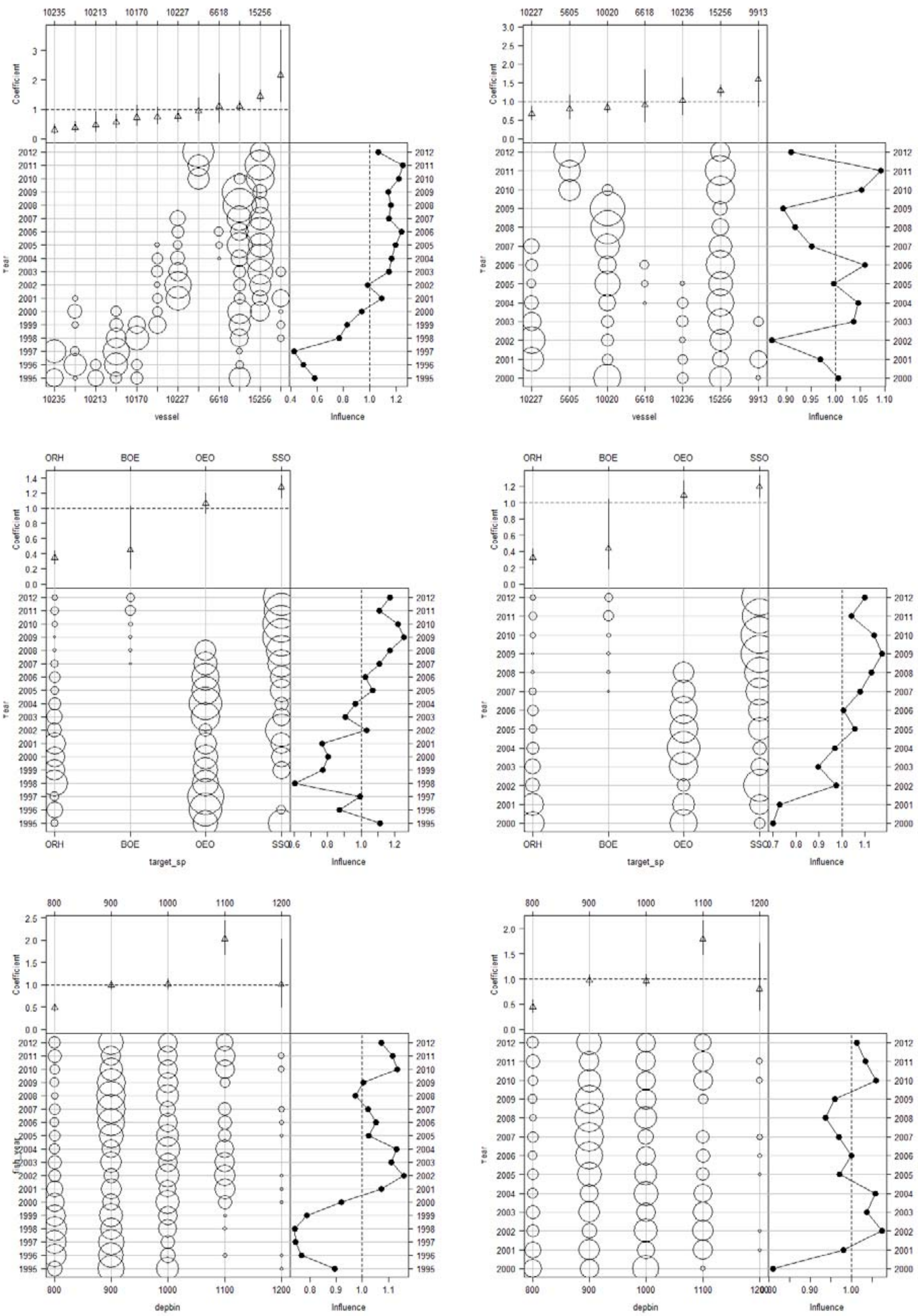
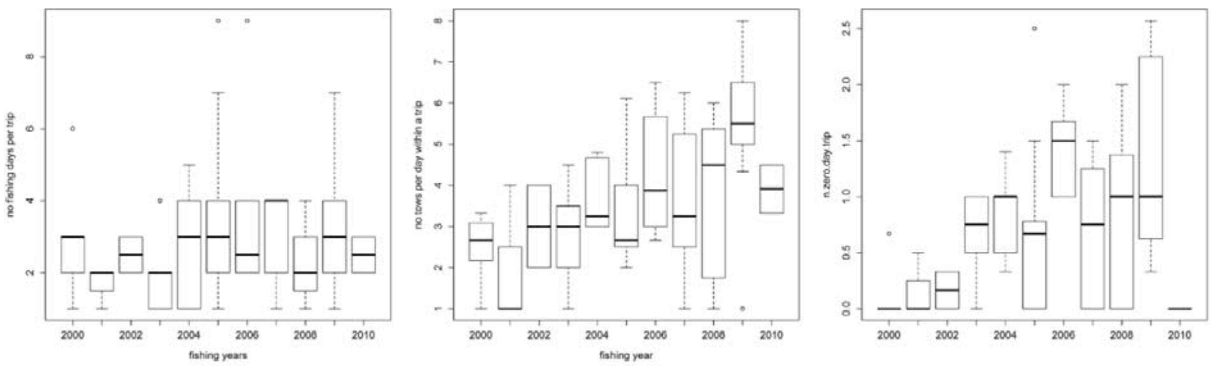


Figure 4: Coefficient-Distribution-Influence plots for selected variables in the 1995–2012 all target (left column) and post-2000 all target (right column) lognormal CPUE models for the Bounty SSO trawl fishery. Top row = vessel; middle row= target species and bottom row= depth strata. Each plot shows the relative effects by levels of the variable (top panel), the relative distribution of the variable by fishing year (bottom left panel) and the calculated influence of the variable on the unstandardized CPUE by fishing year (bottom right panel).ORH= orange roughy; SSO = smooth oreo; BOE =black oreo; OEO= unspecified oreo species.

A)



B)

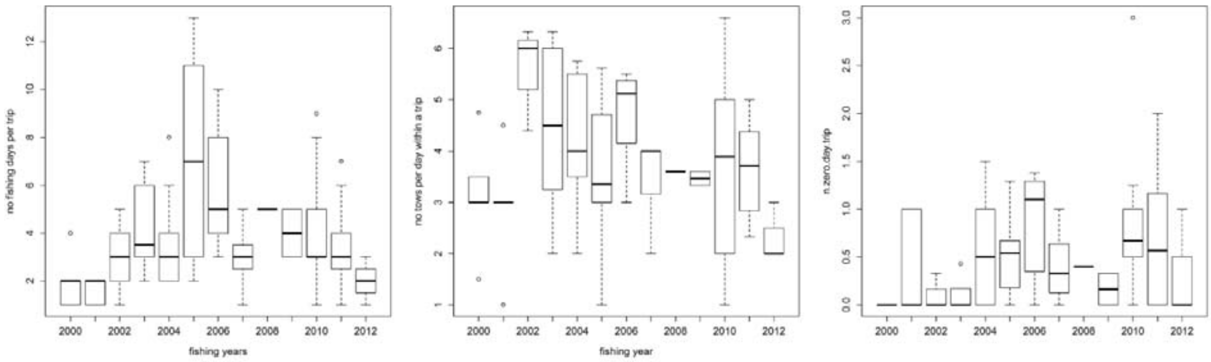


Figure 5: Inter-annual changes in search time as number of fishing days per trip (left), number of daily tows per trip (centre), and number of daily zero tows per trip (right) in two vessels (A and B) that fished for smooth oreo on the Bounty Plateau between 2000 and 2012.

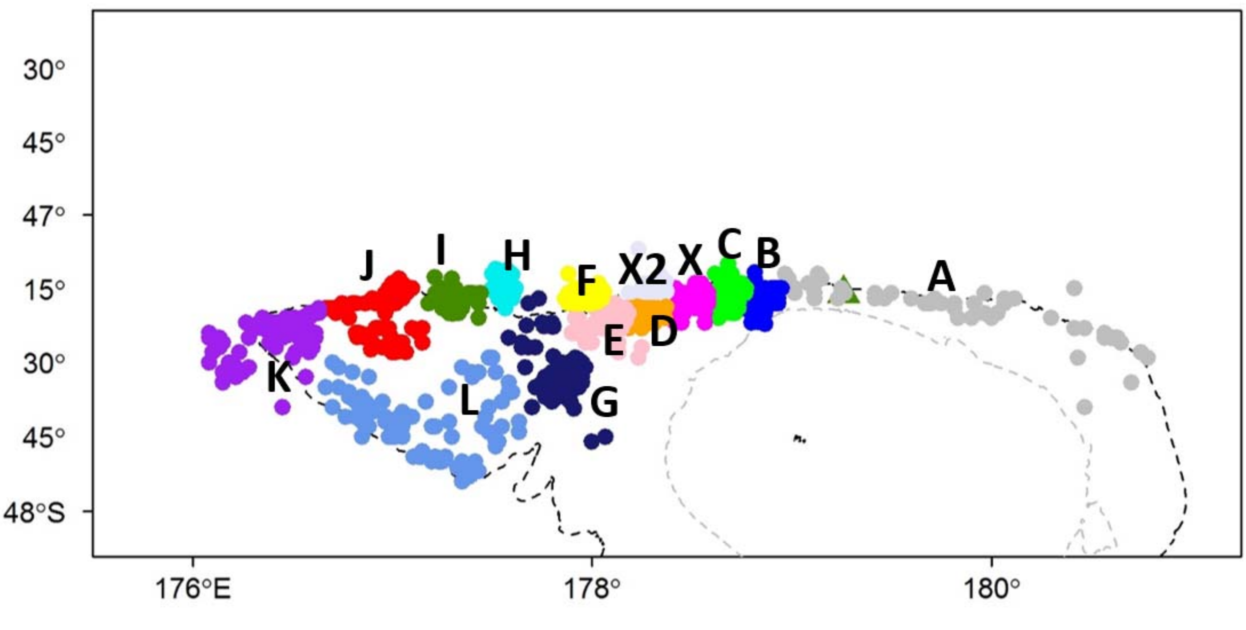


Figure 6. Spatial areas within the Bounty SSO fishery and total effort over the 1995–2012 fishery period. Each dot represents a tow. Area A = 69 tows; Area B = 669 tows; Area C =643 tows; Area X = 98 tows; Area D =463 tows; Area X2 = 193 tows; Area E =295 tows; Area F = 272 tows; Area G = 322 tows; Area H =232 tows; Area I = 223 tows; Area J = 222 tows; Area K =86 tows; Area L = 100 tows.

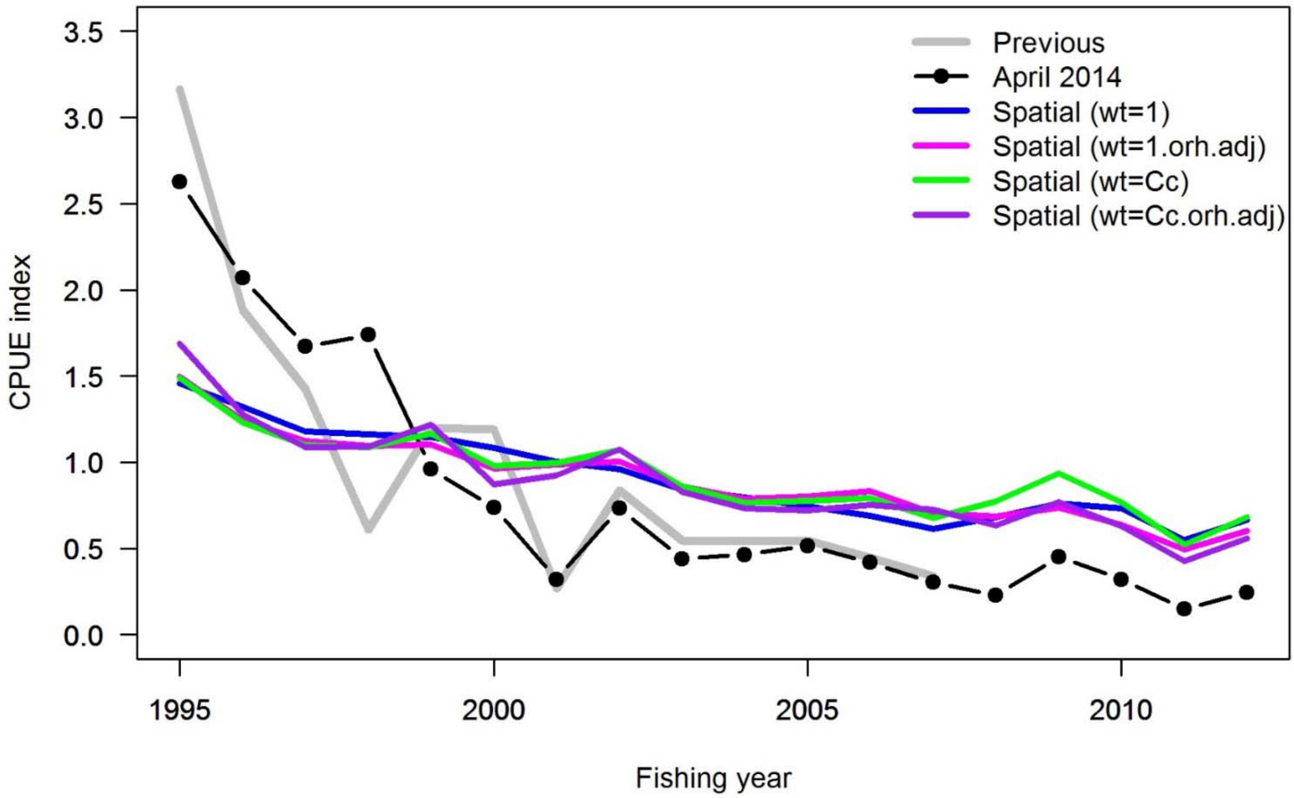
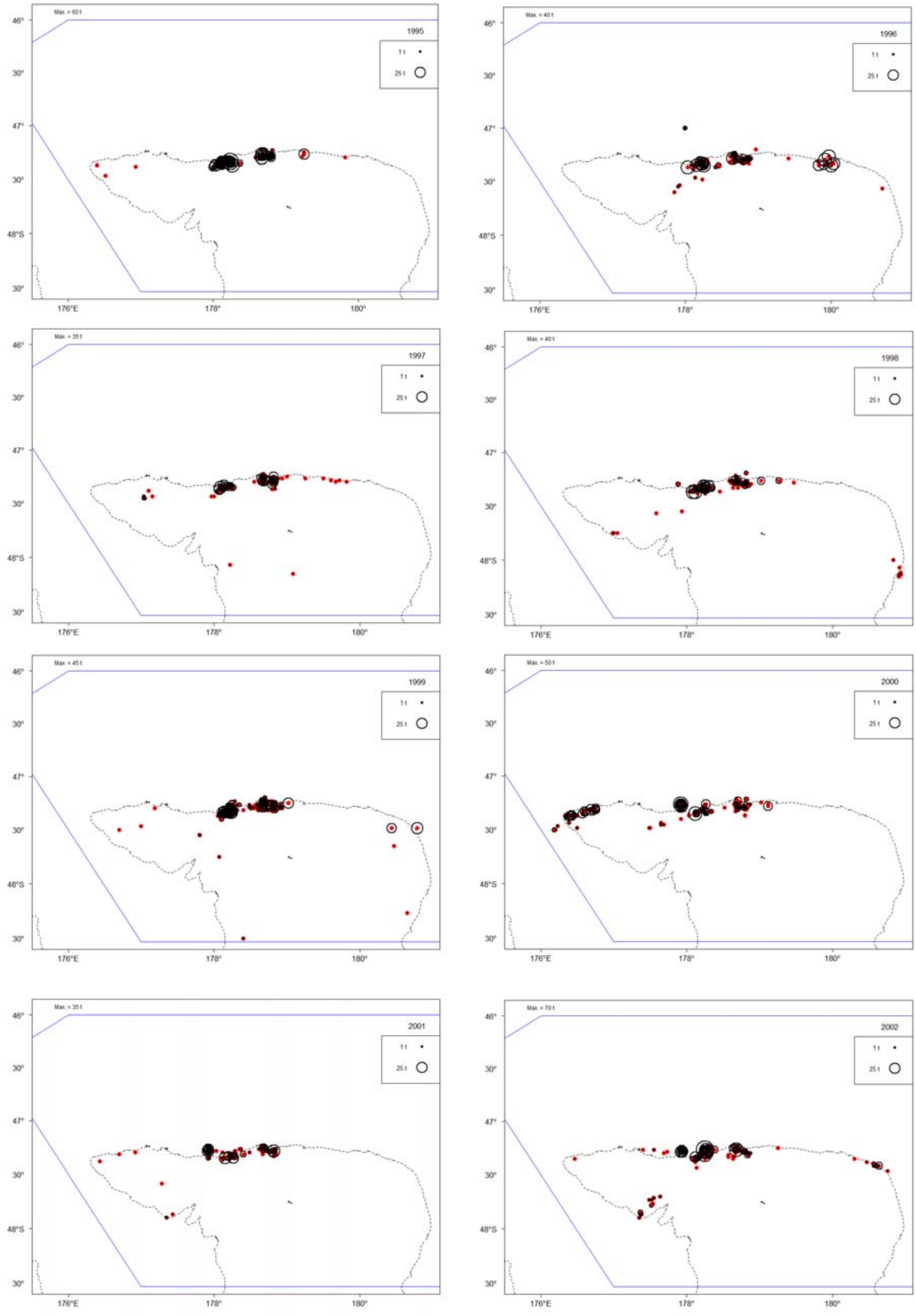
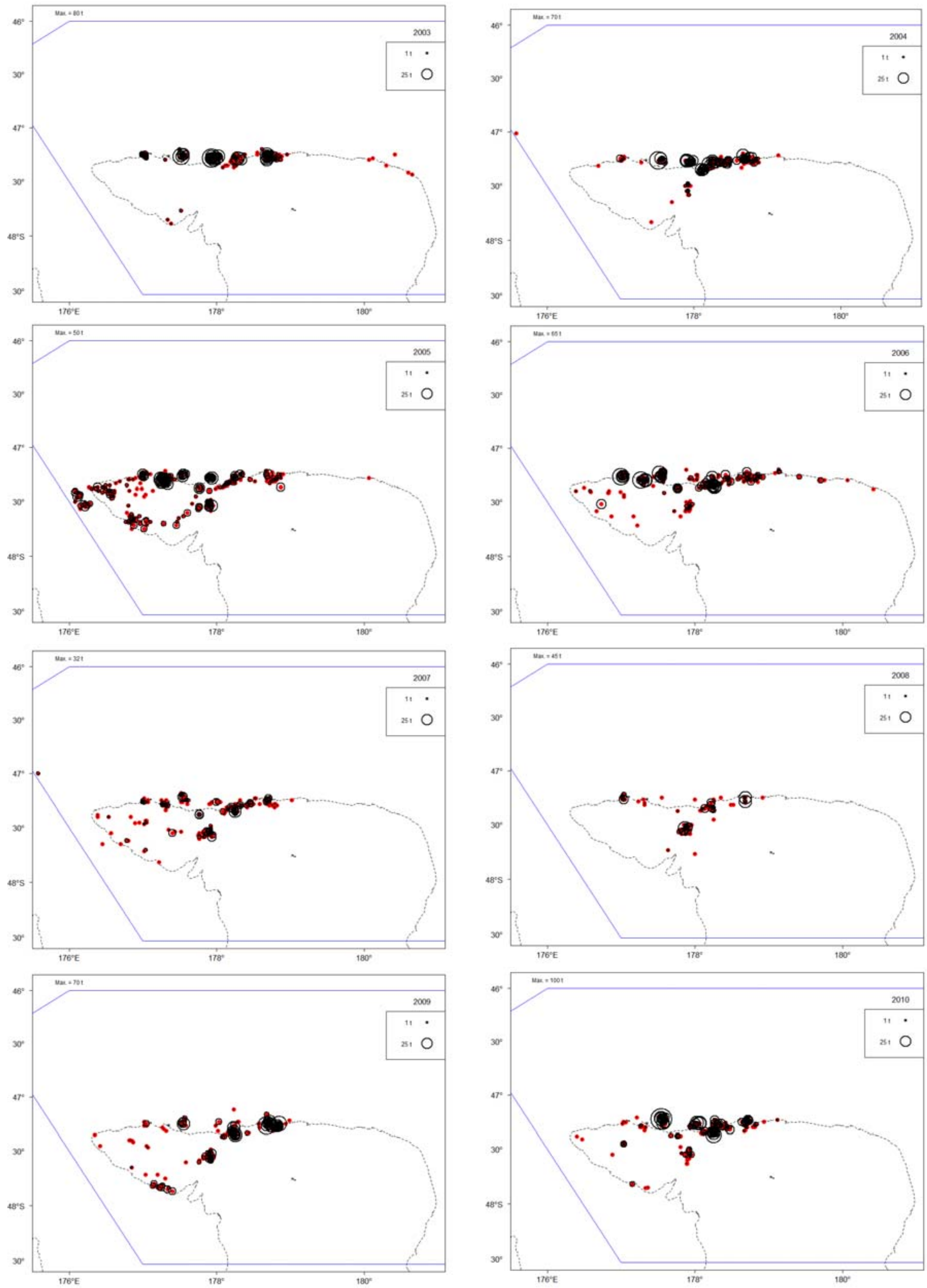


Figure 7: CPUE indices comparisons for Bounty smooth oreo, 1995–2012. 'Previous' is the standardised index developed by McKenzie & Coburn (2009). 'April 2014' corresponds to the all target, 1995–2012 standardised index developed and presented in Section 3.1 of this report.

APPENDIX 1 Spatial Distribution of annual tows (red dots) and catches of smooth oreo (black circles) on the Bounty Plateau, 1994–95 to 2011–12.



APPENDIX 1 (continued).



APPENDIX 1 (continued).