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EXECUTIVE SUMMARY

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This orange roughy CPUE analysis covers the area of Quota Management Area ORH 3B that includes the area of the northern Chatham Rise known as the Spawning Box, the eastern Chatham Rise Northeast Hills, Northeast Flats and Andes hill complexes, the South Chatham Rise Chiefs complex and Hegerville areas, and the Northeast Chatham Rise Graveyard area. The fishery developed in the 1980s, and since, catches then have declined following a series of catch quota reductions.

The area was split into six subareas: the Spawning Box, the Northeast Flats, the Northeast Hills, the Andes, the Chief complex, the Hegerville area, and the Graveyard complex.

Apart from the Spawning Box where we have not modelled the start of the fishery, there are considerable similarities amongst the standardised CPUE index trends. There are strong initial declines, sometimes not commencing until effort builds up in the second or third year of the fishery. During the 2000s the CPUE indices have all been substantially lower than before the decline. All fisheries, whether new or established, show considerable declines between 1992 and 1998, followed by an increase between 1998 and 2002 and a further decline. Only the very small Hegerville fishery shows a further slight increase after 2002. The anomalous fishery is the Northeast Flats where the CPUE index doubled between the late 1980s and the early 1990s. This can be explained by a change in fishing grounds at that time.

The standardised CPUE for the last three years of each fishery has reduced to between 8% and 30% of that of the first three years of each fishery. This is in agreement with previous analyses, with the notable exception of the Northeast Hills and Hegerville. Raw CPUE indices generally produced slightly higher figures, with the exception of Hegerville, where it was more in line with the 2005 analysis.

The Spawning Box post-closure CPUE does not show such a strong trend. The standardised CPUE of 2005–07 has reduced to 82% of that of 1995–97. It is recommended that the Spawning Box standardised CPUE be carried out as a single index over the entire fishery period with a split in 2000.

Fishing pressure was an explanatory variable for the Graveyard CPUE and the Northeast Hills CPUE starting in 1995. These two cases confirmed fishers’ belief that if another vessel had fished a hill before them their catch rate would be lower. Vessel was also an explanatory variable for a number of models, with individual vessels performing better than others consistently across the different areas.

This document is a final report on work carried out as part of the Ministry of Fisheries project ORH2007/02. It covers parts of Objective 2 (“*to update unstandardised and standardised CPUE*”) that concern parts of the ORH 3B fishery.

1. INTRODUCTION

Orange roughy are the focus of an important deepwater fishery in New Zealand, and have been fished for over 20 years (Ministry of Fisheries Science Group 2007). Quota Management Area ORH 3B extends from the northern edge of the Chatham Rise, off the east coast of the South Island, south and west to encompass most of the southern region of the EEZ. The area has been subdivided at 46° S for some years now, which separates the Chatham Rise from areas to the south. For the management of ORH 3B, further subdivisions have taken place; those on the Chatham Rise are described in Figure 1.

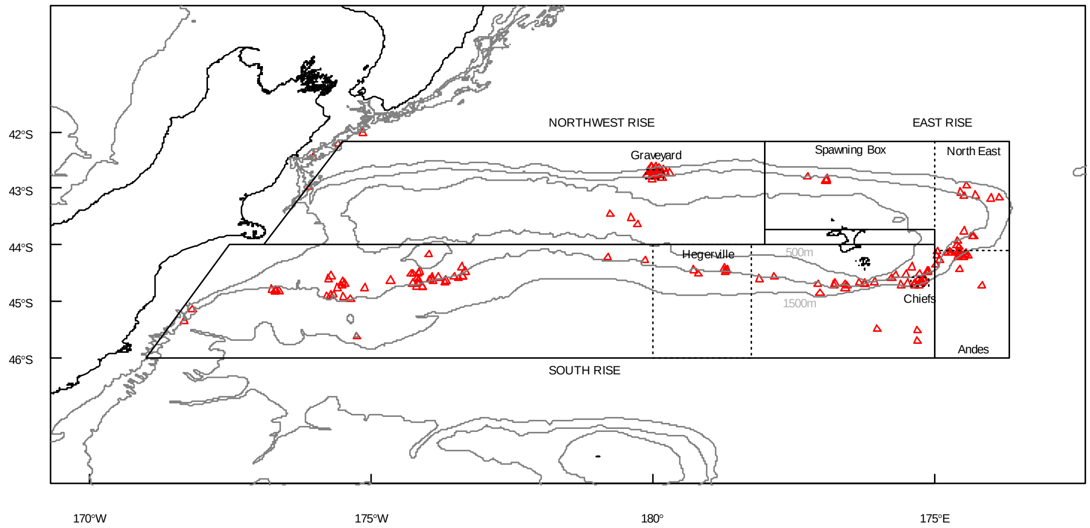

Figure 1: Map of locations of fisheries within ORH 3B. Triangles represent the location of known seamounts.

This report addresses the estimation of catch per unit effort abundance indices in parts of the East Rise (Spawning Box, Northeast Hills, Northeast Flats, and Andes), parts of the South Rise (Chiefs complex and Hegerville complex) and the Graveyard complex in the Northwest Rise. The fishery is described in detail elsewhere (Dunn 2008a).

These areas have been chosen for analysis because they represent all the main hill fisheries on the Chatham Rise and in the main spawning area. The only areas of the Chatham Rise orange roughy fishery not covered here are the Northwest Flats and the Spawning Box pre-closure (before 1994–95). The South Rise Flats standardised CPUE was carried out by Dunn et al. (2008); this area has hardly been fished since 2000–01 and therefore an updated index is expected to be flat. The Northwest Flats standardised CPUE to 2004–05 was carried out by A. McKenzie (NIWA, unpublished results); there again little fishing has occurred since 2005 and an updated index is not expected to provide much further information. Finally the pre-spawning Spawning Box standardised CPUE has been carried out a number of times (Ministry of Fisheries Science Group 2007). With no extra data to add it was not updated here.

This report addresses parts of objective 2 of the Ministry of Fisheries project ORH2007/02 that deal with the ORH 3B fishery: "*To update the unstandardised and standardised catch per unit effort analyses with the inclusion of data up to the end of the 2006/07 fishing year*".

A couple of conventions are used in the remainder of the document. The following general convention on fishing years is applied throughout: fishing years are referred to by the latter year of the fishing season, for example fishing year 1998 refers to fishing which occurred between 1 October 1997 and 30 September 1998. Years used in the document are all fishing years. Additionally, the core figures (Figures 1–8) and tables (Tables 1–15) have been included in the body of the text, and supplementary information can be found in the Appendix.

2. METHODS

2.1 Fishery data source and treatment

The data used for the CPUE analyses were groomed as part of ORH2007/02 Objective 1 (Dunn 2008a). They consisted of TCEPR data only, since there were very few CELR data in these areas. The data covered the 1980 to 2007 fishing years.

The data used for the Northwest Rise, Spawning Box and East Rise included only tows where orange roughy was targeted or caught. Because of the important overlap of the oreo and orange roughy fisheries in the South Rise area, data used for this area included not only tows where orange roughy was targeted or caught, but also tows where any species of oreo (black, smooth, or unspecified) were targeted.

The data used in the present analysis did not contain all tow end locations and therefore the analysis could not be carried out at a tow line level. A *coordinate* variable was created, whereby start positions were allocated to squares of 2’x2’ in size (0º02’ longitude by 0º02’ latitude). This size was chosen because the sides of the box correspond to the median length of an orange roughy tow in the area (2n. miles).

The following explanatory covariates were added to the dataset, with their type in parentheses (categorical or continuous).

- *Coordinate* (categorical): location of each tow, rounded down to the nearest 0º02’ longitude by 0º02’ latitude.
- *Tow type* (categorical): for each tow, the distance of this tow to the nearest known hill was calculated. Individual tows were then categorised as “*hill”* tows if within 1.5 n. miles of the nearest hill, “*flat”* tows if further than 5n. miles from the nearest hill and “*near hill”* otherwise. This categorisation was carried out at tow level and not coordinate level, with each individual coordinate potentially comprising a mixture of *hill*, *near hill,* and *flat* tows.
- *Tow duration* (categorical): tows were categorised as “*short”* if 30 minutes or less in duration and “*long”* otherwise. This categorisation provides a rough guide if tows were carried out specifically on acoustic marks and therefore aggregations or not.
- *Experience* (continuous): each vessel each year was given an *experience* value, being the number of years the vessel has been in the fishery starting from 1980. The use of this variable assumes that vessels gain experience in the fishery, which implies that skippers and crews remain with their vessel throughout. It also ignores any experience before 1980.
- *Fishing pressure* (continuous): three such variables were calculated for each tow. They are the number of tows carried out in a 2’x2’ square within the last 12 hours, 2 days, or 10 days. This pressure area is not equivalent to the coordinate the tow has been carried out in unless the tow started exactly in the centre of the coordinate.
- Three different season categories (categorical): *two months* (Oct-Nov, etc), *quarters* (Oct-Jan, etc) or *spawning*, “*spawning*” being defined here as the months of June and July only and non-spawning being August to May.

- *Depth-bin* (categorical): 100 m bins with a 600 m or less low bin and 1300 m or more upper bin.
- *Depth category* (categorical): "*shallow*" if less than 915 m depth, or "*deep*" otherwise, may have biological significance as suggested by other analyses (Dunn 2007).
- *Depth-bin* for the Spawning box (categorical): <685 m, 685–850 m, 850–950 m, 950–1100 m, 1100–1250 m, >1250 m. This follows the categories used in the last ORH 3B assessment and accounts for behaviour of orange roughy in the Spawning Box described by Dunn (2007).
- *Longitude bin* for the Spawning Box (categorical): east of 178° W, 177.36° W, 176.72° W, 176.2° W, and 176° W. These are roughly equivalent to west of the spawning plume, the spawning plume, between the spawning plume and Mt. Muck, Mt. Muck, and east of Mt. Muck (Dunn 2007).

2.2 Data selection

Only coordinates that have been consistently fished were included in the analysis. For example, out of 1500 coordinates fished on the East Rise, only 100 have been fished 50 times or more during the fishery. The rule used in this analysis is as follows: coordinates that were fished 3 times a year for at least 8 years of the fishery were retained.

In the South Rise dataset, core coordinates were initially selected as described above. Of these coordinates, the ones where no tow was ever targeted at orange roughy and where over 90% of captures in weight over the entire fishery was cardinalfish were removed from the analysis as they clearly represent a different fishery.

The remainder of the data selection was as per previous analyses (Dunn 2007).

- A continuity rule was applied to ensure that the vessel effect could be estimated: vessels that had completed 20 or more tows per year and been in the fishery 3 or more years were included (relaxed to 5 tows per year and 3 years in the fishery for the Hegerville area due to the low number of tows).
- Tows were removed if they were suspected to have "come fast": the criteria used to identify this were tow duration less than 6 minutes, start and finish position the same, and orange roughy catch less than 100 kg.
- All tows from the fishing year 1989 were excluded, as data were considered suspect for this year. This was confirmed during previous analyses (Dunn 2007), where some clear errors in the catch data were found.
- Records were removed where any of the predictor variable fields were null.
- Any tow distance, duration, or time start value of zero was set at 0.01 to allow its use in the model.

It was determined that there was no obvious trend in the data removed, with, for example, a similar proportion of zero catch tows in all years. Therefore it was not anticipated that this data selection introduced a large amount of bias. Some bias was still detected during analyses.

2.3 Model fitting

The standardised CPUE analyses were carried out by fitting a generalised linear model to CPUE. The units of CPUE used were tonnes of orange roughy caught per tow (tonnes per hour for the Spawning Box area where there was a mixture of short and long tows).

For all areas but the South Rise, the proportion of tows with a zero catch was small (8% of all tows with no evident time trend), therefore a single normal model was used, with a normal error distribution and identity link function. The proportion of tows with a zero catch in the South Rise was over 10% and therefore a combined model was used for this area: a binomial model was used to predict if a tow caught orange roughy or not using a logistic distribution, and a normal model was used for the tows that caught orange roughy.

The predictand used was log (CPUE). For each model, the suitability of this transformation was checked by calculating the optimal lambda value using the Box-Cox transformation (Venables & Ripley 1994). In all cases the lambda value was close to 0, confirming that a log transformation was a suitable approximation of the best possible transformation of the data.

Contrasts were set up for all categorical variables. For each of those, the base case was set as the option with most tows. For example, in the Spawning Box, most fishing occurs during the spawning season and therefore the base case for the variable *spawning* was set as "*spawning*".

The predictor variable *fishing year* was forced into the model, and the other variables were tested for inclusion. Variables were added one at a time starting with that which reduced the variance most. Variables were added until the r^2 increase was less than 0.01. Once this limit was reached, it was checked that the added residual deviance of this last added variable accounted for more than 1% of the null residual deviance, and that the following significant variable would not have accounted for more than 1% of the null residual deviance. This was the case each time. Potential interaction variables were then checked for and added if suitable. Interactions with *fishing year* were not allowed. Finally, QQ plots were made to check the validity of the mathematical model and plots of individual coefficients were made to check the model predictions made sense.

The potential explanatory variables available to the models were as follows.

- Continuous variables (untransformed): time of tow start, latitude at start, longitude at start.
- Continuous variable (log scale and second degree polynomial): experience
- Continuous variables (log scale and third degree polynomial): depth, speed, tonnage, fishing day number, distance of tow, duration of tow, distance from nearest hill, 12 hours fishing pressure, 2 day fishing pressure, 10 day fishing pressure.
- Categorical variables: fishing year, month, vessel ID, registration number of nearest hill, depth bin, longitude bin (for the Spawning Box), coordinate, tow type, tow duration, season bin.

Any variable included in any model is subsequently referred to by its name only, with no mention of the transformation carried out; those transformations are assumed throughout.

3. RESULTS

3.1 Andes complex

The Andes fishery essentially started in 1992, with a very few tows carried out in 1991. Short hill tows are characteristic of this fishery, with no flat tows in the core dataset, and very few long tows. Therefore the CPUE was standardised based on short tows on or near hills carried out between 1992 and 2007.

The core fleet during this period was made up of 11 vessels, with some overlap in the fleet composition throughout this time, i.e., in no fishing year was the fleet operating completely new to the fishery. The area covered consisted of 8 major hills (11 hills total) and 9 main coordinates (19 in total), of which 6 have been fished only since 1999. Bubble plots of the core vessels fishing in the Andes and that of the core coordinates being fished are given in the Appendix (Figure 9).

Two CPUE models were fitted to the data: one using the entire period (1992 to 2007) and the other using only data from 1995. The aim of the second model was to check the effect of removing the initial steep decline of CPUE on the rest of the series.

The full CPUE model explained 16% of the deviance and that starting in 1995 explained only 8.6% deviance whilst including five extra coefficients. The reason is that *fishing year* is able to explain some of the variability associated with the catch rate decline in the early years but much less of the lesser decline in later years. The variables retained for inclusion are detailed in Table 1, Figure 10 and 11 (in the Appendix) show the fishing year indices, other coefficients, and QQ plots for the Andes standardised CPUE series starting from 1992 and 1995 respectively. The QQ plots show slight evidence of departure from assumptions of normality and suggest that the upper tail is somewhat shorter than the model predicts, especially for the 1992–2007 series.

Table 1: Details of change in deviance for the Andes standardised CPUE models, Df, degrees of freedom; Dev., deviance; Resid. Df., residual degrees of freedom; Resid. Dev., residual deviance; % dev, percentage deviance explained

	from 1992 to 2007					from 1995 to 2007				
	Df	Dev.	Resid. Df	Resid. Dev	% dev	Df	Dev.	Resid. Df	Resid. Dev	% dev
NULL			6603	19453.6				5063	14095.1	
Fishing year	15	2701.1	6588	16752.4	13.89	12	606.3	5051	13488.8	4.30
Vessel	10	449.0	6578	16303.5	2.31	8	447.8	5043	13041.0	3.18
Name hill						10	165.8	5033	12875.1	1.18
					16.19					8.65

The raw and predicted standardised CPUE series are detailed in Table 2, with the results from the 2005 analysis (Dunn et al. 2008). The raw CPUE is defined as the yearly median catch in tonnes of the tows selected for standardisation; in this case, core coordinates, core fleet, short tows on or near hills. The relative CPUE series are shown in Figure 2, whereby the standardised CPUE is plotted with no change, and every other CPUE trend is plotted such that its mean has the same mean as the corresponding period of the standardised CPUE. This way all trends are comparable yet the scale is still meaningful.

Table 2: Standardised CPUE series for the Andes: the orange roughy catch used in the analysis in tonnes, the present analysis from 1992 (92–07) and its lower and upper confidence interval values (Lower / Upper CI (92–07)), the present analysis from 1995 (95–07), the results of the 2005 analysis, and raw CPUE results.

Fishing year	Catch analysed	92–07	Lower CI (92–07)	Upper CI (92–07)	95–07	2005 analysis	Raw CPUE
1992	4848	9.89	7.46	13.13		6.03	5.00
1993	2652	9.30	6.83	12.66		4.81	5.00
1994	3007	5.29	3.99	7.01		3.27	2.00
1995	1395	2.60	1.96	3.45	3.35	1.40	1.00
1996	1062	1.73	1.29	2.30	1.49	0.82	0.50
1997	643	1.72	1.30	2.28	2.12	0.88	1.00
1998	1009	1.19	0.93	1.54	1.49	0.70	0.50
1999	1178	1.59	1.25	2.02	1.74	0.89	1.00
2000	1923	1.90	1.51	2.40	2.06	1.05	1.00
2001	886	1.46	1.19	1.78	1.61	0.63	1.20
2002	1887	1.69	1.46	1.97	1.85	0.77	1.44
2003	1967	1.18	1.04	1.35	1.27	0.60	0.96
2004	1034	0.89	0.76	1.03	0.95	0.42	0.50
2005	1022	1.00	0.84	1.17	1.07	0.50	0.60
2006	1352	0.85	0.73	0.99	0.89		0.53
2007	1091	0.76	0.64	0.89	0.81		0.53

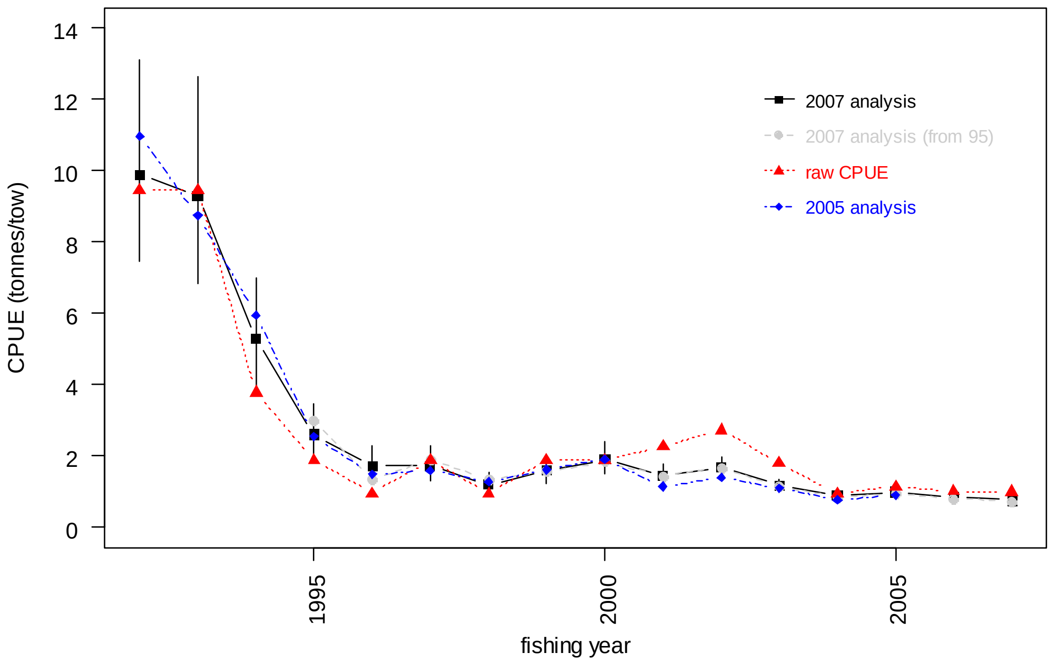

Figure 2: CPUE trends for the Andes complex, relative to the standardised CPUE.

The full model included only *fishing year* and *vessel* variables. The model obtained using the shortened CPUE varied from that with the entire CPUE by the reduction in the percentage variance explained and the introduction of the *hill* variable in the model. The model obtained in 2005 was far more complex again, with a number of other variables included, namely *fishing pressure*, *month*, and *depth*. However, it is worth noting the cut-off used in the 2005 analyses was 0.05% increase deviance explained and not 1% deviance as used in the present analysis, which would have the potential of serious overfitting (adding more variables to the model). The 2005 analysis did not restrict itself to core coordinates.

The standardised CPUE trends obtained were very similar whether the series was started in 1992 or 1995, and similar to the results obtained from the 2005 standardisation. After an initial strong decline between 1992 and 1998, the CPUE trends show a small increase to 2000 then a further decline to 2007. The standardised CPUE over the last three years is 10.6% that of the first three years of the fishery, and the equivalent raw CPUE figure is 13.8%.

3.2 Northeast Hills complex

The Northeast Hills fishery started in 1991. As with the Andes complex, short hill tows are characteristic of this fishery, with no flat tows in the core dataset, and very few long tows. Therefore the CPUE was standardised based on short tows on or near hills carried out between 1992 and 2007.

The core fleet during this period was made up of 10 vessels, with some overlap in the fleet composition throughout this time, but limited overlap in 2000. The area covered consisted of 4 major hills (7 hills total) and 4 main coordinates (14 in total). Two of those 14 core coordinates have been consistently fished only since 2002. Bubble plots of the core vessels fishing in the Northeast Hills and that of the core coordinates being fished are given in the Appendix (Figure 12).

As for the Andes fishery, two CPUE models were fitted to the data: one using the entire period (1992 to 2007) and the other using only data from 1995.

The full CPUE model explained 34% of the deviance and that starting in 1995 explained only 12% deviance whilst including 17 extra coefficients. As in the previous model, the reason is that *fishing year* is able to explain some of the variability associated with the catch rate decline in the early years, but much less of the lesser decline in later years. The variables retained for inclusion are detailed in Table 3. Figure 13 and Figure 14 (in the Appendix) show the fishing year indices, other coefficients, and QQ plots for the Northeast Hills standardised CPUE series starting from 1991 and 1995 respectively. The QQ plots show slight evidence of departure from assumptions of normality and suggest that the upper tail is somewhat shorter than the model predicts, especially for the 1992–2007 series.

Table 3: Details of change in deviance for the Northeast Hills standardised CPUE models, Df, degrees of freedom; Dev., deviance; Resid. Df., residual degrees of freedom; Resid. Dev., residual deviance; % dev, percentage deviance explained

	from 1991 to 2007					from 1995 to 2007				
	Df	Dev.	Resid. Df	Resid. Dev	% dev	Df	Dev.	Resid. Df	Resid. Dev	% dev
NULL	NA	NA	3553	9866.9		NA	NA	2305	6274.2	
Fishing year	16	1410.8	3537	8456.1	14.30	12	240.2	2293	6034.1	3.83
Month	11	279.2	3526	8177.0	2.83	11	241.4	2282	5792.7	3.85
Vessel						8	73.8	2274	5718.9	1.18
Depth bin						6	74.2	2268	5644.6	1.18
Fishing pressure						3	97.3	2265	5547.4	1.55
					17.13					11.59

The raw and predicted standardised CPUE series are detailed in Table 4, with the results from the 2005 analysis (Dunn et al. 2008). The relative CPUE series are shown in Figure 3.

Table 4: Standardised CPUE series for the Northeast Hills: the orange roughy catch used in the analysis in tonnes, the present analysis from 1991 (91–07) and its lower and upper confidence interval values (Lower / Upper CI (91–07)), the present analysis from 1995 (95–07), the results of the 2005 analysis, and raw CPUE results.

Fishing year	Catch analysed	91–07	Lower CI (91–07)	Upper CI (91–07)	95–07	2005 analysis	Raw CPUE
1991	3678	5.24	4.26	6.46		5.75	4.00
1992	2092	3.00	2.35	3.84		2.92	2.33
1993	828	3.97	2.81	5.62		3.17	2.25
1994	848	3.12	2.36	4.13		2.48	2.80
1995	1292	1.81	1.45	2.24	3.20	1.43	1.00
1996	649	1.74	1.32	2.29	1.65	1.33	1.00
1997	915	1.93	1.50	2.49	1.65	1.15	1.50
1998	473	0.81	0.61	1.07	0.82	0.52	0.40
1999	944	1.26	1.00	1.59	1.27	0.80	0.75
2000	799	1.32	1.00	1.73	1.06	0.86	1.00
2001	627	1.36	1.05	1.76	0.93	1.00	1.20
2002	866	1.38	1.06	1.79	1.03	0.75	1.00
2003	805	1.03	0.81	1.32	0.71	0.56	0.80
2004	367	0.86	0.65	1.14	0.60	0.52	0.75
2005	350	1.02	0.76	1.39	0.68	0.54	0.80
2006	440	1.06	0.80	1.42	0.68		0.68
2007	556	0.67	0.52	0.87	0.42		0.52

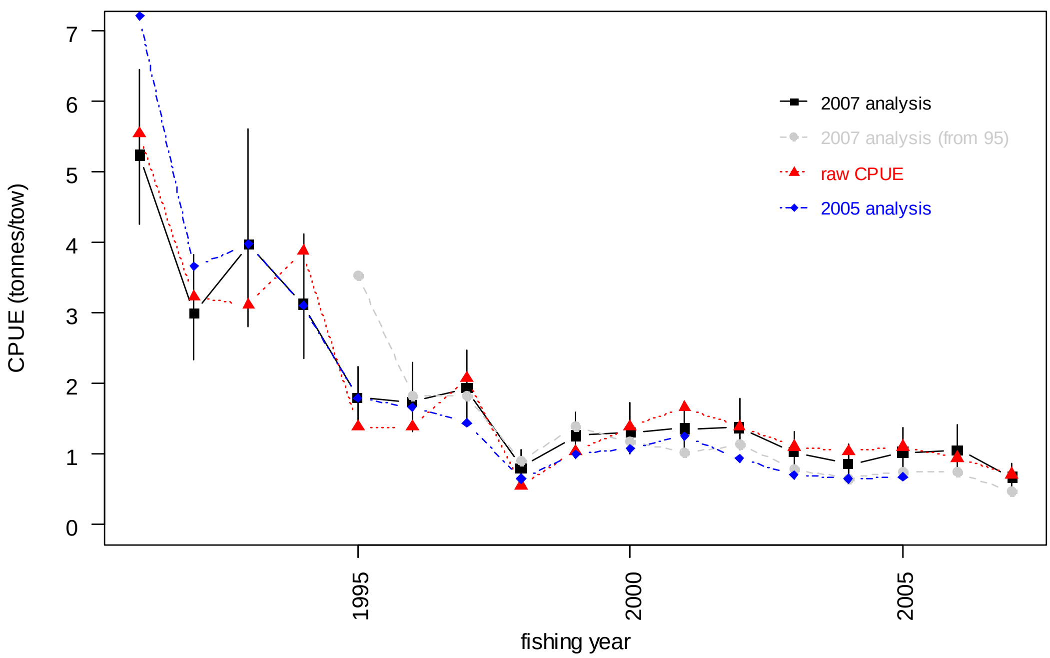

Figure 3: CPUE trends for the Northeast Hills complex, relative to the standardised CPUE.

The full model included only *fishing year* and *month* variables. Unlike the Andes variable, the vessel effect was not considered significant, but the fishing exhibited a strong month effect, with higher catch rates during spawning season (June and July). The model obtained using the shortened CPUE varied from that with the entire CPUE by the reduction in the percentage variance explained and the introduction of the *vessel, depth bin*, and *fishing pressure* variables in the model, each explaining less than 2% of the deviance. The model obtained in 2005 was similar to that obtained for the shortened CPUE and presents the same differences as explained in the previous section.

In both the shortened CPUE and the 2005 model, *fishing pressure* appears in the model. It shows a decreasing CPUE with increasing fishing pressure. This is in agreement with the fishing industry perception that any prior fishing will disturb aggregations and therefore reduce the size of the catch.

The full standardised CPUE trend obtained was similar to the raw CPUE. The shortened CPUE trend was more pessimistic, with increased CPUE at the start of that series in 1995. The results obtained in 2005 were also slightly more pessimistic than the full standardised CPUE, with slightly higher CPUE at the start of the series and lower at the end of the series. The general trend is similar to that of the Andes, with an initial strong decline between 1992 and 1998, a small increase to 2000, then a further decline to 2007. The standardised CPUE over the last three years is 29.6% that of the first three years of the fishery, the equivalent raw CPUE figure is 32.1% when the equivalent calculated on the previous model is only 13.7%. This large difference might be partly attributable to the impact of "exploratory fishing", which would have been captured in the 2005 analysis but excluded in the present analysis through the coordinates selection.

3.3 Spawning Box post-closure

The Spawning Box area was the original orange roughy fishing ground on the Chatham Rise and has been fished since the late 1970s. These grounds were closed to fishing in 1993 and 1994. The two periods are historically considered as different CPUE indices, respectively pre-closure and post-closure (Langley 2001, Ministry of Fisheries Science Group 2006). Pre-closure standardised CPUE has been studied for a number of years and was not repeated here. The post-closure index was started in 1995.

The results below were adopted by the Deepwater Working Group. However, it is not clearly documented why the CPUE index was historically split at the time the fishery was closed. A study of the entire fleet fishing in the Spawning Box throughout the fishery (Appendix, Figure 15) suggests a large change in the fleet in 2000 which could prompt the start of a new CPUE index then but not in 1993. The timing of the fishery itself changed from mainly a spawning fishery to a year-round fishery in 1996 (Appendix, Figure 16), but such a change could possibly be taken into account in a single model with the use of month as a descriptive variable. It is recommended that the Spawning Box fishery be studied as a single index from 1980 in the future, with a possible break in 2000.

Unlike in the Andes and Northeast Hills areas, the Spawning Box orange roughy fishery is characterised by a mixture of long and short tows on flat or near hill areas. Most of these tows are carried out during the spawning season (June and July), but the fishery operates throughout the year. Therefore the CPUE was standardised using all tows from 1995 onwards, and was described in terms of tonnes/hour rather than tonnes/tow. An alternative would have been to carry out the CPUE standardisation based on tonnes/tow and have the tow duration as a potential explanatory variable. The first option was chosen. The raw CPUE presented different trends when plotted as tonnes/tow and tonnes/hour.

The core fleet during this period was made up of four vessels, with only one vessel fishing pre- and post-2000. Dunn (2007) reduced his time series to 2000 onwards. I decided to take the entire time series into consideration and compare it to the raw CPUE and the previous results. The core area consisted of 50 coordinates, over half of which were little fished. The two areas fished most in 1995 were not fished much in the subsequent years. Bubble plots of the core vessels fishing in the Spawning Box from 1995 onwards and that of the core coordinates being fished are given in the Appendix (Figure 17).

The initial CPUE model requested *tow duration* as an explanatory variable, with a very high CPUE at tow duration close to zero, dropping down to almost zero with higher tow duration. This behaviour was deemed an artefact of the different behaviour of short and long tows, where short tows are typical of fishing aggregations on hills, and long tows are carried out on flat grounds with diffuse marks. Therefore the *tow duration* variable was taken out of the model. It was replaced by the categorical variable for "*short*" or "*long*" tows. The final CPUE model starting from 1995 explained 57% of the deviance, with *tow duration* replaced by the *tow duration* categorical variable If *coordinates* was removed, this variable was replaced by *depth bin*, with the loss of 3% deviance. The variables retained for inclusion are detailed in Table 5. Figure 19 (in the Appendix) shows the fishing year indices, other coefficients, and QQ plots for the Spawning Box post-closure standardised CPUE series starting from 1995. The QQ plots show slight evidence of departure from assumptions of normality and suggest that the upper tail is somewhat shorter than the model predicts.

Table 5: Details of change in deviance for the Spawning Box post-closure standardised CPUE models Df, degrees of freedom; Dev., deviance; Resid. Df., residual degrees of freedom; Resid. Dev., residual deviance; % dev, percentage deviance explained

	Df	Dev	Resid. Df	Resid. Dev	% dev
NULL	NA	NA	1640	9045.2	
Fishing year	12	213.3	1628	8831.9	2.36
Tow duration (short/long)	1	3089.7	1627	5742.2	34.16
Month	11	1433.5	1616	4308.7	15.85
Coordinates	48	469.0	1568	3839.7	5.18
					57.55

The raw and predicted standardised CPUE series are detailed in Table 6, with the results from the 2005 analysis and of the acoustics survey (Dunn 2007). The relative CPUE series are shown in Figure 4, whereby the standardised CPUE is plotted with no change, and the other indices are plotted such that its mean has the same mean as the corresponding period of the standardised CPUE.

Table 6: Standardised CPUE series for the Spawning Box post-closure: the orange roughy catch used in the analysis in tonnes, the present analysis from 1995 (95–07) and its lower and upper confidence interval values (Lower / Upper CI (95–07)), the results of the 2005 analysis, raw CPUE results, and biomass calculated from the acoustic surveys.

Fishing year	Catch analysed	95–07	Lower CI (95–07)	Upper CI (95–07)	2005 analysis	Raw CPUE	Acoustics index
1995	485	0.32	0.18	0.54		0.50	
1996	1315	2.01	1.31	3.09		5.00	
1997	948	1.65	1.07	2.54		2.00	
1998	1443	1.77	1.14	2.77		3.25	23.68
1999	430	1.26	0.80	2.01		1.55	
2000	990	3.91	2.30	6.64	4.90	4.00	35.34
2001	944	2.27	1.43	3.60	3.20	3.60	
2002	2297	1.36	0.91	2.03	2.60	4.00	58.04
2003	2485	1.53	1.04	2.26	2.20	4.00	49.17
2004	1567	1.66	1.07	2.57	2.70	4.37	41.82
2005	1593	0.98	0.66	1.47	2.20	4.00	37.36
2006	1149	1.08	0.70	1.67		2.29	
2007	1068	1.19	0.72	1.96		8.00	

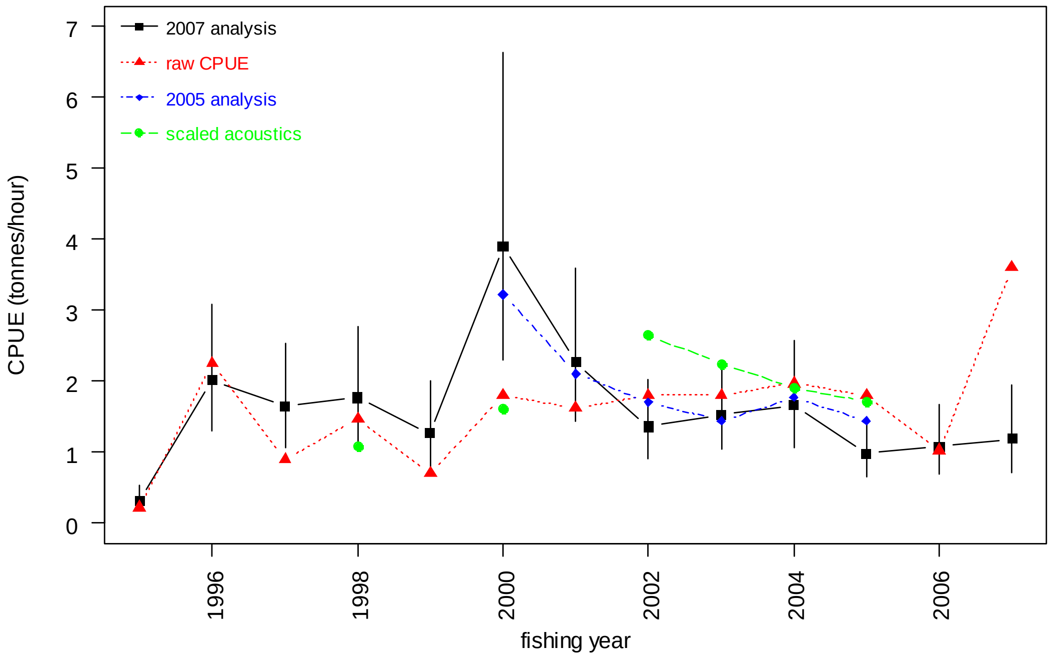

Figure 4: CPUE trends for the Spawning Box post-closure, relative to the standardised CPUE.

The model exhibited a strong *tow duration* effect, with higher catch rates associated with short tows. This result is to be expected since short tows are generally attributed to fishing events on acoustic marks of orange roughy aggregations and long tows are associated with diffuse marks of roughy on flat bottoms (Figure 18). Such attributes were not found in previous models because only short tows were carried out on the Andes and Northeast Hills. *Month* also had a strong effect, with increased CPUE not only during spawning season (June and July) in the Northeast Hills, but also in the couple of months following spawning. This could be attributed to the fishers catching orange roughy as they migrate away from the spawning grounds. Previous in-depth work to investigate possible migrations of orange roughy on the Chatham Rise was summarised by Dunn (2008b). Finally the location of fishing had a strong effect on the catch rates, with some areas being obviously better than others. The effect of the location of fishing was stronger than that of the fishing year (5% vs. 2% deviance explained respectively).

The model obtained in 2005 (Dunn 2007) was quite different, with less than 30% deviance explained and the variables *month*, *vessel*, and *depth* contributing to over 1% deviance each. That model considered the shortened series from 2000 with only two vessels in the fishery.

The general trends obtained were broadly similar in the present study, the 2005 study, and the acoustics biomass trend. However, the present standardised CPUE index trend is more pessimistic than the raw CPUE trend, in particular not capturing the strong increase in raw CPUE in 2007. The standardised CPUE over the last three years is 81.7% that of the first three years of the fishery, the equivalent raw CPUE figure is 190.5%. The equivalent value for the 2005 study was not calculated as the index was only for 2000-05. These values are to be taken with care since the current index is only 10 years long and is showing a complex trend, which exhibits a very low point in 1995 and reasonably high point in 2007. There is also little overlap of fleet in 2000 and therefore this standardised CPUE index may be a poor index of abundance trend.

3.4 Chiefs complex

The Chiefs complex fishery started in 1990. As with the Andes and the Northeast Hills complexes, short hill tows are characteristic of this fishery, with no flat tows in the core dataset, and very few long tows. Therefore the CPUE was standardised based on short tows on or near hills carried out between 1990 and 2007.

The core fleet during this period was made up of 10 vessels, with some overlap in the fleet composition throughout the study period. The area covered consisted of 8 major hills (11 hills total) and 11 main coordinates (15 in total). Bubble plots of the core vessels fishing in the Chiefs complex and that of the core coordinates being fished are given in the Appendix (Figure 20).

As over 10% of the tows did not catch orange roughy, a combined model was carried out to build this index. The binomial model explained 8% of the deviance and the Gaussian model 19%. Both models selected the same variables as predictors: *vessel* and *coordinates*.

The variables retained for inclusion are detailed in Table 7. The fit to each model was good. Figure 21 (in the Appendix) shows the fishing year indices, other coefficients, and QQ plots for the Chiefs complex Gaussian CPUE model. The QQ plots show slight evidence of departure from assumptions of normality and suggest that the upper tail is somewhat shorter than the model predicts.

Table 7: Details of change in deviance for the Chiefs complex standardised CPUE mixed model Df, degrees of freedom; Dev., deviance; Resid. Df., residual degrees of freedom; Resid. Dev., residual deviance; % dev, percentage deviance explained

	Binomial model (non-zero)					Gaussian model (log(CPUE)				
	Df	Dev.	Resid. Df	Resid. Dev	% dev	Df	Dev.	Resid. Df	Resid. Dev	% dev
NULL	NA	NA	4419	4076.0		NA	NA	3653	10730.3	
Fishing year	17	134.6	4402	3941.4	3.30	17	1539.6	3636	9190.7	14.35
Vessel	9	162.4	4393	3779.0	3.98	9	318.1	3627	8872.6	2.96
Coordinates	14	42.4	4379	3736.6	1.04	14	212.4	3613	8660.1	1.98
					8.33					19.29

The raw and predicted standardised CPUE series are detailed in Table 8, with the results from the 2005 analysis (Dunn et al. 2008). However, the 2006 analysis area split was different from that adopted in the present report: it split the South Rise east or west of 179.25º W when the present analysis split it into the Chiefs complex, and the Hegerville area without analysing the rest of the South Rise. These areas are roughly comparable in the case of the Chiefs complex, but less so for the Hegerville area.

The relative CPUE series (including Gaussian and binomial models) are shown in Figure 5, whereby the standardised CPUE is plotted with no change, and every other CPUE trend is plotted such that its mean has the same mean as the corresponding period of the standardised CPUE. The binomial CPUE is plotted unchanged against the right axis.

Table 8: Standardised CPUE series for the Chiefs complex: the orange roughy catch used in the analysis in tonnes, the present analysis from 1990 (90–07) and its standard deviation (SD (90–07)), the results of the 2005 analysis, and raw CPUE results.

Fishing year	Catch analysed	90-07	SD (90–07)	2005 analysis	Raw CPUE
1990	1580	2.97	0.23	2.99	1.50
1991	2382	3.78	0.22	3.52	3.00
1992	632	3.40	0.30	2.74	2.50
1993	2883	2.39	0.16	2.47	2.00
1994	2076	1.59	0.16	1.56	1.00
1995	446	1.20	0.23	1.07	0.80
1996	538	1.34	0.28	0.87	1.00
1997	501	0.89	0.28	0.74	0.50
1998	767	0.68	0.25	0.51	0.40
1999	514	0.75	0.27	0.58	1.00
2000	274	0.78	0.37	0.54	0.50
2001	835	0.85	0.32	0.64	0.95
2002	539	0.90	0.31	0.71	0.92
2003	494	0.61	0.33	0.49	0.50
2004	466	0.49	0.34	0.43	0.50
2005	396	0.50	0.37	0.57	0.49
2006	247	0.37	0.34	0.36	0.30
2007	428	0.46	0.33		0.38

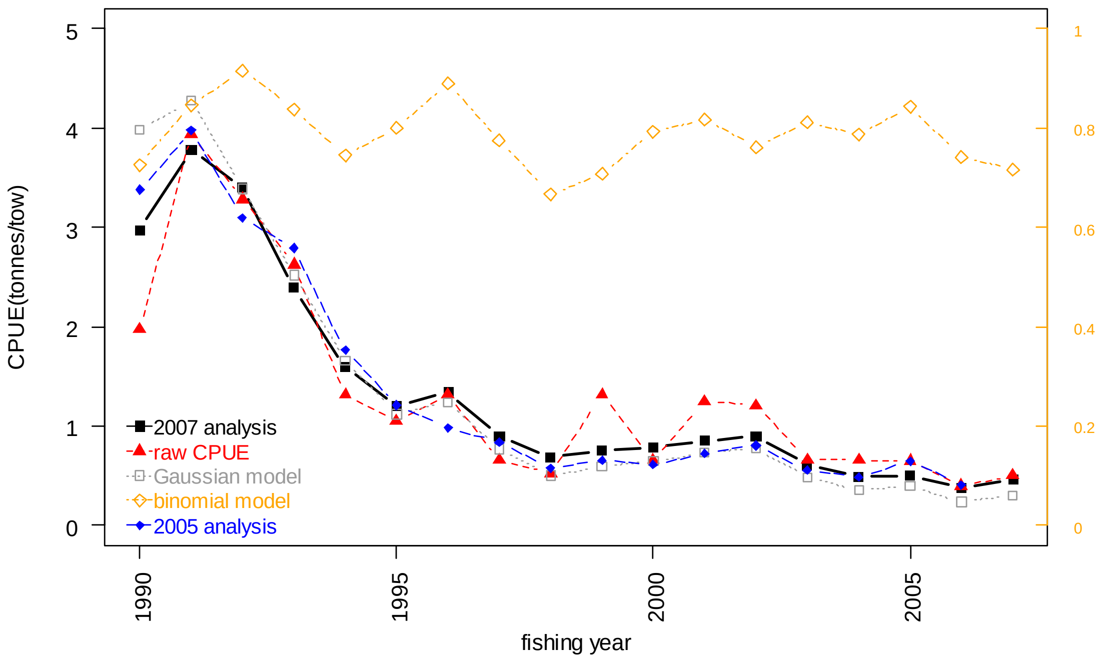

Figure 5: CPUE trends for the Chiefs complex, relative to the standardised CPUE. The binomial CPUE is plotted unmodified against the right axis.

In both binomial and Gaussian models the *fishing year* variable exerted a strong effect, with *vessel* and *coordinates* variables only representing a total deviance under 5%. There was no *month* effect. The general trend of the full model was comparable to that depicted in the 2005 analysis and to that of the raw CPUE. It was also similar to that depicted for the Andes and Northeast Hills areas. The standardised CPUE over the last three years is 13.2% that of the first three years of the fishery, the equivalent raw CPUE figure is 16.8% and the equivalent calculated in 2005 is 14.7%.

3.5 Hegerville area

The Hegerville area was defined as the area between 180º and 178.25º E within the South Rise. The earliest reliable tow by tow data for this fishery were available from 1981. As with the Andes, the Northeast Hills and Chiefs complexes, short hill tows are characteristic of this fishery, with very few long or flat tows in the core dataset. Therefore the CPUE was standardised based on short tows on hills carried out between 1981 and 2007. In 1982 there was only 2 tonnes of orange roughy caught, and therefore data for this year are very imprecise and are shown here only for completeness.

The core fleet during this period is characterised by very few tows carried out by each vessel in any year, possibly on their way to other grounds such as the Spawning Box. Therefore the core vessel criterion was relaxed to 5 tows per year and 3 years in the fishery (from 20 tows per year in the other fisheries). The core fleet was made up of 22 vessels with some degree of overlap over all years, although a large number of vessels were only involved in the fishery for only 3 to 5 years. The area covered consisted of 4 major hills (13 hills total) and 9 main coordinates (23 in total). Bubble plots of the core vessels fishing in the Hegerville area and that of the core coordinates being fished are given in the Appendix (Figure 22).

As with the Chiefs complex, over 10% of the tows did not catch orange roughy, therefore a combined model was carried out in order to build this index. The binomial model explained 19% of the deviance and the Gaussian model 39%, both of which are much higher than for the Chiefs complex. Both models selected the same variables as predictors: *vessel, month*, and *longitude*. The variables retained for inclusion are detailed in Table 9. Figure 23 (in the Appendix) shows the fishing year indices, other coefficients, and QQ plots for the Hegerville area Gaussian CPUE model. The QQ plots show slight evidence of departure from assumptions of normality and suggest that the upper tail is somewhat shorter than the model predicts, especially for the 1992–2007 series.

Table 9: Details of change in deviance for the Hegerville area standardised CPUE mixed model Df, degrees of freedom; Dev., deviance; Resid. Df., residual degrees of freedom; Resid. Dev., residual deviance; % dev, percentage deviance explained

	Binomial model (non-zero)					Gaussian model (log(CPUE)				
	Df	Dev.	Resid. Df	Resid. Dev	% dev	Df	Dev.	Resid. Df	Resid. Dev	% dev
NULL	NA	NA	3901	5056.7		NA	NA	2532	6855.0	
Fishing year	25	527.0	3876	4529.7	10.42	25	2005.4	2507	4849.6	29.25
Vessel	22	317.8	3854	4212.0	6.28	22	473.5	2485	4376.0	6.91
Month	11	57.9	3843	4154.1	1.15	11	84.0	2473	4157.4	1.23
Longitude	1	55.2	3842	4098.9	1.09	1	134.6	2484	4241.4	1.96
					18.94					39.35

The raw and predicted standardised CPUE series are detailed in Table 11, with the results from the 2005 analysis (Dunn et al. 2008). The comparison in this case is for information only as the areas are far from identical.

The relative CPUE series (including Gaussian and binomial models) are shown in Figure 6, whereby the standardised CPUE is plotted with no change, and every other CPUE trend is plotted such that its mean has the same mean as the corresponding period of the standardised CPUE. The binomial CPUE is plotted unchanged against the right axis. It is important to note that the analysis carried out in 2005 is not strictly comparable as the area included all the hills in the South Rise west of 179.5º W.

Table 10: Standardised CPUE series for the Hegerville area: the orange roughy catch used in the analysis in tonnes, the present analysis from 1981 (81–07) and its standard deviation (SD (81–07)), the results of the 2005 analysis, and raw CPUE results.

Fishing year	Catch analysed	81–07	SD (81–07)	2005 analysis	Raw CPUE
1981	612	7.35	0.36	4.14	3.46
1982	2	1.07	0.16	10.10	0.00
1983	4068	8.63	0.32	5.30	4.37
1984	1747	5.19	0.31	3.59	2.08
1985	1550	4.99	0.26	3.55	3.82
1986	1618	2.75	0.30	2.69	0.96
1987	835	2.32	0.28	1.74	0.10
1988	689	1.73	0.31	1.09	0.70
1990	315	1.76	0.30	1.18	0.50
1991	191	2.02	0.40	1.25	0.50
1992	43	1.36	0.33	1.10	0.00
1993	245	2.75	0.47	1.08	0.41
1994	124	1.56	0.44	0.49	0.78
1995	69	1.45	0.36	0.21	0.00
1996	45	0.83	0.27	0.19	0.00
1997	59	1.15	0.28	0.29	0.11
1998	57	1.06	0.31	0.23	0.00
1999	100	1.04	0.35	0.25	0.00
2000	62	1.00	0.56	0.38	0.10
2001	23	0.75	0.49	0.34	0.05
2002	26	1.07	0.57	0.27	0.10
2003	109	2.48	0.67	0.41	1.00
2004	113	1.54	0.61	0.24	0.39
2005	85	1.18	0.48	0.40	0.16
2006	48	1.41	0.60	0.21	0.57
2007	42	1.14	0.44	NA	0.19

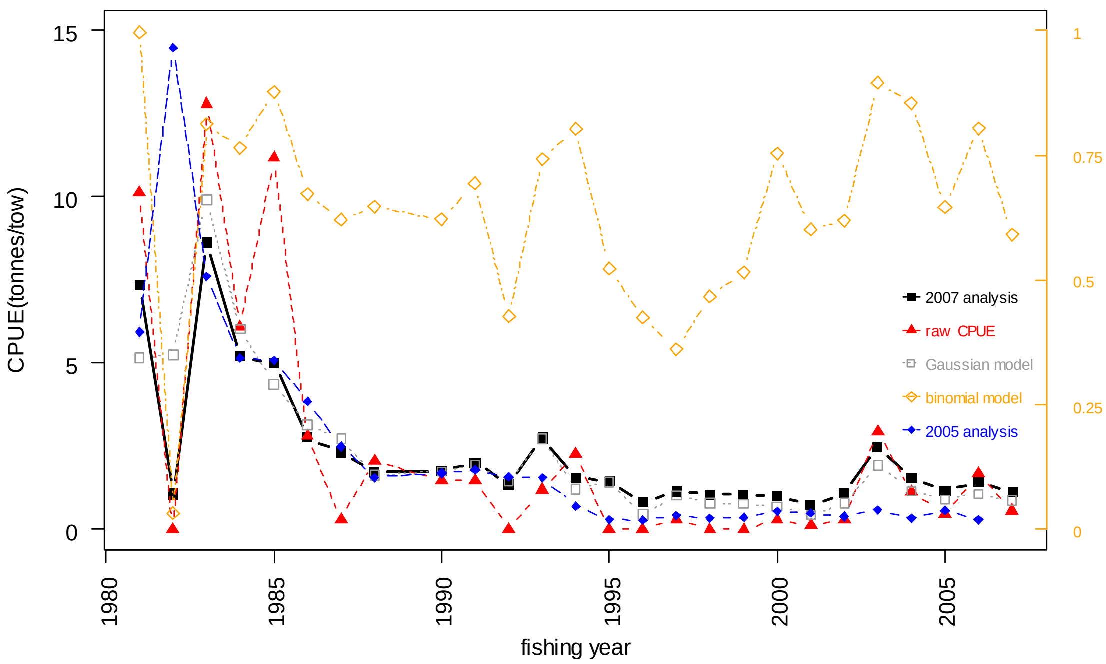

Figure 6: CPUE trends for the Hegerville area, relative to the standardised CPUE. The binomial CPUE is plotted unmodified against the right axis.

In both binomial and Gaussian models the *fishing year* variable exerted a strong effect, with *vessel* contributing to 6% of the deviance explained. The *month* and *longitude* variables only represented a total deviance under 4%, with catch rates decreasing in June and July, with slightly increased rates in August and September. The lowest coefficients are found in June and July, supporting the theory that fish in the Hegerville area are the same stock as those in the rest of the East Chatham Rise and migrate to East Rise or the Spawning Box to spawn (Ministry of Fisheries Science Group 2008).

The general trend of the full model was comparable to that depicted in the 2005 analysis but with a much smaller CPUE decline throughout the series. This could be due to the data selection and not strictly comparable areas. The raw CPUE was much more variable than the standardised trends, with a number of years with a CPUE value of 0. Also, unlike all previous Chatham Rise trends covered in the present document, the Hegerville area is the only one showing some signs of increased CPUE trend in the last few years. It is also the only one with such a long fishery and strongly reduced total orange roughy catches in the last 10 years (see Dunn (2008a) for catch details).

The standardised CPUE over the last three years is 17.6% that of the first three years of the fishery (omitting 1982), the equivalent raw CPUE figure is 9.3%, and the equivalent calculated in 2005 is only 6.5%.

3.6 Graveyard complex

The Graveyard fishery started in 1992. Short hill tows are characteristic of this fishery, with no flat tows in the core dataset, and very few long tows. Therefore the CPUE was standardised based on short tows on hills carried out between 1992 and 2007.

The core fleet during this period was made up of 7 vessels, with some overlap in the fleet composition throughout this time. The area covered consisted of 2 major hills (14 hills total) and 3 main coordinates (8 in total). Bubble plots of the core vessels fishing in the Graveyard and that of the core coordinates being fished are given in the Appendix (Figure 24).

A single CPUE model was fitted to the dataset, ignoring the zero catches. The CPUE model explained 20% of the deviance. The variables retained for inclusion are detailed in Table 11. Figure 25 (in the Appendix) shows fishing year indices, other coefficients, and QQ plots for the Graveyard standardised CPUE series starting from 1992.

Table 11: Details of change in deviance for the Graveyard standardised CPUE model, Df, degrees of freedom; Dev., deviance; Resid. Df., residual degrees of freedom; Resid. Dev., residual deviance; % dev, percentage deviance explained

	Df	Dev.	Resid. Df	Resid. Dev	% dev
NULL	NA	NA	1803	6165.7	
Fishing year	15	627.7	1788	5538.0	10.18
Month	11	450.0	1777	5088.1	7.30
Vessel	6	79.2	1771	5008.9	1.28
2 day fishing pressure	3	70.1	1768	4938.8	1.14
					19.90

The raw and predicted standardised CPUE series are detailed in Table 12; this analysis has not been carried out previously. The relative CPUE series are shown in Figure 7, whereby the standardised CPUE is plotted with no change, and the raw CPUE trend is plotted such that its mean has the same mean as the standardised CPUE.

Table 12: Standardised CPUE series for the Graveyard: the orange roughy catch used in the analysis in tonnes, the present analysis from 1992 (92-07) and its lower and upper confidence interval values (Lower / Upper CI (92-07)), and raw CPUE results.

Fishing year	Catch analysed	92–07	LowerCI (92–07)	Upper CI (92–07)	Raw CPUE
1992	67	3.41	1.23	9.47	2.43
1993	1989	12.60	7.68	20.67	9.88
1994	1574	5.00	3.05	8.20	4.00
1995	607	2.41	1.46	3.98	1.73
1996	834	1.78	1.13	2.81	1.00
1997	351	0.95	0.60	1.49	0.90
1998	656	0.85	0.57	1.28	0.74
1999	693	1.36	0.85	2.18	2.25
2000	371	0.87	0.57	1.35	0.70
2001	835	0.99	0.68	1.43	1.00
2002	560	0.85	0.55	1.33	1.20
2003	923	0.64	0.43	0.96	0.95
2004	248	0.85	0.48	1.50	1.00
2005	372	0.50	0.29	0.87	1.35
2006	504	0.33	0.20	0.53	0.76
2007	255	0.77	0.43	1.39	1.50

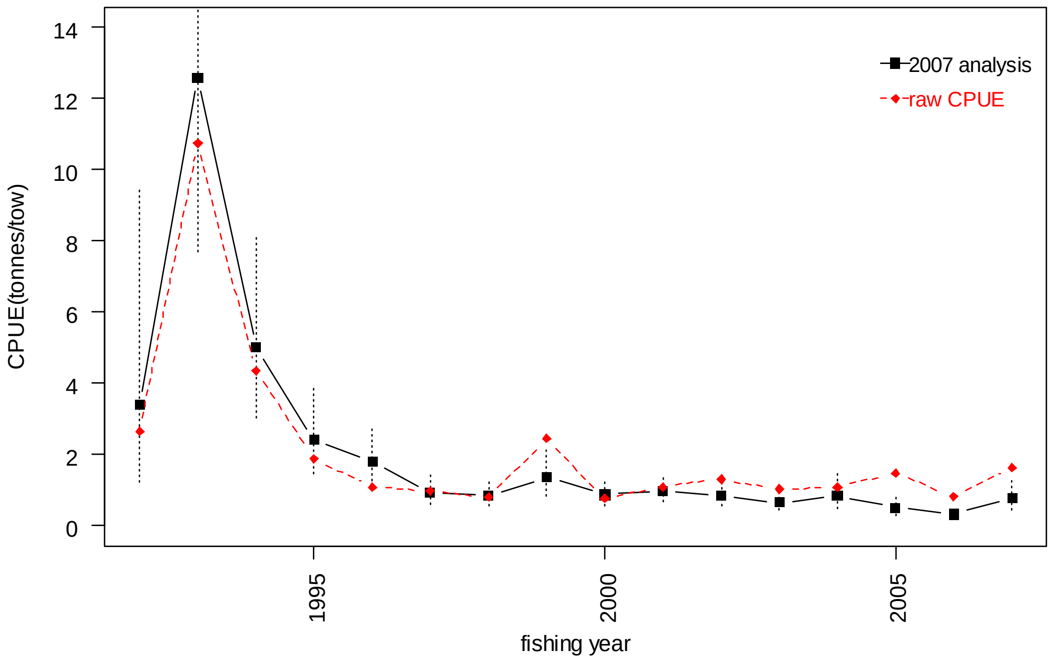

Figure 7: CPUE trends for the Graveyard complex relative to the standardised CPUE.

The full model included *month* at over 7% deviance explained and *vessel* and *2 day fishing pressure* variables each at about 1% deviance explained. The month effect showed an increased catch rate in May to July with highest rate in June, possibly suggesting an early spawning. The fishing pressure effect showed a decreased catch rate with increased fishing pressure. This is in agreement with the fishing industry perception that any prior fishing will disturb aggregations and therefore reduce the size of the catch.

The standardised CPUE trends obtained were similar to that of the raw CPUE and that of other hills studied in the present document: after an initial strong decline between 1992 and 1998, the CPUE trends show a small increase in 1999 then a further decline to 2007. The standardised CPUE over the last three years is 7.6% that of the first three years of the fishery, and the equivalent raw CPUE figure is 22.1%.

3.7 Northeast Flats

The Northeast Flats were defined as all long flat or near hill tows in the entire East Rise area excluding any tows carried out in the Spawning Box (West of 175° W) or the Middle Ground (defined as 174.6° W to 175° W and 44.35° S to 44.63° S). This fishery started in 1980 as a spawning fishery, with fishing occurring between May and August. In the early 1990s it changed into a year-round fishery before becoming a non-spawning fishery in the mid 1990s.

The core fleet was established only from 1982, and during this period was made up of 18 vessels, with some overlap in the fleet composition throughout this time. Because this fishery was neither a hill nor a plume fishery, all coordinates within the area selected were analysed, regardless of the number of times they were fished. Bubble plots of the core vessels fishing in the Northeast Flats and all coordinates fished (664) are given in the Appendix (Figure 26). The coordinates plot shows that there was a change in the area fished in the early 1990s and that the area fished has reduced through both periods before and after the 1990s.

A single CPUE model was fitted to the dataset, ignoring the zero catches. The CPUE model explained 18% of the deviance. The variables retained for inclusion are detailed in Table 13. Figure 27 (in the Appendix) shows the fishing year indices, other coefficients, and QQ plots for the Northeast Flats standardised CPUE series starting from 1982. The QQ plots show slight evidence of departure from assumptions of normality and suggest that the upper tail is somewhat shorter than the model predicts, especially for the 1992–2007 series.

Table 13: Details of change in deviance for the Northeast Flats standardised CPUE model Df, degrees of freedom; Dev., deviance; Resid. Df., residual degrees of freedom; Resid. Dev., residual deviance; % dev, percentage deviance explained

	Df	Dev.	Resid. Df	Resid. Dev	% dev
NULL	NA	NA	14286	41831.50	
Fishing year	25	7051.20	14261	34780.30	16.86
Vessel	17	571.73	14244	34208.57	1.37
					18.22

The raw and predicted standardised CPUE series are detailed in Table 14; this analysis has not been carried out previously. The relative CPUE series are shown in Figure 7, whereby the standardised CPUE is plotted with no change, and the raw CPUE trend is plotted such that its mean has the same mean the standardised CPUE.

Table 14: Standardised CPUE series for the Northeast Flats: the orange roughy catch used in the analysis in tonnes, the present analysis from 1982 (82–07) and its lower and upper confidence interval values (Lower / Upper CI (82–07)), and raw CPUE results.

Fishing year	Catch analysed	CPUE (82–07)	Lower CI (82–07)	Upper CI (82–07)	Raw CPUE
1982	50	2.83	1.03	7.81	3.74
1983	39	1.07	0.50	2.30	1.91
1984	704	5.79	3.69	9.07	6.64
1985	642	8.60	5.13	14.42	9.83
1986	2355	6.66	4.58	9.67	9.41
1987	1135	3.46	2.35	5.07	4.22
1988	1088	3.22	2.17	4.78	6.14
1989	1798	2.98	2.19	4.04	4.00
1990	314	1.97	1.30	2.99	3.00
1991	5468	5.09	4.13	6.29	5.00
1992	11519	5.07	4.20	6.13	5.62
1993	4149	4.58	3.67	5.71	5.00
1994	4240	2.95	2.41	3.61	3.00
1995	3084	1.51	1.25	1.84	1.50
1996	1985	1.26	1.03	1.55	1.30
1997	1797	1.35	1.11	1.63	1.60
1998	1872	0.69	0.58	0.82	0.80
1999	2394	0.92	0.78	1.09	1.00
2000	3042	1.02	0.88	1.18	1.20
2001	1970	1.01	0.88	1.17	1.31
2002	3298	1.11	0.98	1.25	1.50
2003	3547	0.75	0.67	0.83	1.00
2004	1961	0.58	0.52	0.65	0.80
2005	1735	0.61	0.54	0.69	0.72
2006	2894	0.67	0.60	0.75	0.80
2007	2672	0.63	0.57	0.71	0.84

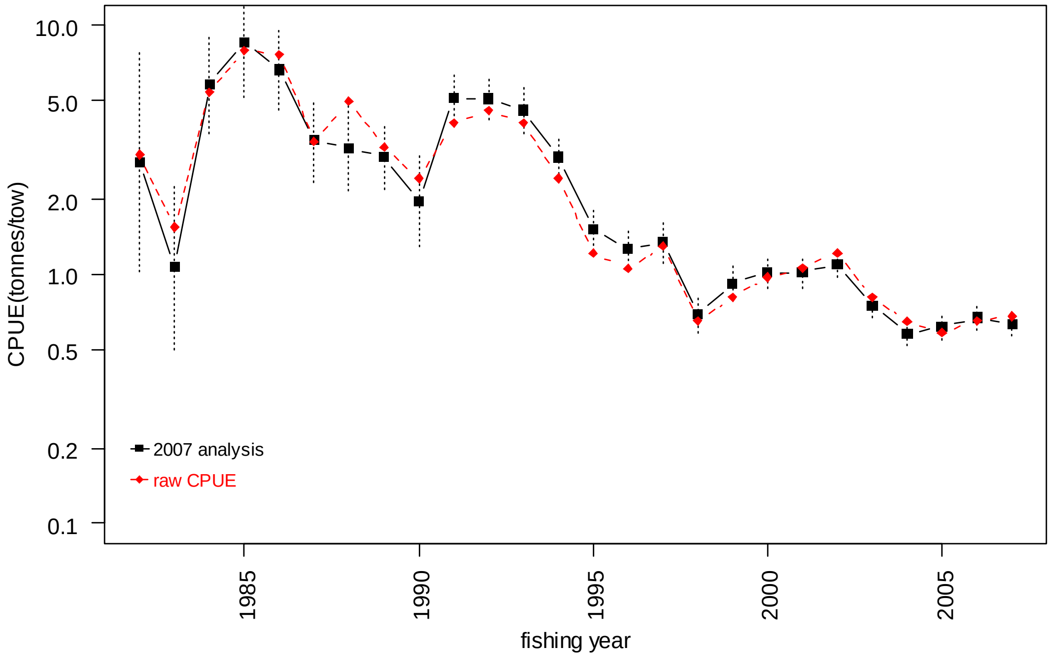

Figure 8: CPUE trends for the East Rise Flats, relative to the standardised CPUE.

Just below 17% of the 18% of deviance was explained by the *fishing year* variable. *Vessel* explained just over 1% of the deviance.

The standardised CPUE trend obtained was similar to that of the raw CPUE. Since the early 1990s the index has similarities with that of other hills studied in the present document: after an initial strong decline between 1992 and 1998, the CPUE trends showed a small increase to 2002 then a further decline to 2007. The standardised CPUE over the last three years is 19.7% that of the first three years of the fishery and the equivalent raw CPUE figure is 19.2%. However, this fishery is very different from all the other fisheries studied in the present document in that it shows an increase between the 1980s and 1990s. However, this increase is probably due to a change in fishing grounds as showed by the coordinates bubble plot (Figure 26).

4. DISCUSSION

The present document considered the standardised CPUE for all main hill fisheries in the Chatham Rise as well as the only remaining main non-hill fishery, the Spawning Box. All other areas historically fished are hardly fished now: the South Rise flats (Dunn et al. 2008) and Northwest Rise Flats (McKenzie, unpublished results.). The Arrow is not considered a part of the Chatham Rise.

Apart from the Spawning Box where we have not modelled the start of the fishery, there are considerable similarities amongst the standardised CPUE index trends. There are strong initial declines, sometimes not commencing until effort builds up in the second or third year of the fishery. During the 2000s the CPUE indices have all been substantially lower than before the decline. All fisheries, whether new or established, show considerable declines between 1992 and 1998, followed by an increase between 1998 and 2002 and a further decline. Only the very small Hegerville fishery shows a further slight increase after 2002. The anomalous fishery is the Northeast Flats where the CPUE index doubled between the late 1980s and the early 1990s, doubling which can be explained by a change in fishing grounds at that time.

The standardised CPUE of the last three years of each fishery has reduced to between 8% and 30% of that of the first three years of each fishery (Table 15). It is in agreement with previous analyses, with the notable exception of the Northeast Hills and Hegerville, at 30% and 22% respectively, but calculated at 14% and 4% in the 2005 analysis. Such discrepancies can be due to the different data selection. Raw CPUE indices generally produced slightly higher figures, with the exception of Hegerville, where it was as low as 12% and more in line with the 2005 analysis.

The Spawning Box post-closure CPUE does not show such a strong trend. The standardised CPUE of 2005–07 has reduced to 82% of that of 1995–97, compared to almost doubled (190%) from the raw CPUE. It is recommended that the Spawning Box standardised CPUE be carried out as a single index over the entire fishery period, and with a split in 2000 but not in 1993.

The *fishing year* variable was forced into the model, and usually explained the highest percentage deviance. The variable *vessel* was present in most analyses, although it explained a much lower percentage of deviance. A *month* effect was present in some models, confirming the "type" of fishery these areas are: the Spawning Box is a spawning and post-spawning fishery, the Northeast Hills is (or was) a spawning fishery, the Graveyard is an early spawning fishery, the Andes and Chiefs are not affected by the spawning season, and Hegerville shows a strong decline in CPUE during the spawning season, potentially indicating an emigration of fish during the spawning season. Some of the findings are summarised in Table 15.

Table 15: Summary of the main CPUE traits for the various areas of the Chatham Rise

Area	Start of fishery	CPUE last 3 years as % of first 3 years			Model ~ fishing year +	Spawning?
		Present study	2005 study	Raw data		
Andes	1992	10.6%	10.8%	13.8%	vessel	Indifferent
NE Hills	1991	29.6%	13.7%	32.1%	vessel + month	Yes
Spawning Box post closure	1995 post closure	81.7%	Different timescale	190.5%	month + duration + coordinates	Yes and post spawning
Chiefs	1990	13.2%	14.7%	16.8%	vessel + coordinates	Indifferent
Hegerville	1981	17.6%	6.5%	9.3%	vessel + month + longitude	Emigrate during spawning
Graveyard	1992	7.6%		22.1%	month + vessel + 2day fishing pressure	Early spawning
NE Flats	1982	19.7%		19.2%	vessel	Indifferent

Fishing pressure was an explanatory variable for the Graveyard CPUE and also the Northeast Hills CPUE starting in 1995. These two cases support fishers' belief that if another vessel has fished a hill before them their catch rate will be lower. Vessel was also an explanatory variable for a number of models, with individual vessels often performing relatively consistently over the different areas, i.e., good vessels performing better than others consistently throughout the different areas. The performance of each vessel relative to one vessel involved in all fisheries is summarised in Table 16.

5. ACKNOWLEDGMENTS

This work was funded by the Ministry of Fisheries (Project ORH2007/02). Thanks to Ralph Coburn (NIWA) for loading the catch-effort data into a relational database and to Owen Anderson and Matthew Dunn for grooming the data.

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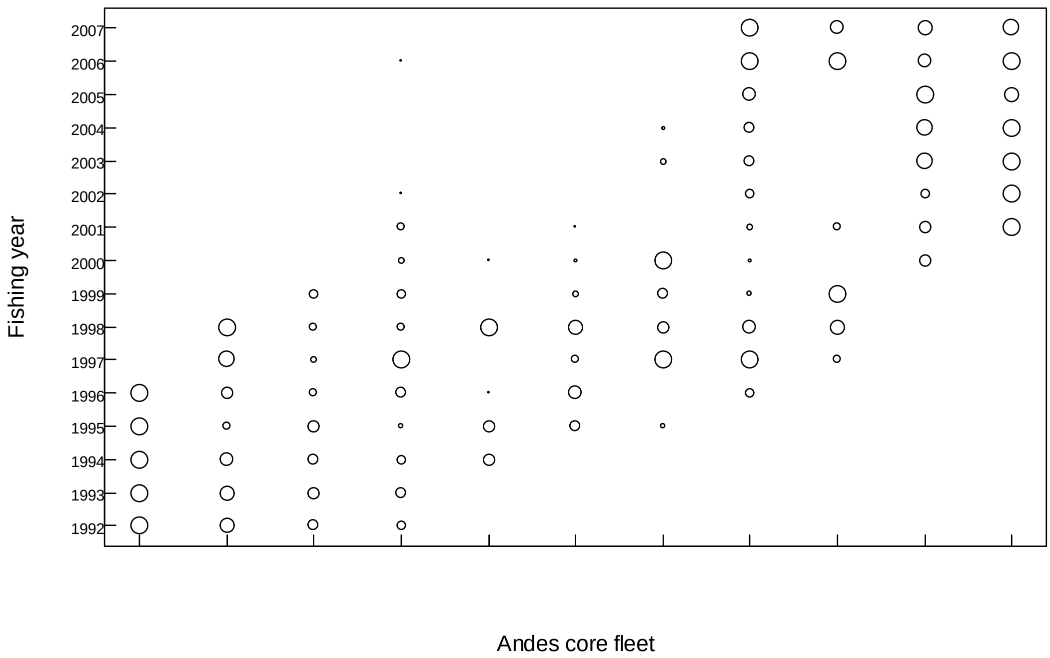
APPENDIX – SUPPLEMENTARY FIGURES AND TABLES

Table 16: The effect of fishing vessels involved in the various fisheries studied where vessel was an explanatory variable; relative to vessel 10020 which was involved in all fisheries.

Vessel	Andes	NE hills	Chiefs	Hegerville	Graveyard	NE flats
10012				1.00		
10015				0.82		
10020	1.00	1.00	1.00	1.00	1.00	1.00
10024			0.55	0.19	0.47	0.70
10031				0.52		1.20
10033				0.71		
10037				0.22		
10046				0.30		0.88
10053				0.70		
10081				0.45		
10082				0.98		
10083	1.40			1.68		1.27
10127				0.91		1.32
10128				0.53		1.42
10170	0.87	0.78	1.20	0.42	0.79	1.12
10171	0.84	0.68	1.18	0.62	0.61	0.87
10176				1.14		
10213	0.77		0.86	0.64		0.80
10215				0.39		
10226	0.74			0.38		0.76
10227	1.54	1.59	1.83	0.40		1.39
10236					0.43	1.05
10242	1.60	1.10	2.17			1.45
10258	1.05	1.42	1.42	0.43	1.00	1.00
12487	1.93	1.31	3.32			1.60
12600		0.81				0.57
12903				0.38		
15256	0.82	1.02	1.02		0.96	0.95



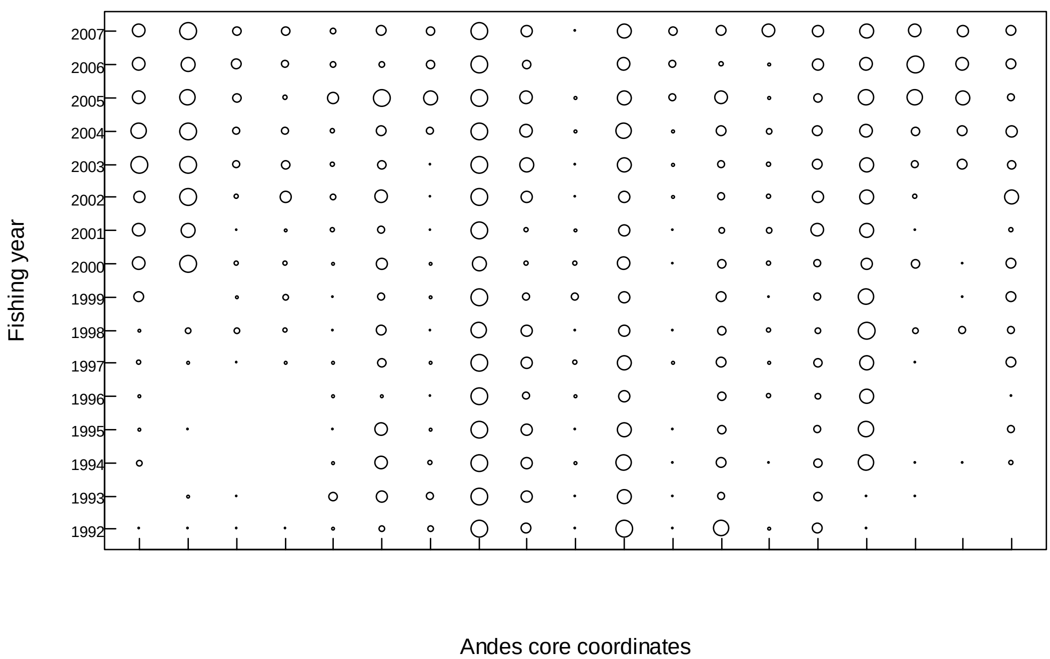


Figure 9: Core vessels fishing in the Andes complex and core coordinates fished. The radius of each circle is proportional to the amount of effort carried out by that vessel or in that coordinate.

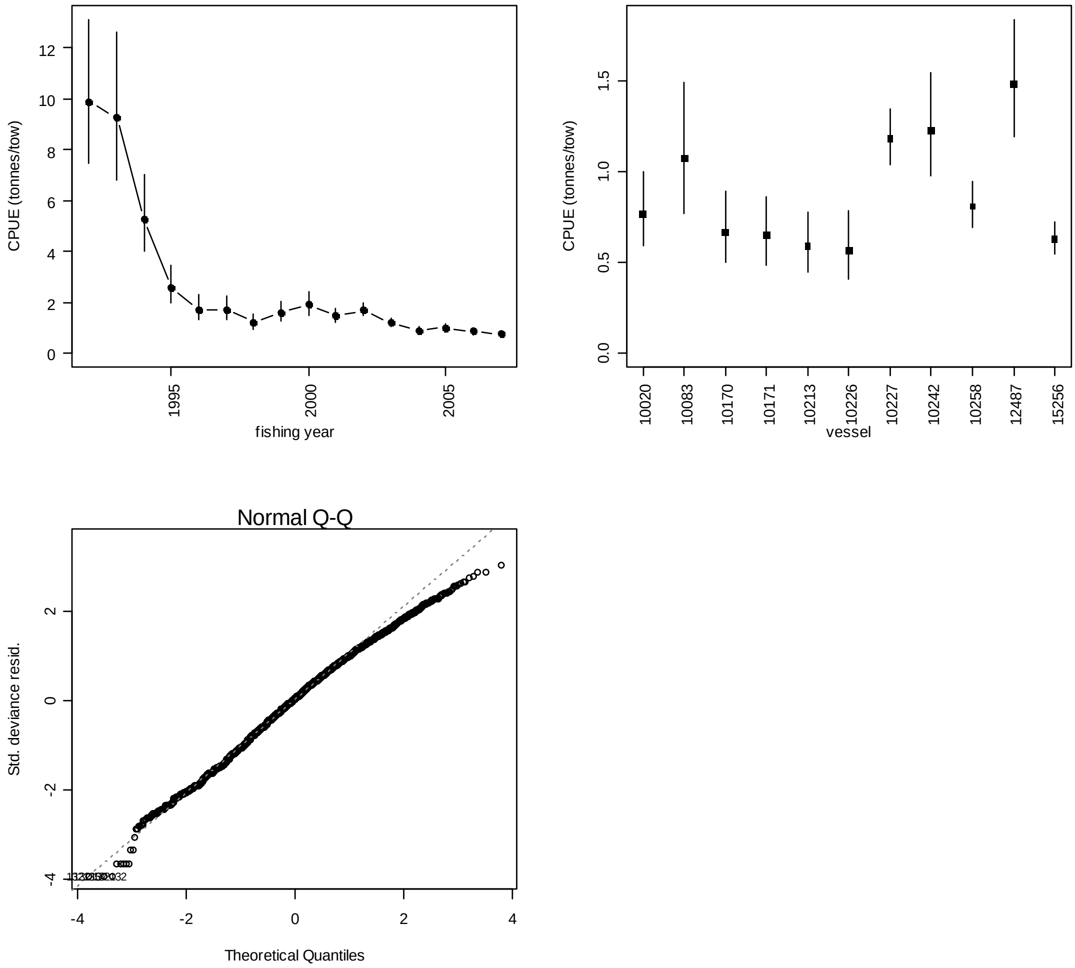


Figure 10: The effects of the model variables for the Andes standardised CPUE series from 1992 with 95% confidence intervals and the QQ plot of the standardised residuals.

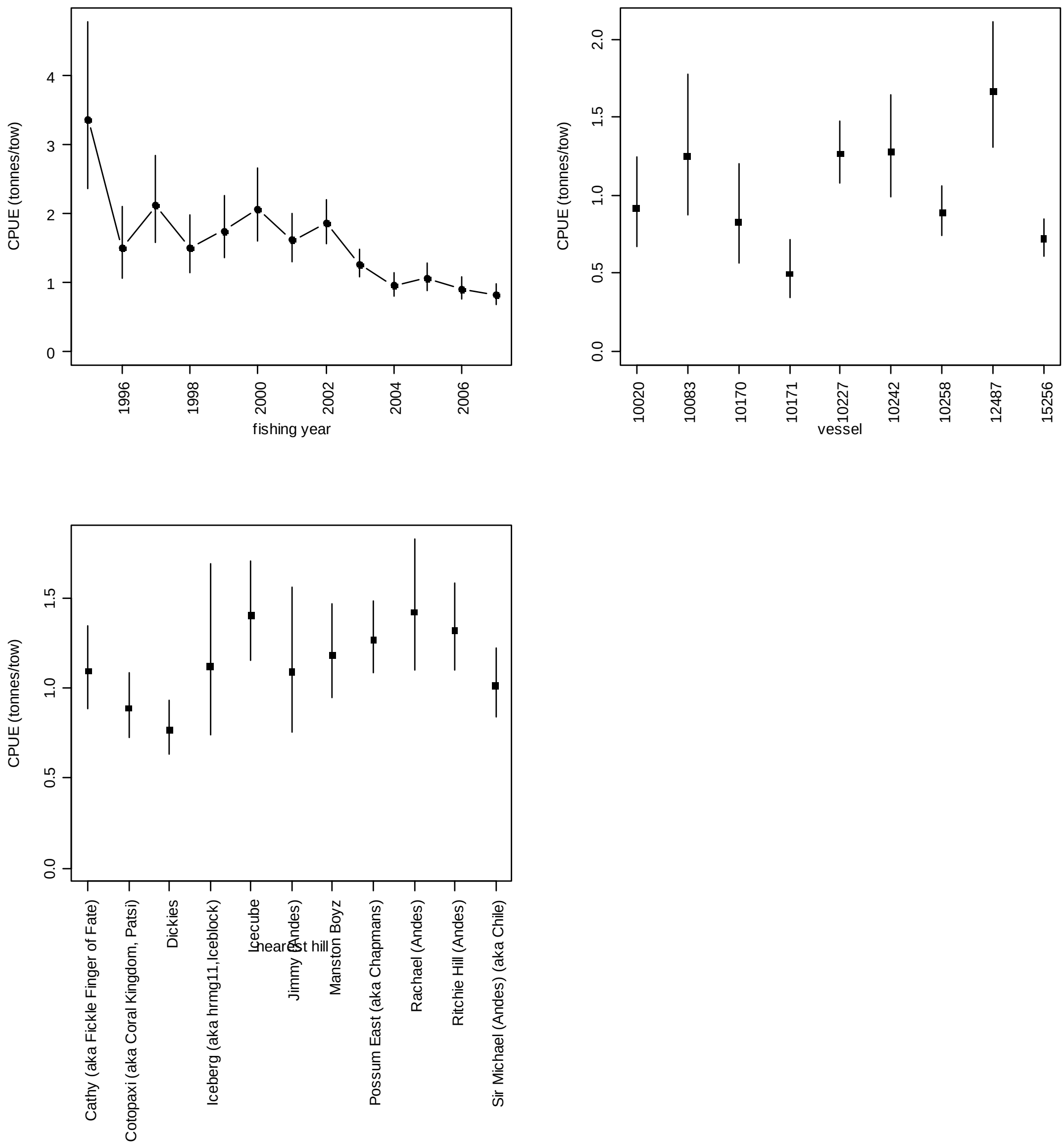
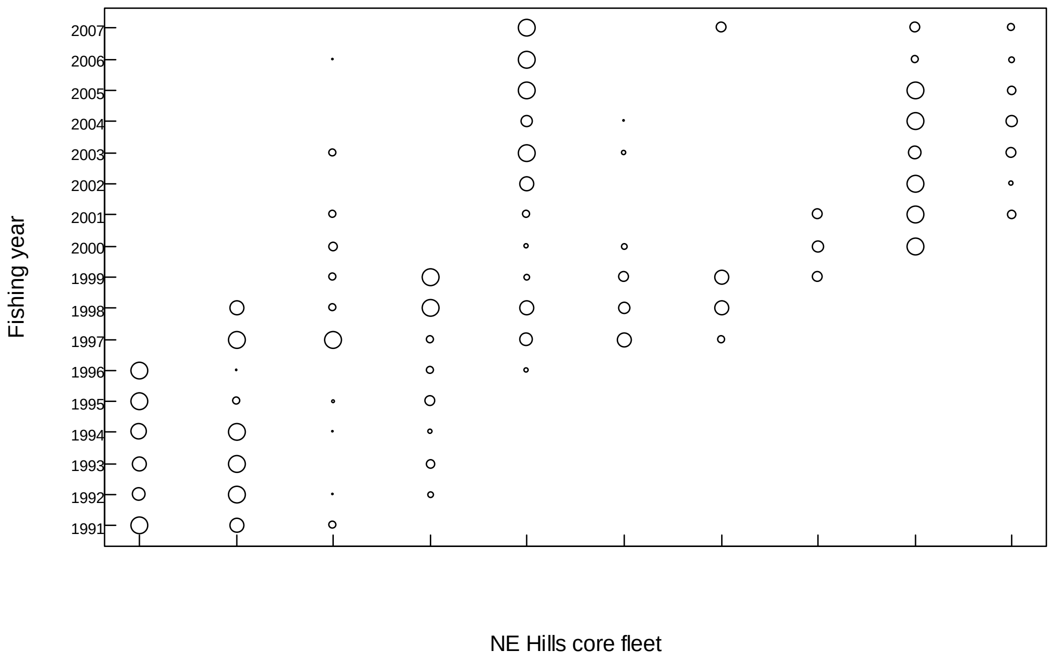


Figure 11: The effects of the model variables for the Andes standardised CPUE series from 1995 with 95% confidence intervals and the QQ plot of the standardised residuals.



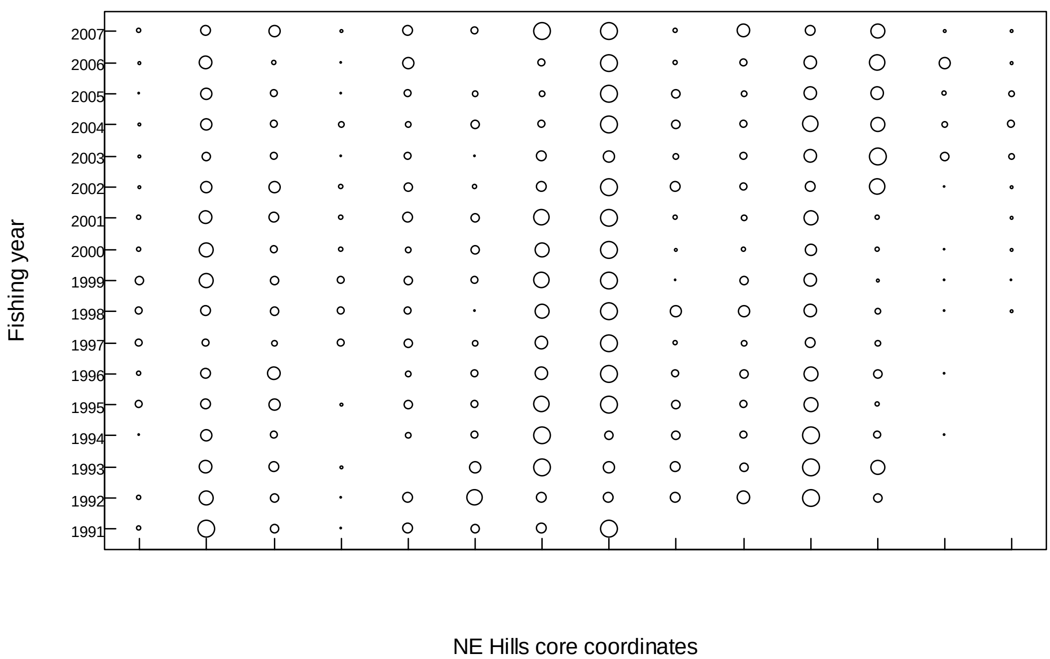


Figure 12: Core vessels fishing in the Northeast Hills complex and core coordinates fished. The radius of each circle is proportional to the amount of effort carried out by that vessel or in that coordinate.

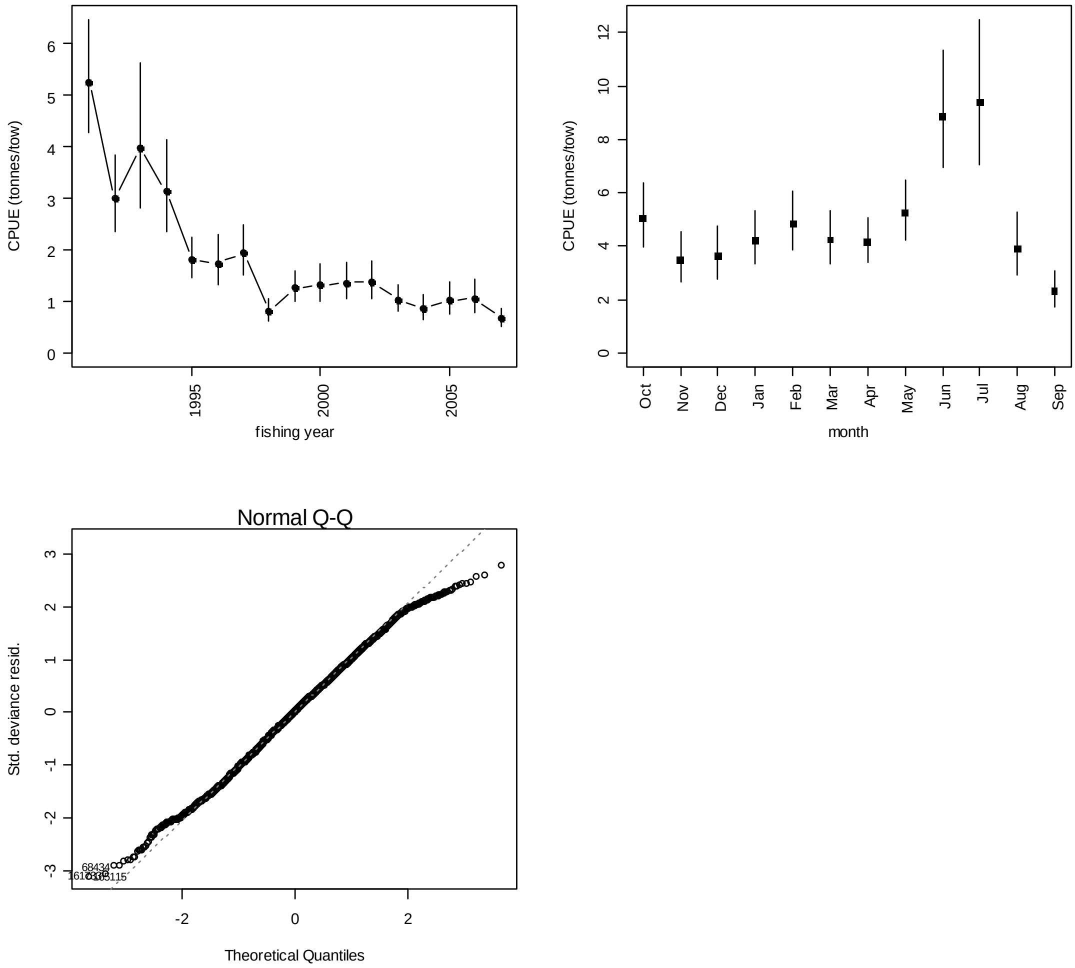


Figure 13: The effects of the model variables for the Northeast Hills standardised CPUE series from 1992 with 95% confidence intervals and the QQ plot of the standardised residuals.

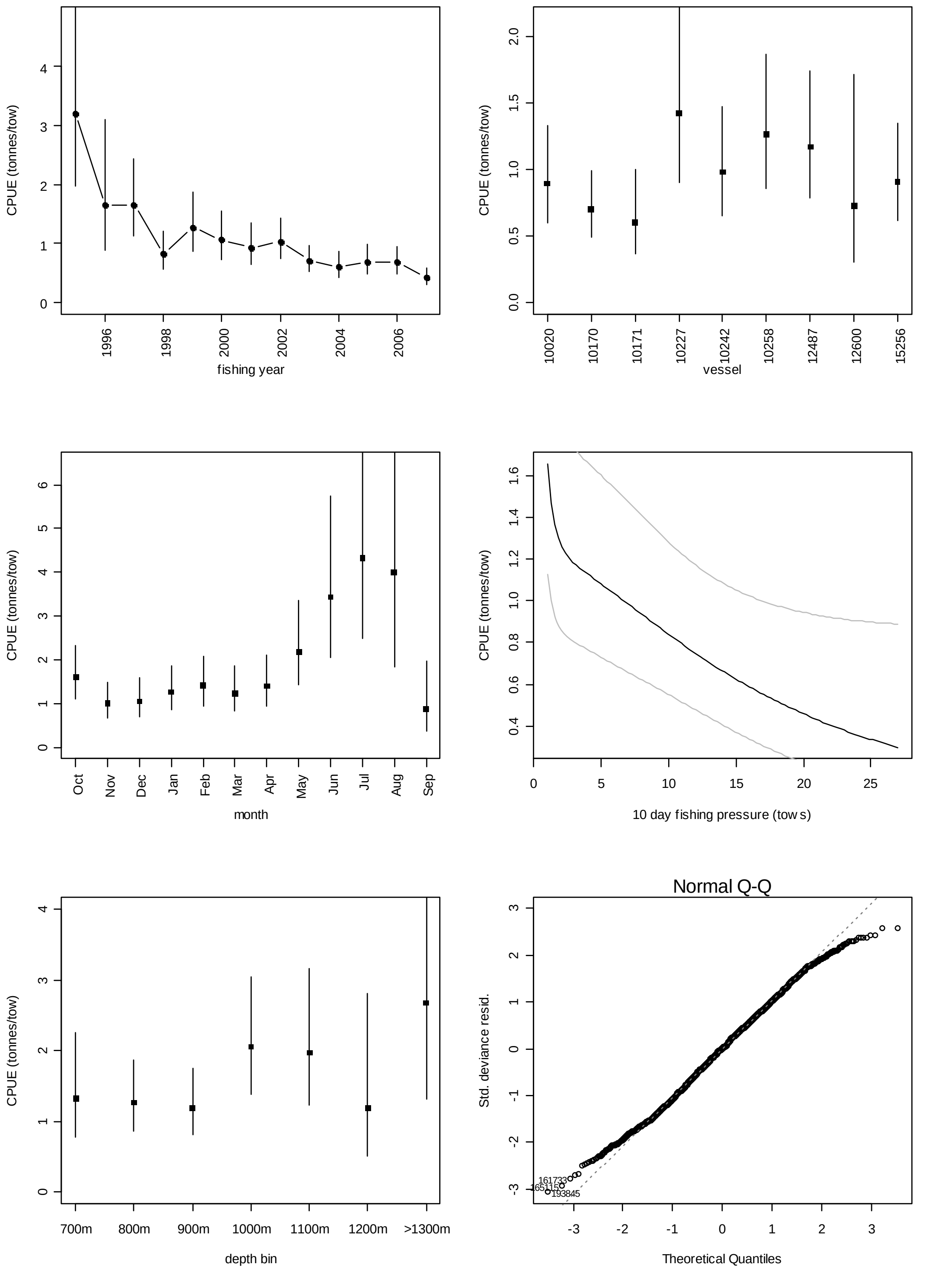


Figure 14: The effects of the model variables for the Northeast Hills standardised CPUE series from 1995 with 95% confidence intervals and the QQ plot of the standardised residuals.

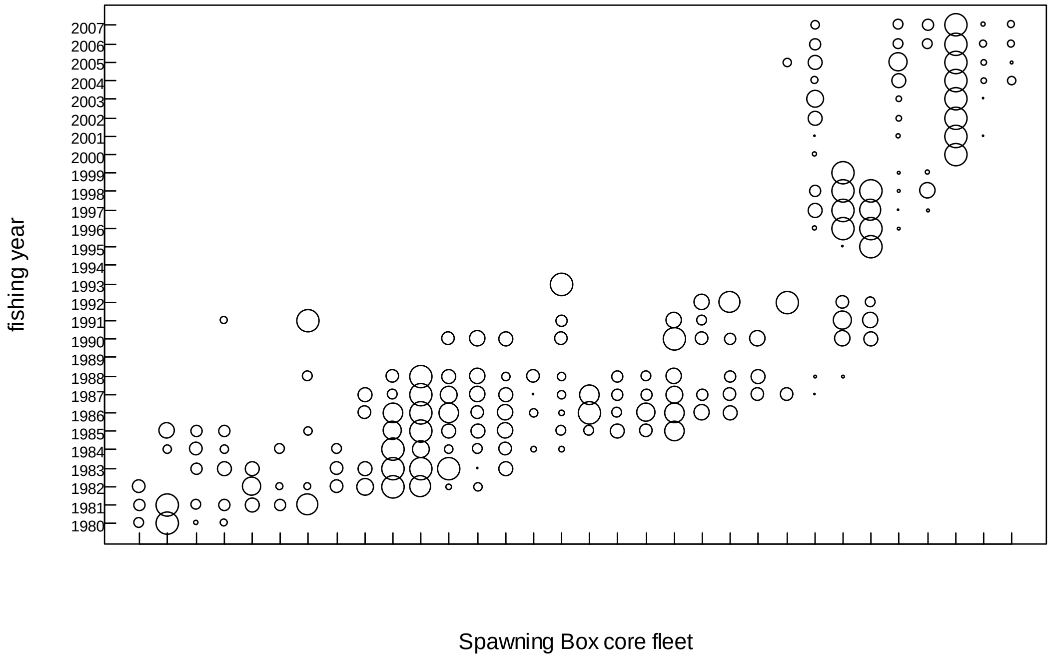


Figure 15: All vessels fishing in the Spawning Box area since 1980. The radius of each circle is proportional to the amount of effort carried out by that vessel.

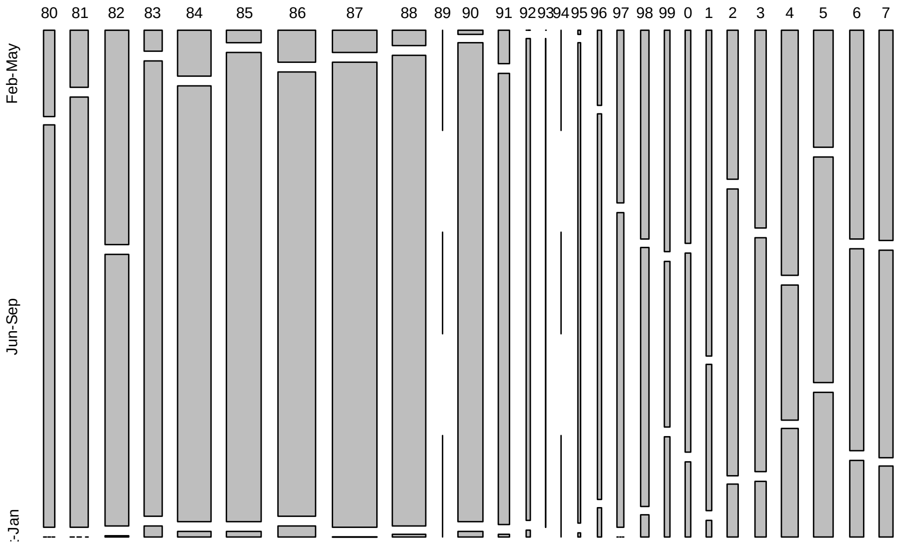
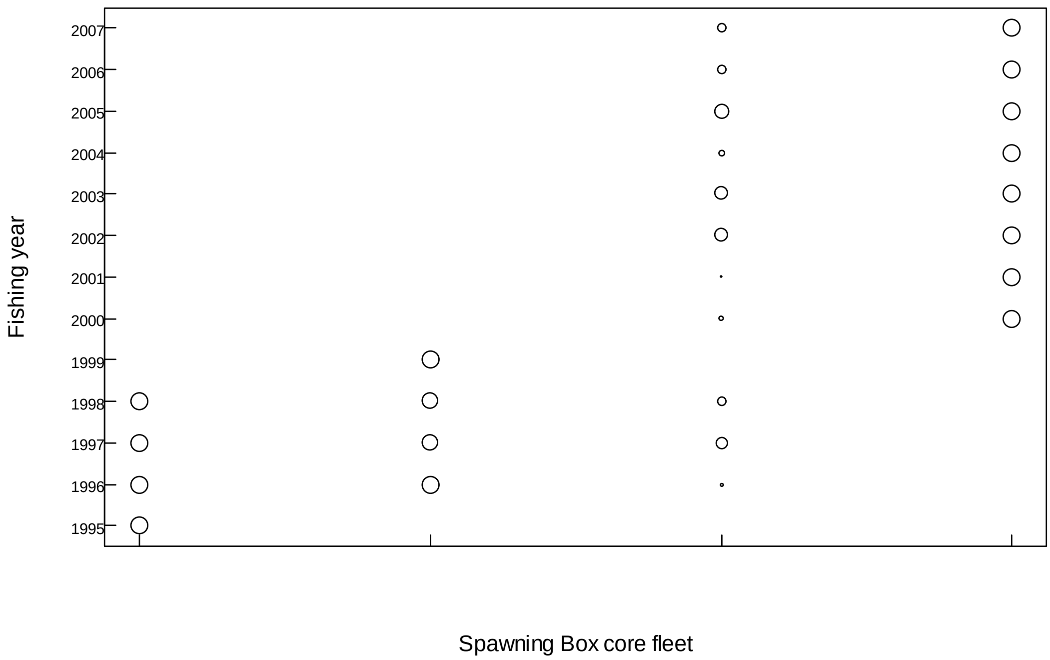


Figure 16: Fishing effort carried out in the Spawning Box at various seasons of each year, from 1980 to 2007.



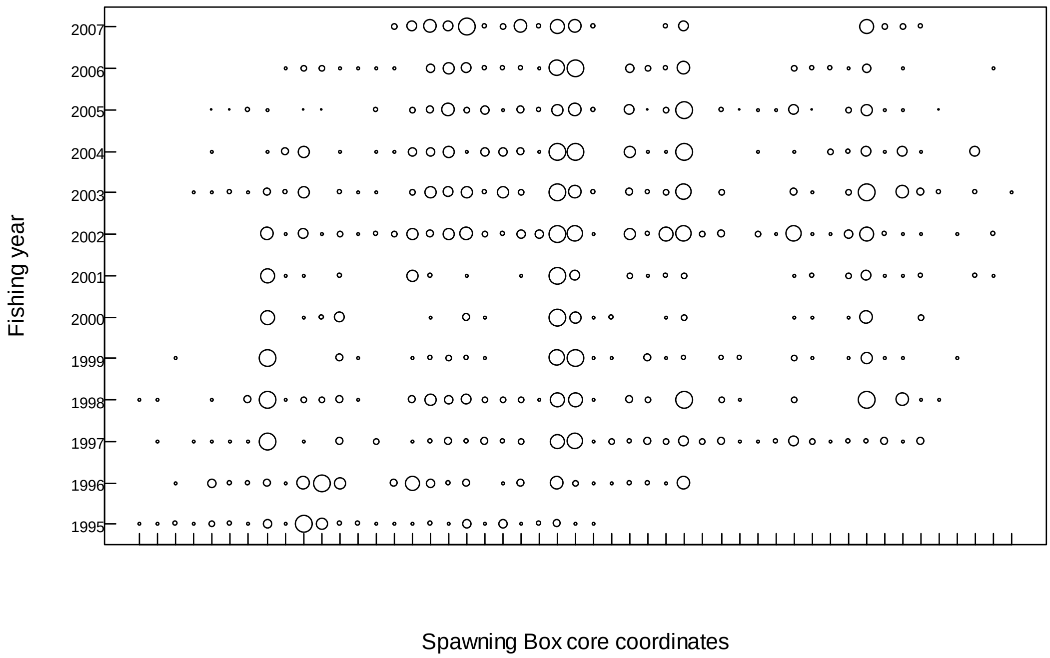


Figure 17: Core vessels fishing in the Spawning Box area post-closure (1995 onwards) and core coordinates fished. The radius of each circle is proportional to the amount of effort carried out by that vessel or in that coordinate.

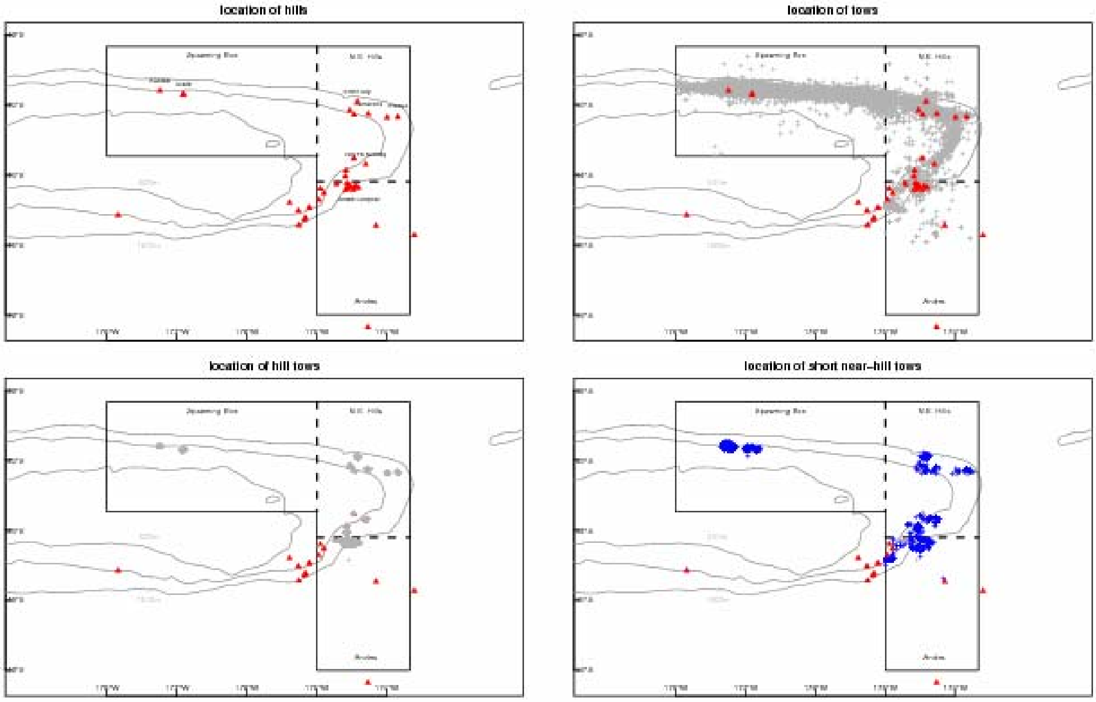


Figure 18: Location of hills, all tows, hill tows, and near-hill tows in the East Chatham Rise.

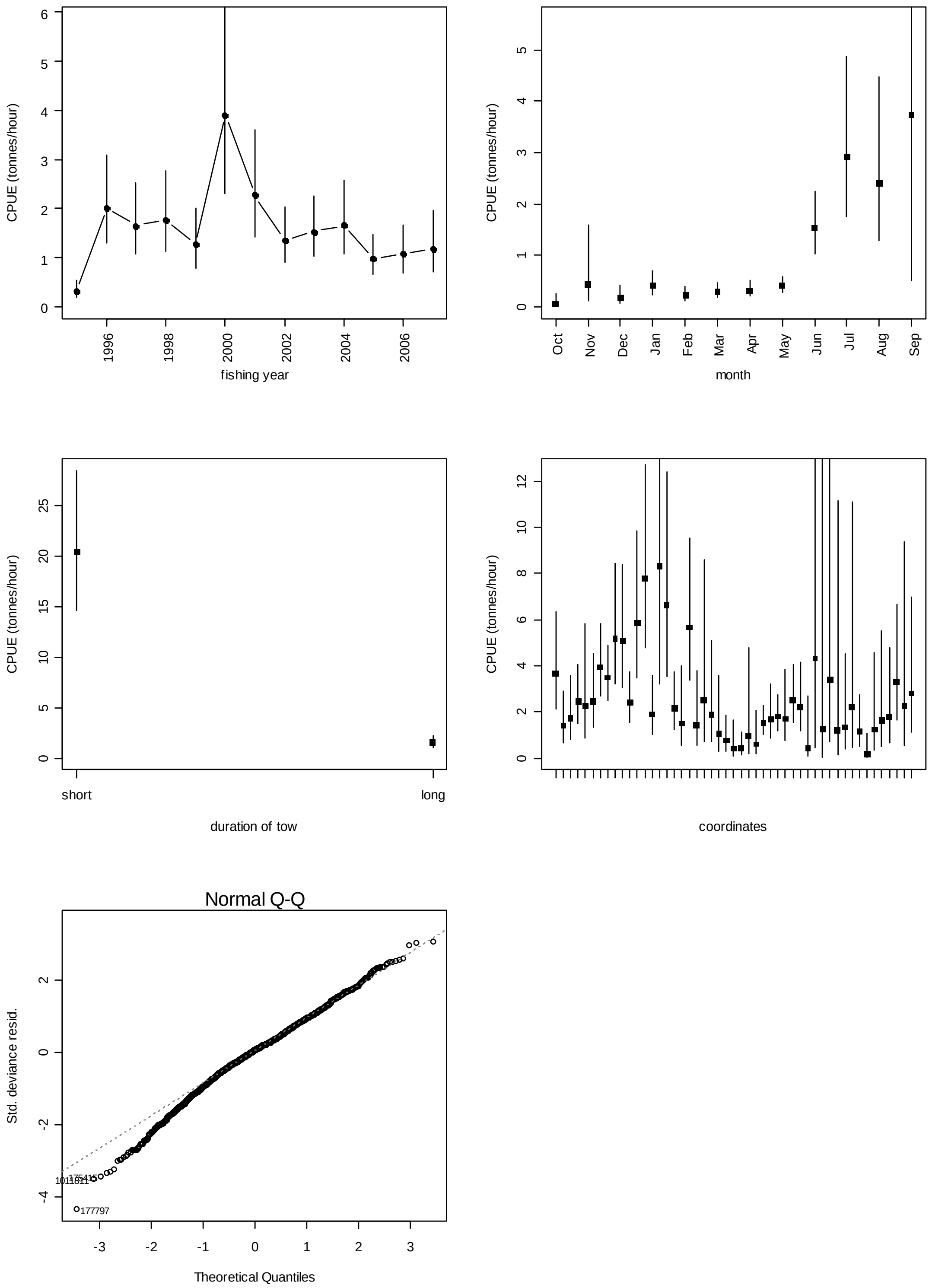
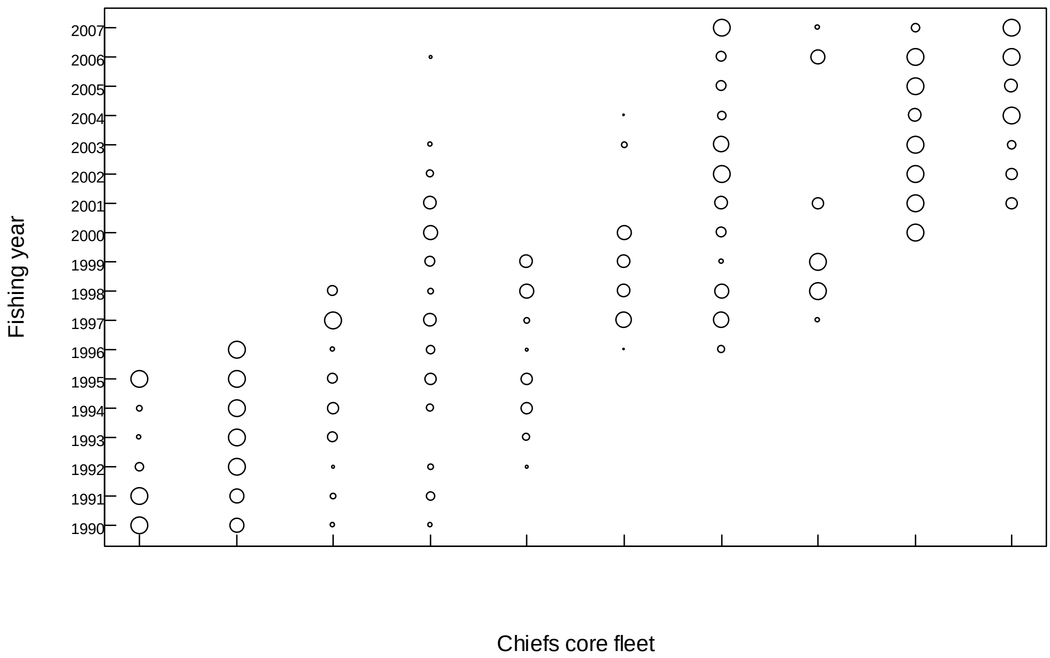


Figure 19: The effects of the model variables for the Spawning Box post-closure standardised CPUE series from 1995 with 95% confidence intervals and the QQ plot of the standardised residuals.



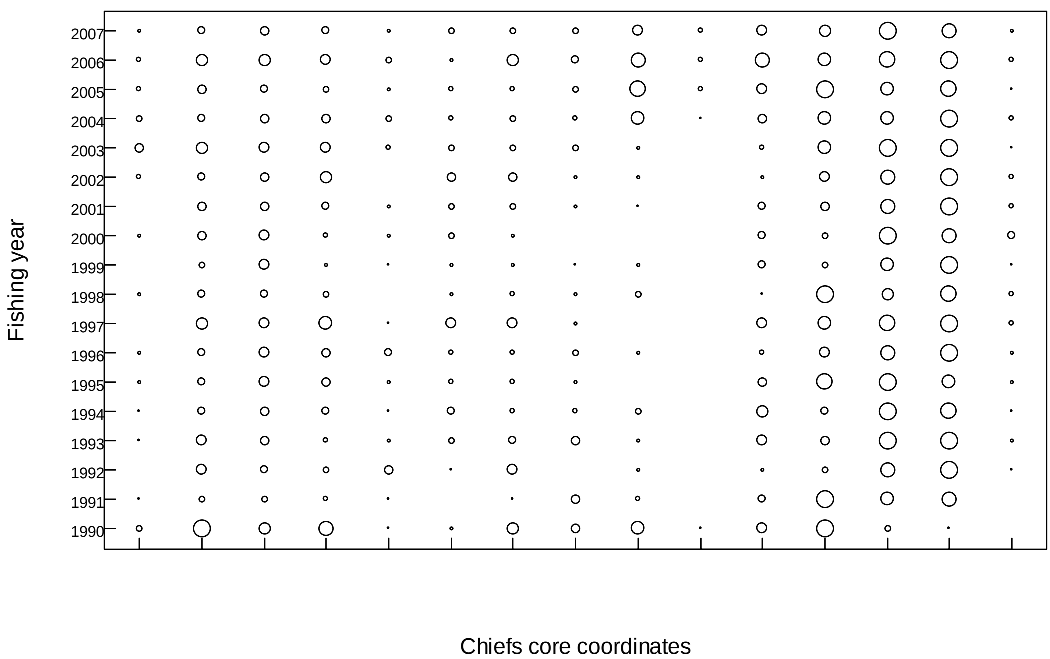


Figure 20: Core vessels fishing in the Chiefs complex and core coordinates fished. The radius of each circle is proportional to the amount of effort carried out by that vessel or in that coordinate.

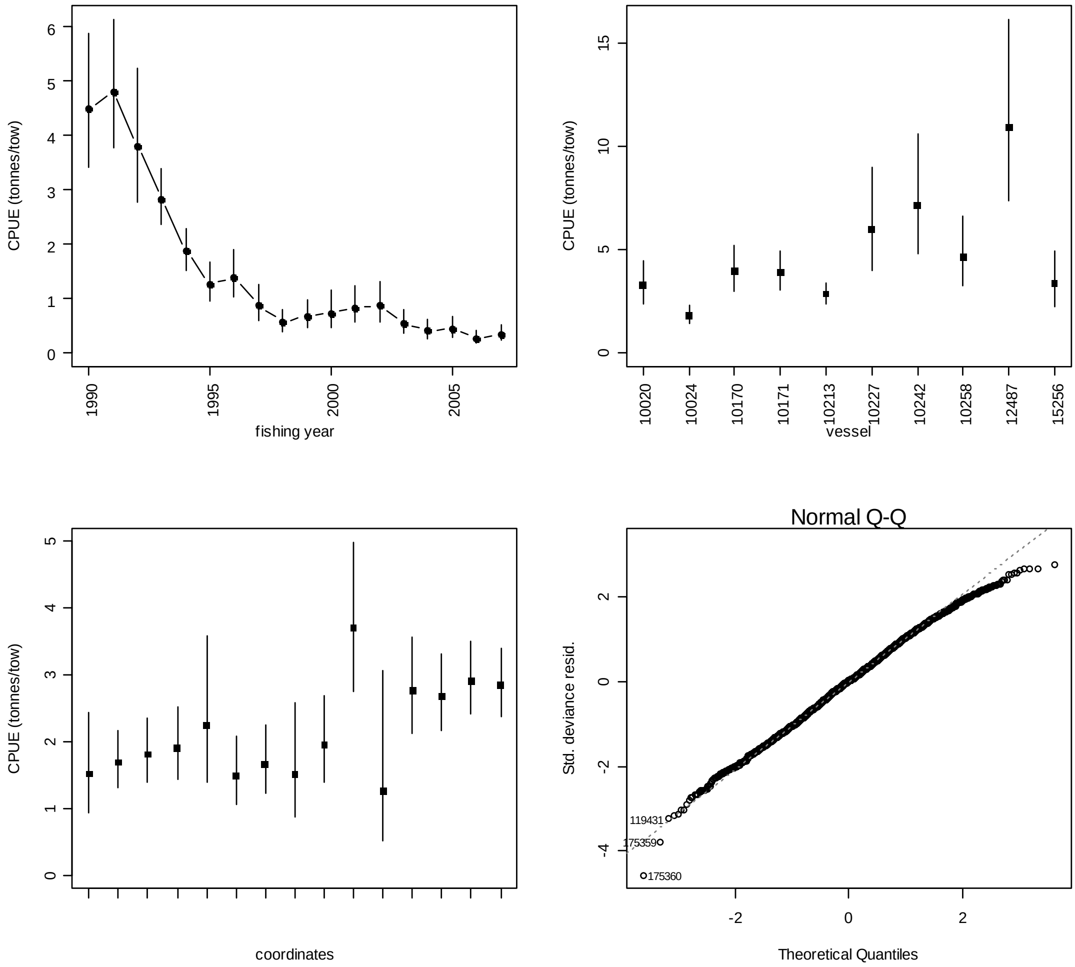
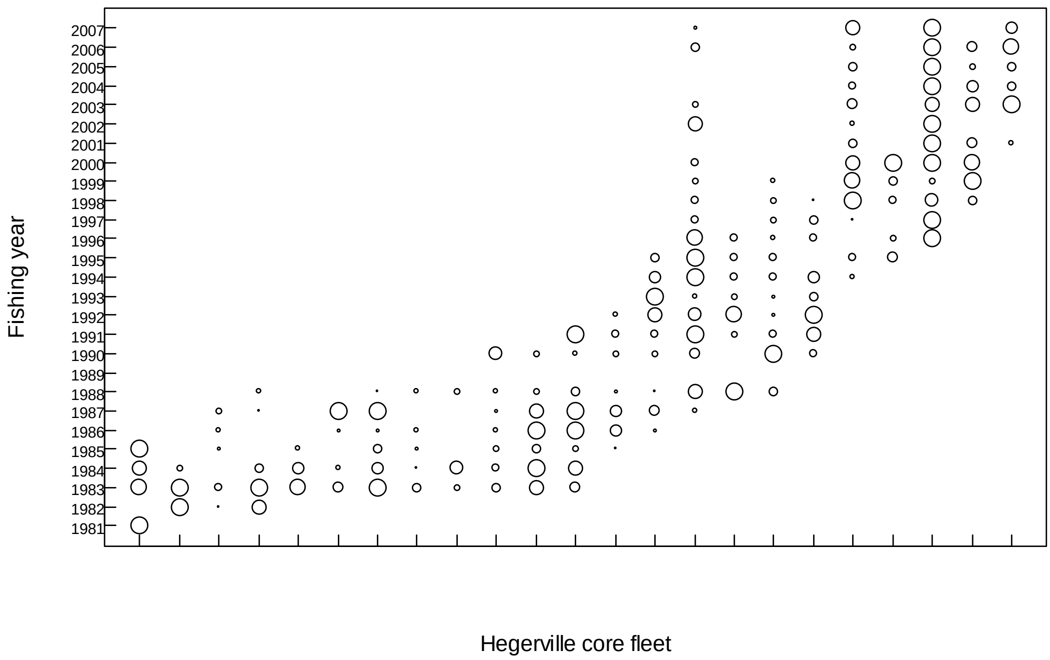


Figure 21: The effects of the model variables for the Chiefs complex Gaussian model from 1990 with 95% confidence intervals and the QQ plot of the standardised residuals.



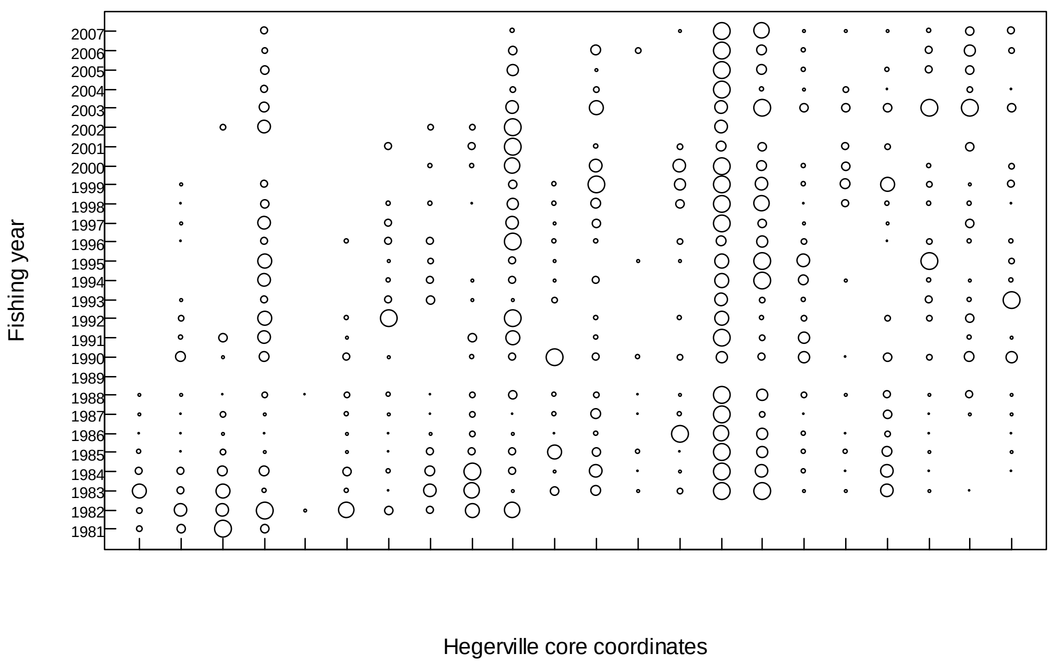


Figure 22: Core vessels fishing in the Hegerville area and core coordinates fished. The radius of each circle is proportional to the amount of effort carried out by that vessel or in that coordinate.

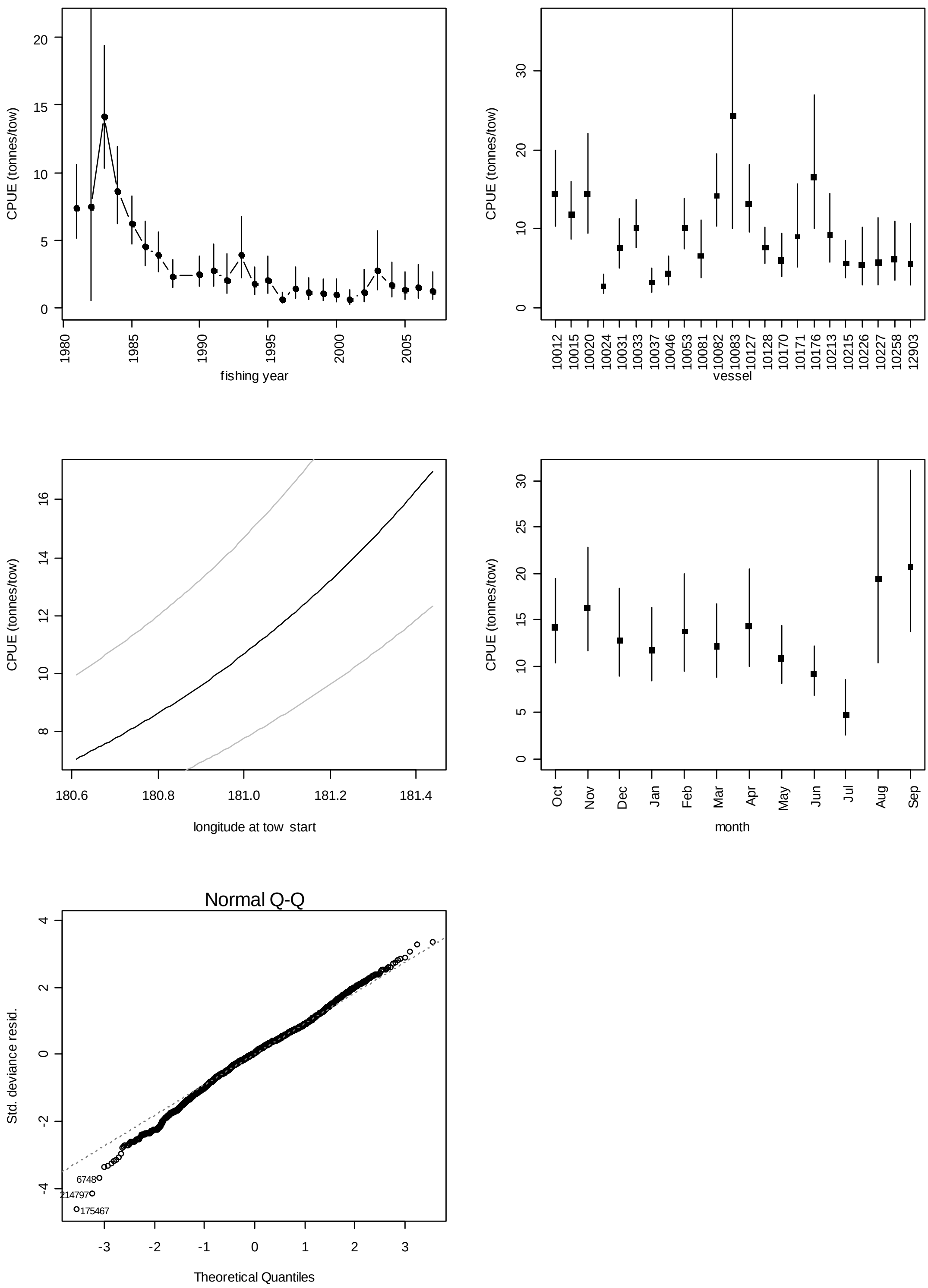
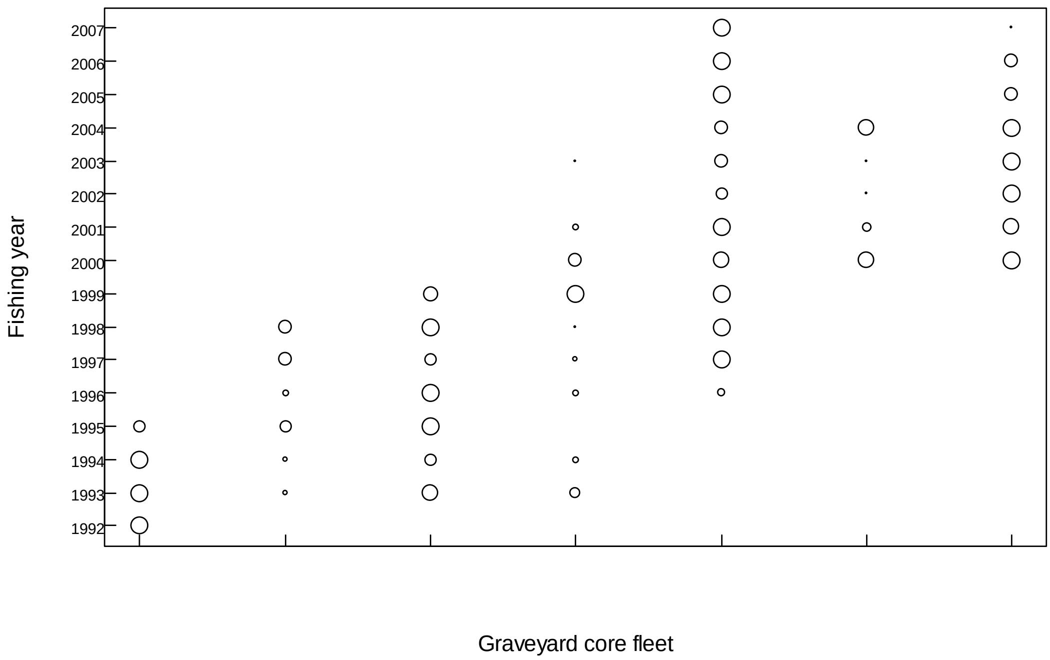


Figure 23: The effects of the model variables for the Hegerville area Gaussian model from 1990 with 95% confidence intervals and the QQ plot of the standardised residuals.



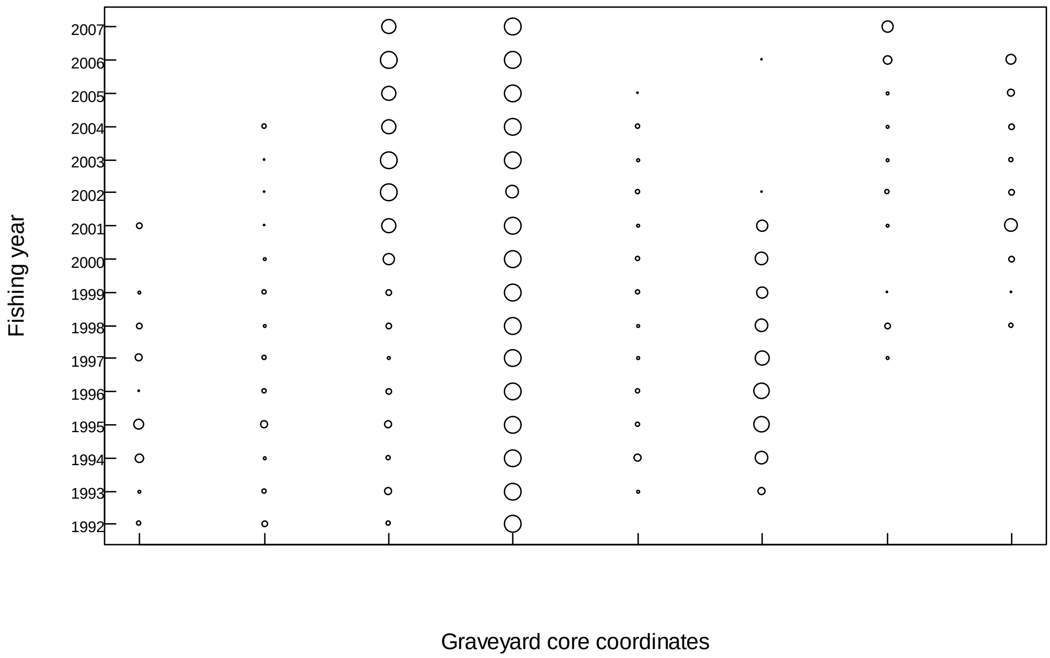


Figure 24: Core vessels fishing in the Graveyard complex and core coordinates fished. The radius of each circle is proportional to the amount of effort carried out by that vessel or in that coordinate.

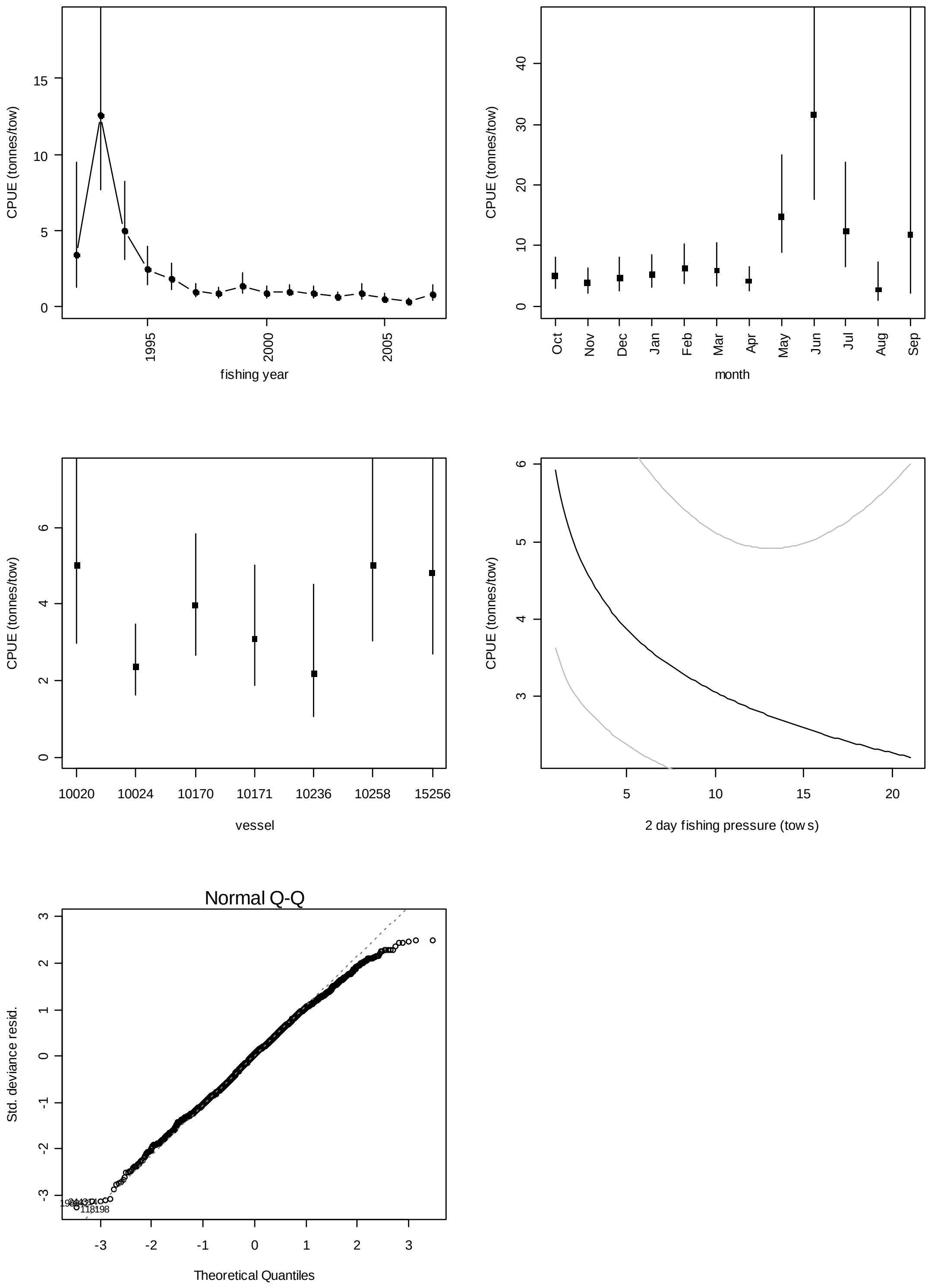
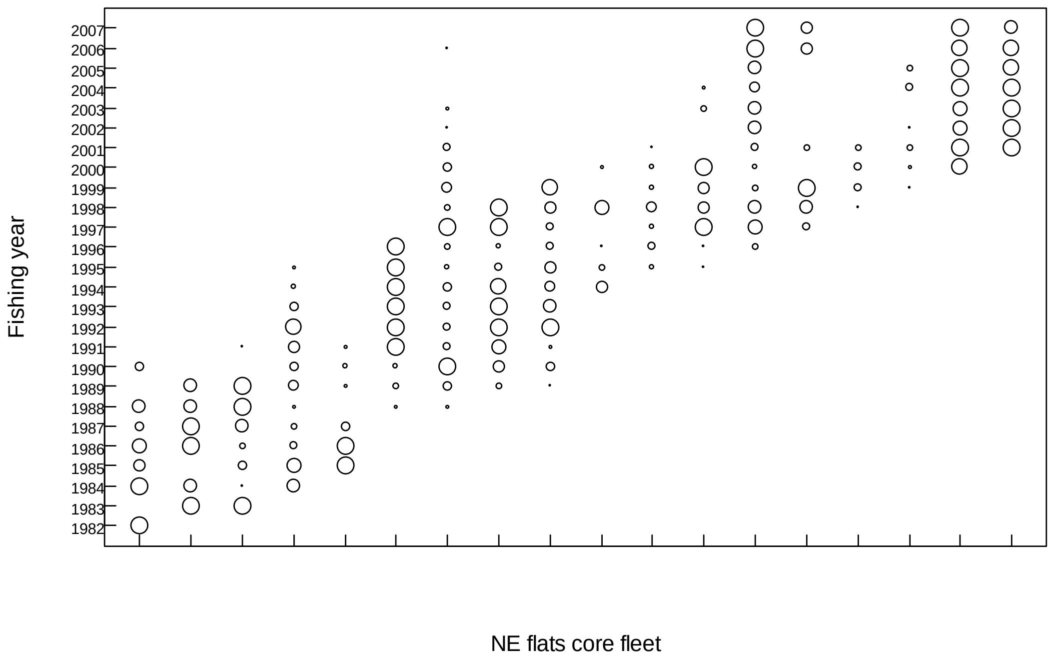


Figure 25: The effects of the model variables for the Graveyard complex model from 1992 with 95% confidence intervals and the QQ plot of the standardised residuals.



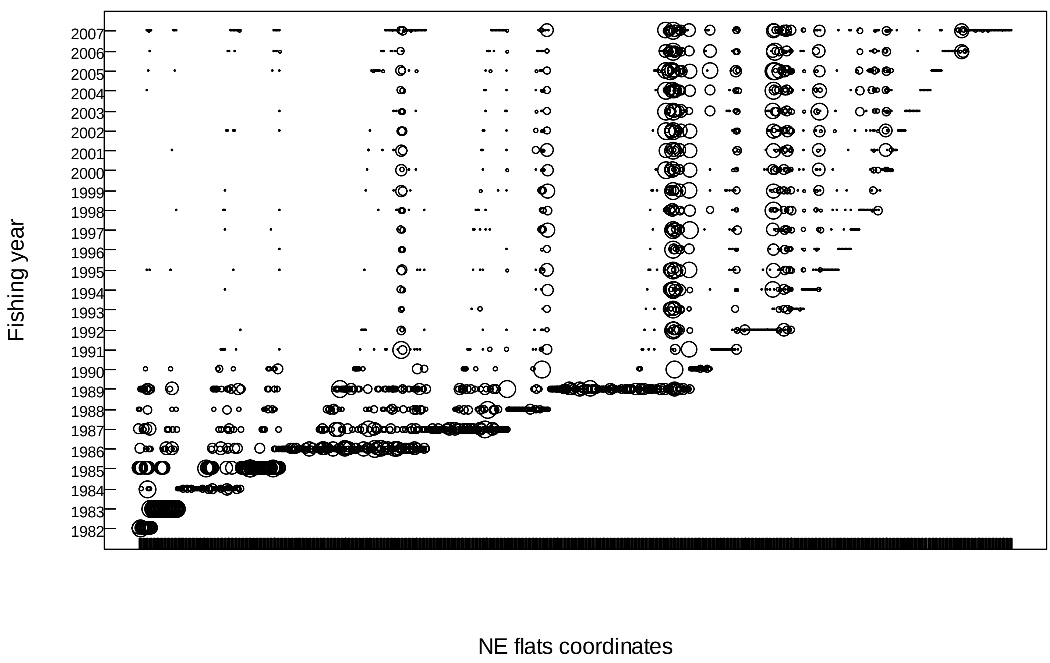


Figure 26: Core vessels fishing in the Northeast Flats. The radius of each circle is proportional to the amount of effort carried out by that vessel.

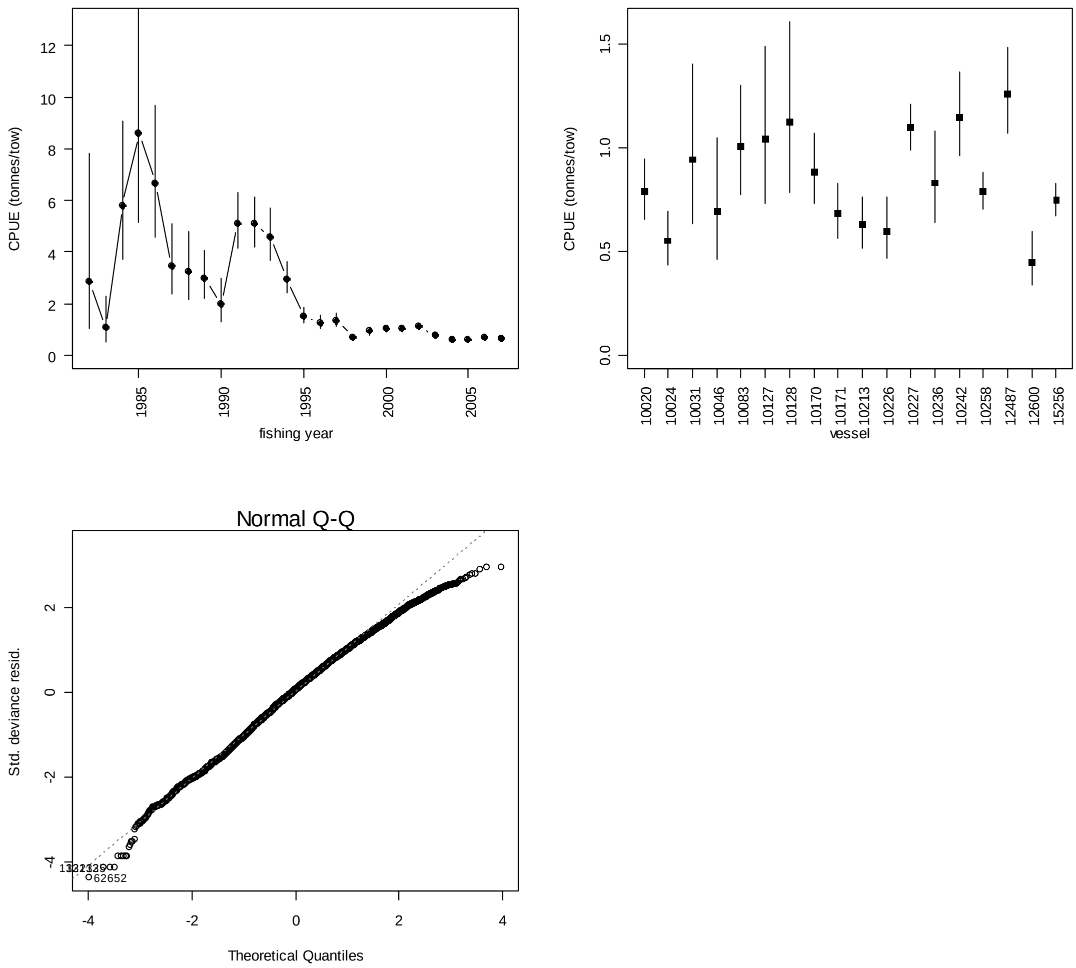


Figure 27: The effects of the model variables for the Northeast Flats model from 1980 with 95% confidence intervals and the QQ plot of the standardised residuals.