



ISSN 1175-1584

MINISTRY OF FISHERIES

Te Tautiaki i nga tini a Tangaroa

**CPUE from commercial fisheries for ling (*Genypterus blacodes*)
in Fishstocks LIN 3, 4, 5, 6, and 7 from 1990 to 2003**

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**Published by Ministry of Fisheries
Wellington
2004**

ISSN 1175-1584

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**Ministry of Fisheries
2004**

Citation:
Horn, P.L. (2004).
CPUE from commercial fisheries for ling (*Genypterus blacodes*)
in Fishstocks LIN 3, 4, 5, 6, and 7 from 1990 to 2003.
New Zealand Fisheries Assessment Report 2004/62. 40 p.

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

EXECUTIVE SUMMARY

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Existing series of CPUE for commercial line fisheries targeting ling on the Chatham Rise (LIN 3&4), the Campbell Plateau (LIN 5&6), the Bounty Plateau (LIN 6B), the west coast of the South Island (WCSI) (LIN 7WC), and Cook Strait (LIN 7CK) were updated to include data to the end of the 2003 calendar year. Series are available for Chatham Rise, WCSI, and Cook Strait from 1990 to 2003, for the Campbell Plateau from 1991 to 2003, and for the Bounty Plateau from 1992 to 2003. Existing series of CPUE for the ling bycatch from the trawl fisheries targeting hoki in Cook Strait since 1990 and WCSI since 1994 were also updated with the addition of 2003 data. A new CPUE analysis of data collected by observers in the WCSI hoki fishery since 1986 is presented.

Data used in the CPUE analyses were groomed to remove as many errors as possible. Data for the longline analyses were selected to ensure that they related to vessels that had consistently targeted and caught significant landings of ling (and so were likely to truly represent experienced and competent ling fishers). For the trawl fishery analyses, only data from vessels that had consistently reported ling bycatch from the chosen years were included. The catch data were modelled using a lognormal linear analysis to produce a set of standardised indices for each stock. Full interaction effects were allowed. Coefficients of selected variables were examined to ensure that they had a plausible range. Any selected interaction variables causing implausible ranges in the coefficients of the main variables were removed from the final models.

The standardised indices indicated that, since the early 1990s, ling stocks targeted by line fisheries had declined by about 20% on the Campbell Plateau, and about 55% on the Chatham Rise and Bounty Plateau. The stock off WCSI had declined but then recovered (although the trend was weak). The Cook Strait stock appeared to have declined slightly throughout the early 1990s, but to have increased since 1995. There are doubts about the reliability of the WCSI and Cook Strait series.

The standardised indices derived from the trawl fishery in Cook Strait indicated ling stocks had declined steadily throughout the early 1990s, and were exhibiting some recovery since about 1999. The index from the trawl fishery off WCSI based on TCEPR data had declined by about 40% since 1996. The index using observer data from the same fishery increased from 1986 to peak around 1997, then declined erratically by about 35% to 2003. Hence, the comparable sections of the two WCSI series are similar.

Differences in line and trawl CPUE series derived for the Cook Strait and WCSI stocks are discussed. The two series from Cook Strait exhibit similar general trends, although the extent of the implied declines and recoveries differ between fisheries. The series from the two WCSI fisheries exhibit totally opposing trends. However, the likely biases on these series (the trawl series has been biased downwards, and the line series may have been biased upwards) are insufficient to account for the difference.

1. INTRODUCTION

This document reports the results of Project LIN2003/01, Objective 1, to update the standardised catch and effort analyses from the ling longline fisheries in LIN 3, 4, 5, 6, and 7 with the addition of data up to the end of the 2002–03 fishing year.

The updated commercial line fishery series are for ling on the Chatham Rise, the west coast South Island (WCSI), and in Cook Strait from 1990 to 2003, the Campbell Plateau from 1991 to 2001, and the Bounty Plateau from 1992 to 2003. These five fisheries account for about 96% of New Zealand's line-caught ling (Horn 2001). The lining method principally used in all areas is bottom longline, although dahn lining is also commonly used in Cook Strait. CPUE analyses of these fisheries were most recently reported by Horn (2004b).

Series of ling CPUE indices derived from trawl fisheries targeting species other than ling were also reported by Horn (2004b). The series from the trawl fishery targeting hoki in Cook Strait from 1990 to 2002 was believed to be a reliable index of abundance of ling vulnerable to that fishery because there had probably been no changes in fishing or reporting practice that would have biased the data, and there was no incentive to either target or avoid ling. A series from the trawl fishery targeting spawning hoki off WCSI used data from 1994 to 2002, years when the reporting of ling catch from this fishery is believed to have been relatively accurate, but is more likely than the Cook Strait series to be biased. Both trawl series are updated here to include data from 2003. Also, a series using catch and effort data collected by observers in the WCSI trawl fishery was constructed in an attempt to validate the WCSI trawl series derived from TCEPR data.

Dunn et al. (2000) proposed four points that should be considered as part of the process to determine whether a CPUE series accurately mirrored fish abundance.

- Is there a good likelihood that CPUE provides an index of abundance (for that part of the population targeted by the fishery)?
- Are the data used in the analyses comprehensive and accurate?
- Was the modelling method valid for the available data?
- Do fishery-independent data support the CPUE trends?

Horn (2002a) showed that the CPUE series from the Chatham Rise and Campbell Plateau longline fisheries met all these criteria, and that the Bounty Plateau and WCSI series met the first three. The Cook Strait longline series probably did not index ling abundance well (Horn 2004b). The CPUE series derived from the two trawl bycatch fisheries were considered likely to have met the first three criteria (Horn 2004b).

Series of longline CPUE indices have been used as inputs into population models for ling since 1996. These were the only indices of relative abundance available from the commercial fisheries on the Chatham Rise, Campbell Plateau, Bounty Plateau, and WCSI up to 2002. A trawl CPUE series was incorporated into the Cook Strait assessment in 2002 (Horn & Dunn 2003), and into the WCSI assessment in 2003 (Horn 2004a). However, the WCSI assessment was complicated because the trawl and longline CPUE series exhibited opposing trends, and no other relative abundance series were available for that stock. Attempts to try to resolve the opposing trends are described below.

The updated longline and trawl series will be incorporated into future ling assessments. The stock units used in the stock modelling (and hence, in the CPUE analyses) are denoted as follows:

- Chatham Rise: QMAs 3 & 4 (LIN 3&4)
- Campbell Plateau: QMA 5, and QMA 6 west of 176° E (LIN 5&6)
- Bounty Plateau: QMA 6 east of 176° E (LIN 6B)
- WCSI: QMA 7 west of Cape Farewell (LIN 7WC)
- Cook Strait: statistical areas 16 and 17 (LIN 7CK)

2. METHODS

2.1 Data grooming

Catch and effort data, extracted from the fishery statistics database managed by the Ministry of Fisheries (MFish), were used in these analyses. All catch effort landing return (CELR) and trawl catch, effort, and processing (TCEPR) records where ling were targeted or caught from anywhere in the New Zealand EEZ were extracted and groomed to rectify as many errors as possible. The kinds of errors included:

- missing values (which could be filled based on preceding and following sets);
- data entry errors owing to unclear writing (e.g., several consecutive days of fishing in area 33 was punctuated by a single set recorded from area 23, target species recorded as "LIM");
- incorrect set positions, owing either to incorrect recording of east or west for longitudes, or to errors of 1° in latitude or longitude (often obvious based on preceding and following sets);
- transposition of some data (e.g., transposition of number of hooks and number of sets);
- recording QMA number as statistical area.

The groomed data (from the 1989–90 fishing year to the end of the 2003 calendar year) are stored in two relational database tables (*t_lin_celr*, and *t_lin_tcepr*) administered by NIWA for MFish. Data from the 2003 calendar year were obtained from MFish in April 2004.

The data used in the longline CPUE analyses are the estimates of ling greenweight caught per day. Horn (2002c) discussed the possibility that records from some vessels had estimated processed (e.g., headed and gutted) weight in this section of the CELR form, and described how this potential source of error was checked for and corrected. Corrections to estimated weights from 10 vessels were required. However, no additional data from these vessels occurred in the 2003 records, so no corrections were required in these updated analyses.

Data collected by observers on trawlers targeting hoki off WCSI were extracted from the *obs* database administered by NIWA for MFish. Catch and effort data were obtained from all observed trawl tows where hoki was the stated target species, and ling was reported caught.

2.2 Variables

Variables used in the analysis are described in Table 1 and are generally similar to those used in previous analyses (Horn 2003, 2004b). Longline CPUE was defined as catch per day (i.e., daily estimated catch in kilograms by a vessel in a particular statistical area), and number of hooks set per day was offered as an explanatory variable. Hook number per day was offered both as an untransformed number and as log-transformed data. Trawl CPUE was defined as catch per tow, with tow duration offered as an explanatory variable.

It would have been desirable to have gear width as one of the explanatory variables offered in the trawl models. However, it was apparent that this field in the TCEPR returns variously contained wingspread and doorspread measurements. Consequently, headline height was the only trawl gear dimension variable that could be offered. Trawling for hoki uses both bottom and midwater gear, so method was offered as an explanatory variable in the trawl analyses. Because midwater trawls are sometimes fished on the bottom, this method was split into two categories (i.e., midwater trawl fished in midwater, and midwater trawl fished on the bottom) based on the reported difference between bottom depth and depth of ground rope.

Season variables of both month and day of year were offered. The Southern Oscillation Index (SOI) was included as a 3-monthly running mean (using the SOI from the month in which fishing occurred, and the two preceding months).

For the first time in analyses of ling CPUE, sea surface temperature (SST) was offered as a variable in the WCSI and Cook Strait areas. The monthly mean SSTs from 1990 to 2003 were obtained from the NIWA climate databases at six positions: one in Cook Strait (41.5° S, 174.5° E), and five off WCSI. The WCSI locations approximated the latitudinal midpoints of statistical reporting areas 032–036 at the 500 m depth contour, i.e., 032, 44.55° S, 167.55° E; 033, 43.55° S, 168.85° E; 034, 42.5° S, 170° E; 035, 41.25° S, 170.65° E; 036, 40° S, 171.75° E. Hence, each fishing record was associated with the SST applicable to the year, month, and statistical area that it occurred in.

In the analyses of CELR and TCEPR data, variables describing vessels were offered to the model both as a categorical vessel identifier and as a series of continuous vessel parameters (i.e., length, breadth, draught, power, tonnage). Any vessel effect is explained either by the categorical variable, or by some of the vessel parameters, but not a combination of both categorical and continuous variables. Offering both categorical and continuous vessel variables allowed the model to select the type that best described any vessel effect.

2.3 Data selection

Data from various groups of statistical areas (Figure 1) were selected as follows:

Chatham Rise (LIN 3&4) — 018–024, 049–052, 401–412, 301

Campbell Plateau (LIN 5&6) — 025–031, 302, 303, 501–504, 601–606, 610–612, 616–620, 623–625

Bounty Plateau (LIN 6B) — 607–609, 613–615, 621, 622

West coast South Island (LIN 7WC) — 032–036, 701–706

Cook Strait (LIN 7CK) — 016–017

Note that these analyses were conducted on the basis of presumed biological stocks, rather than administrative (QMA) stocks. Consequently, the grouping of some statistical areas may appear erroneous, but has been done in a way which best approximates biological stocks. For example, statistical areas 302, 303, and most of 026 are in LIN 3, but they have been included in the Campbell Plateau analysis, as ling in these areas probably derive from the Campbell stock because the Campbell Plateau is the closest submarine shelf to these statistical areas.

CELR and TCEPR data were available from 1 October 1989, but were analysed by calendar year (i.e., 1990 to 2003). Calendar year (rather than fishing year) was used because of a seasonal trend of higher catch rates in most ling line fisheries running from about June to December (see Horn 2001). This ensured that all catches in a particular season peak were included in a single year, rather than being spread between two years.

Some line vessels had been recording individual set data on CELR forms (whereas for most vessels, a single record constitutes a day's fishing). If uncorrected, this would cause bias in CPUE analyses as those vessels would contribute about four times as many records per day fishing as other vessels. Consequently, all longline data were condensed (catches and hooks summed over vessel, day, and statistical area) to ensure that each record represented total catch and effort per statistical area per day.

To ensure that the longline data to be analysed were within plausible ranges and related to vessels that had consistently targeted and caught significant landings of ling (and so were likely to truly represent experienced and competent ling fishers), data were accepted if all the following constraints were met:

- catch was by line (i.e., bottom longline, trot line, dahn line),

- catch was between 1 and 35 000 kg per day,
- number of hooks was between 50 and 50 000 per day,
- number of records for a vessel was greater than 100 in 5 years for LIN 3&4, greater than 30 in 5 years for LIN 7CK, or greater than 50 in 5 years for all other Fishstocks, and all vessels included in any particular stock analysis had fished in more than 1 year,
- target species was reported as ling.

Examination of the zero catch records indicated that most represented either duplicated records (two records for a particular day, one with and one without catches) or obvious mistakes (two or three days fishing with no ling catch). Exceptions to this were data recorded by two vessels fishing around the Chatham Islands (in statistical areas 049–052), and consistently recording ling as their target species but recording zero or small landings of that species. It is suspected that these vessels were actually targeting species other than ling, so their data were removed from the Chatham Rise analysis. After this removal, zero catches made up less than 0.3% of the data. Because of the relatively high number of hooks fished in any set, a zero catch of ling in any set that is genuinely targeting ling is likely to result either from some gear malfunction or from exploratory fishing. The removal of such data points from the analysis will not bias the index of relative abundance of ling on known fishing grounds. Consequently, as in previous analyses, all zero observations were removed.

Trawl data can be recorded on either TCEPR or CELR forms. TCEPR returns contain tow-by-tow data. CELR returns often amalgamate a day's fishing into a single line of data, so some of the data on individual tows may be lost (e.g., duration, towing speed, bottom depth, gear dimensions). In the Cook Strait hoki target fishery from 1990 to 2003 there were about 18 000 records of ling landings on the TCEPR database and just over 2000 records on the CELR database. For the WCSI fishery there were over 37 000 TCEPR records compared with about 2000 CELR records. Consequently, only TCEPR data were used in the CPUE analyses of the trawl fisheries as this data source enabled a greater variety of explanatory variables to be offered.

To ensure that the TCEPR trawl data to be analysed were within plausible ranges and related to vessels that had consistently caught and recorded ling landings, data were accepted if all the following constraints were met:

- target species was hoki,
- ling catch was greater than 5 kg and less than 15 000 kg per tow,
- tow duration was between 0.2 and 8 hours,
- number of tows for a vessel was more than 100 in 5 years in Cook Strait, or 200 in 5 years off WCSI, and all vessels had fished in more than 1 year.

Data from the WCSI trawl fishery collected by observers from 1986 to 2003 were accepted if all the following constraints were met:

- target species was hoki,
- ling catch was greater than 1 kg and less than 15 000 kg per tow,
- tow duration was between 0.2 and 10 hours,
- day of the year ranged from 8 June to 6 September,
- number of tows for a vessel was more than 40, and all vessels had fished in more than 1 year.

2.4 The model

The lognormal linear model was used for all analyses. A forward stepwise multiple regression fitting algorithm (*step.glm*) was employed using the statistical package S-PLUS (Chambers & Hastie 1991, Venables & Ripley 1994). *Year* was forced into the model as the first term, and the algorithm added

variables based on changes in residual deviance. The explanatory power of a particular model was described by the reduction in residual deviance relative to the null deviance defined by a simple intercept model. Variables were added to the model until an improvement of less than 0.5 in the percentage of residual deviance explained was seen following inclusion of an additional variable. 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 for a particular stock were standardised to have a geometric mean of 1. The c.v.s represent the ratio of the standard error to the index. The 95% confidence intervals are also calculated for each index.

Unstandardised CPUE was also derived for each year and Fishstock from the available data sets. The annual indices were calculated as the mean of the individual daily catch (kg) for longline or catch per tow (kg) for trawl.

Variables were either categorical or continuous (Table 1). Model fits to continuous variables were made as third-order polynomials.

Interaction terms allow for the relationship between CPUE and a particular explanatory variable to vary with another explanatory variable (e.g., an interaction between *month* and *statarea* indicates that the relationship between CPUE and *month* differs with *statarea*). Since the primary interest is in relative year effects, possible interactions with *year* were not considered, but interactions between all other principal variables were initially allowed.

Horn (2002a) discussed the problems that the inclusion of interaction effects can have on standardisation analyses, i.e., the amount of data available is insufficient to justify the number of parameters fitted, coefficients for a particular variable can have an implausible range or pattern, and selected interaction variables may be meaningless. In an attempt to overcome these problems and produce the most valid model possible, the following analyses were conducted for each stock.

- a) The lognormal linear model was run using all data, but allowing no interaction effects. If *statarea* was selected into the model, then the number of records derived from each statistical area was calculated. Data from areas contributing very few records were removed from future analyses. Although there was no set threshold below which data would be removed, the amount of data deleted was generally negligible and was never more than 4% of the total available.
- b) The model was re-run, this time allowing interactions between all variables. The variable coefficient ranges were then examined, and if a range was considered implausible, the model was re-run with one or more of the least significant variables deleted until the resulting coefficient ranges of the more significant variables were considered plausible.

Model predictions for all variables selected into the final model are plotted against a vertical axis representing the expected (non-zero) catch. To calculate the y-values for a particular variable, all other model predictors must be fixed. These fixed values were chosen to be 'typical' values (see Francis (2001) for further discussion of this method). Note that if different fixed values were chosen, the values on the y-axis would change but the appearance of the plots would be unchanged.

3. RESULTS

3.1 Ling target longline fishery series

For each of the five stocks, the number of records of days fished in each statistical area (following initial grooming and removal of seldom-fished areas) is listed in Table 2. Total numbers of days fished, the estimated catch of ling from those fishing operations, and the number of vessels involved, by year, for data used in the final standardised analysis are given in Table 3.

3.1.1 Chatham Rise (LIN 3&4)

The Chatham Rise final analysis comprises over 11 000 records of days fished (Table 3). The estimated landings from this effort represent more than 90% of the total estimated landings by line fishing for this stock. Line fishing accounted for about 55% of the LIN 3&4 landings throughout the 1990s (Horn 2001), but has declined to about 45% since 2000 (Horn 2004a). Data from bottom longline, trot line, and dahn line operations were included in this analysis, and fishing method was offered as an explanatory variable. None of the 27 vessels included in this analysis had fished in every year, but 13 vessels had fished in six or more years (Figure 2).

The model run without interactions indicated that *statarea* explained an insignificant amount of the variance. Consequently, data from all but four of the statistical areas were retained in the final analysis. The areas that were deleted (301, 406, 411, 412) contributed only 24 observations over the 14 years of the analysis (i.e., less than 0.2% of the data), and these are probably attributable to reporting errors or exploratory fishing. In the model run with full interactions, two interactions (*vessel:log(hookno)* and *vessel:month*) entered the model. However, their inclusion resulted in some implausible *vessel* coefficients, so they were excluded. This exclusion changed the final standardised series only slightly.

Of the variables entering the model in the final analysis, *log(hookno)* was very dominant as it explained about 66% of the total variance (Table 4). The accepted variables explained 81% of the total variance. The model assumptions are mainly satisfied, and there are no marked patterns in the residuals (Figure 3). The poorly estimated points (i.e., those with residuals less than -3) make up a very small fraction of the total data set.

The effects of the selected variables are shown in Figure 4. The relationship between number of hooks set and daily catch is approximately linear. Data from 27 vessels are incorporated in the model; the difference between the best and worst of all but two of these vessels is less than a factor of 5. This level of between-vessel difference is not great given the inclusion in the analysis of auto-longliners and smaller hand-baiting inshore vessels. Highest catch rates tend to occur from August to December (the probable spawning season), but the best monthly catch rate is less than double the worst.

The standardised year effects (Table 5, Figure 4) show a steady decline from 1990 to 1997, followed by a relatively constant signal since then.

3.1.2 Campbell Plateau (LIN 5&6)

Line fishing accounted for about 25% of the LIN 5&6 (excluding the Bounty Plateau) landings throughout the 1990s (Horn 2001), and this level has been maintained in recent years (Horn 2004a). The Campbell Plateau final analysis includes data from fishing operations responsible for almost 90% of those line landings. This fishery is almost exclusively bottom longline (Horn 2001), so only data from this method were included in the analysis. Data from 12 vessels were included in the final analysis (see Figure 2). No vessel had fished the entire series, but five had fished in six or more years. A new vessel fished in the LIN 5&6 area in 2003, and although it exceeded the 50-day threshold it was excluded from the analysis because it had fished in only one year.

The model run without interactions indicated that *statarea* was a variable with considerable explanatory power (it explained about 6% of the variance). However, 14 statistical areas each had records of 43 or fewer days fished throughout the 13-year series, with most producing fewer than 20 data points. Their removal involved less than 4% of the data, but reduced the number of included statistical areas to 9 (each with over 130 days fished). It is believed that the remaining subset of data would provide a more accurate representation of any *statarea* effect.

In the model run with full interactions, five interaction variables were selected, i.e., *vessel:month*, *vessel:statarea*, *vessel:log(hookno)*, *month:statarea*, and *month:log(hookno)*. However, the inclusion of these resulted in ranges of more than two magnitudes in the coefficients of the *vessel* and *month* variables. The model was re-run restricting *vessel*, or *month*, or *statarea*, or *log(hookno)* from entering any interaction. It was apparent from these runs that interactions including the *vessel* variable were causing the implausible coefficient ranges. Consequently, the final model was derived from a run allowing interactions between all variables except *vessel*. This reduced the total explained variance by about 4%, but the final series of year effects obtained with and without *vessel* interactions were virtually identical.

The variables entering the final model were *vessel*, *log(hookno)*, *statarea*, and *month*, with interactions between the last three. More than 51% of the variance was explained by the *log(hookno)* variable, and total explained variance was 69% (see Table 4). The model assumptions were mainly satisfied, there being only limited deviations from normality (Figure 5).

The effects of the selected variables are shown in Figure 6. The relationship between the number of hooks set and daily catch is approximately linear up to about 30 000 hooks, but with a declining catch per hook at higher hook numbers. Overall catch by *statarea* varied by a factor of about 7. Daily catch by vessel varied by a factor of less than 4. The low expected catch rate in September may be due to a lull in fishing between the non-spawning fishery on the Campbell Plateau and the spawning fishery near Puysegur, and hence, little concerted targeting at this time. The standardised year effects (Table 5, Figure 6) indicate a slight declining trend throughout the series.

3.1.3 Bounty Plateau (LIN 6B)

Line fishing accounts for virtually all the Bounty Plateau ling landings since 1992 (Horn 2004a), and the final analysis presented here includes data from fishing operations responsible for over 98% of those line-caught ling. In 12 years of fishing, over 1500 vessel days have been reported, although three of the years were represented by just over 60 days each (see Table 3). Bottom longline is the only method used in this fishery (Horn 2001). Data from seven vessels were incorporated in the final analysis; one of these vessels had fished in all 12 years, but only two had fished in six or more years (see Figure 2).

The model run without interactions did not select *statarea*. However, as statistical areas 607 and 608 accounted for 99% of the records, data from other statistical areas (i.e., 613 and 614) were deleted as they were probably reporting errors or exploratory fishing. In the model run with full interactions, *month:log(hookno)* and *vessel:log(hookno)* were selected. The inclusion of the *vessel* interaction effect was found to adversely affect the vessel coefficients, so it was excluded.

The variables selected into the final model explained 51% of the total variance (see Table 4). The model assumptions were mainly satisfied, there being only slight deviations from normality (Figure 7).

The effects of the selected variables are shown in Figure 8. The relationship between the number of hooks set and daily catch is approximately linear up to about 30 000 hooks. Overall catch rates for the included vessels vary by a factor of less than 3. Catch rates were high from July to October, and low from November to June.

The standardised year effects (Table 5, Figure 8) indicate a relatively rapid decline from 1992 to 1994, followed by a slight declining trend since then. The lowest index occurred in 2002.

3.1.4 West coast South Island (LIN 7WC)

About 30% of the landings of ling from the WCSI section of LIN 7 were taken by line fishing throughout the 1990s (Horn 2001), and this level of catch has been maintained since then (Horn 2004a). The final analysis below includes data from fishing operations responsible for over 95% of the line landings (see Table 3). This target fishery for ling is conducted primarily by smaller inshore vessels using the bottom longline and trot line methods. Fishing method was offered as an explanatory variable in this analysis. The final analysis included data from 20 vessels (see Figure 2). Three of these had fished in all 14 years of the series, and 11 vessels had fished in six or more years.

The model run without interactions indicated that *statarea* was a variable with some explanatory power. Consequently, data from only three statistical areas (032, 033, 034) were retained in the analysis (areas 035, 036, and 703 contributed only 1% of the available observations). In the model run with full interactions, interactions between *statarea*, *month*, *log(hookno)*, and *vessel* were selected. However, the inclusion of the *vessel* interaction effects produced an implausible range of vessel coefficients, so only interactions between the three other variables were retained. The variables entering the model (*vessel*, *month*, *log(hookno)*, *statarea*, and interactions between the last three) explained 35% of total variance (see Table 4).

The model assumptions were mainly satisfied, but there was evidence of non-normality in the pattern of the residuals (Figure 9). However, the poorly estimated points (i.e., those with residuals smaller than -3) are a very small fraction of the total data set.

The effects of the selected variables are shown in Figure 10. The vessel coefficients were in a relatively narrow range, with the best and worst vessels varying by a factor of less than 4. Catch rates were high from August to October (the spawning season), and low from January to June. Catch per hook increased to a peak at about 2500 hooks, then declined slightly after that. There was little difference in catch rates from the three statistical areas included in the analysis.

The standardised year effects (Table 5, Figure 10) indicate a decline from 1991 to 1996, followed by an increasing trend since then. The most recent indices are at the same level as the peak in 1991–92.

3.1.5 Cook Strait (LIN 7CK)

The line fishery in Cook Strait took about 20% of the ling landings from this area throughout the 1990s (Horn 2001), but this proportion has increased to about 30% in recent years (Horn 2004a). The ling target line fishery had relatively few records from 1997 to 2001 (see Table 3), but data from all years were included in the analysis. Over 95% of days fishing occurred in statistical area 016 (see Table 2). Bottom longline and dahn line are both used, with bottom longline being more dominant. Two large auto-longline vessels fished in this area since 1998. The total number of days fished by one of these vessels met the 5-year threshold (see Section 2.3), so it was included in the model. Data from 14 vessels were incorporated in the final analysis, and one of these had fished in all 13 years of the series (see Figure 2). Five vessels had fished in six or more years. A new vessel fished in the Cook Strait area in 2003, and although it exceeded the 30-day threshold it was excluded from the analysis because it had fished in only one year.

The model run without interactions indicated that *statarea* explained none of the variance, so data from both statistical areas were retained. Interactions between *vessel*, *month*, and *log(hookno)* all entered the full interaction model. However, these interactions gave rise to unrealistic *vessel* and *hookno* coefficients, so they were excluded. Their exclusion caused very minor changes to the standardised series. Of the variables entering the model in the final analysis, *vessel* was dominant and explained about 34% of the variance. *Vessel*, *log(hookno)* and *month* were the selected variables, explaining 63% of the total variance (see Table 4). The model assumptions were mainly satisfied, there being no marked patterns in the residuals and limited deviations from normality (Figure 11).

The effects of the selected variables are shown in Figure 12. Catch rates by all but one of the vessels in the model varied by less than a factor of 7. Expected catch rate per hook declines with increasing hook number. Highest catch rates tend to occur from June to October, although the difference between the best and worst month is less than a factor of 2.

The standardised year effects are quite variable (Table 5, Figure 12) but could be interpreted as showing a slight decline throughout the early 1990s, followed by a steady increase since 1995. An approximate doubling of biomass from 1995 to 2003 is indicated. However, confidence bounds around the 1997 and 1999–2003 indices are wide; most of these indices are from years with the fewest days of ling targeting.

3.2 Trawl fishery ling bycatch series

Index series for the ling bycatch in two target trawl fisheries for hoki (Cook Strait and WCSI) are presented below. For analyses of TCEPR data from both fisheries, total numbers of days fished (by trawl method), the estimated catch of ling from those fishing operations, and the number of vessels involved, by year, for data used in the final standardised analysis (i.e., following initial grooming and removal of seldom-fished areas) are given in Table 6. The numbers of records of days fished in each statistical area (following initial grooming and removal of seldom-fished areas) are listed in Table 7. For the analysis of observer data from the WCSI fishery, summary data are listed in Table 8.

3.2.1 Cook Strait (LIN 7CK)

The trawl fishery targeting hoki in Cook Strait produced a minimum of 612 tows per year, and almost 16 000 tows from 1990 to 2003 (Table 6). The unstandardised indices of catch per tow exhibited a clear declining trend to the late 1990s, followed by a slight increase. Fishing occurs in statistical areas 016 and 017, but area 016 is the more heavily fished (Table 7). There are no apparent consistent changes in effort by area over the period analysed. The fishery is dominated by the midwater trawl method (see Table 6); little bottom trawling for hoki was conducted in this area before 1994. Horn (2003) showed that the CPUE derived from bottom trawl data only, midwater trawl data only, and both methods combined, produced series with virtually identical trends. Consequently, only the 'both methods combined' analysis is updated here. However, the midwater trawl category has been split into two, i.e., fishing on the bottom, and fishing in midwater. Of the 29 vessels included in the final analysis, only three had fished in all years (Figure 13), and three other vessels produced about 50% of the data. Twenty-one of the vessels had fished in six or more years.

In the run with full interactions, interactions between *month*, *duration*, and *headlineht* entered the model; all were retained. Of the variables entering the model in the final analysis, *vessel* was dominant. The final model explained 30% of the total variance (Table 9). The model assumptions were mainly satisfied, there being no marked patterns in the residuals and limited deviations from normality (Figure 14).

The effects of the selected variables are shown in Figure 15. Catch rates by most vessels in the model varied by a factor of less than 4. Ling catch increases approximately linearly with tow duration up to about 5 hours and then declines. The headline height relationship indicates that expected catches of ling are greater in bottom trawls (i.e., low headline height) than midwater trawls (i.e., greater headline heights). *Method* was not selected into the model. Highest catch rates tend to occur from May to October, though differences between any months are less than a factor of 2. The interactions between *month*, *duration*, and *headlineht* stem from a preference to use shorter tows in midwater to catch aggregated hoki during their spawning season from June to September.

The standardised year effects (Table 6, Figure 15) indicate a steady decline from 1990 to 1995, followed by relatively constant indices to 1999, and then an increase since 2000. The individual indices have narrow confidence bounds.

3.2.2 WCSI (LIN 7WC)

TCEPR data from the trawl fishery targeting spawning hoki off WCSI produced a minimum of 645 tows per year after data grooming and selection, and over 21 000 tows from 1994 to 2003 (see Table 6). The number of included tows per year has shown an increasing trend over time. Only data from June to September (the main period of the WCSI hoki target trawl fishery) were included. The unstandardised indices of catch per tow had a slightly declining trend. The fishery is dominated by the midwater trawl method, but there are many bottom and midwater trawl shots in each year (see Table 6). Just less than half the midwater tows were reported to have been fished on the bottom. Data from the three method categories were included in the model, and *method* was offered as an explanatory variable. Of the 48 vessels included in the final analysis, 12 had fished in all years, and 35 had fished in six or more years (see Figure 13).

The model run without interactions indicated that *statarea* explained none of the variance, so data from all statistical areas fished (i.e., areas 033–036 and 703) were retained. In the run with full interactions, interactions between *latitude* and each of *headlineht* and *month* entered the model and were retained. Of the variables entering the model in the final analysis, *vessel* was dominant. The final model explained 23% of the total variance (Table 9). The model assumptions were well satisfied, with very balanced residuals and no deviations from normality (Figure 16).

The effects of the selected variables are shown in Figure 17. Catch rates by all vessels in the model varied by less than a factor of 6, although most vary by a factor of less than 3. The headline height relationship indicates that expected catches of ling are greater in bottom trawls (i.e., low headline height) than midwater trawls (i.e., greater headline heights); the upward trend in catch rates at high headline heights is driven by very few data points. *Method* was not selected into the model. Ling catch peaks at a depth of just less than 400 m, and increases with increased tow duration. The categorical *latitude* variable enters the model, but there is a difference of less than a factor of 2 in all but the southernmost category. Catch rates vary slightly between months, being lowest in August. Catch rates of ling are about 40% higher at midday than midnight.

The standardised year effects (Table 6, Figure 17) have a steady declining trend throughout the entire series, indicating a decline of about 35% between 1994 and 2003. The individual indices have very narrow confidence bounds.

It was considered possible that the WCSI trawl CPUE series could be influenced by the development of 'twin-rig' bottom trawling, and the possible targeting of ling at the start of the season (even though hoki was the reported target species). Consequently, two additional analyses of the TCEPR data were completed. One analysis used only midwater trawl data, so would be free of any twin-rig bias. The other used only data from 7 July to 30 September, a period considered likely to represent the true target fishery for hoki. Both these analyses produced CPUE series very similar to the results from the original 'all data' analysis (Figure 18).

Observer data from the WCSI trawl fishery targeting hoki produced 281 to 1946 tows per year after data grooming and selection, and almost 13 000 tows from 1986 to 2003 (see Table 8). The number of included tows per year tended to be lowest during the middle of the series (1991–97). The unstandardised indices of catch per tow had a slightly increasing trend. The data are dominated by observations of the midwater trawl method. Contributions from bottom trawl fluctuate widely between years, ranging from zero or negligible to more than half the data (see Table 8). Almost a third of the midwater tows were reported to have been fished on the bottom. Data from the three method categories were included in the model, and *method* was offered as an explanatory variable. Of the 67

vessels included in the final analysis, only 15 had been observed in four or more years, and 32 had been observed in only two years (see Figure 13).

In the run with full interactions, an interaction between *method* and *depgndrope* entered the model and was retained. Of the variables entering the model in the final analysis, *day of year* was dominant, but three other variables (*vessel*, *latitude*, and *method*) all explained over 5% of additional variance. The final model explained 38% of the total variance (Table 9). The model assumptions were well satisfied, with very balanced residuals and no deviations from normality (Figure 19).

The effects of the selected variables are shown in Figure 20. Catch rates of ling are highest in June (*doy* = 160–185), and then decline by about half by the end of August (*doy* = 230). Catch rates by all vessels in the model varied by less than a factor of 8, although most vary by less than a factor of 4. Highest catch rates occur in the Hokitika Trench (latitude 42.5° S), and are also relatively high to the immediate north and south of this feature. Expected catches of ling are about seven times greater in bottom trawls than midwater trawls. Ling catches peak at depths of about 450–550 m, but are relatively high at depths between 300 and 700 m. Catches increase with increased tow duration.

The standardised year effects (Table 8, Figure 20) are quite variable between years, but indicate that current biomass is not markedly different from its value at the start of the 18-year series. However, an overall increase in abundance from 1986 to 1997–99, followed by a decline to 2003, could be interpreted from the series. Individual indices have moderate confidence bounds.

4. DISCUSSION

4.1 Ling target longline fishery series

In recent assessments of ling stocks around the South Island, series of CPUE indices derived from commercial fisheries have been used as indices of abundance (e.g., Horn & Dunn 2003, Horn 2004a). CPUE has been the only relative abundance series available for LIN 6B, LIN 7WC, and LIN 7CK, but are used in conjunction with indices from trawl survey series for LIN 3&4 and LIN 5&6. Although the line fisheries in LIN 5&6 account for only about a quarter of the total ling catch from that stock, the resulting CPUE series is still believed to be a good abundance index because it is based on a large volume of data from a consistent fishery. Horn (2002a) showed that most of the ling line CPUE series appeared to perform well in relation to the four discussion points raised by Dunn et al. (2000), and so were probably reasonable indices of abundance (for that part of the population targeted by the line fishery). The exception was the Cook Strait longline series.

As would be expected, the trends in the indices for the various stocks, and the variables selected into the models, have not changed markedly between the previous (Horn 2004b) and current analyses. Because the five longline fisheries examined here target a single species using similar methods, the sets of variables selected into the model for each stock might be expected to have some similarities. In all the analyses, *log(hookno)*, *vessel*, and *month* were selected into the model. With the CPUE unit being 'kg per day', it would be expected that the number of hooks set per day would be a very influential variable. This is certainly the case for LIN 3&4, LIN 5&6, and LIN 6B, where *log(hookno)* is the most influential variable, accounting for the largest proportion of the explained variance. Skill levels and/or gear efficiency will vary between vessels so the selection of a *vessel* variable in each model would be expected, although vessel catch rates seldom differed by more than a factor of 4 in each stock. Clearly, catch rates in all areas vary throughout the year, probably in relation to the spawning season for ling. Hence, *month* becomes an important explanatory variable.

It is apparent from Figure 2 that the fleet dynamics in some of the line fisheries have changed quite considerably, with periods when several vessels ceased to operate and new ones entered the fishery. The most obvious breaks are on the Chatham Rise about 1997–98 and on the Campbell Plateau about 1998–99. Horn (2004b) tested whether such a change had any effect on the LIN 3&4 CPUE series by

completing separate analyses for 1990 to 1997 and 1997 to 2002, and comparing the results with the "all years" indices. The two shorter series, when standardised to 1997, produce a pattern of indices almost identical to that from the initial CPUE analysis, indicating that the change in fleet dynamics has not biased the CPUE series. Less obvious breaks are also apparent about 1998 in the Bounty Plateau and Cook Strait fisheries. However, it is fortunate that, in both these series, single vessels producing a lot of data have fished in every year of the analysis.

In the Cook Strait line series, data from an auto-longliner were used in the analysis for the first time. The vessel had fished in the area for five years, but only met the threshold criterion of days fished in 2003. The relatively large daily catches by this vessel markedly increases the unstandardised indices of catch per day in this fishery (see Table 5). However, in a comparison of the previous Cook Strait indices calculated to 2002 (Horn 2004b) with those from the current analysis, only slight differences are apparent. Hence, the inclusion of the auto-longliner data has not altered the implied trend of relative abundance.

It is possible that experienced fishers in a target fishery may be able to maintain their catch rates (or at least reduce the rate of their decline) despite real declines in abundance, through learning and technological advances that improve fishing efficiency. This would bias a CPUE series by holding the later indices at artificially high levels. Learning by fishers is a factor that would be very difficult to incorporate into any analysis, but technological advances or changes in fishing practice can be examined. Horn (2004c) looked for any changes over time in the information collected by observers on auto-longliner trips targeting ling. Data relating to fishing efficiency (e.g., percentage of hooks baited, number of hooks lost), fishing practice (e.g., bait type, bottom topography), and catch outcome (e.g., identification and count of individuals caught) were available. Most variables showed no consistent trends over time. Hook saturation has probably rarely occurred at any time or in any area of the fishery. Ling rarely took more than 15% of the hooks, even during times of peak aggregation, and hook occupancy by all species combined very rarely exceeded more than 50% of the hooks baited. A weak positive trend over time was apparent in the efficiency of the automatic baiters (and confirmed by longline operators). However, much of this variance was explained by a vessel effect (which is already incorporated into the CPUE analysis process), and the remaining variance was wide. A reduction over time was indicated in the proportion of hooks lost per set. Data were discontinuous (none were available before 1994, or in 1996–97) and relatively sparse before 1999, so it was not possible to calculate a reliable correction factor. Any biasing of the CPUE series by this change is likely to be slight. Hence, Horn (2004c) concluded that the analysis of observer data indicated no changes in practice that were likely to have biased the estimated series of CPUE by altering the catchability of ling.

Data on hook spacing has not been recorded on CELR forms or by observers, but longline operators indicate that it has decreased over time in the ling fishery. In other line fisheries, catch per hook has been shown to increase with increasing hook spacing, but at a progressively decreasing rate, e.g., for halibut in the North Pacific (Hamley & Skud 1978) and Atlantic cod (Milliken et al. 2000). If the same effect has occurred in the ling fishery, then recent CPUE will have been biased downwards.

The CPUE from the Cook Strait ling line fishery is considered to be the least reliable of all the line series. The lack of precision in the indices from the years with few data is reflected in the relatively high c.v.s for these points (see Table 5). This series may be biased owing to the existence of target line fisheries for bluenose and hapuku. Ling is often taken as a bycatch in these fisheries, and the distributions of the three species overlap in depth and area. The CPUE analysis uses only data where ling was the stated target species. If it is general practice to define the reported target species as the most abundant species once the catch is onboard, then any real decline in ling abundance would be under-estimated in the CPUE series (because only sets where ling was the most abundant species would be included in the analysis). However, fishing practices and areas differ when targeting each of the three species, so the reported target is often likely to be the true target. The approximate doubling of biomass since the mid 1990s indicated by the CPUE series could have been achieved through growth and recruitment, but if so, it does represent an exceptional increase for a fished population.

The possibility of population enhancement by migration from other areas cannot be ruled out. Hence, although the reliability of this CPUE series is questionable, there are no factors that have obviously biased this series.

The line fishery CPUE analyses presented here for all stocks except Cook Strait provide sets of indices that are probably valid as relative abundance series (for that section of the population exploited by the fisheries) in stock assessment models for ling. The Cook Strait CPUE is questionable, but cannot be ruled out as a reliable relative abundance series.

4.2 Trawl fishery ling bycatch series

This document updates CPUE series for ling bycatch in the target trawl fisheries for hoki in Cook Strait and off WCSI, using TCEPR data. Horn (2004b) discussed in detail the likely reliability of the catch and effort data available from these fisheries; a summary of his conclusions follows.

- Both fisheries take ling as a significant, and generally the most abundant, bycatch species (averaging about 7% of the total wetfish landings over the years analysed), so it is expected that ling would be sufficiently abundant to be consistently reported on the TCEPR forms.
- Reporting of the ling catch has probably been reasonably accurate in Cook Strait since the start of that fishery, and since 1994 in the WCSI fishery.
- Changes in fishing practice have probably been accounted for by the variables accepted into the CPUE models.

Horn (2004b) stated that unless there have been consistent changes over time in the way skippers estimate or report the ling bycatch, changes in ling CPUE in the two hoki trawl fisheries probably reflect changes in abundance of ling vulnerable to trawl in these areas. However, recent discussions with trawl fishers who participated in the WCSI fishery suggest that in the last 2–3 years there has been an increase in efforts to actively avoid ling. Vessels either move away from areas where ling bycatch is unacceptably high, or change from bottom trawl to midwater gear (that catches relatively less ling). A more avid avoidance of areas where ling are relatively abundant would have the effect of depressing the ling CPUE. The change to midwater gear would have a lesser effect on CPUE as headline height (which acts as a proxy for gear type) is accepted into the models. Under-reporting of the WCSI ling catch is strongly believed to have occurred before 1994, and it is acknowledged that there are still strong incentives to avoid ling in this fishery, and possibly to dump or under-report. Hence, while the Cook Strait trawl CPUE series is still believed to provide a reasonable index of ling available to that fishery, there were greater doubts about the reliability of the WCSI series, particularly given its contrast to the WCSI line CPUE series (see Section 4.3).

In an attempt to validate or refute the WCSI TCEPR series, an analysis was conducted using ling catch per tow data collected by observers. The observer series has fewer of data points than the TCEPR series (an average of 700 tows per year, compared to 2100 per year), and few vessels that produced data from more than 3 years. However, confidence in the accuracy of the observer records is high. The overall impression from the observer CPUE is one of a relatively constant level of ling biomass throughout the series. However, there are very similar trends in the TCEPR and observer series (Figure 21). The TCEPR series increases from 1994 to peak in 1996, then steadily declines, but with a sub-peak in 1999. The observer series increases from 1994 to 1997, and then erratically declines, with sub-peaks in 1999 and 2002. The extent of the indicated decline from 1996–97 to 2003 (based on linear regressions to the estimated annual indices) is about 35–40% in both series. It was noted that the high index for 2002 in the observer series occurred in the only year when more than half the data derived from bottom trawl tows. The influence of 'twin-rig' bottom trawling on the observer CPUE series is unknown because the use of this method has not been formally recorded by observers. However, a re-analysis of the observer data using only midwater trawl tows produced a CPUE series very similar to that from the complete data set (see Figure 21). Hence, it appears that the

TCEPR and observer CPUE series are indexing the abundance of ling in the WCSI hoki trawl fishery similarly. Owing to data limitations, the observer series is less smooth, and its indices have wider confidence bounds, than the TCEPR series. However, a question still remains: Are these series indexing the overall abundance of ling off WCSI?

It should be noted that these trawl CPUE analyses did not include any tows where hoki were caught, but ling were not. The catch of ling per tow in the Cook Strait and WCSI hoki fisheries generally ranges between 30 and 500 kg. While ling remains a relatively abundant bycatch in the hoki fishery, tows with zero ling catch will be rare, so any bias resulting from their removal will be slight. However, should the relative abundance of ling decline to low levels, the exclusion of zero catches will have the effect of maintaining the CPUE at an artificially high level.

4.3 Comparison of relative abundance series

For the Cook Strait and WCSI stocks, CPUE series from both the line and trawl fisheries are available, and are plotted for comparison in Figure 21. The pairs of indices from an individual stock would not necessarily be expected to exhibit similar trends, owing to different fishing selectivities in the trawl and longline fisheries. Where comparable catch-at-length data are available, smaller fish are more heavily selected by trawl, compared to line, fisheries (Horn 2002b). Hence, if biomass available to the fishery is increased by the recruitment of young fish, it would be expected that such an increase would be observed in trawl CPUE before line CPUE. The opposite to this is observed in the Cook Strait series; an apparent recent increase in the biomass available to the line fishery was not first observed as an increase in trawl CPUE (see Figure 21). However, the selectivity ogives for the Cook Strait and WCSI line fisheries are unknown as few length-frequency data are available from them. Hence, based on current perceptions of the differences between trawl and line selectivity, the differences between the pairs of CPUE series from Cook Strait and WCSI are difficult to interpret, and give rise to doubts about the reliability of at least one of each of these pairs.

Both Cook Strait CPUE series exhibit similar overall trends of a decline followed by a recovery; the decline is more apparent in the trawl series, while the recovery dominates the line series (see Figure 21). The line series is disadvantaged by having few participants, low data volumes in some years, and the potential for some bias as a result of being able to determine the target species after the catch is landed. The trawl series is based on extensive data from a fishery that is believed to have changed little throughout the time series, but is reliant on consistent and relatively accurate reporting of a bycatch species. There may have been some recent incentive to more avidly avoid ling bycatch, and if this occurred, the recent trawl CPUE indices would be slightly depressed. There are no fishery-independent data available to validate either of the Cook Strait CPUE series, but the trawl series is believed to be the more reliable of the two. The compatibility of the two series in a stock modelling exercise has yet to be tested.

The WCSI line CPUE series exhibits an opposing trend to the two trawl CPUE series. The line series declines from 1990 to 1996 and then increases, while the trawl series increase from 1991 until about 1997 and then decline (Figure 21). All the series are based on large volumes of data, and the vessels included in the TCEPR and line analyses generally have a long history in the respective fisheries. There is some potential for the longline series to be biased as a result of being able to determine the target species after the catch is landed. However, line fisheries targeting bluenose, hapuku, and bass in this area tend to occur on grounds different to those when targeting ling, so when ling is reported as the target it is likely to be accurate (ling line fishers, pers. comm.). The series are not compatible in stock assessment models, and catch-at-age data from the trawl fishery are consistent with a fishing down of the larger older fish (Horn 2004a). There is some potential (and incentive) for the ling taken as a trawl bycatch to be under-reported; inaccurate reporting is known to have occurred at least before 1994. However, the comparison of the trawl TCEPR series with the 'reliable' observer series has indicated that any such bias in the TCEPR series is slight. There are no fishery-independent data available to validate either of the WCSI CPUE series.

Some differences in the input data available from the two WCSI fisheries are apparent, and these were examined to determine whether they could influence the CPUE series. The trawl series uses data only from June to September each year because little hoki targeting is conducted outside those months, whereas the line fishery occurs all year. However, an analysis of CPUE from the line fishery in June to September only included about 55% of the line data and produced a series with trends almost identical to the 'all year' analysis. A depth variable is accepted into the trawl CPUE model, but no depth data are available from the line fishery. However, depth explained less than 2% of the variance in the trawl model, so it is unlikely that its inclusion in the line model would markedly change the resulting series. The areal distributions of the two fisheries also exhibit differences (Figure 22); both are concentrated around statistical area 034, but only the line fishery extends further south, and effort further north is almost exclusively by trawl. It was considered possible that some environmental variable acting clinally along the west coast could influence the distribution of ling, and hence, produce variations in catchability between the different statistical areas. Sea surface temperature (SST) was the only available environmental variable that was likely to vary between statistical areas, and this variable has been shown to strongly influence the distribution of other demersal species (e.g., Zheng et al. 2001). Because of the strong upwelling off WCSI, SST was believed to be a reasonable proxy for water temperatures at the depths where ling are abundant. The between-area variation in SST was generally not great (i.e., about 1.5 °C between areas 032 and 035), but between-year differences were more pronounced (i.e., a difference of about 3 °C at similar months and areas over years 1990 to 2003). However, SST was not selected into any of the WCSI models (nor into either of the two Cook Strait models). In all the models where it was offered, it explained less than 0.3% of the residual variance.

Discussions with fishers who have participated in the WCSI ling line or hoki trawl fisheries have indicated some changes that may have influenced CPUE, and would not be indexed by any of the variables offered in the models. For the trawl fishery (as noted above), the incentive to avoid ling bycatch has increased in recent years, primarily to avoid the financial penalties arising from landing a species without quota. Active avoidance of ling is likely to depress the CPUE indices. The use of twin-rigged bottom trawls probably results in increased catches of ling per hour towed, so would act to raise the CPUE indices. This method was introduced to the WCSI hoki fishery about 2000, but it is likely to have accounted for less than 30% of the bottom trawl tows since then. Hence, the analysis would still be strongly weighted towards vessels that did not use twin-rigs; at the most extreme, 15% of tows from any year since 2000 may have used this method. A CPUE analysis using only midwater trawl data would be free of any twin-rig bias, and also likely to be less influenced by purposeful avoidance of ling (because catches of ling in midwater gear tend to be lower than when fishing on the bottom). Such an analysis was completed (see Figure 18), and there was little difference between the 'all trawl' and 'midwater' series, so it appears unlikely that active ling avoidance or twin-rig trawling have seriously biased the 'all trawl' CPUE series. Other changes in recent years (i.e., longer tow durations and variation in the split between bottom and midwater trawling) would be accounted for in the analysis by the *duration* and *headlineht* variables which are both selected into the final model.

For the line fishery, two changes probably not indexed by CPUE have occurred. First, the improvements in GPS technology in the early to mid 1990s have enabled more precise fishing on features producing higher ling catch rates. Second, it is suggested that the hoki trawlers sometimes direct the line vessels to areas with apparently high ling abundance, as indicated by the trawl bycatch. The trawler operators see this as an opportunity to have increased fishing pressure on a species they are trying to avoid, and it enables the line fishers to reduce their search time and/or fish in areas that are likely to produce relatively high ling catch rates. These two factors would tend to bias the line CPUE upwards. Line fishers also perceive that the mean size of ling has decreased since the mid 1990s. This is indicative of a fishing down of older biomass and/or recruitment to the fishery of some relatively strong year classes; catch-at-age data from the trawl fishery have indicated that both have occurred (Horn 2004a). Based on their catch rates, there was no perception by the line fishers that the WCSI ling stock had declined in recent years.

In summary, factors unaccounted for in CPUE analyses of the WCSI fisheries are most likely to have biased the recent trawl indices downwards, and biased the recent line indices upwards. While this may go some way towards explaining the different trends in the two indices from a single stock, it cannot explain the entire differences between the series from the two fisheries. The opposing trends throughout the common duration of the analyses of the two fisheries (i.e., 1990 to 2003) raises the notion that when ling are more available to the trawl fishery they are less available to the line fishery. There are no apparent logical reasons for this, particularly given the temporal and areal overlap of the two fisheries. Hence, it appears that a relative abundance index that can confidently be used in stock assessments of LIN 7WC has still not been identified.

5. ACKNOWLEDGMENTS

I thank Alistair Dunn for assistance with the analysis, Neil Bagley and several fishers for useful discussions on various aspects of the ling fishery, and Susan Kim for comments on a draft of this manuscript. This research was funded by the Ministry of Fisheries under Project LIN2003/01.

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Table 1: Summary of the variables offered in the CPUE models for the trawl and line fisheries.

Variable	Type	Description
Year	Categorical	Calendar year
Month	Categorical	Month of year
Statistical area	Categorical	Statistical area for the set
Vessel	Categorical	Unique vessel identifier
Day of year (doy)	Continuous	Julian day, starting at 1 on 1 January
SOI	Continuous	Southern Oscillation Index, 3-month running mean
SST	Continuous	Monthly mean sea surface temperature (WCSI and Cook Strait only)
Length	Continuous	Overall length of the vessel, in metres
Breadth	Continuous	Breadth of the vessel, in metres
Draught	Continuous	Draught of the vessel, in metres
LBD	Continuous	Vessel length × breadth × draft
Power	Continuous	Power of the vessel engine, in kilowatts
Tonnage	Continuous	Gross registered tonnage of the vessel, in tonnes
Line fisheries		
Method	Categorical	Fishing method (bottom longline, trot line, dahn line)
Hookno	Continuous	Number of hooks set per day in a statistical area
Log(hookno)	Continuous	Logarithm of variable Hookno
CPUE	Continuous	Ling catch (kg) per day in a statistical area
Trawl fisheries		
Method	Categorical	Trawl method (bottom trawl, midwater trawl on bottom, midwater trawl)
Headlineht	Continuous	Distance between trawl headline and groundrope (m)
Duration	Continuous	Tow duration, in hours
Starttime	Continuous	Start time of tow, 24-hour clock
Midtime	Continuous	Time at the midpoint of the tow, 24-hour clock
Depbtm	Continuous	Bottom depth (m)
Depgndrp	Continuous	Depth of groundrope (m)
Speed	Continuous	Towing speed (kts)
Latitude	Categorical	Latitude in 0.25° or 0.5° bins (WCSI fishery only)
CPUE	Continuous	Ling catch (kg) per tow

Table 2: Summary of records of days fished (Days) by statistical area (Statarea) used in the analyses of the target ling longline fisheries in each ling stock.

Chatham 1990-2003		Campbell 1991-2003		Bounty 1992-2003		WCSI 1990-2003		Cook Strait 1990-2003	
Statarea	Days	Statarea	Days	Statarea	Days	Statarea	Days	Statarea	Days
018	1 697	030	1 365	607	600	032	1 030	016	1 141
019	49	602	350	608	969	033	2 966	017	49
020	2 057	603	325			034	3 424		
021	509	604	333						
022	38	605	188						
023	252	610	697						
024	48	611	131						
401	1 096	618	795						
402	831	619	596						
403	451								
404	1 024								
405	77								
407	339								
408	365								
409	214								
410	1 108								
049	364								
050	61								
051	46								
052	448								

Table 3: Summary of data (by calendar year) used in the final standardised longline CPUE analysis for each stock. Days, number of individual records of days fished; Catch, estimated catch (t) from the accepted records; Vessels, number of vessels contributing to the accepted records. The total in the "Vessels" column indicates the number of unique vessels contributing to the accepted records throughout the time series.

Year	Chatham Rise (LIN 3&4)		Campbell Plateau (LIN 5&6)		Bounty Plateau (LIN 6B)		WCSI (LIN 7WC)		Cook Strait (LIN 7CK)		
	Days	Catch Vessels	Days	Catch Vessels	Days	Catch Vessels	Days	Catch Vessels	Days	Catch Vessels	
1990	233	190	4	—	—	—	293	240	97	40	7
1991	719	1 719	11	116	465	—	438	450	91	36	9
1992	691	2 932	11	245	1 077	—	655	769	125	53	9
1993	810	3 250	13	280	1 162	171	446	616	168	71	10
1994	1 010	3 853	13	344	1 418	221	534	799	165	34	9
1995	991	4 493	10	339	1 809	137	550	786	94	28	7
1996	916	3 915	12	362	1 903	62	667	871	70	28	5
1997	1 140	3 275	11	649	3 199	91	679	991	32	12	4
1998	742	2 409	11	692	3 015	62	616	997	55	20	2
1999	911	2 379	12	654	2 689	68	529	780	32	89	3
2000	764	2 310	11	458	2 190	99	514	693	30	61	3
2001	685	2 416	9	307	1 695	171	525	779	31	90	3
2002	885	2 087	9	223	1 276	192	450	607	96	107	4
2003	577	1 525	7	108	455	156	524	693	104	80	4
Total	11 074	36 753	27	4 777	22 353	1 569	7 420	10 071	1 161	749	14

Table 4: Standardised CPUE models for the target ling line fisheries from the five stocks, showing the percentages of residual deviance explained as each new variable was added.

Step	Variable	% deviance
Chatham Rise (LIN 3&4)		
	Year	8.6
1	log(hookno)	75.0
2	Vessel	79.2
3	Month	80.8
Campbell Plateau (LIN 5&6)		
	Year	3.1
1	log(hookno)	54.7
2	Statarea	60.8
3	Vessel	62.7
4	Statarea:log(hookno)	64.2
5	Month	65.0
6	Statarea:Month	67.8
7	log(hookno):Month	69.4
Bounty Plateau (LIN 6B)		
	Year	3.9
1	log(hookno)	36.0
2	Vessel	43.4
3	Month	47.7
4	Month:log(hookno)	51.5
West Coast South Island (LIN 7WC)		
	Year	2.8
1	Vessel	18.4
2	Month	28.4
3	log(hookno)	33.1
4	Statarea	33.7
5	Statarea:Month	34.2
6	log(hookno):Month	34.8
7	log(hookno):Statarea	35.3
Cook Strait (LIN 7CK)		
	Year	23.4
1	Vessel	58.1
2	log(hookno)	61.6
3	Month	62.7

Table 5: Unstandardised (Unstd) and standardised (Std, with 95% confidence intervals and c.v.s) year effects for the target ling line fisheries in five areas.

Year	Unstd	Std	95% CI	c.v.	Unstd	Std	95% CI	c.v.
	<u>Chatham Rise (LIN 3&4)</u>				<u>Campbell Plateau (LIN 5&6)</u>			
1990	0.22	1.62	1.38–1.89	0.08	–	–	–	–
1991	0.47	1.31	1.20–1.43	0.05	0.85	0.96	0.78–1.18	0.11
1992	1.55	1.79	1.64–1.96	0.04	0.90	1.26	1.07–1.49	0.08
1993	1.36	1.31	1.21–1.42	0.04	0.80	1.25	1.07–1.47	0.08
1994	1.29	1.27	1.18–1.36	0.04	0.77	0.99	0.87–1.13	0.07
1995	1.93	1.28	1.19–1.37	0.04	1.20	1.17	1.03–1.34	0.07
1996	1.64	1.08	1.01–1.17	0.04	1.15	1.04	0.92–1.18	0.06
1997	0.96	0.77	0.72–0.82	0.03	1.12	1.11	1.01–1.23	0.05
1998	1.01	0.76	0.71–0.83	0.04	0.97	1.00	0.91–1.10	0.05
1999	0.75	0.67	0.62–0.73	0.04	0.90	0.76	0.68–0.85	0.06
2000	1.01	0.78	0.71–0.85	0.04	1.10	0.86	0.75–0.99	0.07
2001	1.56	0.76	0.70–0.84	0.05	1.29	0.98	0.84–1.13	0.07
2002	0.96	0.63	0.58–0.69	0.04	1.28	1.01	0.87–1.19	0.08
2003	1.03	0.77	0.70–0.86	0.05	0.84	0.75	0.61–0.93	0.10
	<u>Bounty Plateau (LIN 6B)</u>				<u>WCSI (LIN 7WC)</u>			
1990	–	–	–	–	0.63	0.95	0.84–1.09	0.07
1991	–	–	–	–	0.80	1.16	1.04–1.29	0.05
1992	1.01	1.73	1.35–2.21	0.12	0.91	1.15	1.05–1.26	0.05
1993	0.93	1.52	1.25–1.85	0.10	1.04	0.93	0.84–1.03	0.05
1994	0.82	1.03	0.80–1.33	0.13	1.07	0.97	0.88–1.06	0.04
1995	1.06	1.09	0.84–1.40	0.13	1.07	0.98	0.90–1.07	0.04
1996	0.86	1.00	0.80–1.26	0.11	0.94	0.77	0.71–0.84	0.04
1997	0.77	0.82	0.64–1.05	0.13	1.04	0.85	0.78–0.93	0.04
1998	1.34	1.00	0.79–1.27	0.12	1.31	0.96	0.88–1.05	0.04
1999	1.28	1.02	0.83–1.27	0.11	1.14	0.98	0.89–1.08	0.05
2000	1.18	0.93	0.77–1.13	0.10	1.12	0.98	0.89–1.07	0.05
2001	0.92	0.80	0.66–0.97	0.10	1.19	1.13	1.03–1.24	0.05
2002	0.90	0.71	0.59–0.86	0.10	1.03	1.08	1.00–1.22	0.05
2003	1.09	0.76	0.63–0.92	0.09	1.01	1.17	1.07–1.28	0.05
	<u>Cook Strait (LIN 7CK)</u>							
1990	0.88	0.75	0.55–1.02	0.15				
1991	0.60	1.09	0.85–1.39	0.13				
1992	0.70	1.01	0.81–1.25	0.11				
1993	0.55	0.73	0.59–0.90	0.10				
1994	0.36	0.65	0.53–0.80	0.10				
1995	0.43	0.62	0.50–0.77	0.11				
1996	0.62	0.77	0.60–0.98	0.13				
1997	0.76	1.07	0.75–1.52	0.18				
1998	0.61	0.70	0.52–0.93	0.14				
1999	4.34	1.43	0.98–2.07	0.19				
2000	2.21	1.42	0.98–2.05	0.18				
2001	3.44	1.45	0.97–2.15	0.20				
2002	2.14	1.74	1.37–2.21	0.12				
2003	1.57	1.41	1.07–1.85	0.13				

Table 6: Summary of TCEPR data used in the final CPUE analyses of ling catch in the target trawl fisheries for hoki, and the unstandardised (Unstd) and standardised (Std, with 95% confidence intervals and c.v.s) year effects for those fisheries. Tows, number of individual tows recorded; Catch, estimated catch (t) from the accepted records; Vessel nos., number of vessels contributing to the accepted records. The total in the "Vessel nos." column indicates the number of unique vessels contributing to the accepted records throughout the time series. Method: BT, bottom trawl; MWB, midwater trawl on the bottom; MWM, midwater trawl in midwater.

Cook Strait hoki trawl fishery

Year	Tows	Catch (t)	Vessel nos.	Method			CPUE indices			
				BT	MWB	MWM	Unstd	Std	95% CI	c.v.
1990	612	195	13	3	122	487	1.94	1.60	1.44-1.77	0.05
1991	1 083	298	17	4	293	786	1.46	1.39	1.28-1.50	0.04
1992	748	178	16	6	220	522	1.31	1.28	1.17-1.39	0.04
1993	720	183	12	16	435	269	1.36	1.33	1.23-1.45	0.04
1994	801	132	15	209	212	380	1.05	0.92	0.85-0.99	0.04
1995	1 396	186	19	546	325	525	0.96	0.80	0.75-0.86	0.03
1996	1 382	178	20	637	378	367	0.96	0.80	0.75-0.85	0.03
1997	1 546	200	20	622	280	644	0.81	0.75	0.71-0.79	0.03
1998	1 452	175	16	424	377	651	0.79	0.79	0.74-0.84	0.03
1999	1 664	190	17	583	342	739	0.69	0.75	0.71-0.79	0.03
2000	1 444	162	17	412	311	721	0.69	0.84	0.79-0.89	0.03
2001	1 245	156	16	178	392	675	0.75	1.03	0.97-1.10	0.03
2002	843	117	12	172	268	403	0.92	1.04	0.97-1.12	0.04
2003	1 017	151	13	139	381	497	0.96	1.13	1.05-1.21	0.04
Total	15 953	2 501	29							

WCSI hoki trawl fishery

Year	Tows	Catch (t)	Vessel nos.	Method			CPUE indices			
				BT	MWB	MWM	Unstd	Std	95% CI	c.v.
1994	645	274	22	253	167	225	1.08	1.14	1.06-1.23	0.04
1995	1 054	583	26	311	339	404	1.24	1.27	1.19-1.35	0.03
1996	1 407	631	29	400	386	621	1.13	1.31	1.24-1.38	0.03
1997	1 255	553	37	394	337	524	1.05	1.11	1.05-1.17	0.03
1998	1 930	753	41	441	769	720	0.86	0.97	0.93-1.02	0.02
1999	2 393	1 102	39	897	739	757	1.07	1.11	1.06-1.15	0.02
2000	2 641	1 086	38	995	663	983	0.95	0.95	0.91-0.99	0.02
2001	3 455	1 301	41	1 404	1 085	966	0.91	0.84	0.81-0.87	0.02
2002	3 428	1 380	39	1 690	780	958	0.90	0.79	0.76-0.82	0.02
2003	3 155	1 068	37	1 486	848	821	0.89	0.70	0.67-0.73	0.02
Total	21 363	8 731	48							

Table 7: Summary of records of days fished (Days) by statistical area (Statarea) used in the analyses of the ling bycatch from TCEPR data in the target hoki trawl fisheries.

Cook Strait 1990-2003		WCSI 1994-2003	
Statarea	Days	Statarea	Days
16	10 660	33	27
17	5 293	34	16 332
		35	4 584
		36	323
		703	97

Table 8: Summary of observer data used in the final CPUE analyses of ling catch in the WCSI target trawl fisheries for hoki, and the unstandardised (Unstd) and standardised (Std, with 95% confidence intervals and c.v.s) year effects for that fishery. Tows, number of individual tows recorded; Catch, estimated catch (t) from the accepted records; Vessel nos., number of vessels contributing to the accepted records. The total in the "Vessel nos." column indicates the number of unique vessels contributing to the accepted records throughout the time series. Method: BT, bottom trawl; MWB, midwater trawl on the bottom; MWM, midwater trawl in midwater.

Year	Tows	Catch (t)	Vessel nos.	Method			CPUE indices			
				BT	MWB	MWM	Unstd	Std	95% CI	c.v.
1986	671	185	8	173	221	277	0.86	1.10	0.96-1.25	0.07
1987	1 946	354	20	172	174	1 600	0.56	0.59	0.54-0.66	0.05
1988	1 673	626	16	20	100	1 573	0.93	0.84	0.76-0.91	0.05
1989	668	259	8	104	192	372	1.05	1.06	0.94-1.18	0.06
1990	850	321	8	167	233	450	1.40	1.21	1.09-1.34	0.05
1991	392	105	6	22	78	292	0.92	0.77	0.68-0.88	0.06
1992	281	108	6	54	104	123	0.98	0.66	0.57-0.77	0.07
1993	447	138	11	203	55	189	0.91	1.08	0.96-1.22	0.06
1994	531	108	10	53	216	262	0.47	0.80	0.72-0.89	0.05
1995	356	91	7	52	108	196	1.07	1.10	0.97-1.25	0.06
1996	505	145	9	127	77	301	0.99	1.27	1.13-1.43	0.06
1997	399	123	10	0	147	252	0.80	1.40	1.24-1.58	0.06
1998	563	229	11	79	187	297	1.35	1.20	1.07-1.34	0.05
1999	743	226	12	259	166	318	1.35	1.47	1.33-1.64	0.05
2000	649	210	13	214	87	348	1.17	1.07	0.97-1.19	0.05
2001	565	164	16	97	252	216	1.05	0.93	0.83-1.04	0.06
2002	1 080	476	14	594	232	254	1.89	1.32	1.19-1.47	0.05
2003	567	151	12	284	145	138	1.08	0.72	0.64-0.81	0.06
Total	12 906	4 019	67							

Table 9: Standardised CPUE models for the two trawl fisheries, showing the percentages of residual deviance explained as each new variable was added.

Step	Variable	% deviance
Cook Strait (LIN 7CK)		
	Year	5.8
1	Vessel	17.5
2	Duration	23.2
3	Headlineht	25.2
4	Month	27.6
5	Duration:Headlineht	28.7
6	Month:Headlineht	29.5
7	Month:Duration	30.1
WCSI (LIN 7WC) — TCEPR data		
	Year	0.9
1	Vessel	9.0
2	Headlineht	13.5
3	Depgndrope	15.3
4	Duration	17.2
5	Latitude	18.3
6	Headlineht:Latitude	19.2
7	Month	20.0
8	Midtime	20.6
9	Month:Latitude	21.3
WCSI (LIN 7WC) — Observer data		
	Year	5.1
1	Day of year	12.8
2	Vessel	18.8
3	Latitude	23.2
4	Method	29.3
5	Depgndrope	32.6
6	Duration	35.7
7	Method:Depgndrope	36.9
8	Bottom depth	37.7

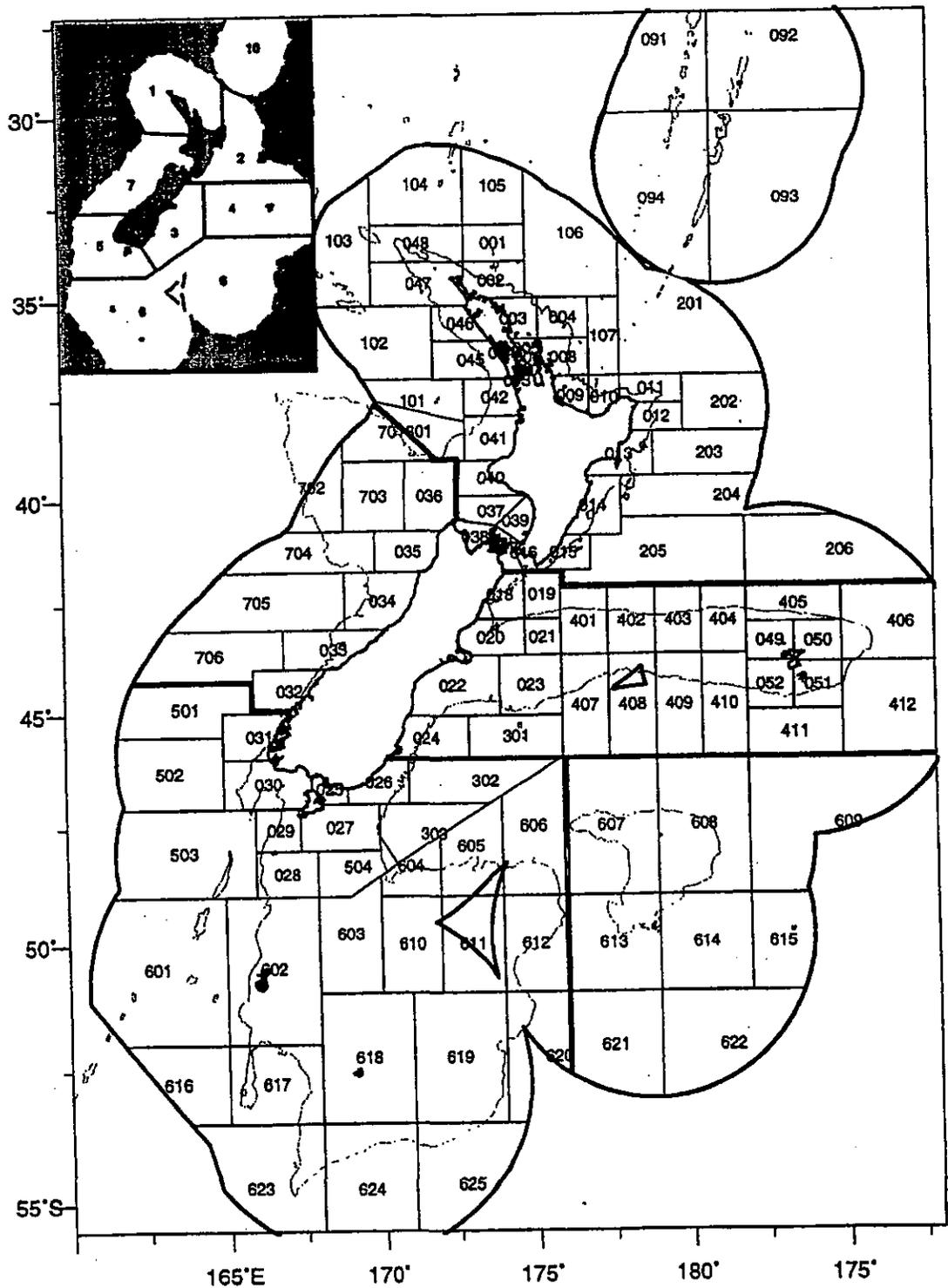


Figure 1: Map of the New Zealand EEZ with statistical areas (numbers from 001 to 801), showing how they were grouped (thick lines) to construct the five stock areas used in this analysis. The 1000 m isobath is also plotted. Administrative ling Fishstock areas are shown on the inset.

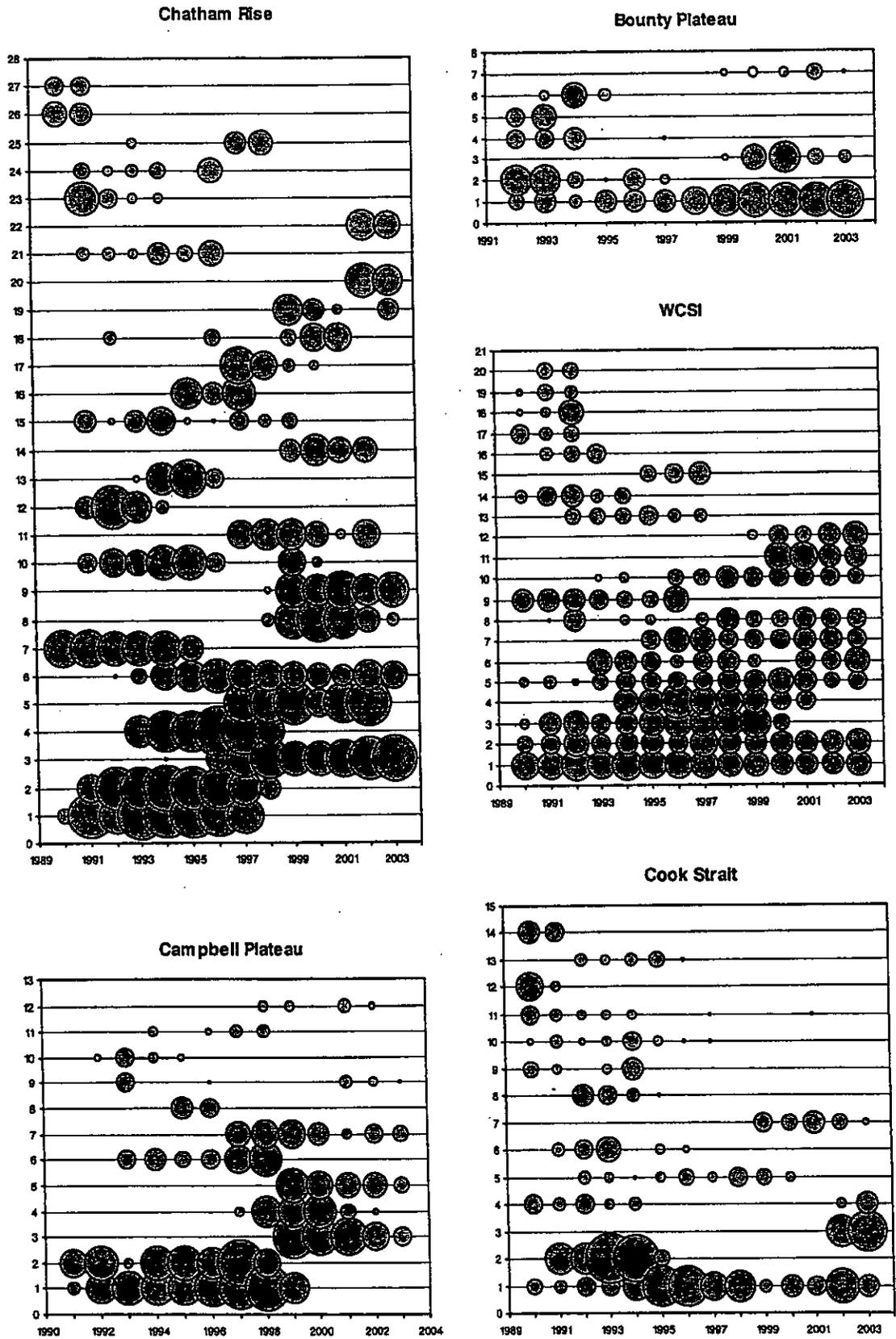


Figure 2: Fishing effort (where circle area is proportional to number of days fished) by year for individual vessels included in the final longline CPUE analyses for the five stocks.

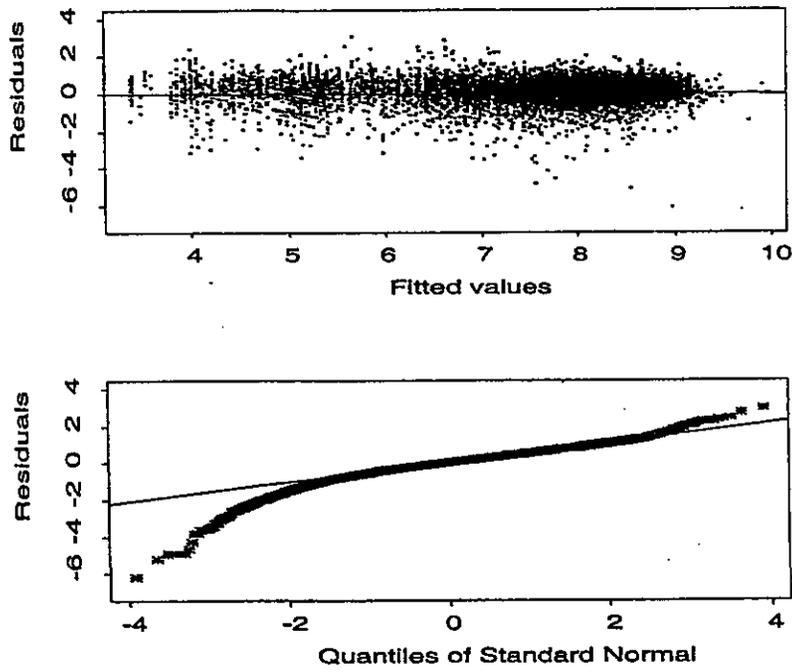


Figure 3: Diagnostic plots for the CPUE model of the Chatham Rise (LIN 3&4) ling line fishery.

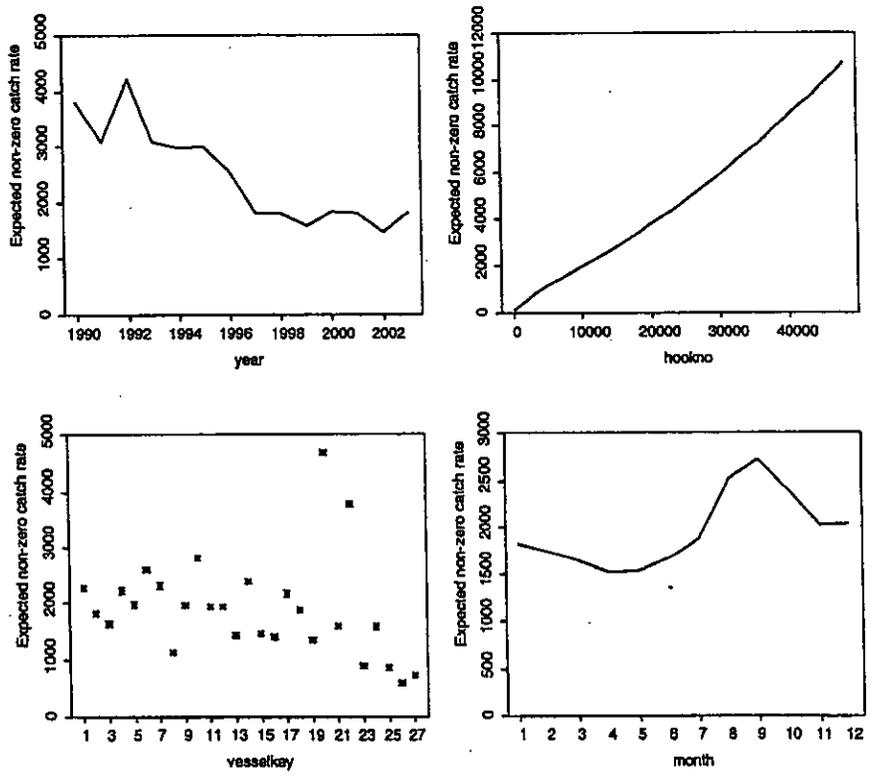


Figure 4: Expected variable effects for variables selected into the CPUE model for the Chatham Rise (LIN 3&4) ling line fishery. "Expected non-zero catch rate" is kg per day in this fishery.

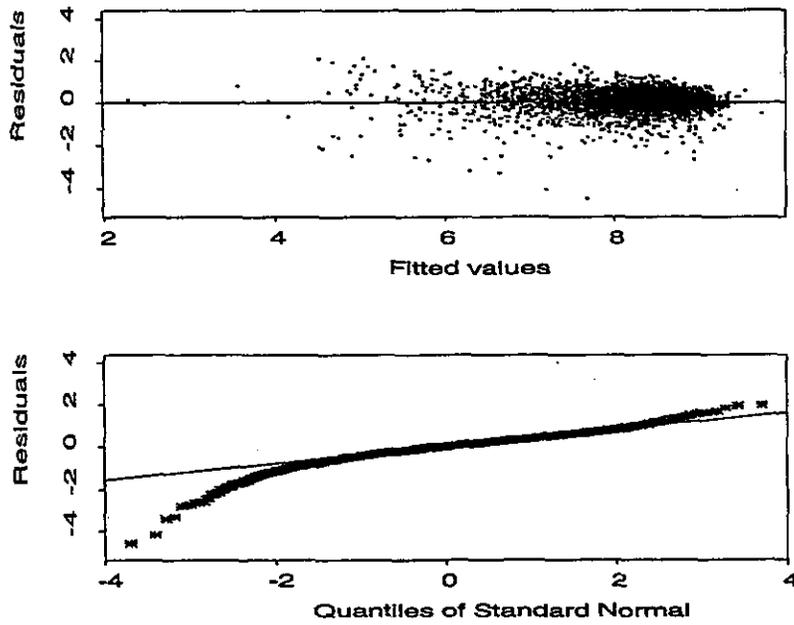


Figure 5: Diagnostic plots for the CPUE model of the Campbell Plateau (LIN 5&6) ling line fishery.

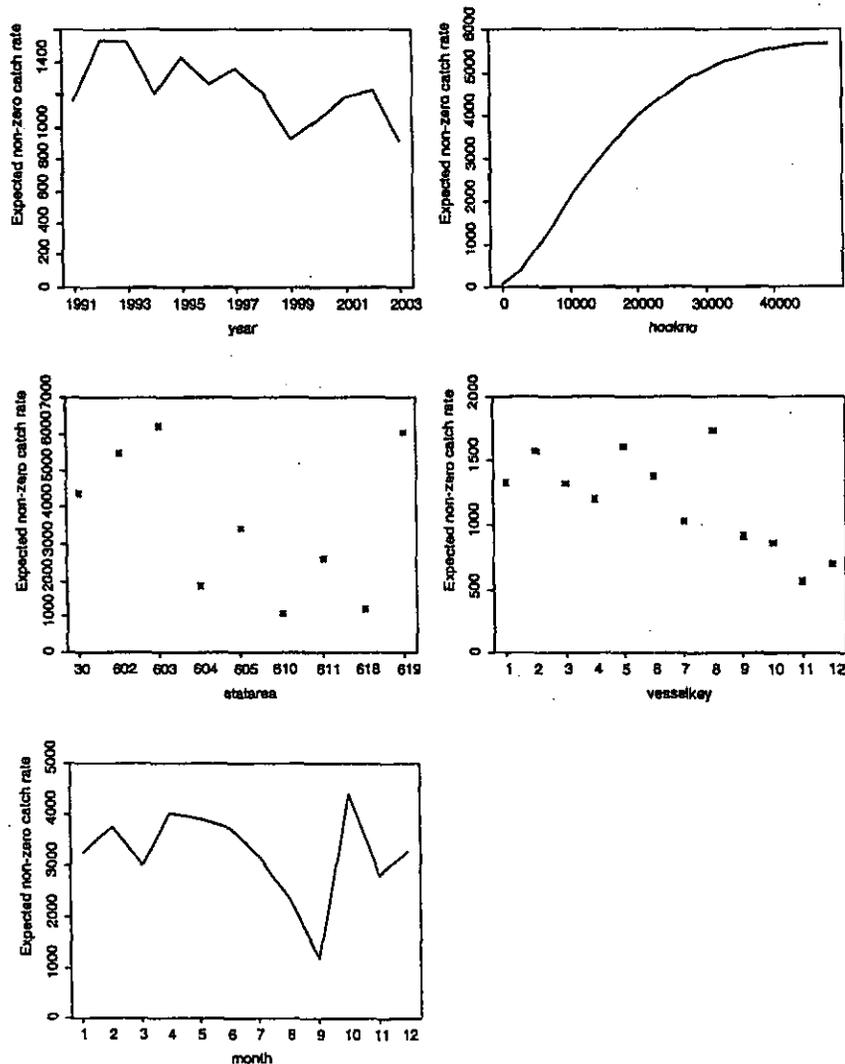


Figure 6: Expected variable effects for variables selected into the CPUE model for the Campbell Plateau (LIN 5&6) ling line fishery. "Expected non-zero catch rate" is kg per day in this fishery.

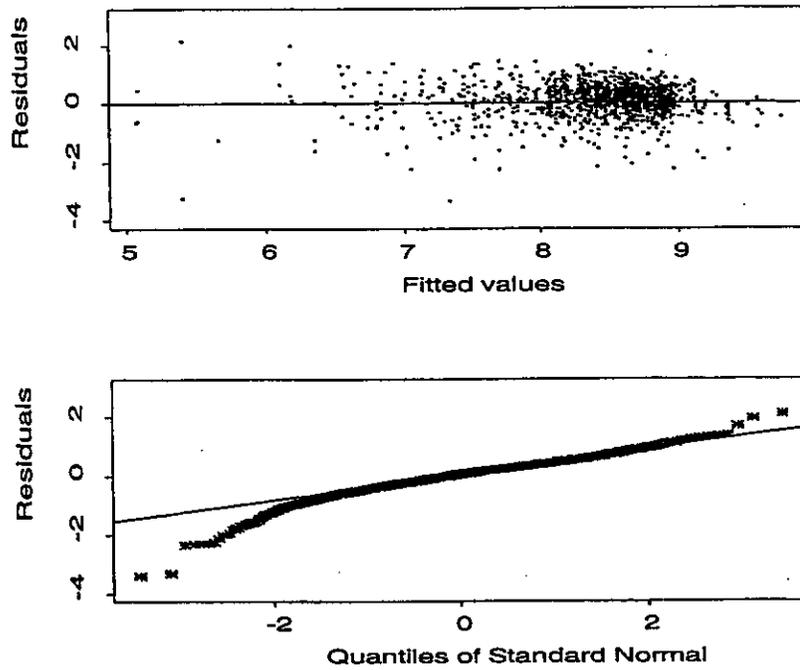


Figure 7: Diagnostic plots for the CPUE model of the Bounty Plateau (LIN 6B) ling line fishery.

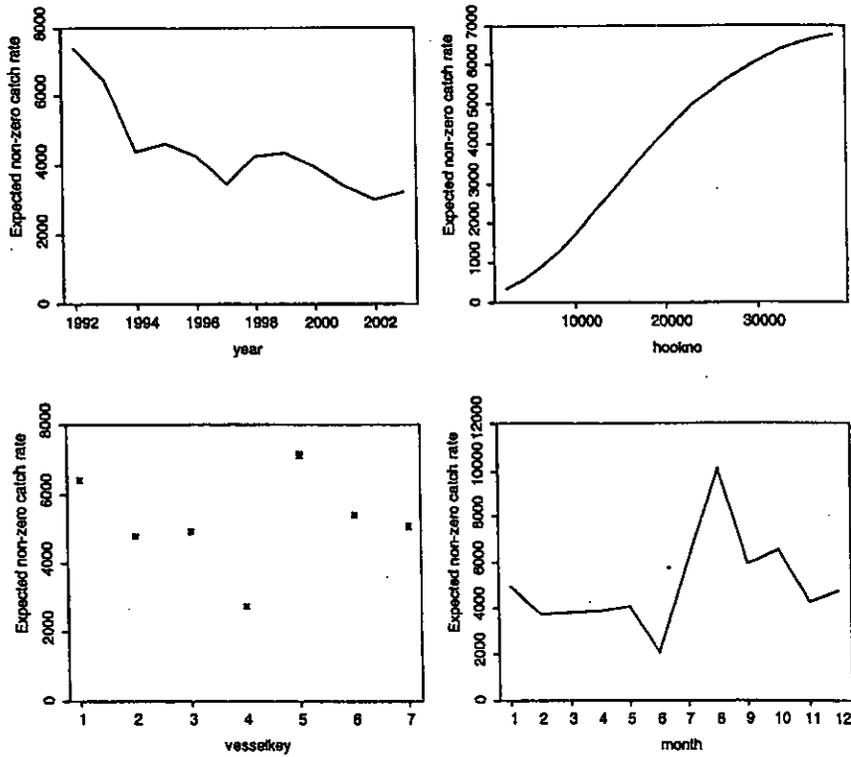


Figure 8: Expected variable effects for variables selected into the CPUE model for the Bounty Plateau (LIN 6B) ling line fishery. "Expected non-zero catch rate" is kg per day in this fishery.

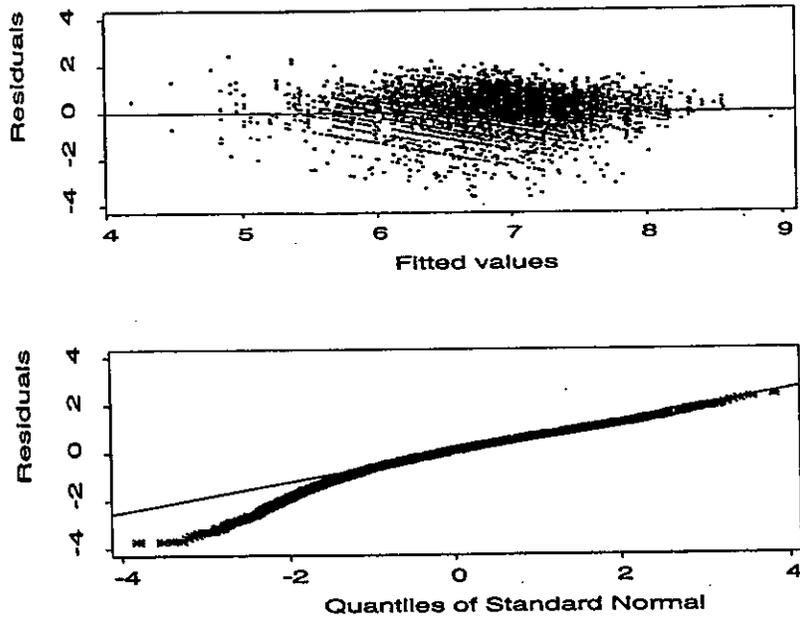


Figure 9: Diagnostic plots for the CPUE model of the WCSI (LIN 7WC) ling line fishery.

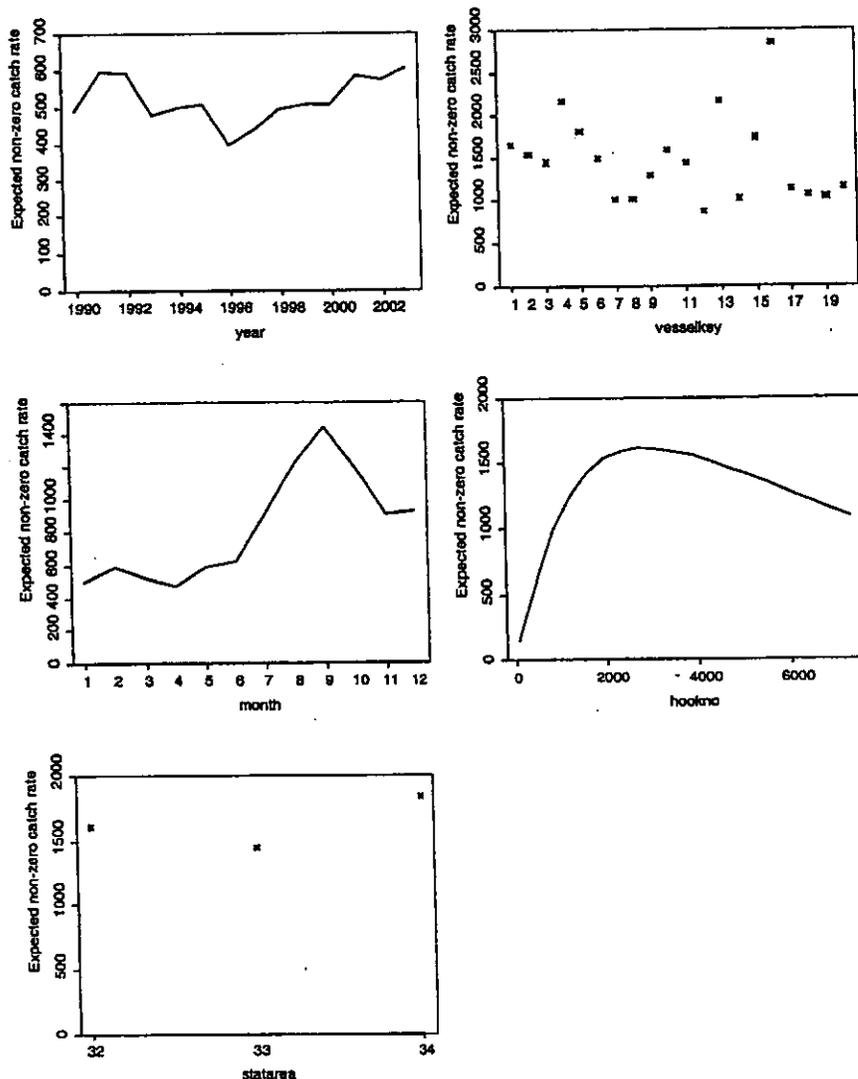


Figure 10: Expected variable effects for variables selected into the CPUE model for the WCSI (LIN 7WC) ling line fishery. "Expected non-zero catch rate" is kg per day in this fishery.

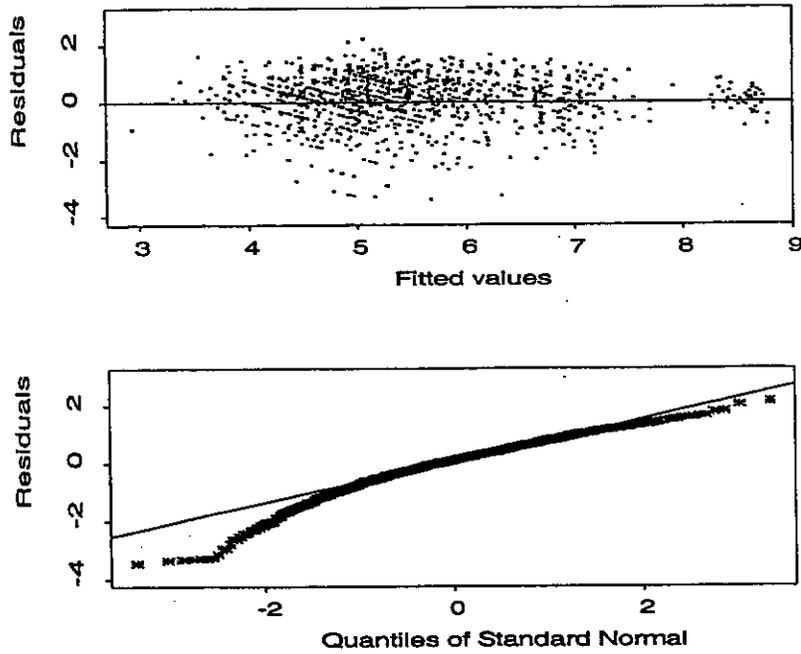


Figure 11: Diagnostic plots for the CPUE model of the Cook Strait (LIN 7CK) ling line fishery.

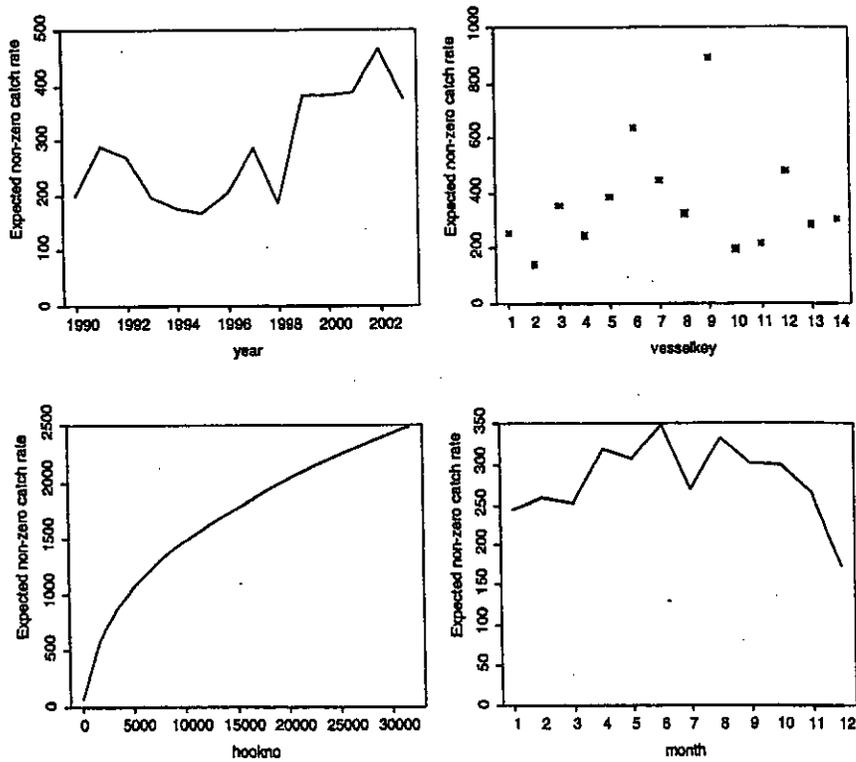
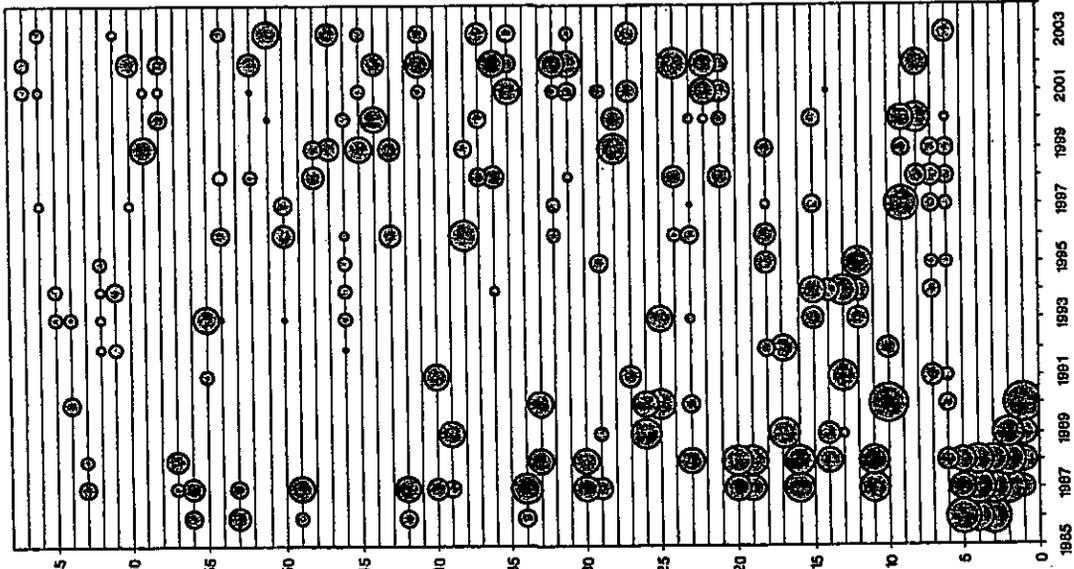
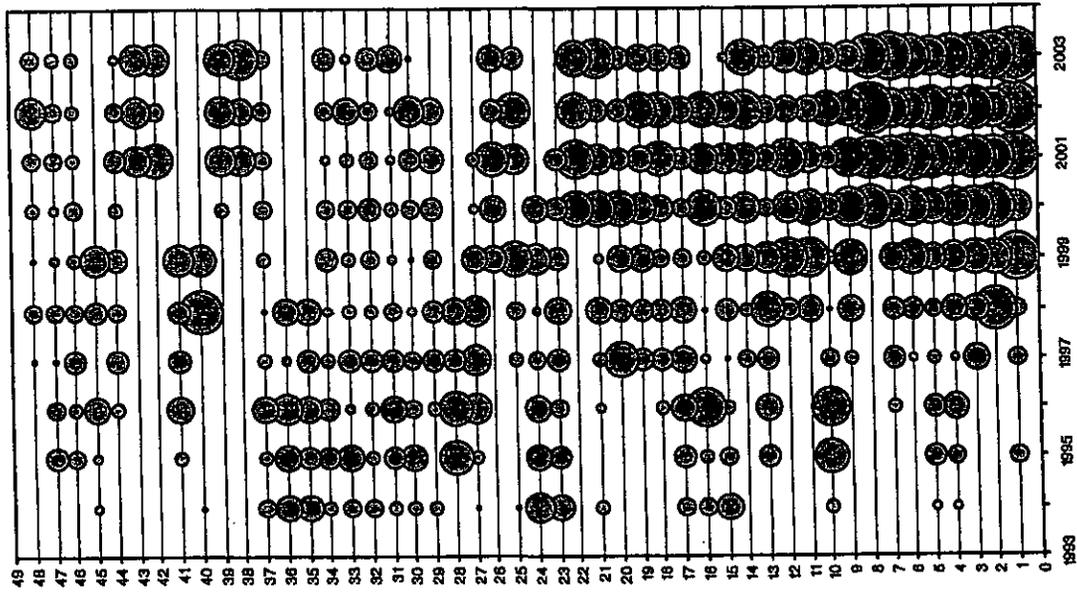


Figure 12: Expected variable effects for variables selected into the CPUE model for the Cook Strait (LIN 7CK) ling line fishery. "Expected non-zero catch rate" is kg per day in this fishery.

WCSI (Observer)



WCSI (TCPR)



Cook Strait

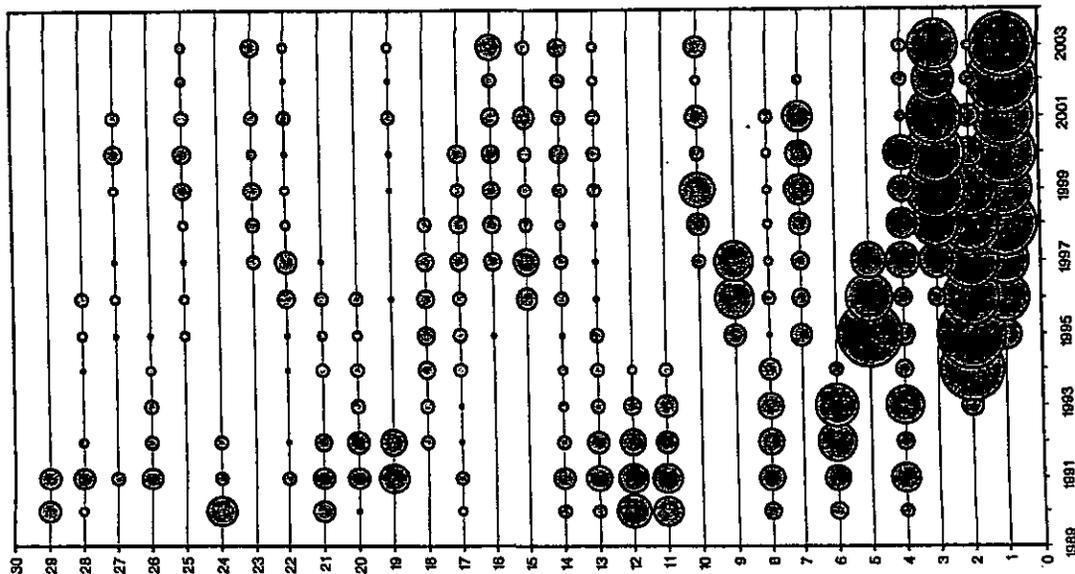


Figure 13: Fishing effort (where circle area is proportional to number of days fished) by year for individual vessels included in the final trawl CPUE analyses.

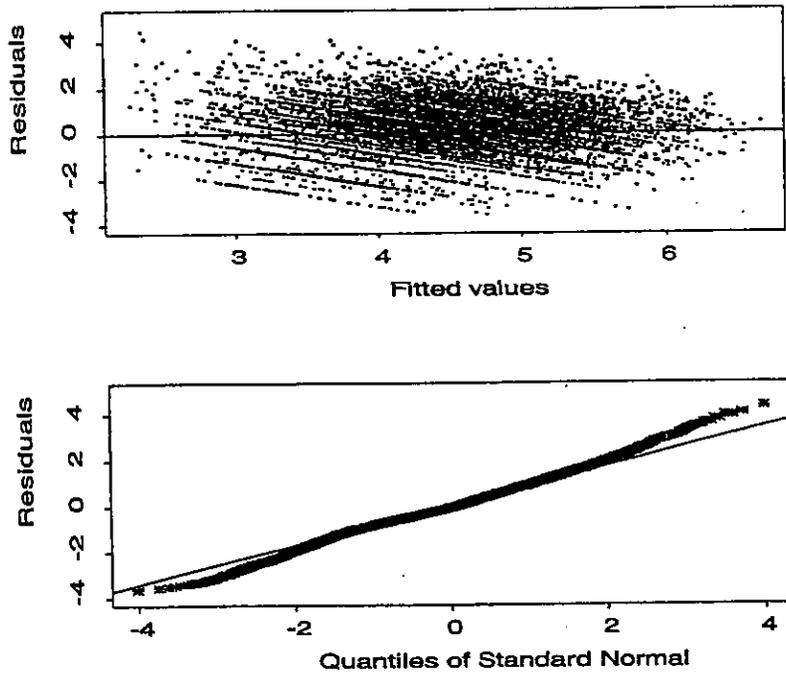


Figure 14: Diagnostic plots for the CPUE model of the Cook Strait (LIN 7CK) hoki trawl fishery.

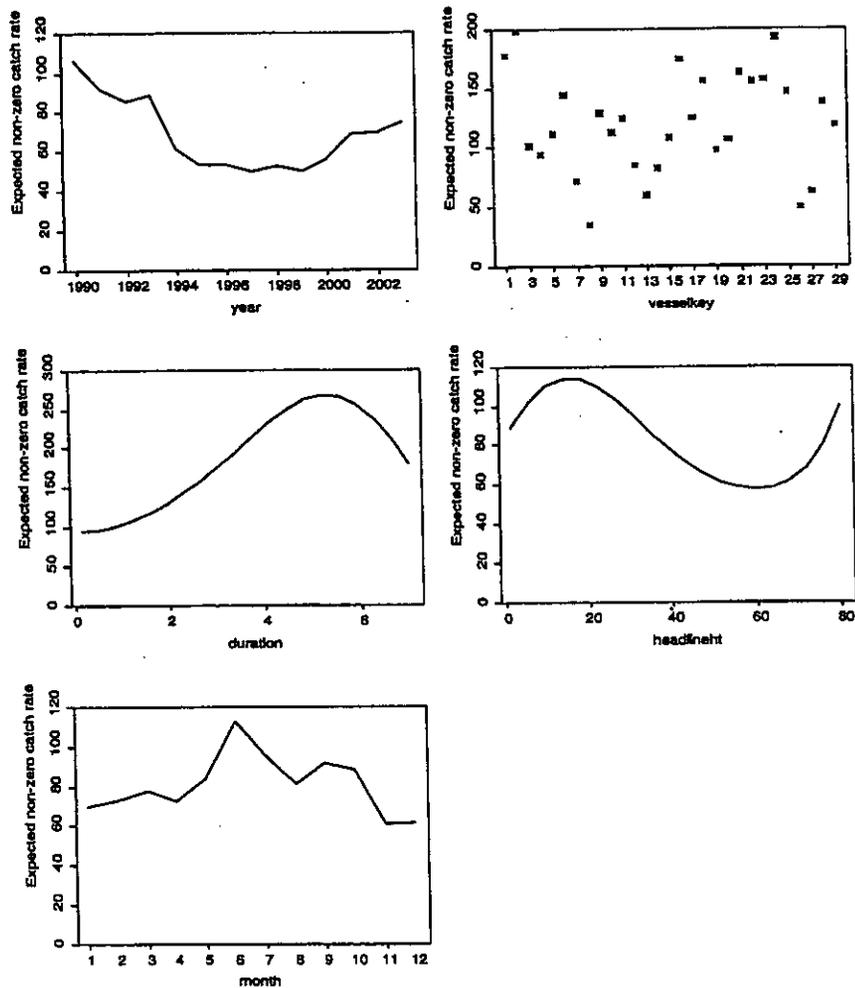


Figure 15: Expected variable effects for variables selected into the CPUE model for the Cook Strait (LIN 7CK) hoki trawl fishery. "Expected non-zero catch rate" is kg per tow in this fishery.

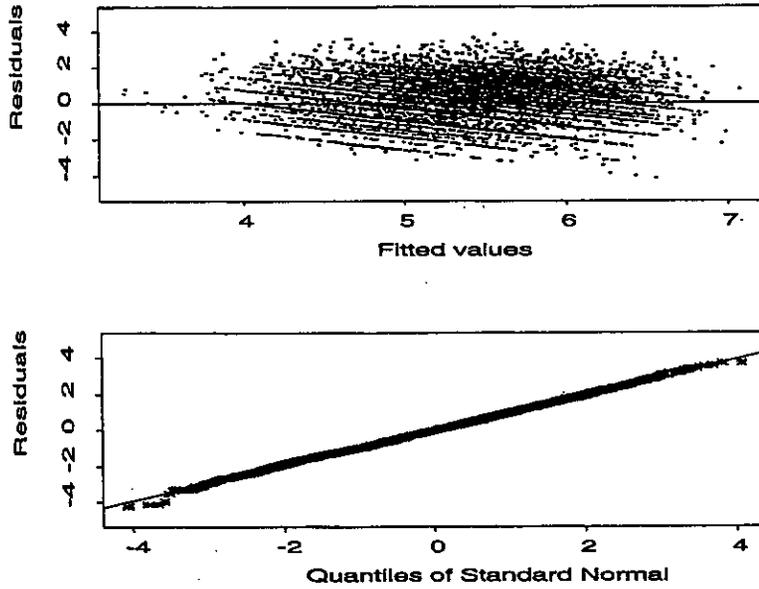


Figure 16: Diagnostic plots for the CPUE model using TCEPR data from the WCSI (LIN 7WC) hoki trawl fishery.

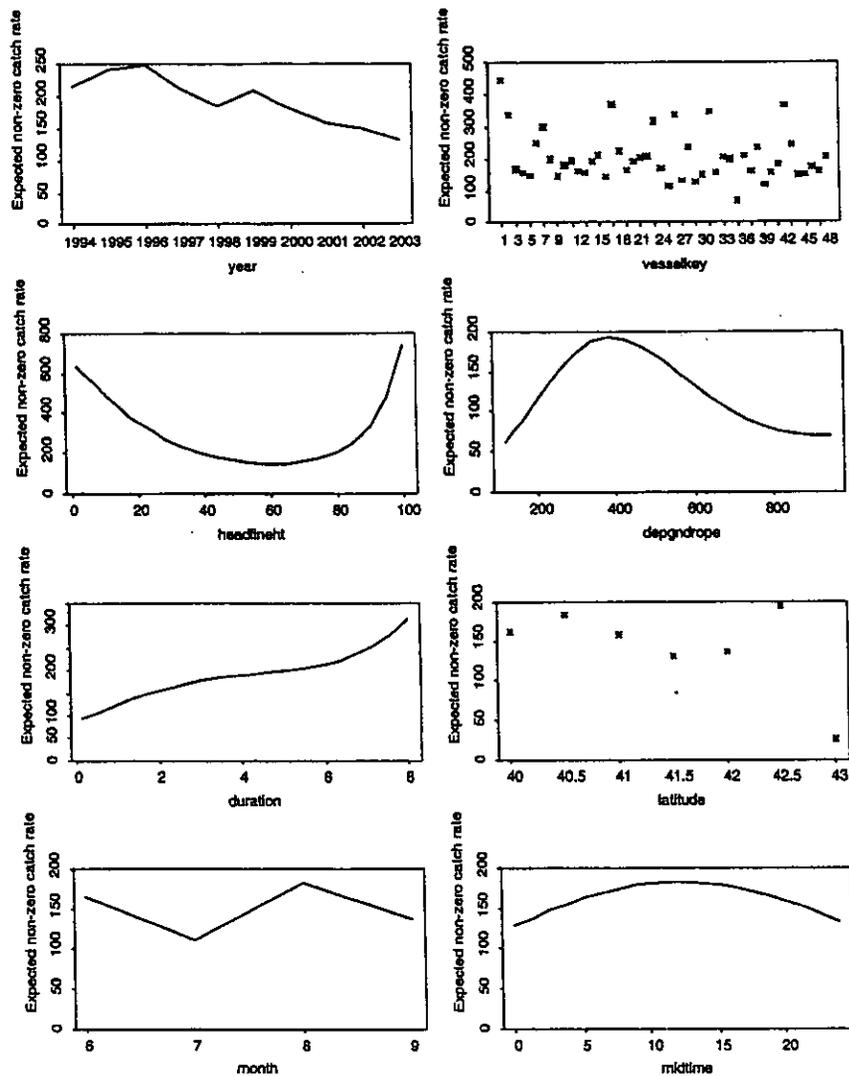


Figure 17: Expected variable effects for variables selected into the CPUE model using TCEPR data from the WCSI (LIN 7WC) hoki trawl fishery. "Expected non-zero catch rate" is kg per tow in this fishery.

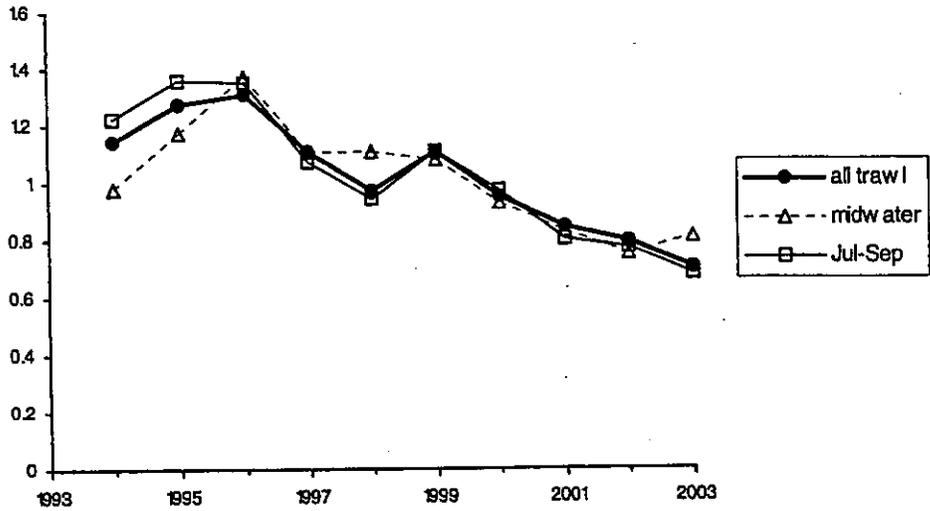


Figure 18: CPUE indices from the three analyses of the WCSI TCEPR data, i.e., all trawl data, midwater trawl only, and all trawl data from 7 July to 30 September.

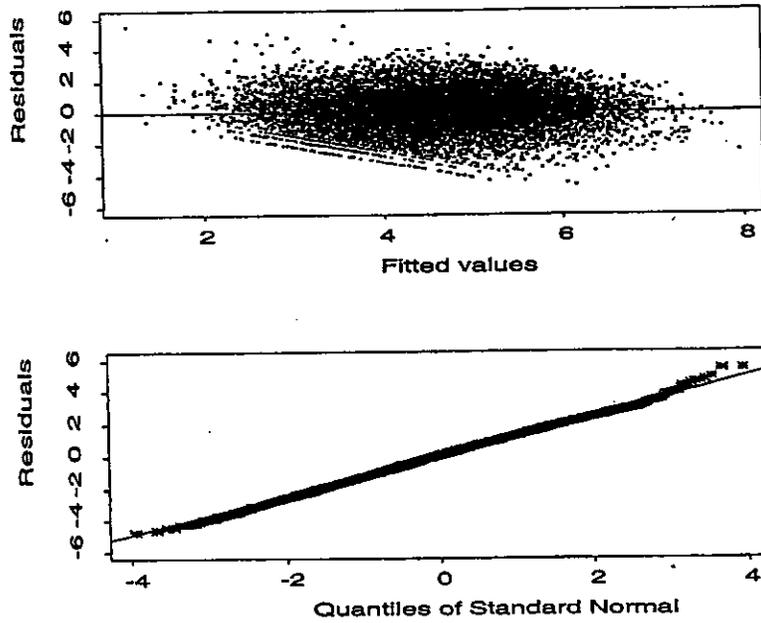


Figure 19: Diagnostic plots for the CPUE model using Observer data from the WCSI (LIN 7WC) hoki trawl fishery.

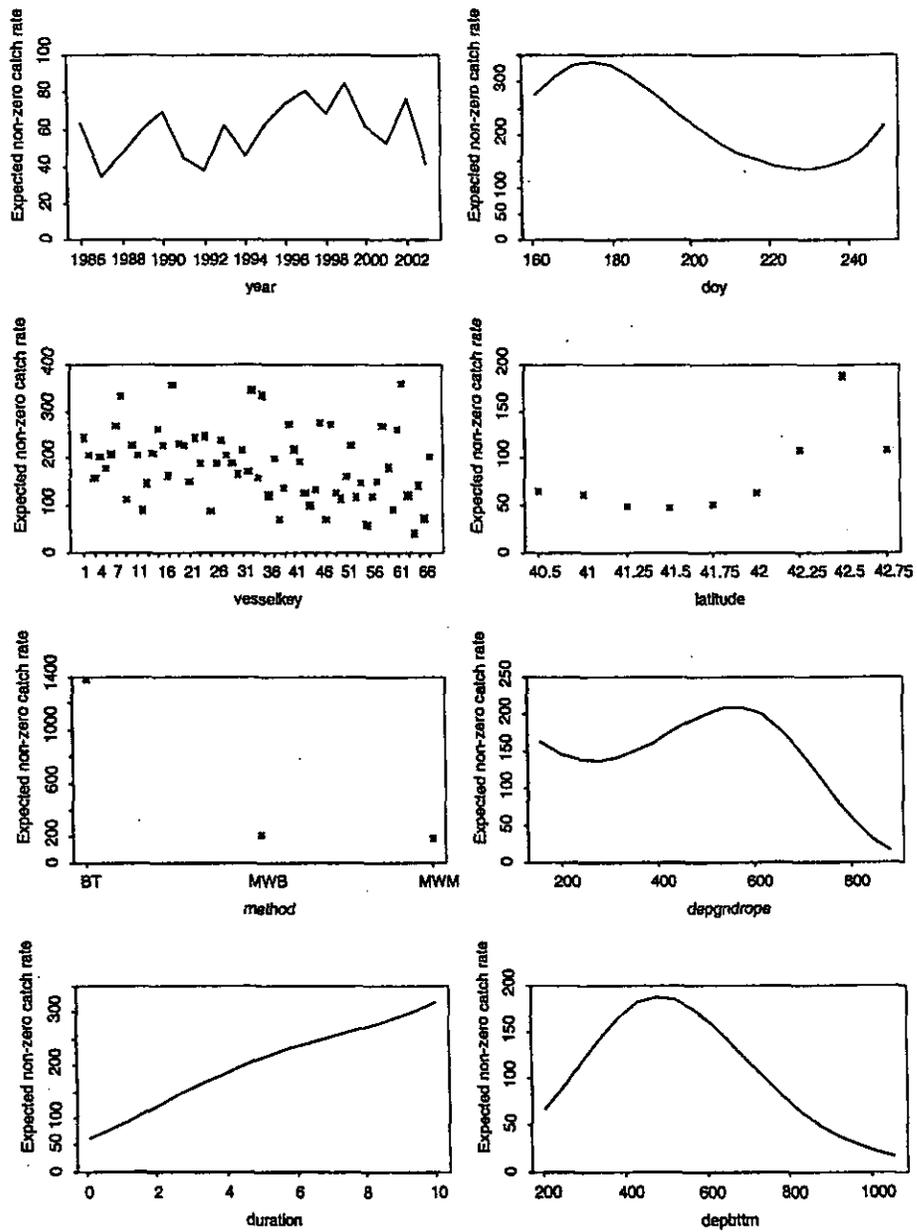


Figure 20: Expected variable effects for variables selected into the CPUE model using observer data from the WCSI (LIN 7WC) hoki trawl fishery. "Expected non-zero catch rate" is kg per tow in this fishery.

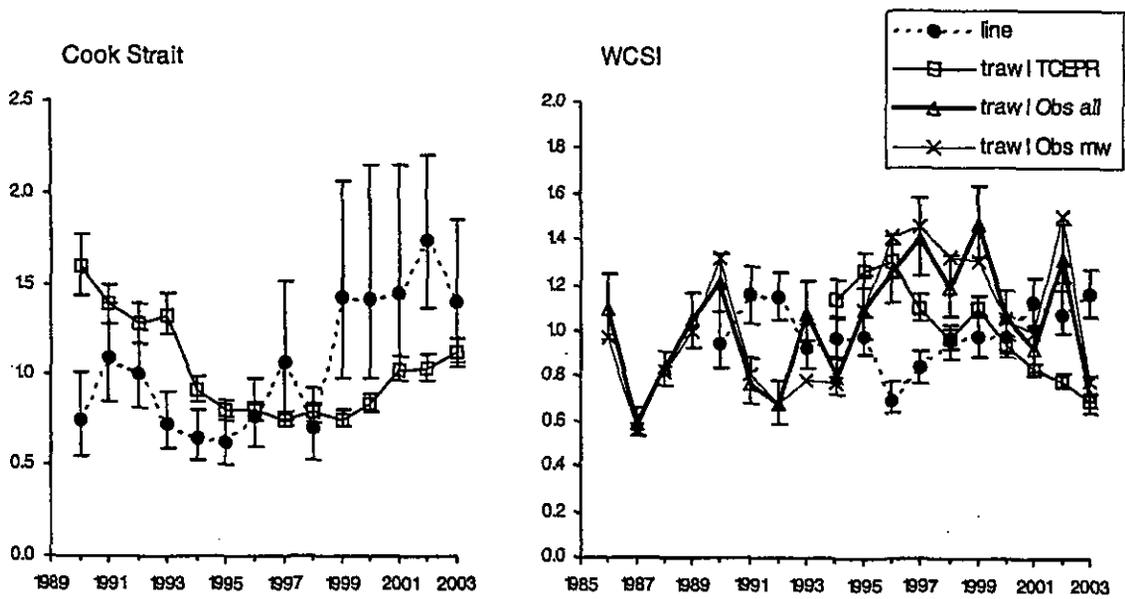


Figure 21: CPUE indices (with 95% confidence intervals) for stocks where both line and trawl series were calculated. The values in each series are scaled to average 1. For the WCSI trawl fishery, three series are presented: all TCEPR trawl data, all Observer trawl data (trawl Obs all), and Observer data of midwater trawling only (trawl Obs mw).

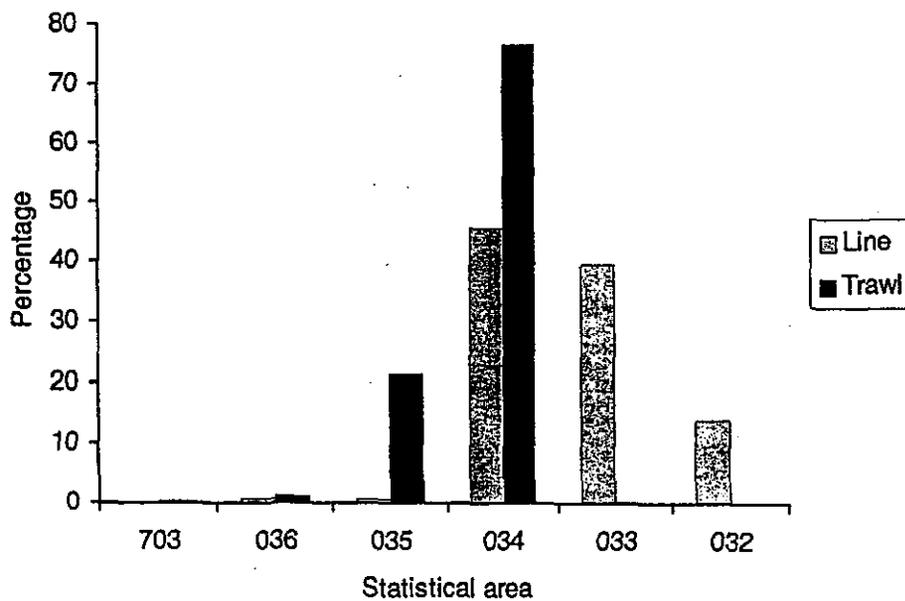


Figure 22: Percentage of records by statistical area for the line and trawl fisheries off WCSI, following data grooming and application of the thresholds on minimum numbers of fishing days by a vessel. (Note: the line data from areas 035 and 036 were excluded from the final CPUE model.)