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Descriptive analysis of the fishery for hake (*Merluccius australis*) in HAK 1, 4 and 7 from 1989–90 to 2012–13, and a catch-per-unit-effort (CPUE) analysis for Sub-Antarctic hake

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EXECUTIVE SUMMARY

Ballara, S.L. (2015). Descriptive analysis of the fishery for hake (*Merluccius australis*) in HAK 1, 4 and 7 from 1989–90 to 2012–13, and a catch-per-unit-effort (CPUE) analysis for Sub-Antarctic hake.

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This report provides a descriptive analysis of the catch and effort data for hake from the WCSI (HAK 7), Chatham Rise (HAK 4), and Sub-Antarctic (HAK 1) stocks for 1989–90 to 2012–13. Updated CPUE series for Sub-Antarctic hake are also presented.

Commercial catch and effort data were groomed to correct errors and misreported data. Tow-by-tow data were combined into vessel-day summary records. Vessel-days that targeted either hake, hoki, or ling on any tow but did not process any hake were considered to be a zero catch day. A complete extract of data was undertaken, so this analysis captures the latest data available, and all variables were error groomed and interpreted in a similar manner.

The WCSI fishery peaks during June–September, mainly as a bycatch of the hoki fishery, but with some targeting before or after the main hoki season. The Chatham Rise fishery is concentrated on the northern and western Rise, mainly from September to February, with targeting mainly on spawning aggregations. The Sub-Antarctic fishery is concentrated off the south and east of the Snares shelf, also with targeting mainly on spawning aggregations. The timing of the peak Sub-Antarctic fishery has shifted from September–November in the early 1990s to December–February since the mid-2000s.

In CPUE analyses, estimates of relative year effects were obtained from a forward stepwise multiple regression method, where the data were fitted using lognormal models. The data used for each analysis consisted of all records from core vessels that targeted hoki, hake, or ling; core vessels were those that reported about 80% of the hake catch and were involved in the fishery for at least four years.

The amount of deviance explained by the Sub-Antarctic CPUE models was relatively high (43–59%), with target species and vessel accounting for most of the explanation. The variables included were logical and generally consistent between the models. The CPUE indices from various sources (i.e., daily processed catch, tow-by-tow estimated catch, and observer data) all showed similar trends and are indicative of a slight overall decline. However, much of the underlying variability was not explained in most models. The diagnostic plots for the CPUE analyses show that the lognormal model was unable to capture the extremes in catch rates observed in the fishery.

CPUE may be influenced by changes in fishing behaviour and reporting. Combined lognormal-binomial models were not attempted as although there was a trend over time of more species being reported on the TCEPR tow-by-tow estimated form, there is evidence that some vessels may not be filling out all retained species in a tow in recent years for hoki target tows. There was reasonable agreement between the two Sub-Antarctic trawl survey biomass series and CPUE indices. Years with big catches where spawning aggregations were targeted had a large effect on CPUE indices, suggesting that this CPUE series may not be useful as an index of relative abundance.

1. INTRODUCTION

This document reports the results of objective 1 of Ministry for Primary Industries Project DEE201002HAKC. The specific project objective was to carry out a descriptive analysis of the commercial catch and effort data for hake from HAK 1, 4 and 7, and to update the standardised analysis of the commercial catch and effort for HAK 1 for the Sub-Antarctic with the addition of data up to the end of the 2012–13 fishing year.

Hake are widely distributed throughout the middle depths, mainly from 250 to 800 m and primarily south of latitude 40° S (Colman 1995). Adults have been found as deep as 1200 m and juveniles (0+) are often found in shallower inshore regions (less than 250 m depth) (Hurst et al. 2000). Hake within the New Zealand Exclusive Economic Zone (EEZ) are managed as three separate Fishstocks: the Challenger Plateau and west coast of the South Island (HAK 7), the eastern Chatham Rise (HAK 4), and the remainder of the EEZ (HAK 1), which includes waters around the North Island, east coast of the South Island and Sub-Antarctic, and excludes the Kermadec area (Figure 1).

Hake are currently believed to consist of three biological stocks (Colman 1998), i.e., West coast South Island (WCSI, HAK 7), Sub-Antarctic (the area of HAK 1 encompassing the Sub-Antarctic), and Chatham Rise (HAK 4 and the area of HAK 1 on the western Chatham Rise and east coast of the North Island) (Figure 1). Differences in growth parameters, size frequencies, and morphometrics were shown to exist between hake from the three areas (Horn 1997, 1998). In addition, there are three areas where spawning is known to occur consistently: the west coast of the South Island (WCSI), north-west of the Chatham Islands, and on the Campbell Plateau south of the Snares shelf (Dunn 1998).

A comprehensive descriptive analysis of New Zealand hake fisheries was produced by Devine (2009) and the last descriptive analysis of commercial catch and effort data for hake was completed for the fishing years 1989–90 to 2010–11 (Ballara 2013). Both these reports showed how the hake fisheries in the New Zealand EEZ have evolved and operated. They also aimed to define seasonal and areal patterns of fish distribution. The work presented here updates the analysis done for fishing years 1989–90 to 2010–11 by Ballara (2013) to fishing years 1989–90 to 2012–13 (i.e., catch by area) by method, to determine whether any marked changes have occurred in the fisheries in the last two years.

Commercial catch and effort data were analysed to produce catch-per-unit-effort (CPUE) indices for HAK 1 and 4 in 1998 (Kendrick 1998), and were updated, using the methodology of Gavaris (1980) and Vignaux (1994) in 1999 (Dunn et al. 2000b). Subsequent analyses of CPUE for hake have been reported by Phillips & Livingston (2004), Phillips (2005), Dunn & Phillips (2006), Devine & Dunn (2008), Devine (2010), Ballara & Horn (2011), and Ballara (2012, 2013). Evidence of misreporting of catch by a small number of vessels was detected during the 2001 update. Hake caught in HAK 7 were misreported as catch on the Chatham Rise and Sub-Antarctic in HAK 4 and HAK 1 (Dunn 2003).

In 2002, the misreported catch-effort data were corrected (Dunn 2003) and data were used to estimate CPUE indices using mixed effect models. Concerns that hoki and hake target tows, where no hake were recorded (zero tows), were not adequately modelled led to a re-analysis that included zero tows. Changes in the proportion of zero tows between years were believed to be partially explained by changes in behaviour of fishers in the recording of very low or zero hake catches, probably as a consequence of the relationship of hake catch to the catch of other species when recording the top five species on the Trawl Catch Effort Processing Returns (TCEPR). Hence, an update by Phillips (2005) for the 2002–03 fishing year used daily processed catch from the processing summaries (from the bottom half of the TCEPR forms) to estimate CPUE indices for the Chatham Rise. All catch processed on each day is recorded on the daily processed summaries, and these data are believed to provide a more accurate account of low and zero catch observations. In Ballara (2012, 2013) the estimated tow-by-tow and daily processed catches were similar, and CPUE analyses were found to have similar trends so the estimated tow-by-tow CPUE lognormal model is now used as an input in stock assessment models.

This report presents an analysis to update the series of CPUE indices from the trawl fishery for hake on the Sub-Antarctic (HAK 1). CPUE analyses of the Sub-Antarctic fishery was most recently reported by Ballara (2012).

2. METHODS

2.1 Data and variable selection

Catch-effort, daily processed, and landed data were extracted from the MPI catch-effort database “warehou” as extract 9171 and consist of all fishing and landing events associated with a set of fishing trips that reported a positive catch or landing of hoki, hake, or ling in areas from fishing years 1989–90 to 2012–13. This included all fishing recorded on Trawl Catch, Effort and Processing Returns (TCEPRs); Trawl Catch Effort Returns (TCERs); Catch, Effort and Landing Returns (CELRs); LCERs (Lining Catch Effort Returns); LTCERs (Lining Trip Catch Effort Returns); NCELRs (Netting Catch Effort Landing Returns); and included high seas versions of these forms. The MPI observer sampling programme catch effort data for hake (administered by NIWA in the *cod* database) were also extracted.

Commercial and observer catch-effort data often contain significant errors, most commonly invalid codes and missing or implausible values. TCEPR and observer tow-by-tow data were checked for errors, using simple checking and imputation algorithms similar to those used by Ballara & O'Driscoll (2014). Data were groomed for errors using simple checking and imputation algorithms developed in the statistical software package ‘R’ (R Development Core Team 2013). Individual tow or set locations were investigated and errors were corrected using median imputation for start/finish latitude or longitude, fishing method, target species, tow speed, net depth, bottom depth, wingspread, duration, and headline height for each fishing day for a vessel. Range checks were defined for the remaining attributes to identify outliers in the data. The outliers were checked and corrected if possible with mean imputation on larger ranges of data such as vessel, target species and fishing method for a year or month, or the record was removed from the data set. Statistical areas were calculated from positions where these were available. Transposition of some data was carried out (e.g., bottom depth and depth of net).

Hake trawl data can be recorded on TCEPR, TCER, or CELR forms. TCEPR and TCER 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). Only TCEPR data were used in the analyses as there was found to be little difference between CPUE indices including or excluding TCER data (Ballara & Horn 2011).

The estimated hake catch associated with the fishing events were mainly reported on TCEPR and CELR forms. TCEPR forms record tow-by-tow data and summarise the estimated catch for the top five species (by weight) for individual tows. The daily processed part of the TCEPR form contains information regarding the catch that was processed that day. The processed fish are weighed and a conversion factor (depending on processing type) allows the weight of the fish before processing (i.e., green weight) to be estimated. CELR forms summarise daily catches, which are further stratified by statistical area, method of capture, and target species. Trawl vessels less than 28 m long used to use either CELR or TCEPR forms; trawl vessels over 28 m used TCEPR forms. However, from 1 October 2007, TCER forms replaced CELR forms for trawl vessels less than 28 m, and enabled the recording of estimated catches of up to the top eight species by tow. The green weight for landing events for catch associated with the TCEPR or TCER form is reported on the associated Catch Landing Return (CLR), and for catch reported on the CELR the landing events are reported on the bottom part of the CELR form.

Analyses by Phillips (2005) for the 1989–90 to 2002–03 fishing years found that changes in behaviour of fishers in the recording of very low or zero hake catches could partially explain changes in the ratio of zero tows. The most likely explanation for this was that a change in the recording of the top five species on the top of the TCEPR form changed the relationship between hake catch and catch of other species, which could be due to regulation changes. Hence, Phillips (2005) used the daily processed catch from the TCEPR processing summaries to estimate catch and derive CPUE indices for the Chatham Rise.

The same approach was used by Dunn & Phillips (2006), Devine & Dunn (2008), and Devine (2010) to update the CPUE indices for the Chatham Rise and Sub-Antarctic hake stocks. Tow-by-tow data were combined into vessel-day summary records. The location and depth of fishing were defined as the median value of these variables for the day's fishing for a particular vessel from all of its individual tows. Total daily processed catch was calculated from the daily processing summaries of the TCEPR forms and merged with the combined tow-by-tow data. The variable vessel-day from the combined tow-by-tow data and the daily processing summary was used to link the data.

Target species associated with the daily processed catch data is not reported, hence target species was defined as the most common target species specified in the tow-by-tow data. Vessel-days that targeted either hake or hoki on any tow but did not process any hake were considered to be a zero day. Both hake and hoki target tows were selected, as hake form a significant and important bycatch of the more dominant hoki fishery. For the Sub-Antarctic analysis, hoki, hake, and ling target tows were used.

The tow-by-tow commercial and observed catches of hake were corrected for possible misreporting, using the method of Dunn (2003). Catch data from the daily processing summaries for a vessel-day were excluded from further analyses if the vessel-day was identified as having a misreported catch in any of its associated tow-by-tow data.

Most of the variables extracted from the catch-effort database are self-explanatory and are summarised in Table 1. Those that require further explanation are described below, but in general, most variables were defined as the median of the equivalent variable from the tow-by-tow records that were made on the same day as the daily processing summary record.

Fishing method was bottom trawl, midwater trawl, or midwater trawl fished on the bottom; midwater gear was classified as fishing on the bottom if reported net depth was within 5 m of bottom depth. Year was a categorical variable covering differing months for different areas: for the Chatham Rise and Sub-Antarctic, year was September–August, and for WCSI it was May–October.

The Chatham Rise, WCSI, and Sub-Antarctic stocks were each divided into sub-areas based on tree regression analyses of mean fish length (by sex) in the catches sampled by the Ministry for Primary Industries observers (Horn & Dunn 2007, Horn 2008, Horn & Sutton 2010). Mean fish size differed between the sub-areas, and it was necessary to estimate annual catches from each sub-area to more accurately scale up data collected by observers in the fisheries.

Chatham Rise sub-areas were defined as: Area 404 (Statistical Area 404); East Chatham Rise (east of 178.1° E and excluding Statistical Area 404); West Chatham Rise deep (west of 178.1° E and greater than 530 m depth); and West Chatham Rise shallow (west of 178.1° E and less than 530 m depth) (Figure 2a).

WCSI sub-areas included North shallow (north of 42.55° S and less than 629 m depth); South shallow (south of 42.55° S and less than 629 m depth); and Deep (greater than 629 m depth) (Figure 2b).

Sub-Antarctic sub-areas were defined as Puysegur, Snares-Pukaki, Auckland Islands, and Campbell Island (Figure 2c). Data from areas on the Sub-Antarctic that were outside these sub-areas were excluded from the CPUE analyses presented below.

2.2 Catch per unit effort analysis

The analysis of CPUE for the Sub-Antarctic hake fisheries is updated here. Annual unstandardised (raw) CPUE indices were calculated as the mean of the catch per tow (in kilograms) for tow by tow data, or catch per vessel-day for daily processed data. Estimates of relative year effects were obtained from a stepwise multiple regression method, where the data were fitted using a lognormal model using log transformed non-zero catch-effort data. A forward stepwise multiple-regression fitting algorithm (Chambers & Hastie 1991) implemented in the R statistical programming language (R Development Core Team 2013) was used to fit all models. The algorithm generates a final regression model iteratively and used the year term as the initial or base model in all cases. The reduction in residual deviance (denoted r^2) was calculated for each single term added to the base model. The term that resulted in the greatest reduction in the residual deviance was then added to the base model, where the change was at least 1%. The algorithm was then repeated, updating the base model, until no more terms were added. A stopping rule of 1% change in residual deviance was used because this results in a relatively parsimonious model with moderate explanatory power. Alternative stopping rules or error structures were not investigated.

The variable *year* was treated as a categorical value so that the regression coefficients of each year could vary independently within the model. The relative year effects calculated from the regression coefficients represent the change in CPUE through time, all other effects having been taken into account, and represents a possible index of abundance. *Year* was standardised to the first year. *Year* indices were standardised to the mean and were presented in canonical form (Francis 1999). Variables are either categorical or continuous, with model fits to continuous variables being made as third-order polynomials, although a fourth-order polynomial was also offered to the models for duration. The CVs represent the ratio of the standard error to the index. The 95% confidence intervals are also calculated for each index. For the estimated catch runs, all variables were included. For the processed catch runs, *date*, *start time*, and *time mid* (mid time of tow) were not included because they were unavailable. *Date* was included in the processed catch runs as *year* and *month*, or *day of year*. Interaction terms and nested terms were not used as all Sub-Antarctic data were for bottom tows only.

Vessel was incorporated into the CPUE standardisation to allow for differences in fishing power between vessels. Vessels not involved in the fishery for at least three consecutive years should be excluded because they provide little information for the standardisations, which could result in model over-fitting (Francis 2001). Data was investigated for level of catch and effort for different years of vessel participation in the fishery, and thus CPUE analyses were undertaken for "core" vessels only, which together reported approximately 80% of positive hake catches in the defined fishery and were each involved in the fishery for a significant number of years and for a significant number of tows or vessel-days in a year.

The data used for each CPUE analysis consisted of all records from core vessels that targeted hoki, hake or ling. To ensure that the data were in plausible ranges and related to vessels that had consistently targeted and caught significant landings of hake, data were accepted if all the constraints were met (Table 2). Catches believed to be misreported were excluded. Core vessel analyses were run for the Sub-Antarctic for both TCEPR and observer tow-by-tow data, and for TCEPR daily processed data.

The influence of each variable accepted into the lognormal models was described by coefficient–distribution–influence (CDI) plots (Bentley et al. 2012). These plots show the combined effect of (a) the expected log catch for each level of the variable (model coefficients) and (b) the distribution of the levels of the variable in each year, and therefore describe the influence that the variable has on the unstandardised CPUE and that is accounted for by the standardisation.

Model fits to the lognormal component of the combined model were investigated using standard residual diagnostics. For each model, a plot of residuals against fitted values and a plot of residuals against quantiles of the standard normal distribution were produced to check for departures from the regression assumptions of homoscedasticity and normality of errors in log-space (i.e., log-normal errors).

3. RESULTS

3.1 Descriptive analyses

Estimated catches, reported landings, and TACC by stock from 1989–90 to 2012–13 are shown in Table 3 and Figure 3 for the main hake stocks. Most hake catches since 1989–90 have been reported on the TCEPR form (Table 4). Other reporting forms have been introduced in several years since 2003–04, but in 2012–13 most hake catch (96.3%) is still reported on TCEPRs, with TCERs (212 t, 2.7%) accounting for the second highest proportion. The distribution and density of the catch recorded on these two form types in 2012–13 (Figure 4) shows that TCEPR hake is mainly caught on the Chatham Rise, WCSI, and Sub-Antarctic, whereas the TCER caught hake is mainly on the WCSI.

3.1.1 Chatham Rise

On the Chatham Rise, hake have been caught mainly by bottom trawlers targeting hake or hoki (Table 5, Figure 5a). Generally, hake are caught on the northern edge of the Chatham Rise and in the deep channel along the western part of the Chatham Rise, but with most of the catch taken from Statistical Area 404 (Figure 6a) where vessels target the hake spawning aggregation (Devine 2010). However, catches from Area 404 since 2006 have been low relative to the previous 14 years (Figure 6a). The proportion of hake caught in hoki target tows has been slowly decreasing since the late 1990s (Table 5, Figure 6a), although most of the Chatham Rise catch in 2011–12 and 2012–13 was caught by target hoki fishing. More than 99% of the Chatham Rise catch is reported on the TCEPR form.

Hake are caught on the Chatham Rise all year around, but more commonly between September and February (Figure 7a, Table 6). In October 2004, a large aggregation of possibly mature or maturing hake was fished on the western Chatham Rise, west of the Mernoo Bank in Statistical Area 020; approximately 2000 t of hake were caught over a four week period (Table 6, Figure 6a) (Devine 2010). The reasons for the presence of this aggregation are not known, although periodic and minor aggregations of pre-mature and mature hake have been found in that area in previous years and also in October–November 2008, and in Statistical Area 018 in October–November 2010 (Figure 6a). In 2012–13 Statistical Area 018 had the largest catch in November 2012, however most of this was reported as target hoki catch.

In 2006, very little catch was taken from any area. In 2007 and 2008, most of the catch was taken in January–February from the Eastern Chatham Rise and Statistical Area 404 subareas. In 2009, most of the catch was taken between October 2008 and February 2009 in Statistical Area 404 and west of the Mernoo Bank (Table 6, Figure 6a). The catch since 2010 has been low; 194 t in 2012 was the lowest from all years since 1990, and in 2013 at 344 t the catch was still relatively low.

For target hoki and hake vessels, bottom tows have shown an overall slight increase in mean duration to 2009, and a decrease in speed since 2002, followed by an increase in both in 2010 and 2011 (Figure 8a), which can be attributed in part to the increased bottom tow catches from 2002 by smaller Korean vessels. Mean hoki catch per tow has increased since 2004.

3.1.2 WCSI

The WCSI hake fishery is mainly bycatch of the much larger hoki fishery (Table 7), but has undergone a number of changes during the last decade (Devine 2010). These include changes in

TACCs for both hake and hoki, and changes in fishing practices such as the gear used, tow duration, and strategies to limit hake bycatch. Most of the hake catches are from hake or hoki target tows, although the hake caught in hoki target tows has decreased steadily since 2005 (Figure 6b, Table 7).

The timing of the catch on the WCSI has varied slightly between years, but most catch has been taken between June and September (Figure 6b, Table 8). Targeted hake catches were relatively high early in the fishing season in 1995, 1996, 1999, 2001, 2004, 2005, and 2007 (Figure 6b). In some years there has been a hake target fishery in September after the peak of the hoki fishery is over, particularly in 1992, 1993, 2006, and 2009–2013 (Table 8, Figure 7b). More than 2000 t of hake was taken during September in 1993 and 2006. In 2010 the catch of 2282 t was the lowest in any year since 1990 (Table 8) and was taken mainly from July to September by mid-sized Korean vessels targeting hake with bottom trawl. In 2011–2013, catches increased and were taken mainly from July to September. Catches are taken mainly in Statistical Areas 034 and 035, and in the last four years mainly from sub-area North shallow (Figure 6b). In 2013, 5171 t of hake was caught with 1900 t in September, and most was taken immediately north of the Hokitika Canyon in the North shallow sub-area (Table 8, Figures 5b and 6b).

Mean duration, distance, and depth per tow were relatively high, and speed relatively low, from 2006–2009 (Figure 8b), which can be attributed in part to the increased activity of smaller Korean vessels. In 2013, relative to 2012, there was a slight increase in mean duration and distance towed (Figure 8b) and an increase in catches by midwater trawl on the bottom (Table 7). For hake target vessels, there was a steady increase in tow duration, a decrease in fishing speed, and recent slight increases in hoki catch (Figure 8c). Target hake catches were concentrated in particular times and locations, especially in earlier years (Figure 9).

3.1.3 Sub-Antarctic

Sub-Antarctic hake are caught mainly by bottom trawlers targeting hoki, hake, or ling (Table 9, Figure 5c). Significant targeting for hake occurs around the Norwegian Hole and at the southern end of the Snares shelf (Devine 2010). The majority of the catch is taken from the Snares-Pukaki sub-area (Figures 5c and 6c). Since 2000, 1000–2000 t of targeted hake have been caught annually, but since 2005 hake caught in hoki target tows has been decreasing (Table 9, Figure 6c). More than 99% of the hake catch in the Sub-Antarctic is reported on the TCEPR form.

The timing of the catch in the Sub-Antarctic shifted over the years (Figure 7c, Table 10). Most catch was taken from September to November in the early 1990s, October to December in the late 1990s, November to January during the early 2000s, and December to February from 2006. In December 2005, 2000 t of hake was taken (Figure 7c) in an area of rough ground on the Stewart-Snares shelf where commercial fishing vessels reported an aggregation of spawning hake (O'Driscoll & Bagley 2006). In 2013, most of the catch was taken from December to January on the southern Snares shelf (Figures 5c and 6c). In general, hake were caught mostly along the edge of the Stewart-Snares shelf, in the Norwegian Hole, and, in smaller amounts, on the northern Campbell Plateau, southern Auckland Island shelf, and Puysegur Bank (Figure 5c).

For vessels targeting hoki or hake, bottom tows showed a decrease in mean distance, speed, and depth of net and bottom since 2002 (Figure 8d), which can be attributed in part to the increased bottom tow catches by smaller Korean vessels. Mean hoki catches decreased in the early 2000s but have since increased.

3.2 CPUE indices

CPUE indices for Sub-Antarctic hake

A total of 198 unique vessels (range 19–45 vessels each year) targeting hake, hoki, or ling caught an estimated 49 361 t of hake since 1991, from 80 422 tows (Table 11a). Core vessels for the tow-by-tow index were selected using the criteria described in Section 2.2 and were defined as those taking approximately 80% of the catch, with each vessel participating in the fishery for five or more years and having at least 20 tows in a year (Table 2, Figure 10). Twenty-six core vessels (range 3–20 per year) caught an estimated 41 072 t of hake, representing 83% of the total estimated catch. Estimated hake catches for core vessels targeting hake, hoki, or ling ranged from 314–2928 t annually (Table 11a). The proportion of zero tows for all vessels ranged between 0.23 and 0.58, and showed an increasing trend for both core and all vessels, although the trend flattened off from 2005 (Table 11a, Figure 11a). The proportion of zero tows in target hake data was low, i.e., generally less than 0.1 (Figure 11b). Overall the mean number of species reported on the TCEPR tow-by-tow estimated part of the form increased from 1991 to 2013 (Figure 11c), however the overall number of species was higher in 1999–2005 and then decreased (Figure 11d) indicating that since 2005 some vessels may not be filling out the estimated part of the form with all top five species.

Vessels targeting hake, hoki, or ling fished for 21 665 vessel-days, averaging 985 days per year since 1991 (Table 11b). The 42 core vessels producing data for the daily processed index were defined as those taking approximately 80% of the catch and each with participation in the fishery for five or more years (Table 2, Figure 10). The selected core vessels fished for 17 888 vessel-days averaging 813 vessel-days per year. The proportion of zero days (i.e., days fished where either hoki, hake, or ling was targeted, but no hake was processed) for all vessels fishing ranged between 0.04 and 0.21, and was higher in earlier years of the fishery. The proportion of zero days was much lower than for tow-by-tow data (Table 11b, Figure 11a). The total estimated catch was 91% of the total processed catch (Table 11b, Figure 12), although the estimated catch corrected and scaled to the QMR figures was 106% of the processed catch.

The number of all vessels has declined steadily since its peak in the 1990s (Table 11. One core vessel took most of the hake catch from 1995 to 2005 with relatively low levels of effort (Figure 13a and b). Another core vessel strongly dominated the catch from 2007 to 2013, although it had been fishing consistently since 2003.

A total of 42 observed vessels (range 5–19 vessels each year) targeting hake, hoki, or ling caught an estimated 8743 t of hake since 2000, from 6815 tows (Table 11c). Core vessels for the observed tow-by-tow index were defined as those observed in the fishery for four or more years; selecting those observed for five or more years (i.e., closer to the 80% catch) resulted in too many years with only 1 or 2 vessels in the core dataset (Table 2, Figure 10). The final core dataset comprised 17 vessels (range 2–10 per year) that caught an estimated 7929 t of hake, representing 91% of the total estimated catch, with annual catches ranging 42–1177 t (Table 11c. The proportion of zero tows for all vessels fluctuated between 0.06 and 0.22, and showed an increasing trend for both core and all vessels to 2007, with a decrease to 2012 and an increase in 2013 (Table 11c).

For the tow-by-tow estimated core data analysis, six variables were selected into the lognormal model, resulting in a total r^2 of 44%, with *target species* explaining 33% of the residual deviance (Table 12). The other variables selected were *vessel*, *statistical area*, *month*, and *start latitude*. For the processed core data and observer tow-by-tow core analyses, the same first five variables as in the estimated core analysis were selected into the lognormal models, with *vessel* and *statistical area* explaining 35% of the residual deviance for the daily processed model, and *target species* explaining 60% of the residual deviance for the observer tow-by-tow model.

CPUE series are presented in Table 13 and Figures 14–16. The tow-by-tow estimated catch index exhibits an overall slight decrease. The daily processed catch index also exhibits an overall decline, but is more spiky than the tow-by-tow series. The observer tow-by-tow estimated catch index shows a steady decline. Unstandardised indices in all three datasets did not follow the same trend as the standardised indices; they were generally lower in earlier years and higher in later years. and the differences can be attributed mainly to the influence of the variable target species in the TCEPR and observer tow-by-tow data and vessel in the daily processed data (Figures 14 and 15). Both the TCEPR tow-by-tow estimated and daily processed series show similar trends to the previous analysis despite changes in core vessel definition (Figure 16). All three series produced here are similar, and are indicative of a slight overall decline in the 23 years covered by the analyses (Figure 16). Estimated CPUE indices follow a similar trend to summer and autumn trawl survey indices, although between 1992 and 1993 the survey indices show a large decrease not seen in CPUE indices (Figure 17).

Influence plots (Figures 18a) for the lognormal tow-by-tow model show that for all variables except start latitude there is a negative trend in influence until about 2005 when there is a positive shift in influence; start latitude showed the opposite trend. Influence of target species shows that there is a positive influence on CPUE when hake are targeted, especially in 2006, 2009, 2010 and 2012 (Figure 18a).Vessel has a large positive influence on CPUE in the last eight years, suggesting a change in fleet dynamics. Vessels with more overall catch tended to have higher expected catches and lower variability. Expected catch varied between statistical areas; it was highest around the Norwegian Hole and along the Snares Shelf with the influence of latitude on CPUE more positive for northerly latitudes and from August to December (Figures 18a). Predicted CPUE by statistical area generally followed the overall lognormal CPUE trend for most statistical areas, although there were some exceptions in individual years (Figure 19). Influence plots for the daily processed lognormal model similarly showed a large positive influence on target species and month in later years. There is a positive influence on CPUE when hake are targeted, especially in 2009 and 2010, and expected catch rates were higher for target hake catches. There was a more positive influence when more effort was put in in October, and expected catch rates with higher catches were expected from September to March. There was little influence from other variables as most values were between 0.9 and 1.1 (Figure 18b). Influence plots for the observer lognormal model similarly showed a large positive influence from target species and vessel in later years especially in 2012 (Figure 18c). There was little influence from other variables as most values were between 0.9 and 1.1, except that statistical area had negative influence in 2007 when there was little effort in statistical area 603.

The diagnostics for all models were poor and the quantile-quantile plots indicated a deviation from the normal distribution of the residuals at both the lower and upper ends, i.e., very small and very large catch rates were not well modelled (Figure 20). This suggests that the lognormal models can be improved, and there may be violations of model assumptions (i.e., the assumption of normally distributed constant variance residual errors).

4. SUMMARY

The data used in the analyses were groomed to correct errors where catch may have been misreported, and where incorrect data was recorded or punched. Although some errors may still be present, they would have had only a negligible effect on the CPUE analysis due to the large size of the data sets used (e.g., Dunn & Harley 1999). A complete extract of data was undertaken, so all variables in all years were error groomed and interpreted in a similar manner.

The hake catches from fisheries in all three areas are a consequence of direct targeting for the species and a bycatch of targeting for hoki. The WCSI fishery is of short duration (June–September), with hake mainly a bycatch of hoki, but with some targeting occurring generally before or after the main hoki season. The Chatham Rise fishery is concentrated on the northern and western Rise, mainly from September to February, with targeting for hake concentrating on spawning aggregations. The Sub-Antarctic fishery is concentrated off the south and east of the Snares shelf out to the Pukaki Rise; target fishing here also concentrates on spawning aggregations. The timing of the peak Sub-Antarctic fishery has shifted over time, from September–November in the early 1990s to December–February since the mid-2000s.

The CPUE analysis by Phillips (2005) indicated that low or zero catches may have been inconsistently recorded over time, and there may have also been some problems due to hake not being one of the top five species recorded on the TCEPR tow by tow data. Although there has been a trend of more species being reported on the TCEPR tow-by-tow estimated form, there is evidence that some vessels may not be filling out all hake catches in a tow in recent years for hoki target tows. Daily processed data includes most species as a daily summary, and had low proportions of zero hake tows as more species are more likely to be reported in a daily summary. However, the Sub-Antarctic analyses presented above using the daily processed summaries for hake may not be superior to a tow-by-tow analysis, as the estimated and processed indices generally showed similar trends, and estimated and processed catches are of a similar order. However, this may not be true for species that are rarely recorded as one of the top five on the TCEPR form. Ballara (2012) also showed strong similarities between daily processed and tow-by-tow CPUE for Sub-Antarctic hake, and also found that trends in the combined and lognormal indices were similar, implying that little was gained by adding data from zero catches into that analysis. In addition, daily processed data may not capture changes in conversion factors.

It is assumed that there is a proportional relationship between CPUE and abundance. However, there are specific areas and times (e.g., Statistical Area 404 on the Chatham Rise during the spawning season, and in December 2005 on the Stewart-Snares shelf where commercial fishing vessels reported an aggregation of spawning hake) when hake were more available and hence targeted, and therefore the indices from this area may have a hyperstable relationship between CPUE and abundance (Dunn et al. 2000a). Big catches occurred when spawning aggregations were targeted, and this could easily have biased the data, producing CPUE series that do not track abundance. There was reasonable agreement between the two Sub-Antarctic trawl survey biomass series and the CPUE series. There was a slight decreasing trend in the TCEPR tow-by-tow and daily processed CPUE indices, although credence may be given to these indices as they are very similar to the Sub-Antarctic observed tow-by-tow data series.

The r^2 values for the Sub-Antarctic CPUE models were relatively high (43–59%), with target species and vessel accounting for most of the deviance explained. Most of the explanatory power was from the first two or three variables. However, a large proportion of the underlying variability was not explained. While this is not unusual for CPUE analyses (e.g., Vignaux 1994, Punt et al. 2000), it may be a reflection of a lack of explanatory information available to the models to explain catch rates. For example, individual skippers' experience was not available, even though the number of years the vessel has been in the fishery was included as a variable. There were almost certainly different skippers over the time period. Other effects on catching ability, such as improvements or changes in net and bottom rig design and electronic equipment could not be quantified but might have resulted in an increase in the overall deviance explained.

The diagnostic plots for the CPUE analyses show that the lognormal model was unable to capture the extremes in catch rates observed in the fishery and tended to underestimate the lower catch rates. This suggests that the lognormal models can be improved, and there may be violations of model assumptions (i.e., the assumption of normally distributed constant variance residual errors). Other models may need investigating.

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Table 1: Description of variables used in the CPUE analysis for the estimated tow-by-tow dataset and the daily processed dataset. Continuous variables were fitted as third order polynomials except for tow duration which was offered as both third and fourth order polynomials.

Variable	Type	Estimated tow-by-tow catch dataset	Daily processed catch dataset
Year	Categorical	Fishing year Sep–Aug	Fishing year as Sep–Aug
Vessel	Categorical	Unique (encrypted) vessel identification number	Unique (encrypted) vessel identification number
Statarea	Categorical	Statistical area	Statistical area
Subarea	Categorical	Defined by fishing effort distribution and depth for a tow	Defined by fishing effort distribution and depth for a given day
Effort	Continuous	–	Number of tows for a given day
Primary method	Categorical	Fishing method for a tow	Fishing method for a given day
Tow duration	Continuous	Duration of tow (hrs)	Duration of all tows (hrs) on a given day
Tow distance	Continuous	Distance of tow	Distance of all tows on a given day
Distance2	Continuous	Distance of tow (speed in knots× duration)	Distance (as speed × duration) of all tows on a given day
Headline height	Continuous	Headline height (m) of the net for a tow	Median headline height (m) of the net on a given day
Bottom depth	Continuous	Seabed depth (m) for a tow	Median seabed depth (m) on a given day
Speed	Continuous	Vessel speed (knots) for a tow	Median vessel speed (knots) on a given day
Wingspread	Continuous	Wingspread (m) of the net for a tow	Median wingspread (m) of the net on a given day
Vessel experience	Continuous	Number of years the vessel has been involved in the fishery	Number of years the vessel has been involved in the fishery
Twin trawl vessel	Categorical	T/F variable for a vessel that used a twin trawl in that tow	T/F variable for a vessel that has used a twin trawl that day
Catch	Continuous	Estimated green weight of hake (t) caught from a tow	Estimated green weight of hake (t) caught on a given day
Longitude	Continuous	Longitude of the vessel for a tow	Median longitude of the vessel on a given day
Latitude	Continuous	Latitude of the vessel for a tow	Median latitude of the vessel on a given day
Target species	Categorical	Target species of tow	Main target species on a given day
Date	Continuous	Date of the tow	Date the fish were processed
Month	Categorical	Month of the year	Month of the year
Fday	Continuous	Day of the year	Day of the year
Time start	Continuous	Start time of tow	–
Time mid	Continuous	Mid time of tow	–

Table 2: CPUE data constraints for each dataset.

	Dataset		
	TCEPR tow-by-tow	TCEPR daily processed	Observer tow-by-tow
Data source	TCEPR tow-by-tow	TCEPR daily processed	Observer tow-by-tow
Year range	1991–2013	1991–2013	2000–2013
Year definition	August–September	August–September	August–September
Fisheries	Auckland Island; Campbell Island; Puysegur; Snares-Pukaki	Auckland Island; Campbell Island; Puysegur; Snares-Pukaki	
Statistical Areas	At least 100 tows: 026–028, 030, 504, 602, 603, 610	026–028, 030, 504, 602, 603, 610	026–028, 504, 602, 603, 610
Method	BT	BT	BT
Target	HOK, HAK, LIN	HOK, HAK, LIN	HOK, HAK, LIN
Catch	< 100 t	< 100 t	< 100 t
Bottom depth	150–1000 m	150–1000 m	150–1000 m
Duration	0.2–15 hours	0.2–24 hours	0.2–15 hours
Other	Exclude misreported tows	Exclude days with misreported tows One vessel removed (odd catch values) Latitude > 46º ; Longitude < 172º	
Core vessel selection	Approx. 80% of catch, ≥ 5 years vessel participation and number of vessel-days per year ≥ 20	Approx. 80% of catch, ≥ 5 years vessel participation	Approx. 80% of catch, ≥ 4 years vessel participation

Table 3: Estimated hake catch (t) (TCEPR and CELR were scaled to reported QMR or MHR catch totals and adjusted for misreporting), reported landings (t) from QMR records, and TACC (t) by QMA from 1989–90 to 2012–13. Estimated data also includes LCER (from 2003–04), and NCELR estimated data (from 2006–07), TCER and LTCER data (from 2007–08), and TLCER data. All catches have been rounded to the nearest tonne.

	Estimated catch			Reported catch			TACC		
Year	HAK1	HAK4	HAK7	HAK1	HAK4	HAK7	HAK1	HAK4	HAK7
1989–90	2 115	763	4 903	2 115	763	4 903	2 610	1 000	3 310
1990–91	2 593	726	6 175	2 603	743	6 148	2 610	1 000	3 310
1991–92	3 141	2 007	3 048	3 156	2 013	3 027	3 500	3 500	6 770
1992–93	3 522	2 546	7 157	3 525	2 546	7 154	3 501	3 500	6 835
1993–94	1 787	2 587	2 990	1 803	2 587	2 974	3 501	3 500	6 835
1994–95	2 218	2 826	9 736	2 572	3 369	8 841	3 632	3 500	6 835
1995–96	3 810	3 031	9 148	3 956	3 466	8 678	3 632	3 500	6 835
1996–97	3 285	2 862	6 952	3 534	3 524	6 118	3 632	3 500	6 835
1997–98	3 659	3 061	7 857	3 809	3 523	7 416	3 632	3 500	6 835
1998–99	3 705	2 657	9 150	3 845	3 324	8 165	3 632	3 500	6 835
1999–00	3 747	2 448	7 086	3 899	2 803	6 898	3 632	3 500	6 835
2000–01	3 429	2 321	8 351	3 429	2 321	8 360	3 632	3 500	6 835
2001–02	2 865	1 420	7 499	2 870	1 424	7 519	3 701	3 500	6 835
2002–03	3 334	805	7 406	3 336	811	7 433	3 701	3 500	6 835
2003–04	3 455	2 254	7 943	3 466	2 275	7 945	3 701	3 500	6 835
2004–05	4 795	1 260	7 302	4 795	1 264	7 317	3 701	1 800	6 835
2005–06	2 742	305	6 897	2 743	305	6 906	3 701	1 800	7 700
2006–07	2 006	900	7 660	2 025	900	7 668	3 701	1 800	7 700
2007–08	2 442	865	2 615	2 445	865	2 620	3 701	1 800	7 700
2008–09	3 409	854	5 945	3 415	856	5 954	3 701	1 800	7 700
2009–10	2 156	208	2 340	2 156	208	2 352	3 701	1 800	7 700
2010–11	1 904	179	3 716	1 904	179	3 754	3 701	1 800	7 700
2011–12	1 948	161	4 428	1 948	161	4 459	3 701	1 800	7 700
2012–13	2 056	177	5 426	2 079	177	5 434	3 701	1 800	7 700

Table 4: Estimated hake catches (t) by form type and fishing year.

							Catches
Year	TCEPR	TCER	CELR	LCER	LTCER	NCELR	Total
1989–90	7 780.1	-	1.0	-	-	-	7 781.1
1990–91	9 474.1	-	19.7	-	-	-	9 493.9
1991–92	8 187.3	-	8.1	-	-	-	8 195.4
1992–93	13 188.4	-	36.1	-	-	-	13 224.5
1993–94	7 358.9	-	4.7	-	-	-	7 363.6
1994–95	14 775.2	-	5.2	-	-	-	14 780.4
1995–96	15 984.1	-	4.6	-	-	-	15 988.6
1996–97	13 096.1	-	2.4	-	-	-	13 098.5
1997–98	14 572.6	-	3.9	-	-	-	14 576.5
1998–99	15 505.0	-	8.4	-	-	-	15 513.3
1999–00	13 271.8	-	9.2	-	-	-	13 281.0
2000–01	14 098.5	-	3.0	-	-	-	14 101.5
2001–02	11 778.3	-	5.3	-	-	-	11 783.6
2002–03	11 543.2	-	1.8	-	-	-	11 545.0
2003–04	13 648.3	-	1.8	1.1	-	-	13 651.1
2004–05	13 355.1	-	0.4	1.9	-	-	13 357.4
2005–06	9 938.1	-	5.1	0.7	-	-	9 944.0
2006–07	10 560.3	-	1.3	3.7	-	0.9	10 566.1
2007–08	5 880.4	19.6	5.8	3.4	11.5	1.8	5 922.5
2008–09	10 164.5	20.8	-	6.4	14.0	2.3	10 208.0
2009–10	4 631.0	36.4	-	9.6	25.1	1.9	4 703.9
2010–11	5 700.2	53.4	-	10.2	34.3	1.1	5 799.2
2011–12	6 385.1	93.5	-	7.7	49.5	0.7	6 536.5
2012–13	7 377.6	211.9	-	5.7	63.3	0.6	7 659.0

Table 5: Chatham Rise hake TCEPR catch by target species and fishing method, 1989–90 to 2012–13. Values have been rounded to the nearest tonne, so '0' denotes catches from 1 to 499 kg and '–' denotes zero catch.

	Bottom trawl			Midwater trawl			Midwater, on bottom		
Year	Hake	Hoki	Other	Hake	Hoki	Other	Hake	Hoki	Other
1989–90	531	381	39	–	0	0	–	0	0
1990–91	109	556	82	0	21	0	–	162	0
1991–92	1 514	756	72	6	15	0	20	12	0
1992–93	1 630	829	54	4	9	0	236	35	1
1993–94	856	365	65	23	43	0	1 501	78	2
1994–95	781	752	60	236	31	0	1 200	208	1
1995–96	2 610	929	105	7	41	0	71	195	0
1996–97	2 061	1 401	78	–	65	2	75	209	0
1997–98	1 985	1 158	255	0	64	0	360	250	0
1998–99	2 222	976	152	–	26	1	46	151	0
1999–00	1 274	904	243	382	33	0	234	104	0
2000–01	1 787	901	69	38	15	0	120	32	0
2001–02	1 112	515	36	0	44	0	2	61	0
2002–03	532	672	43	0	91	0	1	63	0
2003–04	1 782	542	59	–	12	0	–	70	0
2004–05	1 372	438	15	1 104	292	0	157	138	0
2005–06	166	248	31	0	6	0	–	38	0
2006–07	694	294	84	0	2	0	–	7	0
2007–08	657	356	73	–	3	0	–	6	0
2008–09	1 412	349	61	0	1	0	0	1	1
2009–10	86	226	63	0	3	0	–	12	0
2010–11	36	263	10	610	25	0	5	1	0
2011–12	1	184	4	–	3	1	–	1	0
2012–13	2	193	2	9	133	0	–	5	0

Table 6: Chatham Rise estimated hake TCEPR catch (t) by month from 1989–90 to 2012–13. Values have been rounded to the nearest tonne, so '0' denotes catches from 1 to 499 kg and '–' denotes zero catch.

												Month	
Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1989–90	82	30	304	167	15	50	144	88	24	17	3	26	950
1990–91	7	38	268	99	48	177	114	63	62	14	29	14	931
1991–92	78	59	520	572	146	99	83	48	32	54	119	588	2 397
1992–93	1 194	132	87	219	90	87	59	24	90	62	12	742	2 798
1993–94	219	2 086	64	38	26	8	11	32	43	25	6	374	2 934
1994–95	913	1 072	632	61	39	13	13	51	102	39	28	309	3 271
1995–96	299	1 074	986	659	57	22	44	93	144	172	90	318	3 959
1996–97	627	267	1 484	133	72	112	82	101	84	357	4	568	3 890
1997–98	302	469	284	95	65	173	107	112	175	209	1	2 082	4 074
1998–99	327	610	624	349	73	278	46	37	270	212	1	762	3 589
1999–00	879	373	299	107	71	122	57	28	575	131	1	531	3 174
2000–01	138	493	772	385	52	143	70	149	625	16	0	119	2 962
2001–02	108	396	385	255	24	53	36	59	36	14	18	385	1 770
2002–03	236	185	91	42	24	45	71	85	30	31	2	562	1 401
2003–04	197	446	694	421	44	68	65	70	53	14	7	384	2 465
2004–05	2 388	90	546	278	18	13	14	17	15	3	14	119	3 518
2005–06	90	58	191	14	10	8	19	14	38	7	4	38	489
2006–07	98	51	46	133	330	76	73	75	24	8	8	160	1 081
2007–08	38	40	47	418	248	58	27	62	24	19	20	94	1 096
2008–09	467	417	107	492	249	19	12	13	17	10	6	17	1 825
2009–10	99	21	85	29	30	18	6	41	30	13	12	7	391
2010–11	113	605	25	26	26	32	61	15	10	13	0	24	951
2011–12	30	16	23	19	63	11	1	7	4	2	3	16	194
2012–13	29	154	28	38	19	28	6	21	7	3	1	10	344

Table 7: WCSI hake TCEPR catch (t) by target species and fishing method, 1989–90 to 2012–13. Values have been rounded to the nearest tonne denotes catches from 1 to 499 kg and '–' denotes zero catch.

	Bottom trawl			Midwater trawl			Midwater, on bottom		
Year	Hake	Hoki	Other	Hake	Hoki	Other	Hake	Hoki	Other
1989–90	4	614	4	2	3 392	0	1	885	0
1990–91	–	247	3	0	4 626	2	5	1 246	44
1991–92	1 224	360	74	45	852	1	249	232	2
1992–93	536	607	21	962	1 026	0	2 548	1 407	15
1993–94	53	638	20	173	934	2	761	386	3
1994–95	0	583	92	785	4 778	19	1 724	1 738	13
1995–96	232	1 237	96	1 186	4 357	24	215	1 736	48
1996–97	56	1 080	45	511	3 045	46	280	1 585	71
1997–98	58	839	5	255	4 202	20	297	2 007	1
1998–99	370	1 443	40	1 046	3 021	7	1 212	1 325	162
1999–00	286	1 905	51	396	2 314	2	587	1 501	15
2000–01	333	1 547	15	2 164	1 400	0	1 172	1 514	0
2001–02	427	2 886	20	213	1 477	0	143	1 934	1
2002–03	2 158	1 984	7	434	990	0	528	1 296	1
2003–04	2 706	1 564	2	224	585	2	1 274	1 581	2
2004–05	2 675	743	3	842	454	1	2 123	457	0
2005–06	2 576	672	22	700	409	0	1 936	575	0
2006–07	1 592	373	10	4 266	447	0	914	51	7
2007–08	2 322	127	3	2	8	0	70	50	0
2008–09	2 504	122	4	1 206	6	0	2 002	69	0
2009–10	1 948	159	9	10	11	0	68	78	0
2010–11	2 811	499	14	1	36	0	12	90	0
2011–12	3 148	925	3	2	65	0	4	152	0
2012–13	3 292	1 044	3	–	100	0	113	618	0

Table 8: WCSI estimated hake TCEPR catch (t) by month from 1989–90 to 2012–13. Values have been rounded to the nearest tonne, so '0' denotes catches from 1 to 499 kg and '–' denotes zero catch.

												Month	
Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1989–90	0	0	0	–	0	0	0	0	1 107	3 075	696	25	4 903
1990–91	0	–	0	0	0	0	0	0	758	5 065	327	22	6 173
1991–92	0	0	–	0	0	0	0	0	213	771	172	1 884	3 040
1992–93	3	0	0	0	0	4	0	1	556	1 383	1 832	3 343	7 122
1993–94	0	0	0	0	0	1	0	0	885	1 234	381	470	2 971
1994–95	12	0	2	0	0	2	1	22	3 285	2 535	3 449	424	9 733
1995–96	168	0	0	0	0	1	0	1	2 506	2 599	2 766	1 097	9 138
1996–97	56	0	0	0	0	0	0	0	1 012	2 484	2 033	1 358	6 944
1997–98	64	31	0	0	0	0	2	15	1 749	3 338	2 156	492	7 848
1998–99	48	332	15	0	0	4	1	30	3 316	3 567	1 153	641	9 107
1999–00	195	0	–	–	0	2	1	44	1 776	3 586	835	637	7 076
2000–01	71	0	0	–	0	–	3	17	3 607	2 308	1 675	665	8 346
2001–02	0	2	0	0	–	0	0	0	824	3 471	2 920	281	7 498
2002–03	92	0	2	0	0	–	2	109	1 119	3 416	1 001	1 664	7 404
2003–04	280	0	0	0	–	0	–	39	2 850	1 548	2 249	972	7 939
2004–05	192	64	0	–	0	0	0	4	3 373	2 014	1 031	620	7 298
2005–06	286	19	0	0	0	0	0	0	773	1 090	2 182	2 543	6 892
2006–07	61	0	0	0	0	0	0	73	1 919	4 602	637	368	7 660
2007–08	65	0	–	0	–	–	–	59	510	578	772	598	2 583
2008–09	11	0	–	–	–	0	–	168	448	709	2 655	1 922	5 912
2009–10	13	0	–	–	–	–	–	14	209	517	716	813	2 282
2010–11	131	0	0	–	–	0	–	0	494	836	1 396	606	3 462
2011–12	25	–	–	0	–	–	–	0	283	1 371	1 526	1 092	4 299
2012–13	0	–	–	–	0	–	–	5	1 143	814	1 284	1 924	5 171

Table 9: Sub-Antarctic hake TCEPR catch (t) by target species and fishing method, 1989–90 to 2012–13. Values have been rounded to the nearest tonne, so '0' denotes catches from 1 to 499 kg and '–' denotes zero catch.

	Bottom trawl			Midwater trawl			Midwater, on bottom		
Year	Hake	Hoki	Other	Hake	Hoki	Other	Hake	Hoki	Other
1989–90	610	724	477	–	5	44	–	5	61
1990–91	241	1 477	603	–	7	18	–	3	22
1991–92	544	1 610	549	3	18	12	0	4	10
1992–93	76	2 212	278	–	418	6	–	276	3
1993–94	148	547	317	43	368	3	9	10	7
1994–95	831	432	295	–	140	9	–	42	1
1995–96	1 203	460	1 071	–	86	0	–	62	0
1996–97	555	954	590	–	155	6	–	0	1
1997–98	738	1 198	658	–	6	4	–	0	2
1998–99	946	1 141	645	0	36	3	0	22	2
1999–00	906	1 460	252	0	356	2	–	32	10
2000–01	1 157	1 273	200	1	71	5	0	41	43
2001–02	1 039	1 238	154	–	6	4	–	8	62
2002–03	1 498	1 015	152	–	16	8	–	10	39
2003–04	1 224	1 537	426	–	8	15	–	12	23
2004–05	1 069	447	917	41	1	6	12	13	34
2005–06	2 033	117	368	2	11	5	0	4	16
2006–07	1 029	278	480	0	0	10	0	3	18
2007–08	1 558	188	436	–	0	7	–	–	13
2008–09	1 918	147	355	–	0	4	0	0	3
2009–10	1 493	245	206	–	1	2	–	0	10
2010–11	1 005	148	106	–	0	10	–	1	18
2011–12	1 468	132	272	–	5	2	–	9	3
2012–13	1 188	102	554	–	4	6	–	4	6

Table 10: Sub-Antarctic estimated hake TCEPR catch (t) recorded by month, 1989–90 to 2012–13. Values have been rounded to the nearest tonne, so '0' denotes catches from 1 to 499 kg.

	Month												
Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1989–90	222	11	18	22	26	45	79	156	107	8	64	1 169	1 927
1990–91	230	82	57	16	92	84	106	167	187	25	166	1 159	2 370
1991–92	272	92	78	75	106	127	200	139	171	125	265	1 100	2 750
1992–93	1 515	570	103	90	72	95	112	118	39	8	120	427	3 269
1993–94	648	126	54	78	66	48	45	23	78	1	3	284	1 453
1994–95	560	490	24	37	34	121	52	75	34	0	148	197	1 771
1995–96	1 234	675	210	23	14	145	60	51	34	139	75	225	2 884
1996–97	294	791	120	66	50	19	50	71	158	46	16	582	2 262
1997–98	554	1 024	84	44	122	136	88	195	101	21	7	230	2 606
1998–99	478	427	305	35	339	196	174	149	320	163	37	172	2 796
1999–00	295	851	435	253	322	120	142	194	307	14	4	84	3 020
2000–01	413	825	343	190	147	60	100	207	378	40	33	55	2 790
2001–02	177	1 007	390	191	106	124	96	97	120	28	54	121	2 510
2002–03	210	1 190	804	135	10	54	84	57	111	0	0	82	2 738
2003–04	432	1 246	862	254	38	6	12	137	143	4	5	105	3 245
2004–05	443	971	876	82	26	2	30	14	19	8	4	65	2 539
2005–06	215	185	2 038	1	1	11	22	15	8	1	4	59	2 557
2006–07	268	194	536	164	342	9	13	36	21	10	57	168	1 818
2007–08	228	609	509	214	560	11	8	3	2	3	14	40	2 202
2008–09	72	294	727	876	346	49	23	5	5	7	2	22	2 427
2009–10	109	84	586	619	302	41	32	92	33	3	3	53	1 958
2010–11	77	58	357	441	246	19	20	24	10	2	12	22	1 288
2011–12	94	187	502	266	645	112	30	19	16	2	5	13	1 892
2012–13	483	778	251	241	3	12	25	24	17	3	9	18	1 863

Table 11: Summary of data for all and core vessels included in the CPUE datasets, by year. Data include: number of unique vessels fishing (Vessels), number of tow records (trawl tow-by-tow data) or number of vessel-days (daily processed data) (Effort), proportion of tows (trawl tow-by-tow data) or vessel-days (daily processed data) that caught zero catch (Zeros), estimated catch, and unstandardised CPUE (CPUE).

(a) Sub-Antarctic TCEPR tow-by-tow data

	All vessels					Core vessels				
Year	Vessels	Catch	Effort	Zeros	CPUE	Vessels	Catch	Effort	Zeros	CPUE
1991	38	2 167.9	4 606	0.29	0.67	3	418.4	372	0.37	1.79
1992	45	2 569.7	6 765	0.34	0.58	8	890.7	2 279	0.23	0.51
1993	40	3 089.7	5 752	0.34	0.81	8	1 394.0	2 481	0.26	0.76
1994	27	890.5	2 445	0.30	0.52	4	314.4	1 300	0.22	0.31
1995	26	1 390.7	3 034	0.29	0.65	7	1 139.5	1 972	0.26	0.78
1996	32	2 458.8	3 206	0.47	1.45	11	2 113.1	2 087	0.46	1.86
1997	41	1 733.5	3 974	0.42	0.76	15	1 499.7	2 838	0.37	0.84
1998	43	2 650.9	4 975	0.32	0.78	17	2 527.4	4 300	0.28	0.81
1999	34	2 342.9	3 684	0.30	0.91	17	2 095.9	2 960	0.26	0.95
2000	31	2 443.6	5 756	0.39	0.69	19	2 401.5	5 157	0.34	0.71
2001	34	2 565.5	5 377	0.41	0.81	20	2 500.4	4 787	0.39	0.86
2002	35	2 243.5	5 789	0.41	0.66	16	2 175.7	5 006	0.36	0.68
2003	37	2 631.8	4 373	0.48	1.15	16	2 549.1	3 769	0.43	1.18
2004	27	2 962.3	3 164	0.39	1.55	10	2 928.5	2 772	0.34	1.60
2005	27	2 250.8	2 104	0.47	2.01	10	1 981.7	1 644	0.41	2.03
2006	23	2 206.3	1 857	0.56	2.67	10	2 175.6	1 471	0.50	2.94
2007	22	1 592.7	2 246	0.59	1.74	10	1 535.3	1 806	0.59	2.05
2008	23	2 249.1	2 303	0.48	1.87	9	1 929.2	1 802	0.44	1.90
2009	19	2 350.8	1 850	0.46	2.35	8	2 255.9	1 609	0.44	2.49
2010	19	1 841.8	1 747	0.45	1.93	6	1 701.8	1 516	0.43	1.98
2011	20	1 261.8	1 770	0.54	1.56	5	1 227.9	1 455	0.50	1.69
2012	21	1 654.9	1 657	0.48	1.92	8	1 613.6	1 334	0.46	2.25
2013	21	1 811.4	1 988	0.49	1.80	6	1 702.0	1 557	0.45	2

(b) Sub-Antarctic TCEPR daily processed data.

	All vessels					Core vessels				
Year	Vessels	Catch	Effort	Zeros	CPUE	Vessels	Catch	Effort	Zeros	CPUE
1991	31	1 836.0	938	0.12	1.96	10	312.8	119	0.21	2.63
1992	40	2 211.4	1 548	0.10	1.43	15	739.8	581	0.12	1.27
1993	33	2 606.8	1 185	0.13	2.20	17	1 142.5	583	0.15	1.96
1994	24	722.4	531	0.13	1.36	13	417.3	361	0.13	1.16
1995	25	1 096.5	680	0.07	1.61	18	959.7	519	0.08	1.85
1996	28	902.2	555	0.14	1.63	19	837.2	486	0.08	1.72
1997	39	962.2	924	0.11	1.04	25	828.5	820	0.09	1.01
1998	40	1 927.1	1 308	0.06	1.47	28	1 841.9	1 208	0.06	1.52
1999	31	1 742.8	952	0.07	1.83	25	1 711.0	917	0.06	1.87
2000	29	2 148.8	1 444	0.07	1.49	29	2 148.8	1 444	0.07	1.49
2001	32	2 267.9	1 376	0.08	1.65	28	2 235.6	1 318	0.08	1.70
2002	33	2 008.2	1 409	0.10	1.43	30	1 975.2	1 369	0.10	1.44
2003	34	2 095.3	1 089	0.08	1.92	30	2 086.0	1 068	0.08	1.95
2004	25	2 490.7	818	0.08	3.04	23	2 490.5	815	0.07	3.06
2005	25	1 696.5	574	0.10	2.96	25	1 696.5	574	0.10	2.96
2006	21	1 879.6	431	0.11	4.36	18	1 866.1	412	0.10	4.53
2007	21	1 215.8	685	0.10	1.77	20	1 215.8	685	0.10	1.77
2008	22	1 523.5	684	0.08	2.23	20	1 522.0	663	0.07	2.30
2009	18	2 106.3	531	0.07	3.97	16	2 105.0	508	0.04	4.14
2010	18	1 575.9	503	0.05	3.13	18	1 575.9	503	0.05	3.13
2011	19	1 127.3	503	0.05	2.24	17	1 124.9	479	0.06	2.35
2012	21	1 409.1	498	0.05	2.83	19	1 393.3	458	0.04	3.04
2013	21	1 552.9	591	0.06	2.63	18	1 492.3	543	0.05	2.75

Table 11 continued.

(c) Sub-Antarctic Observer tow-by-tow data

	All vessels					Core vessels				
Year	**Vessels**	**Catch**	**Effort**	**Zeros**	**CPUE**	**Vessels**	**Catch**	**Effort**	**Zeros**	**CPUE**
2000	9	892.4	640	0.10	1.39	6	718.0	425	0.13	1.69
2001	15	143.0	308	0.06	0.46	6	83.8	106	0.06	0.79
2002	9	445.7	461	0.06	0.97	7	443.4	456	0.06	0.97
2003	11	71.4	385	0.15	0.19	6	42.1	168	0.07	0.25
2004	8	462.3	217	0.08	2.13	5	460.4	206	0.05	2.23
2005	5	54.2	140	0.15	0.39	4	54.2	138	0.15	0.39
2006	5	842.7	300	0.12	2.81	5	842.7	300	0.12	2.81
2007	10	428.7	246	0.27	1.74	10	424.2	186	0.30	2.28
2008	12	400.2	516	0.13	0.78	8	154.3	359	0.15	0.43
2009	8	688.9	484	0.10	1.42	6	685.2	470	0.10	1.46
2010	7	1 183.5	641	0.14	1.85	7	1 177.7	616	0.11	1.91
2011	10	884.2	396	0.12	2.23	7	827.5	306	0.12	2.70
2012	8	1 140.9	357	0.09	3.20	4	1 062.3	202	0.02	5.26
2013	19	1 105.0	808	0.22	1.37	10	953.7	375	0.23	2.54

Table 12: Variables retained in order of decreasing explanatory value by each model for each dataset, with the corresponding total r^2 value.

(a) Sub-Antarctic TCEPR tow-by-tow data

Variable	r^2
Year	4.37
Target species	33.47
Vessel	38.21
Statistical area	41.56
Month	43.23
Latitude	44.44

(b) Sub-Antarctic TCEPR daily processed data

Variable	r^2
Fishing year	2.07
Vessel	24.84
Statistical area	35.53
Target species	42.23
Month	43.55

(c) Sub-Antarctic Observer tow-by-tow data

Variable	r^2
Year	6.68
Target species	52.08
Statistical area	56.70
Vessel	58.09
Month	59.64

Table 13: Lognormal CPUE standardised CPUE indices (with 95% confidence intervals and CVs).

(a) Sub-Antarctic TCEPR tow-by-tow data

Year	Index	CI	CV
1991	1.19	1.04–1.37	0.07
1992	1.18	1.11–1.25	0.03
1993	1.37	1.29–1.45	0.03
1994	1.04	0.96–1.12	0.04
1995	0.84	0.79–0.89	0.03
1996	0.93	0.87–0.99	0.03
1997	1.04	0.99–1.10	0.03
1998	1.11	1.07–1.16	0.02
1999	1.03	0.98–1.08	0.02
2000	1.13	1.09–1.18	0.02
2001	1.14	1.09–1.18	0.02
2002	1.00	0.96–1.04	0.02
2003	1.00	0.95–1.04	0.02
2004	1.20	1.14–1.27	0.03
2005	1.00	0.94–1.07	0.03
2006	0.91	0.84–0.99	0.04
2007	1.03	0.96–1.12	0.04
2008	0.95	0.89–1.01	0.03
2009	0.90	0.83–0.96	0.04
2010	0.87	0.81–0.93	0.04
2011	0.75	0.70–0.81	0.04
2012	0.77	0.71–0.83	0.04
2013	0.86	0.80–0.93	0.04

(b) Sub-Antarctic TCEPR daily processed data

Year	Index	CI	CV
1991	0.89	0.74–1.08	0.09
1992	1.38	1.26–1.52	0.05
1993	1.27	1.16–1.39	0.05
1994	1.17	1.05–1.31	0.06
1995	1.06	0.97–1.17	0.05
1996	1.00	0.90–1.10	0.05
1997	1.04	0.96–1.12	0.04
1998	1.06	0.99–1.13	0.03
1999	1.32	1.23–1.42	0.04
2000	1.23	1.16–1.30	0.03
2001	1.19	1.12–1.27	0.03
2002	1.00	0.95–1.07	0.03
2003	0.88	0.83–0.94	0.03
2004	1.20	1.11–1.29	0.04
2005	0.95	0.87–1.03	0.04
2006	0.83	0.75–0.92	0.05
2007	0.68	0.62–0.74	0.04
2008	0.75	0.69–0.81	0.04
2009	0.92	0.84–1.01	0.05
2010	1.02	0.93–1.12	0.05
2011	0.81	0.74–0.89	0.05
2012	0.88	0.80–0.97	0.05
2013	0.85	0.78–0.93	0.04

(c) Sub-Antarctic Observer tow-by-tow data

Year	Index	CI	CV
2000	1.35	1.20–1.53	0.06
2001	1.10	0.86–1.41	0.12
2002	1.34	1.18–1.53	0.07
2003	1.28	1.08–1.53	0.09
2004	1.26	1.06–1.50	0.09
2005	1.27	1.06–1.52	0.09
2006	1.10	0.96–1.28	0.07
2007	1.13	0.95–1.35	0.09
2008	0.93	0.82–1.05	0.06
2009	0.79	0.70–0.90	0.06
2010	0.78	0.71–0.86	0.05
2011	0.66	0.57–0.75	0.07
2012	0.72	0.61–0.85	0.08
2013	0.72	0.64–0.80	0.06

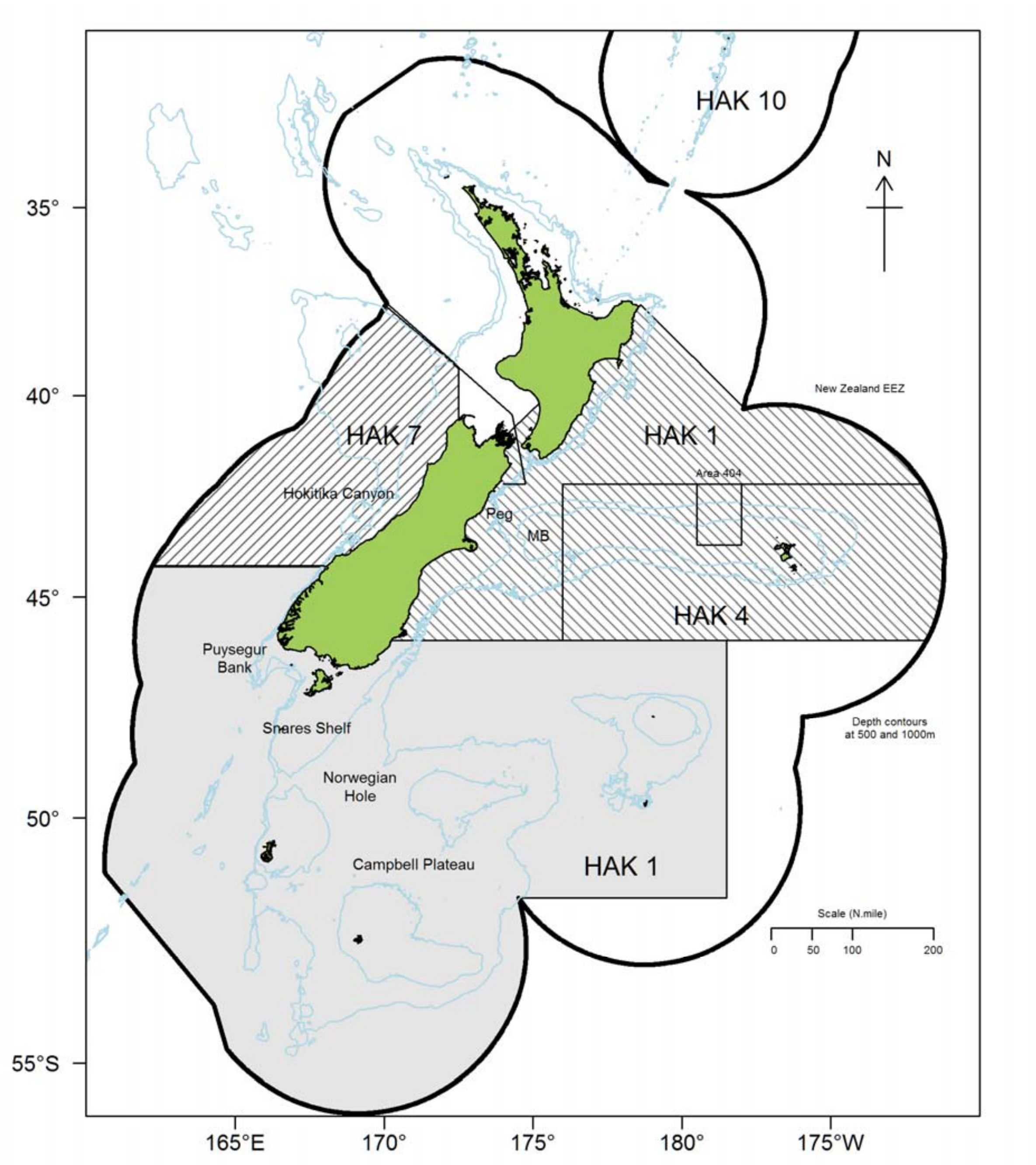


Figure 1: Quota Management Areas (QMAs) HAK 1, 4, 7, and 10, and hake biological stock boundaries, as assumed in this report: West coast South Island (dark stripes over HAK7), Chatham Rise (light stripes over HAK1 and HAK4), and Sub-Antarctic (grey shading over HAK1). Place names referred to in the text are also noted, including: Peg, Pegasus Bay; MB, Mernoo Bank.

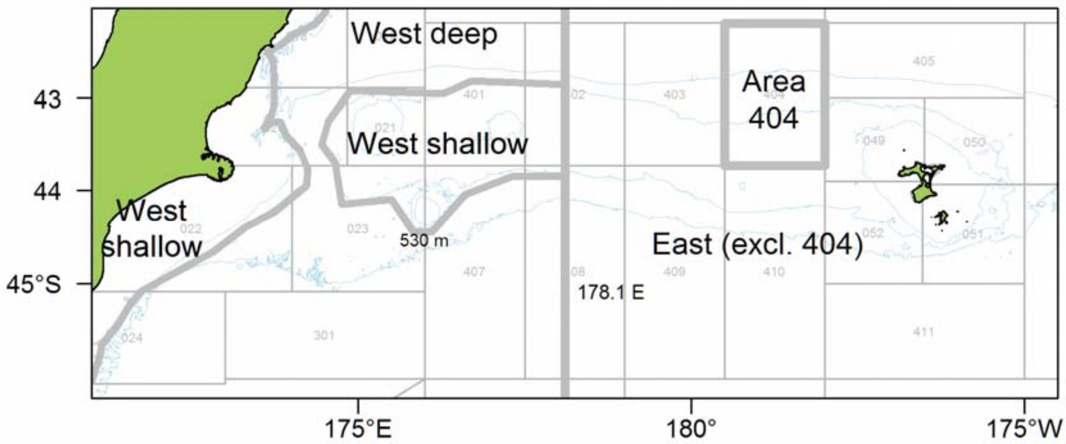


Figure 2a: Location and boundaries of the four Chatham Rise sub-areas used in this analysis: West deep (at least 530 m deep); West shallow (less than 530 m deep); East, excluding Statistical Area 404; and Statistical Area 404.

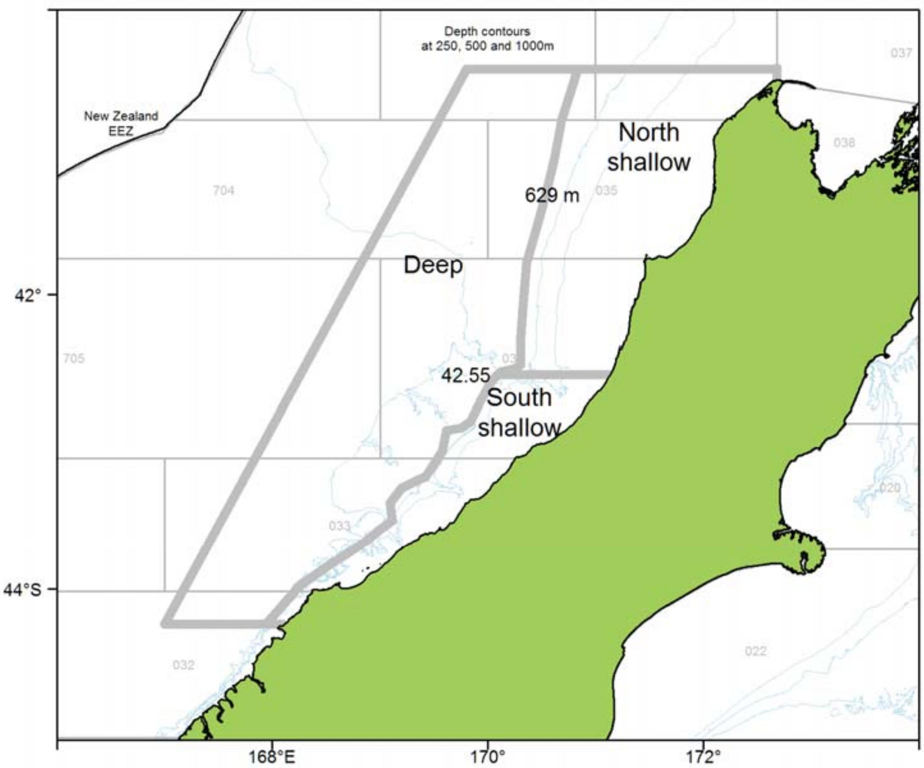


Figure 2b: Location and boundaries of the three WCSI sub-areas used in this analysis: Deep (at least 530 m deep); North shallow (less than 530 m deep, north of 42.55° S); South shallow (less than 530 m deep, south of 42.55° S).

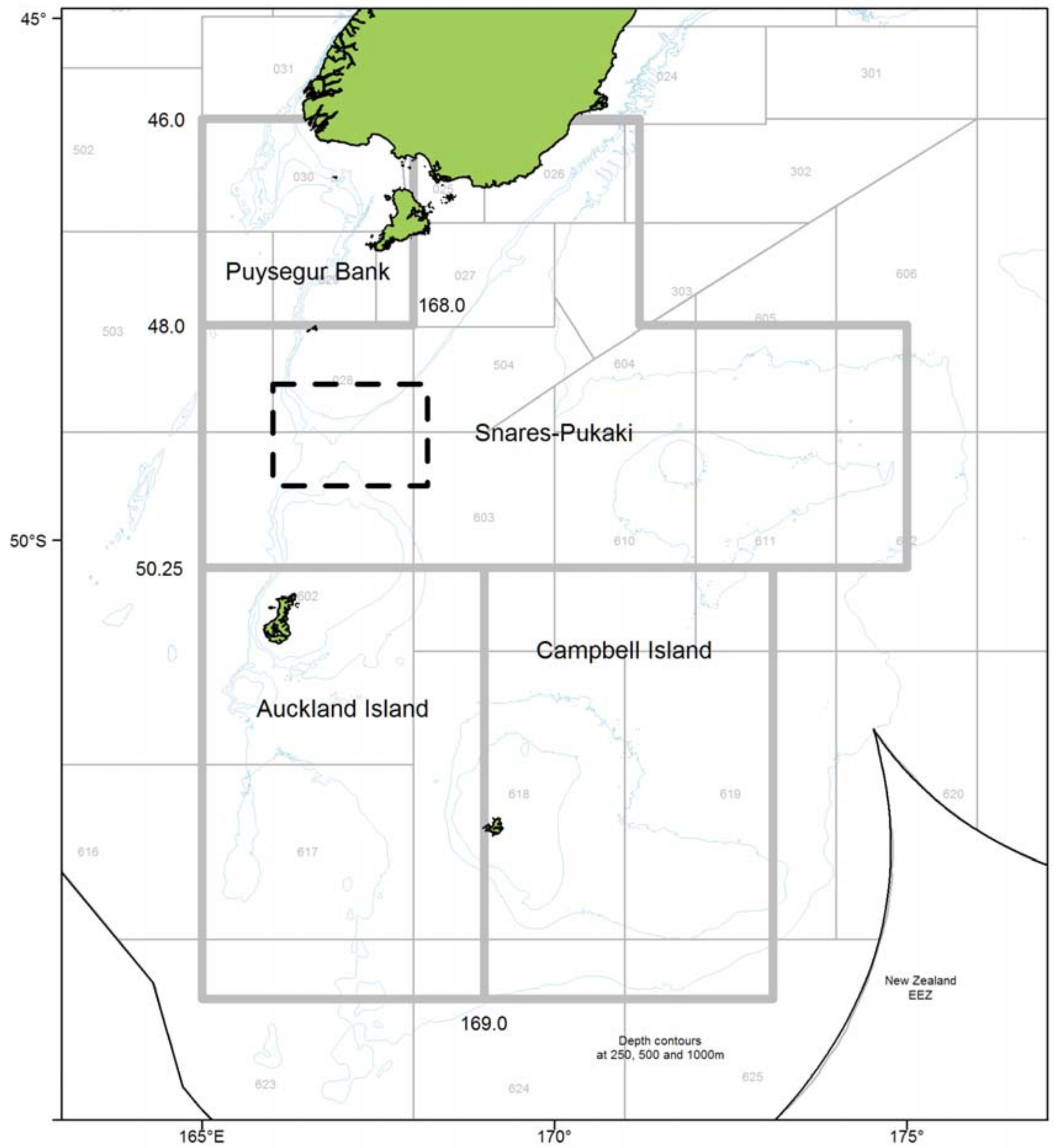


Figure 2c: Location and boundaries of the four Sub-Antarctic sub-areas used in this analysis: Puysegur Bank; Snares-Pukaki; Auckland Island; and Campbell Island. Dotted lines shows the southern Snares Shelf area used in CPUE sensitivity analyses.

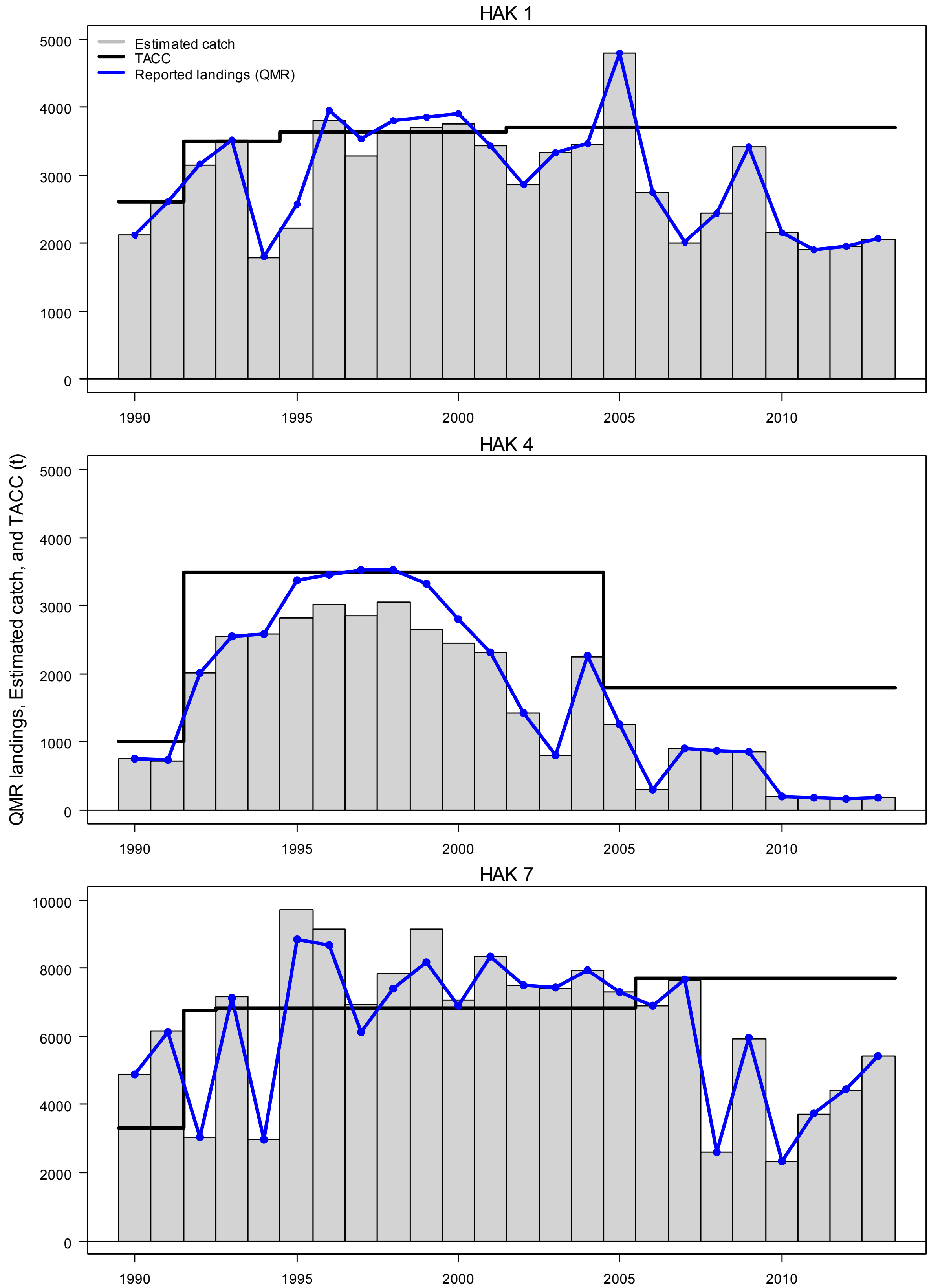
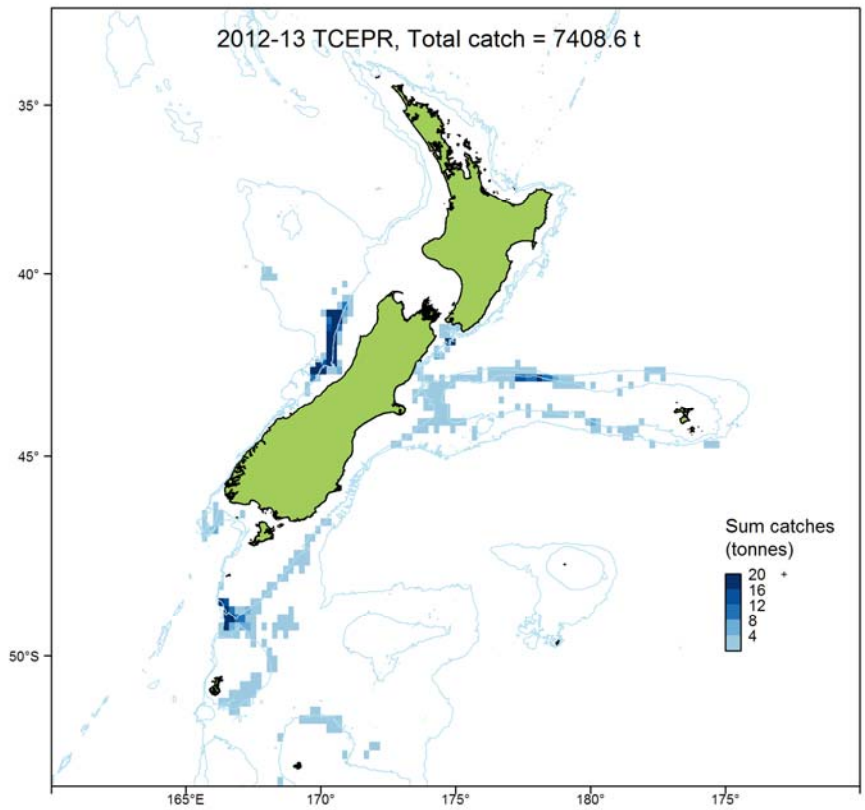


Figure 3: QMR landings (blue line with dots), scaled estimated catch corrected for misreporting (shaded bars), and TACC (solid black line) for HAK 1, HAK 4, and HAK 7, for the fishing years 1989–90 (1990) to 2012–13 (2013).



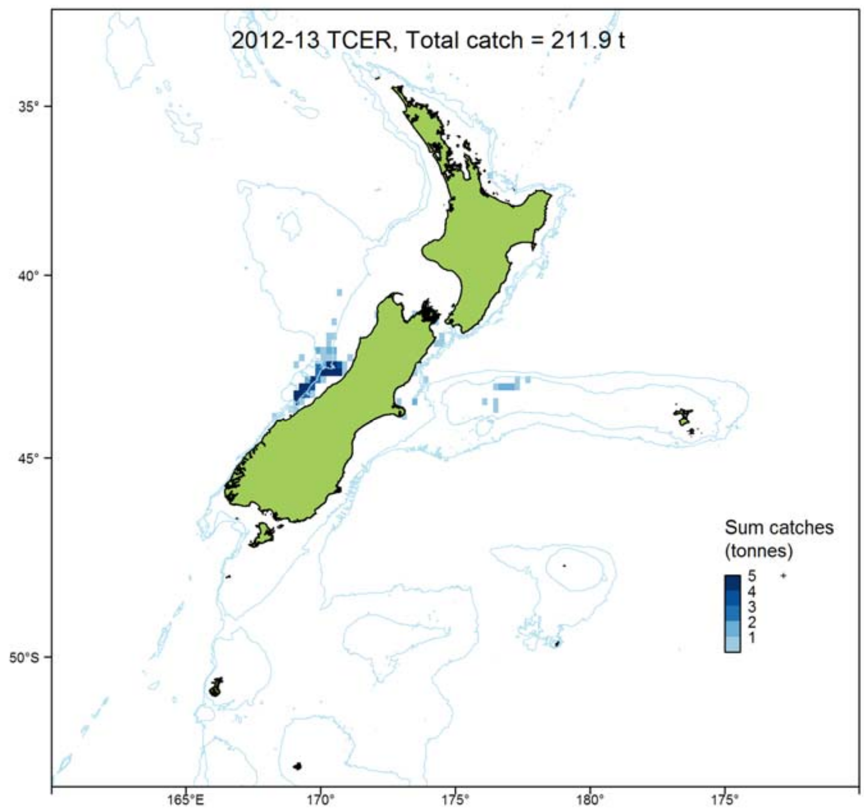


Figure 4: Density plots of all commercial TCEPR and TCER trawls where hake was caught in the 2012–13 fishing year.

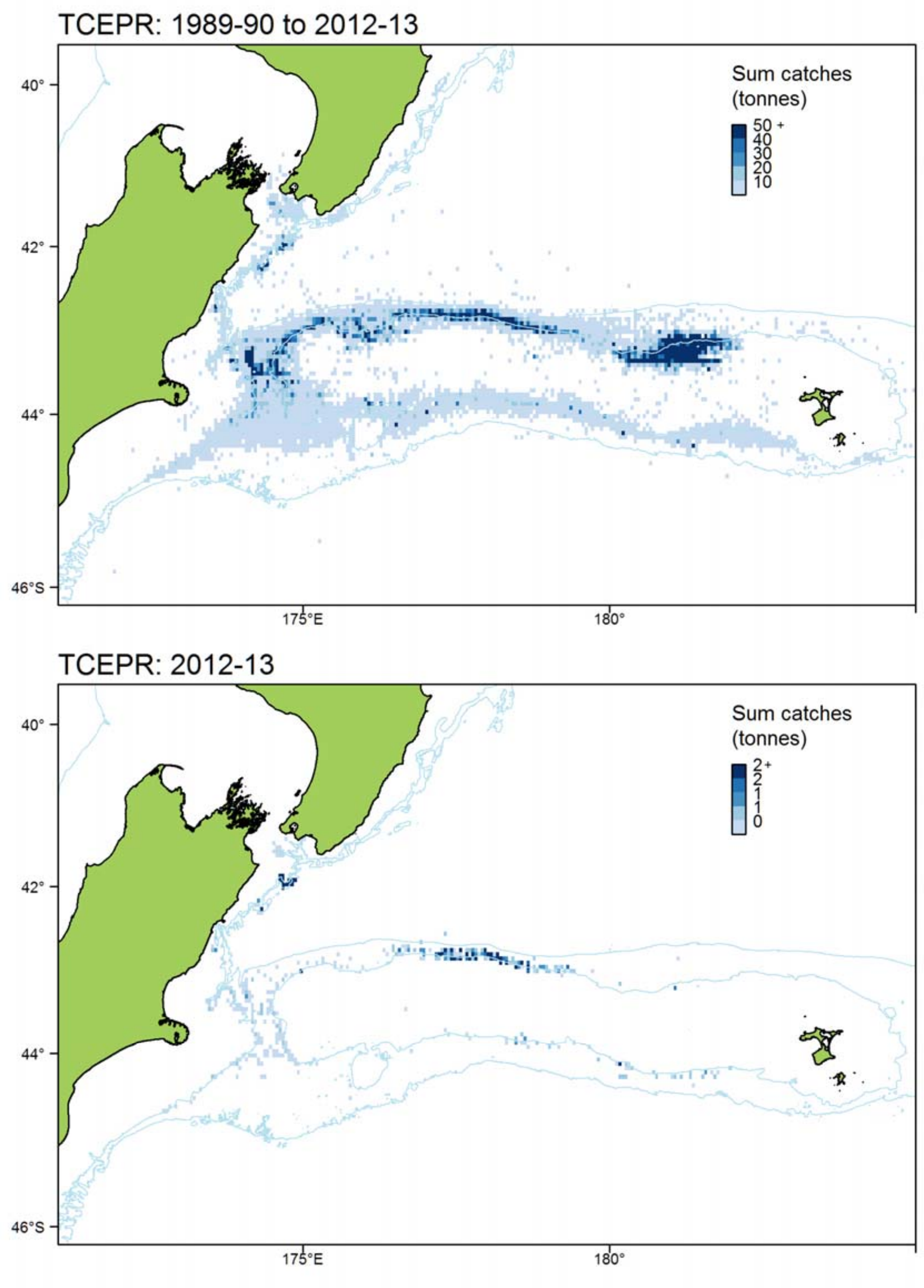


Figure 5a: Density plots of Chatham Rise commercial hake catches from TCEPR records for all fishing years combined (1989–90 to 2012–13), and for the 2012–13 fishing year.

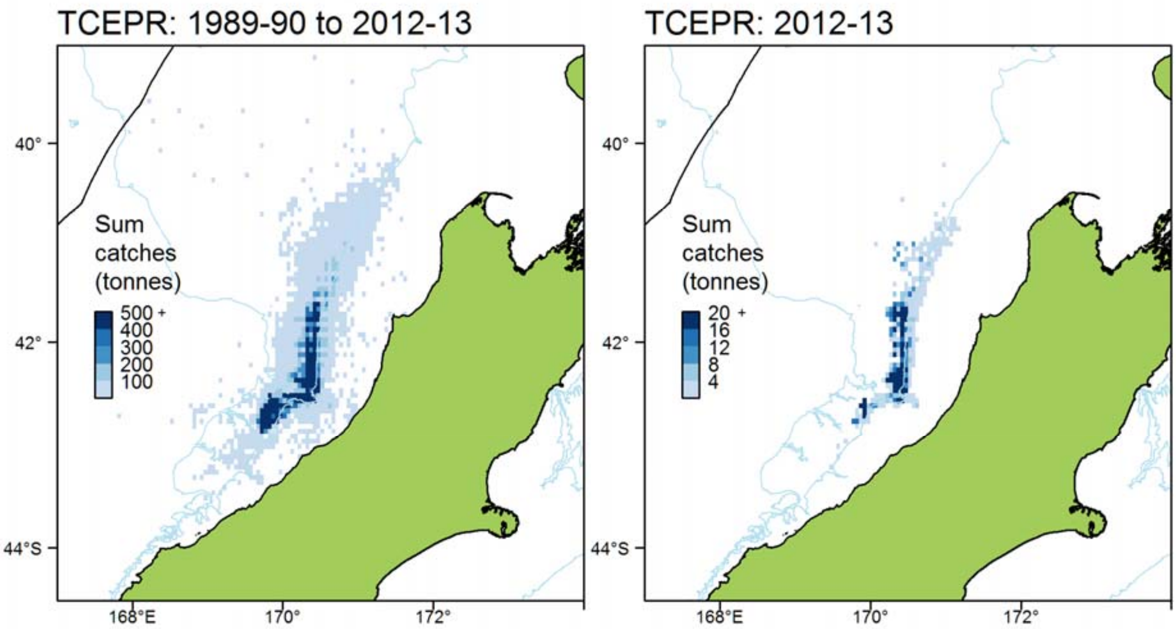


Figure 5b: Density plots of WCSI commercial hake catches from TCEPR records for all fishing years combined (1989–90 to 2012–13), and for the 2012–13 fishing year.

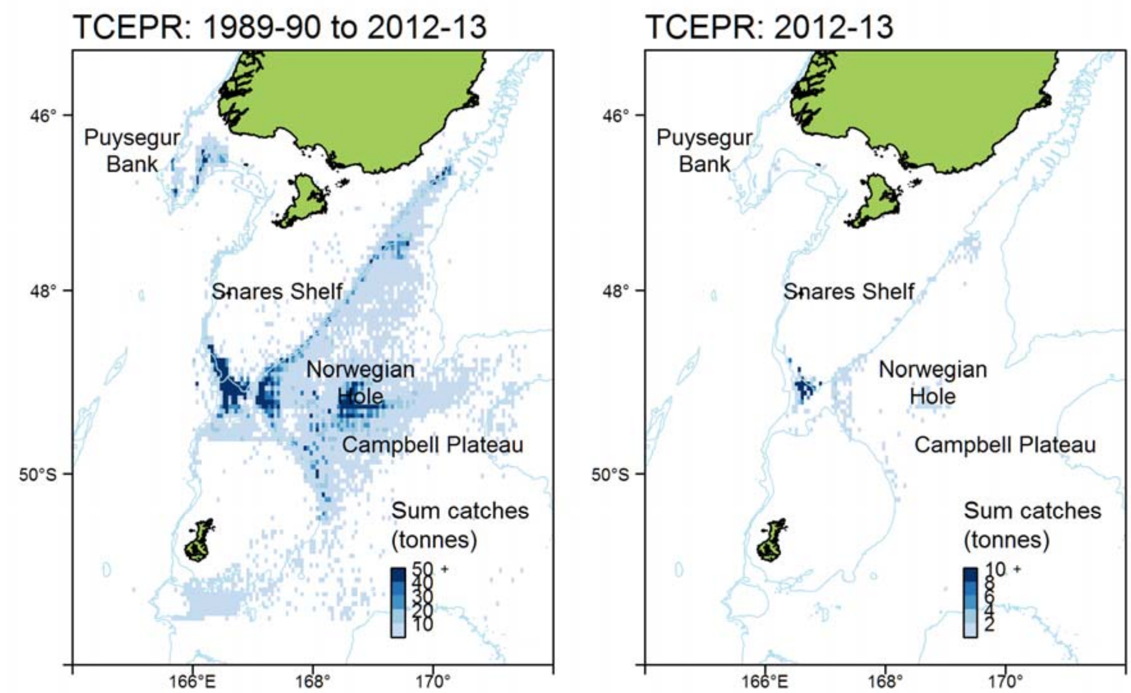


Figure 5c: Density plots of Sub-Antarctic commercial hake catches from TCEPR estimated catch records for all fishing years combined (1989–90 to 2012–13), and for the 2012–13 fishing year.

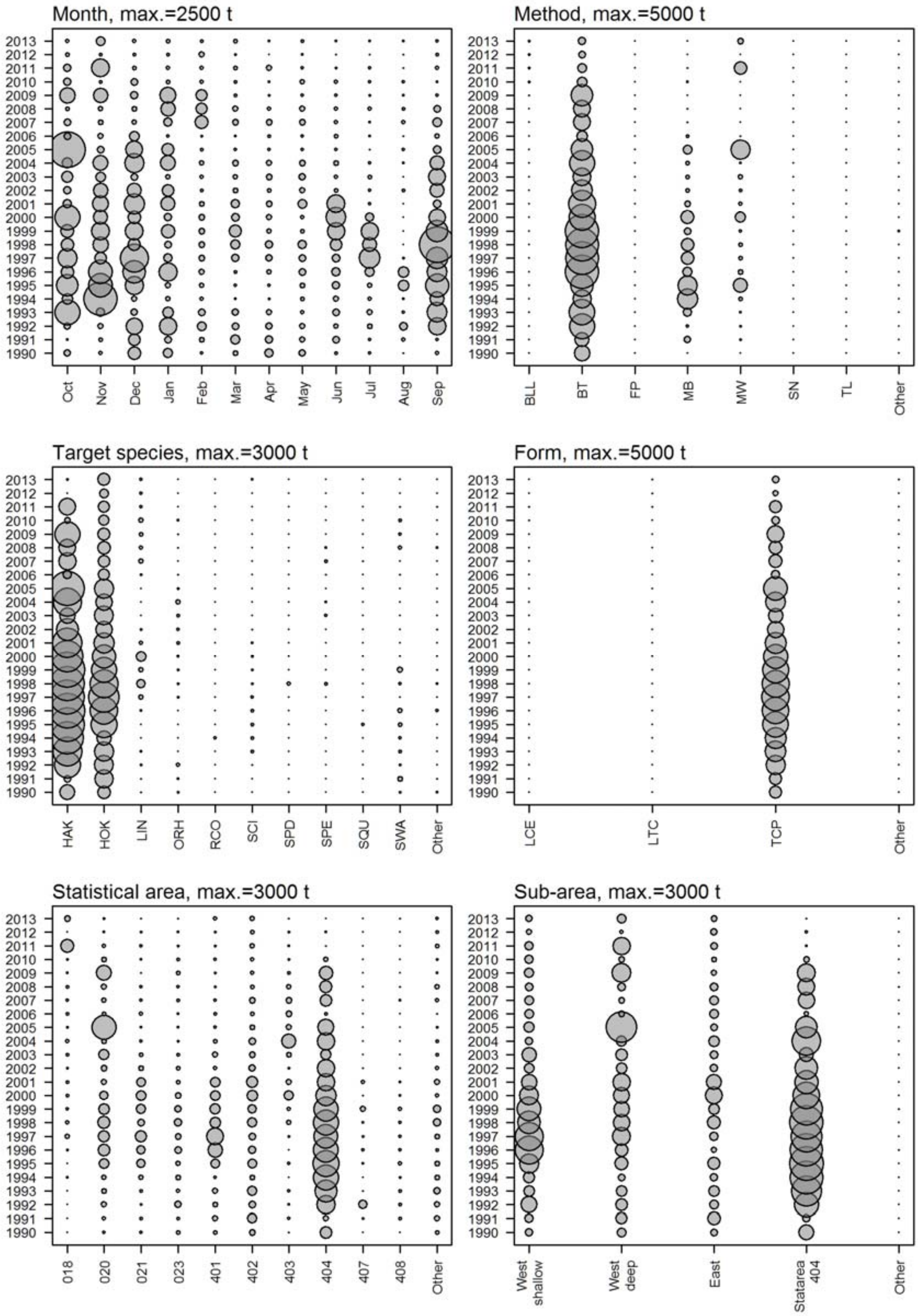


Figure 6a: Distribution of Chatham Rise TCEPR tow-by-tow hake trawl catch by month, statistical area, method, target species, form type, and sub-area by fishing year since 1989–90 (1990). Circle size is proportional to catch; maximum circle size is indicated on the top of each plot. Statistical areas and sub-areas are defined in Figure 2. Form types: LCE is Lining Catch Effort Return; LTC is Lining Trip Catch, Effort return; TCP is Trawl, Catch, Effort, and Processing Return. Method definitions: BLL, bottom longlining; BT, bottom trawl; MB, midwater trawl within 5 m of the bottom; FP, fish traps; MW, midwater trawl; SN, set net; TL, trot line. Species codes: HAK, hake; HOK, hoki; LIN, ling; ORH: orange roughy; RCO, red cod; SCI, scampi; SPD, spiny dogfish; SPE, sea perch; SQU, arrow squid; SWA, silver warehou.

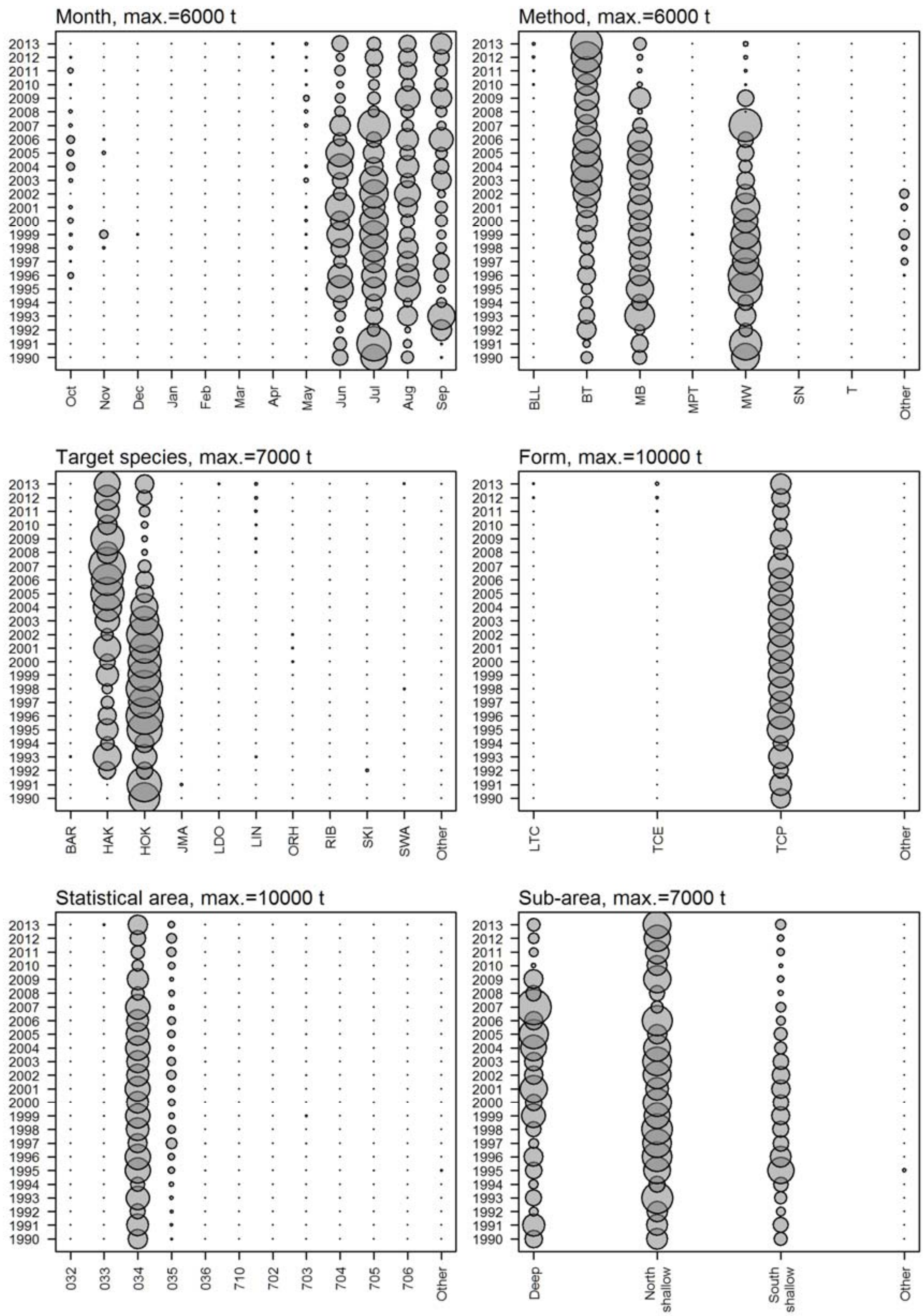


Figure 6b: Distribution of WCSI TCEPR tow-by-tow hake trawl catch by month, statistical area, method, target species, form type, and sub-area by fishing year since 1989–90 (1990). Circle size is proportional to catch; maximum circle size is indicated on the top of each plot. Statistical areas and sub-areas are defined in Figure 2. Form types: LTC is Lining Trip Catch, Effort return; TCE is Trawl, Catch, Effort Return; TCP is Trawl, Catch, Effort, and Processing Return. Method definitions: BLL, bottom longlining; BT, bottom trawl; MB, midwater trawl within 5 m of the bottom; MPT: midwater pair trawl; MW, midwater trawl; SN, set net; T, trolling. Species codes: BAR, barracouta; HAK, hake; HOK, hoki; JMA, jack mackerels; LDO: lookdown dory; LIN, ling; ORH, orange roughy; RIB, ribaldo; SKI, gemfish; SWA, silver warehou.

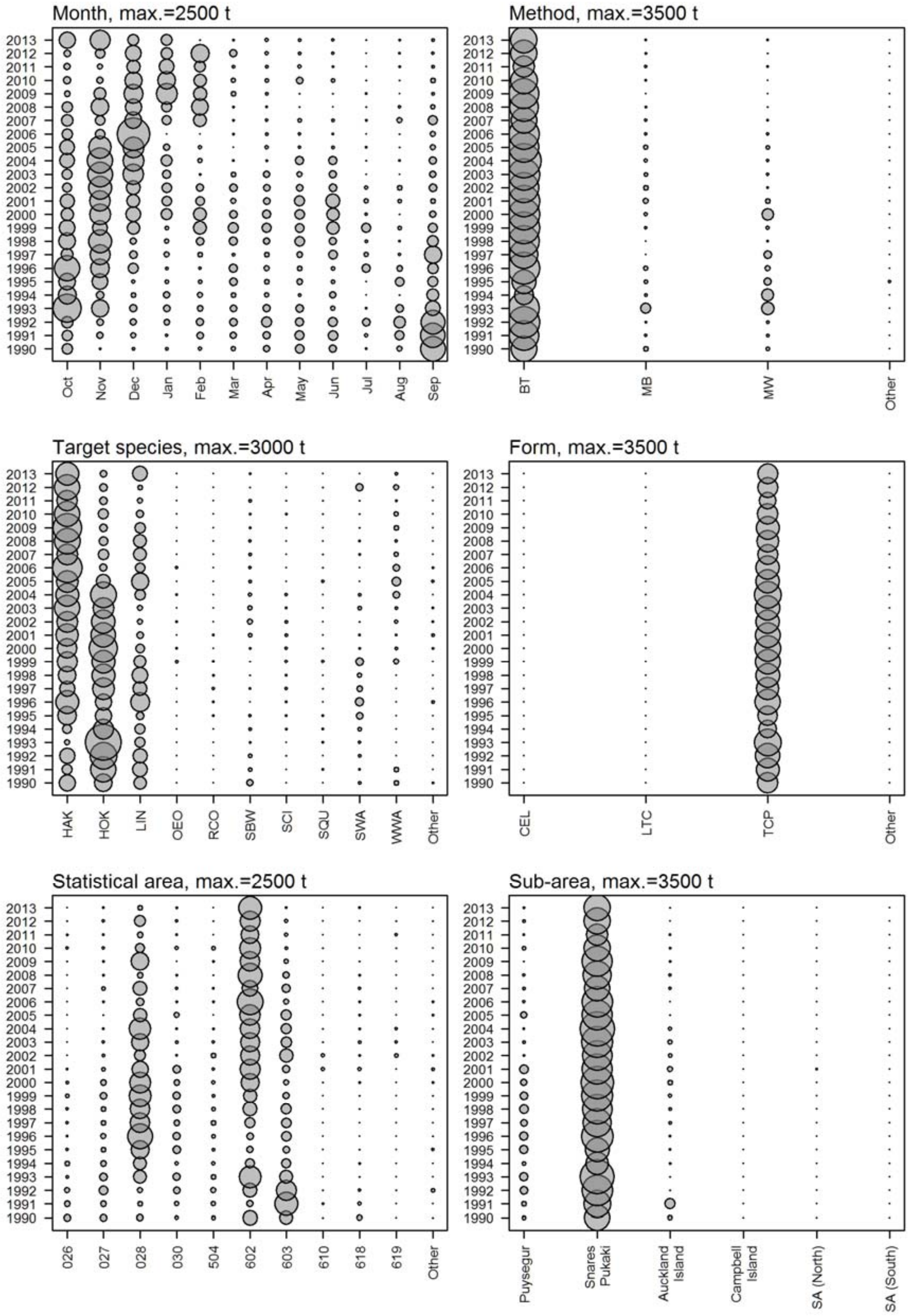


Figure 6c: Distribution of Sub-Antarctic TCEPR tow-by-tow hake trawl catch by month, statistical area, method, target species, form type, and sub-area by fishing year since 1989–90 (1990). Circle size is proportional to catch; maximum circle size is indicated on the top of each plot. Statistical areas and sub-areas are defined in Figure 2. Form types: CEL is Catch, Effort, Landing Return; LTC is Lining Trip Catch, Effort return; TCP is Trawl, Catch, Effort, and Processing Return. Method definitions: BT, bottom trawl; MB, midwater trawl within 5 m of the bottom; MW, midwater trawl. Species codes: HAK, hake; HOK, hoki; LIN, ling; OEO, oreos (black, smooth, and spiky); RCO, red cod; SBW, southern blue whiting; SCI, scampi; SQU, arrow squid; SWA, silver warehou; WWA, white warehou.

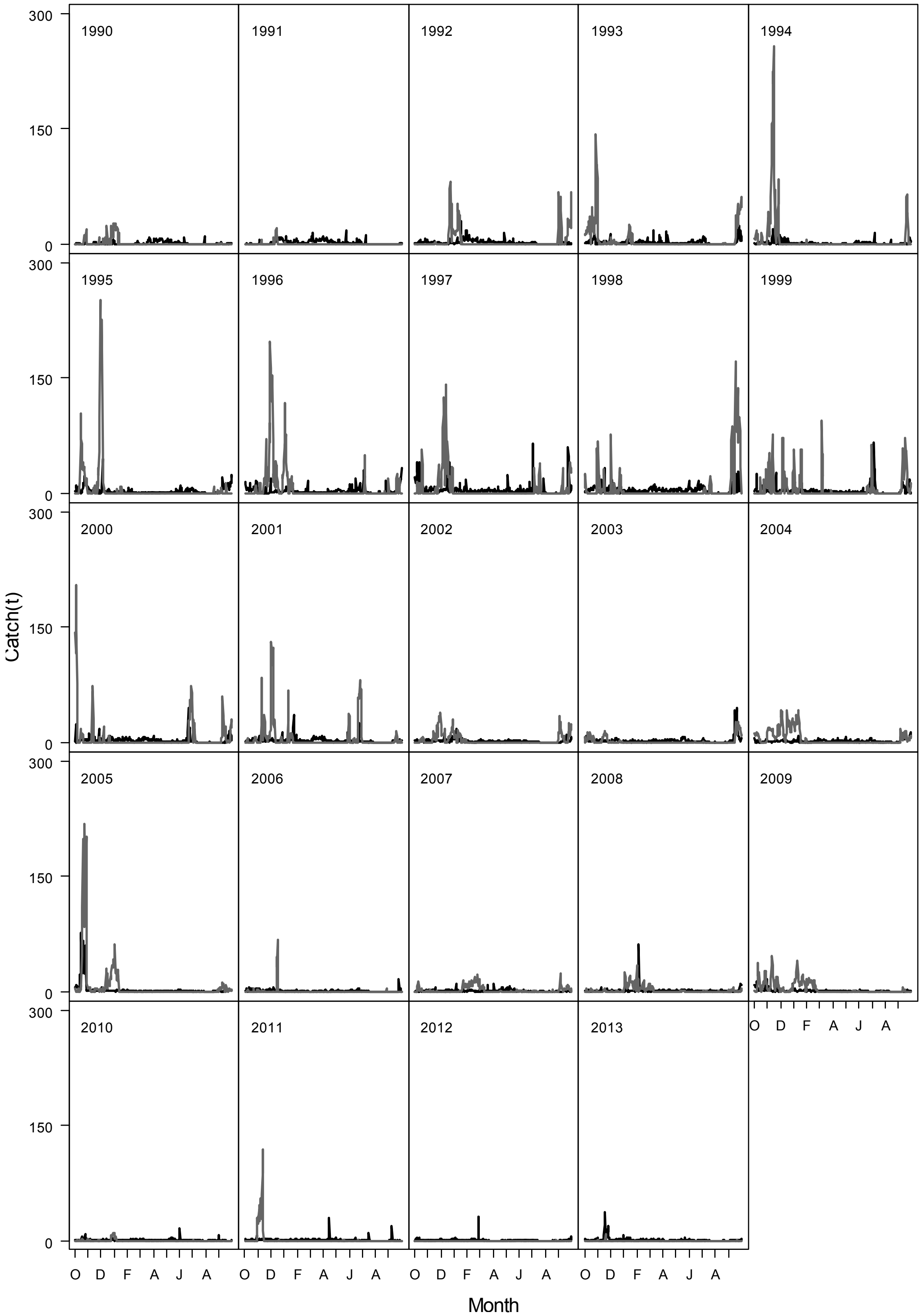


Figure 7a: Chatham Rise daily hake catch by fishing year 1989–90 (1990) to 2012–13 (2013). Grey lines are catches from target hake tows; black lines are catches from target hoki tows.

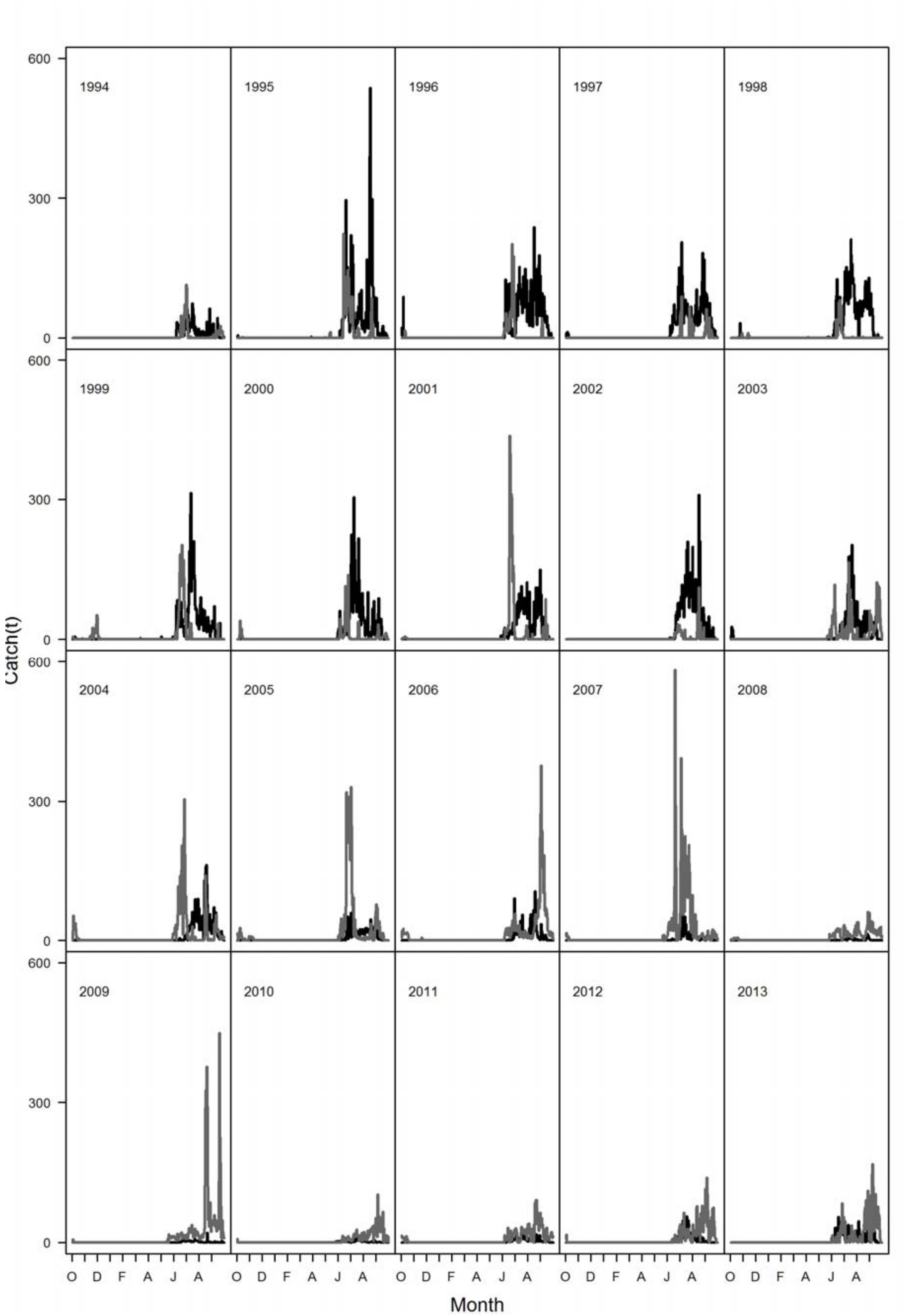


Figure 7b: WCSI daily hake catch by fishing year 1989–90 (1990) to 2012–13 (2013). Grey lines are catches from target hake tows; black lines are catches from target hoki tows.

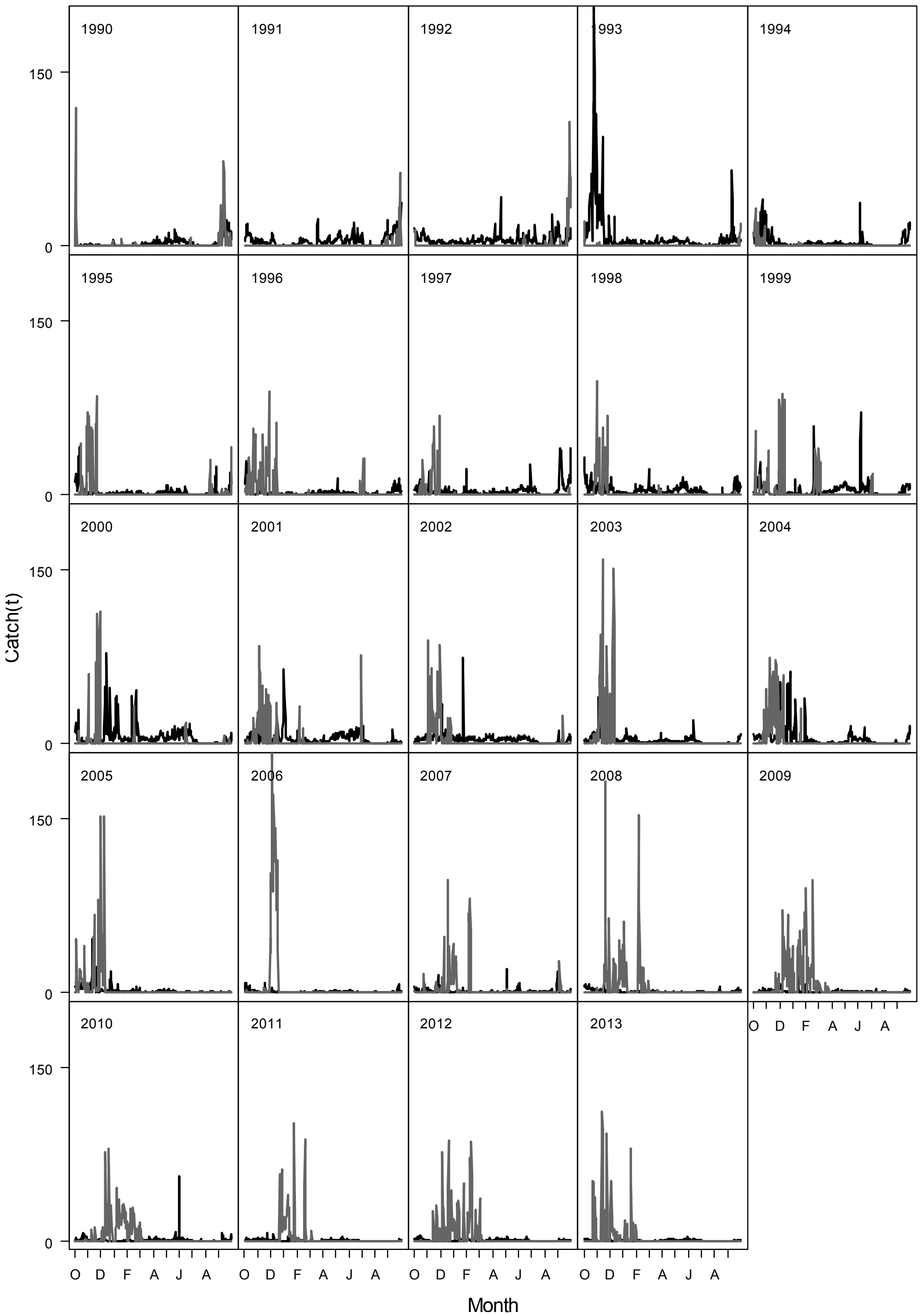


Figure 7c: Sub-Antarctic daily hake catch by fishing year 1989–90 (1990) to 2012–13 (2013). Grey lines are catches from target hake tows; black lines are catches from target hoki tows.

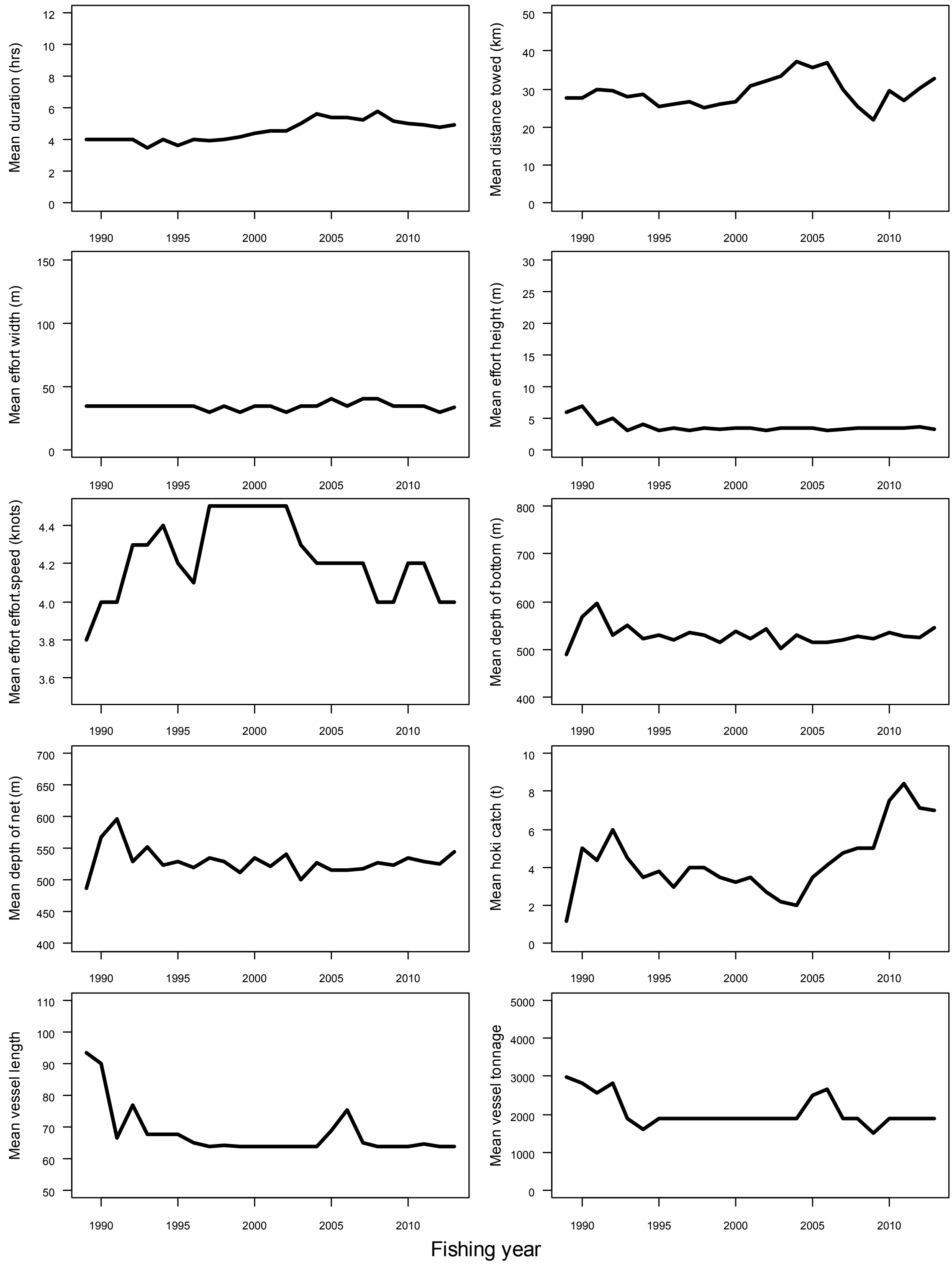


Figure 8a: Means of effort variables by fishing year for Chatham Rise vessels using bottom trawl targeting hake or hoki.

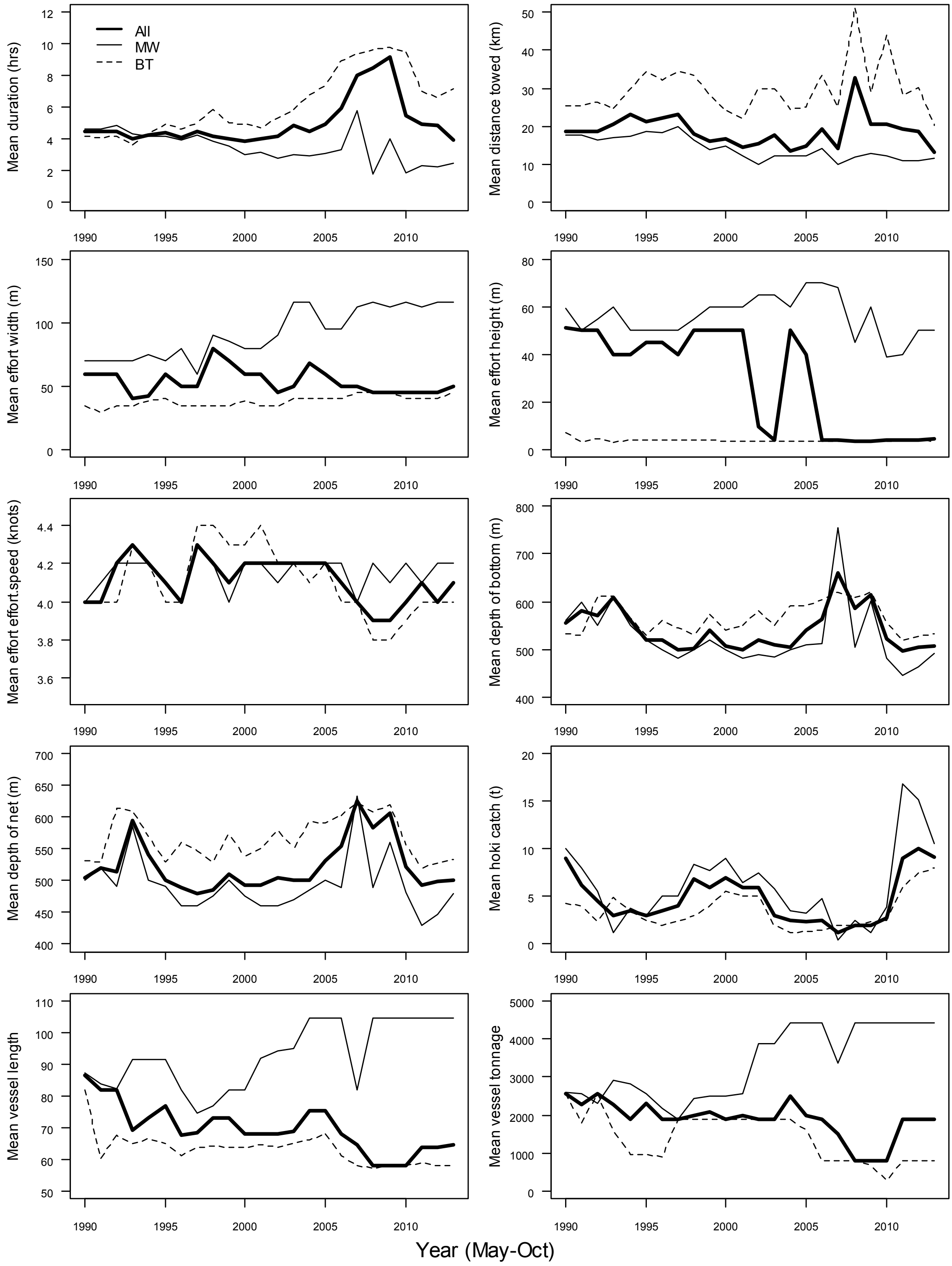


Figure 8b: Means of effort variables by fishing year for WCSI vessels targeting hake or hoki, for all tows (All), bottom tows (BT), and midwater tows (MW).

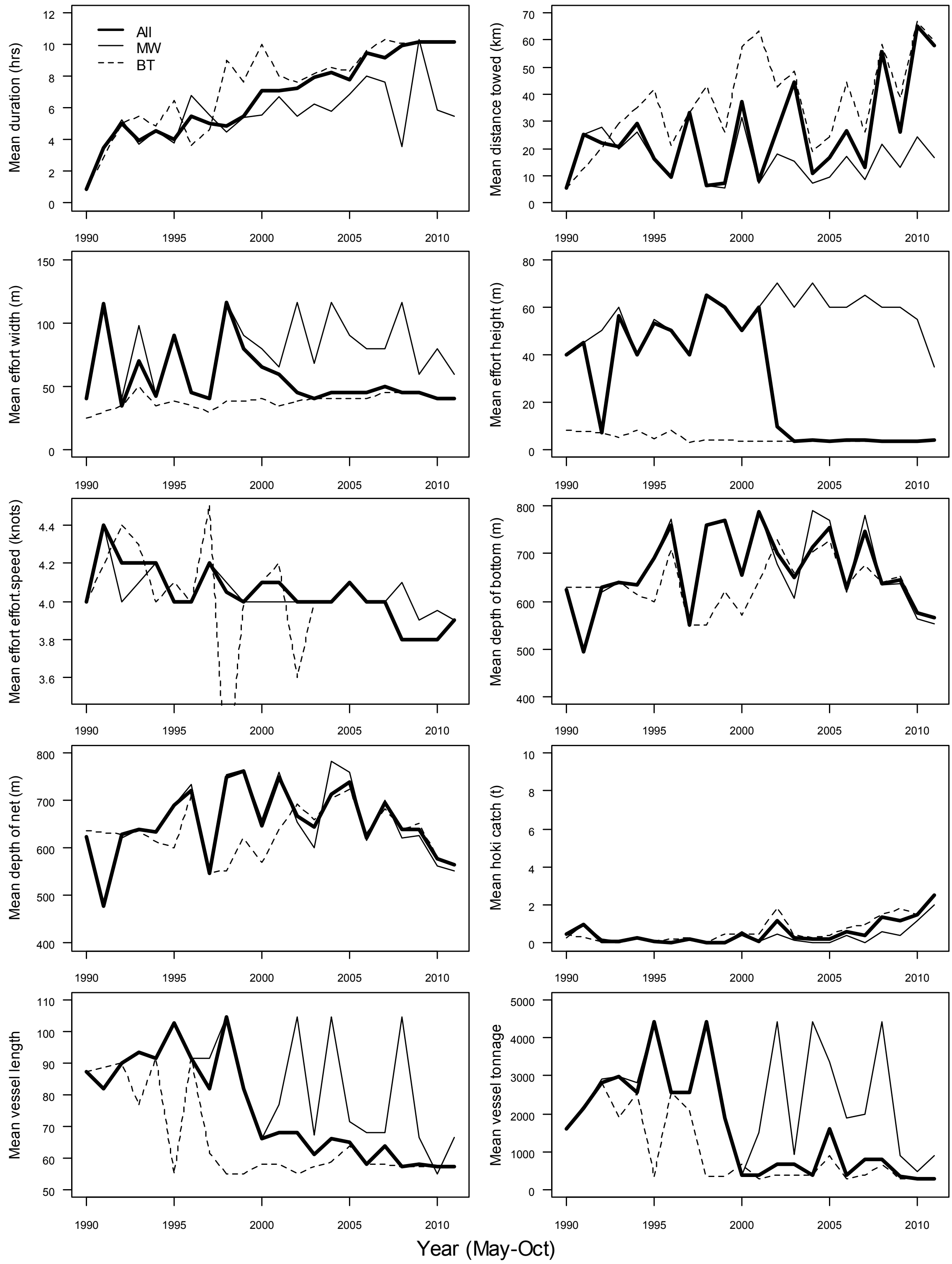


Figure 8c: Means of effort variables by fishing year for WCSI vessels targeting hake, for all tows (All), bottom tows (BT), and midwater tows (MW).

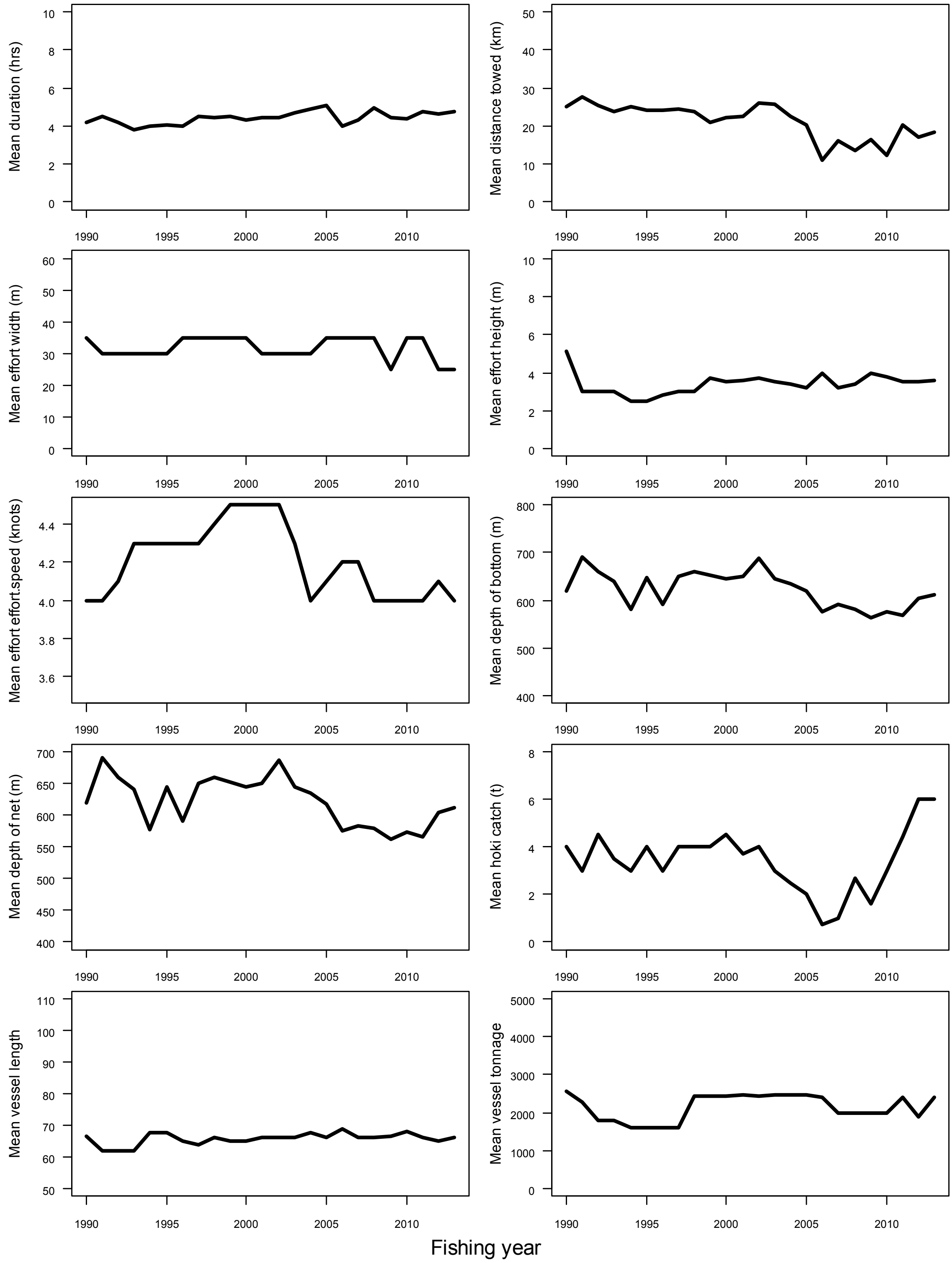


Figure 8d: Means of effort variables by fishing year for Sub-Antarctic vessels using bottom trawl targeting hake or hoki.

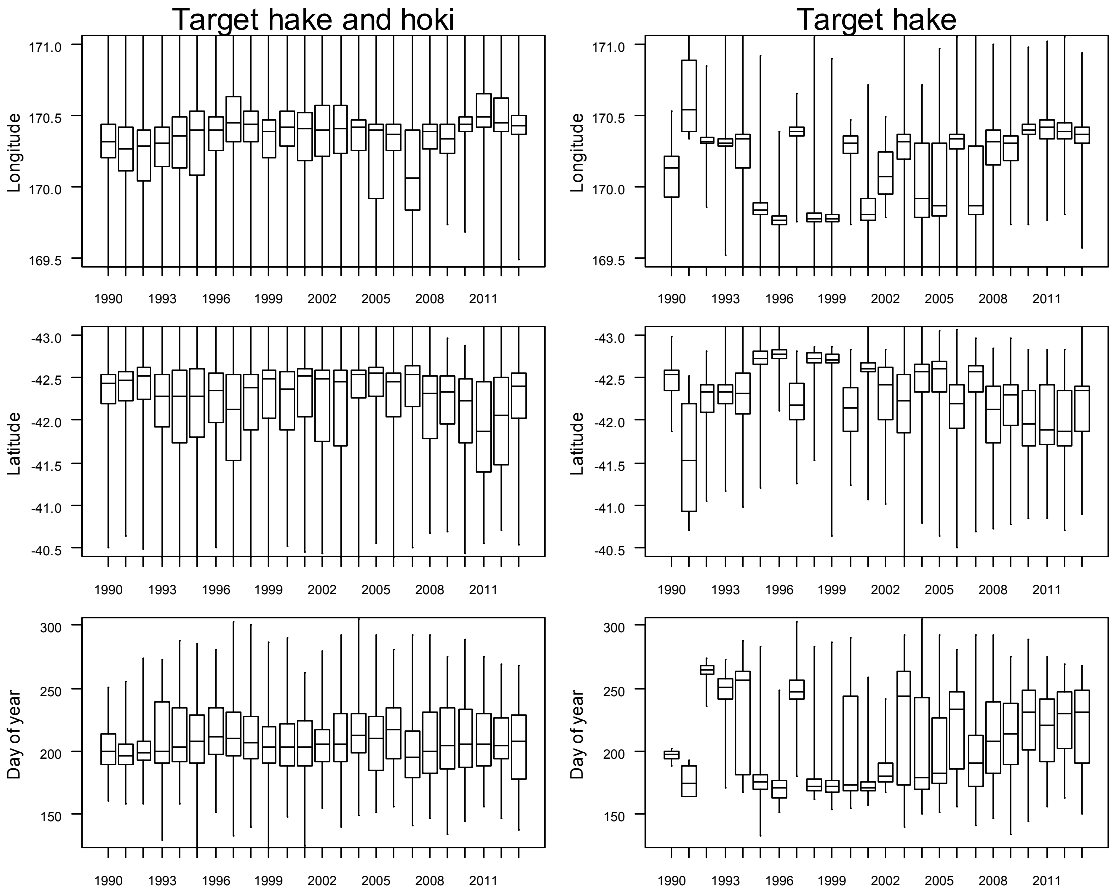
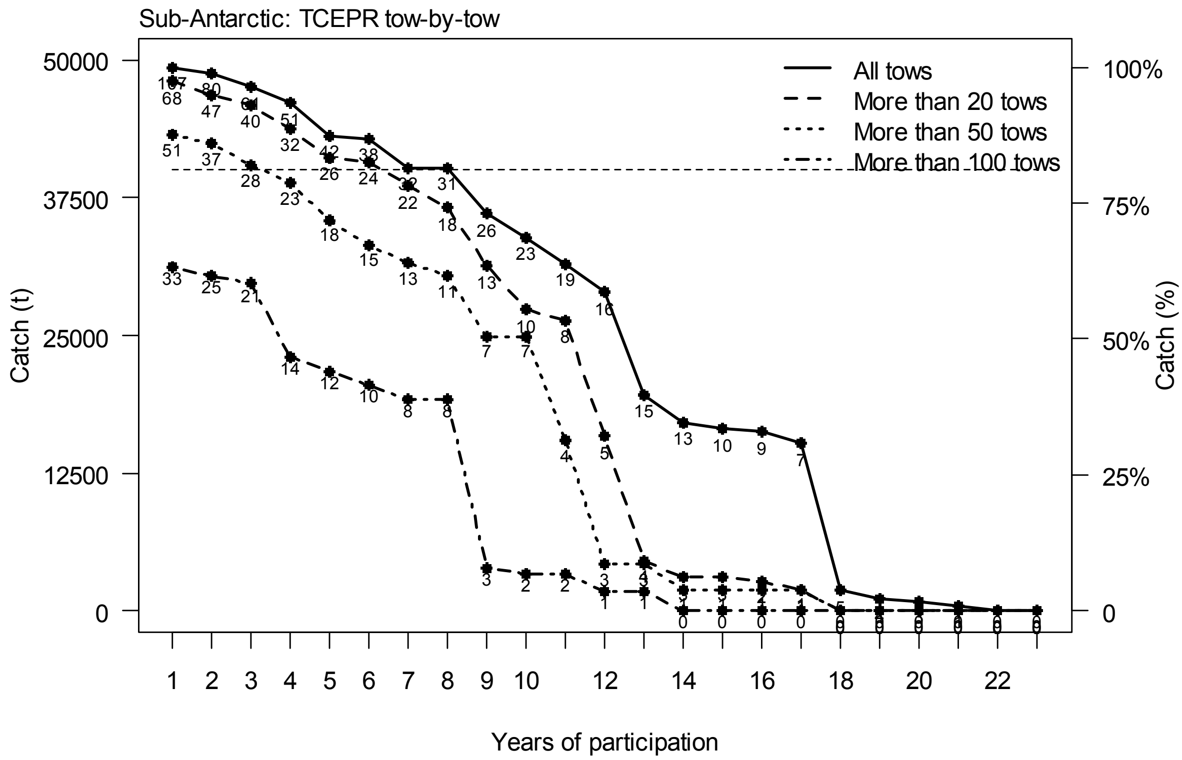


Figure 9: Box and whisker plots of longitude, latitude, and day of year for WCSI vessels targeting hake or hoki, or targeting hake only. The plots show medians and lower and upper quartiles in the box, and whiskers extending up to 1.5 times the interquartile range.



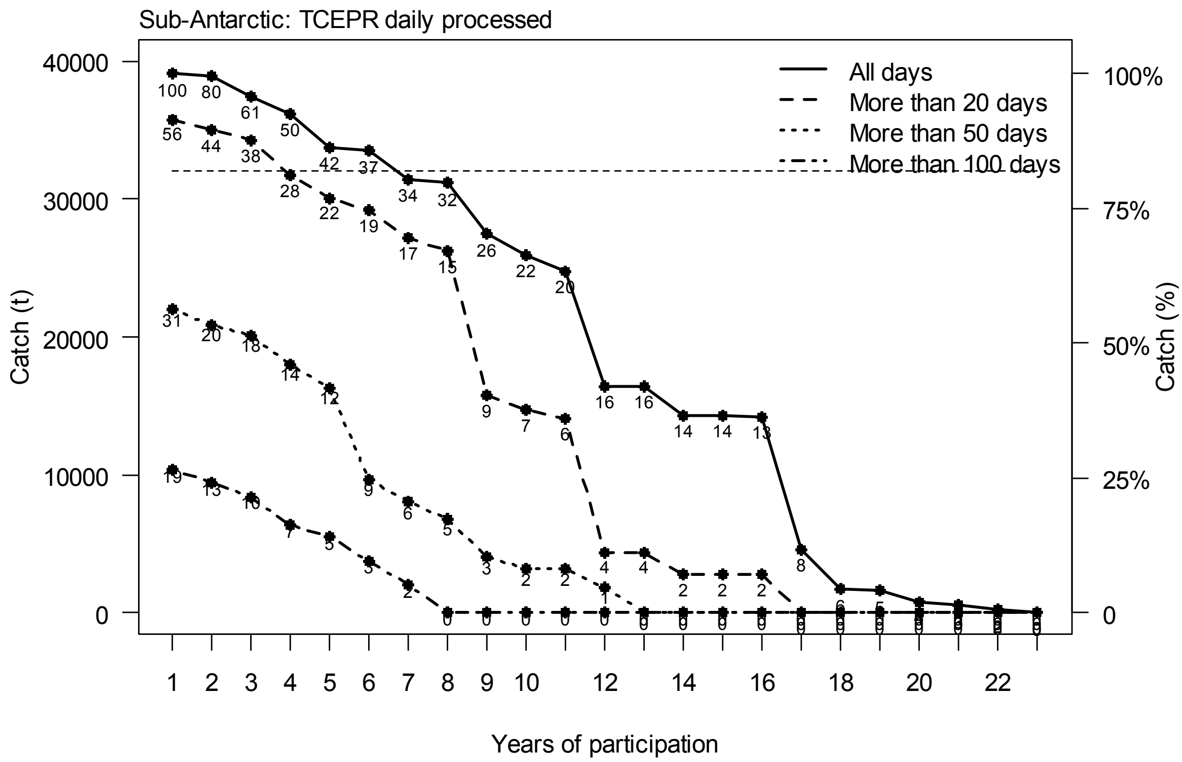


Figure 10: Relationship between the number of years of vessel participation and total hake catch by those vessels, for the trawl target hoki, hake, and ling fisheries in the Sub-Antarctic. The number under each circle indicates the number of vessels with the corresponding number of years of participation. The dotted horizontal line represents 80% of the catch.

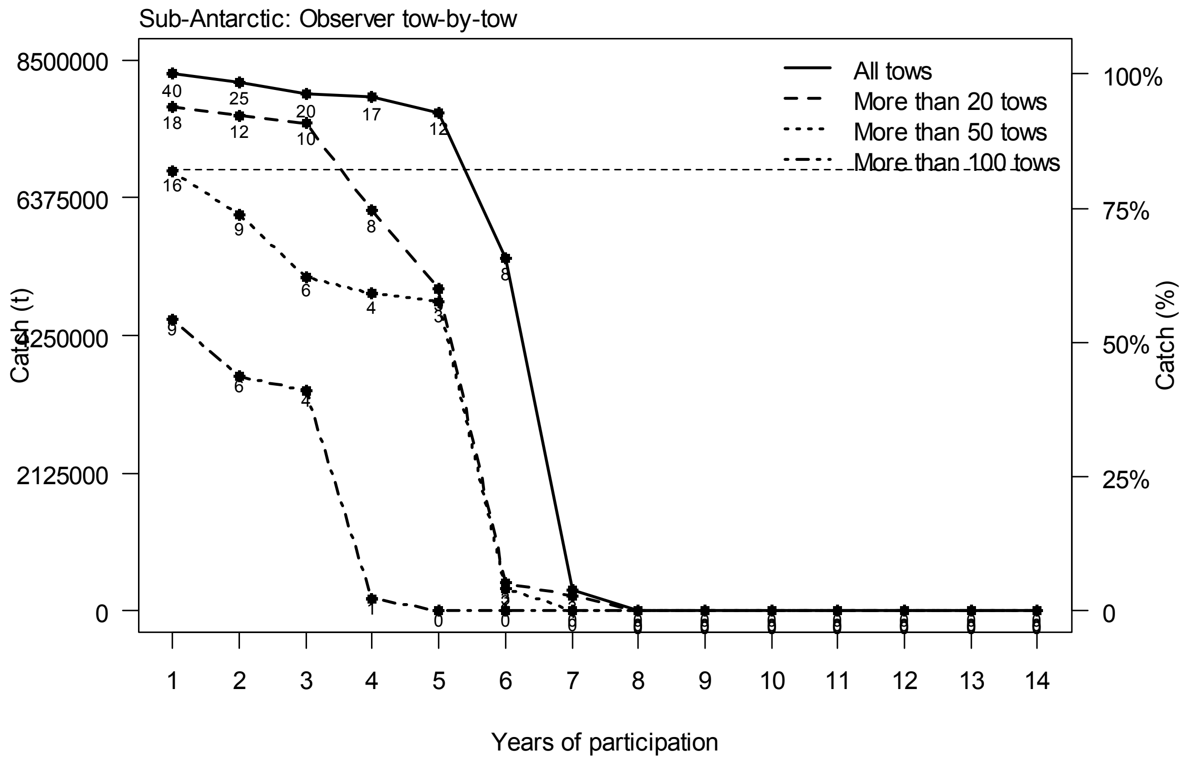


Figure 10 ctd.

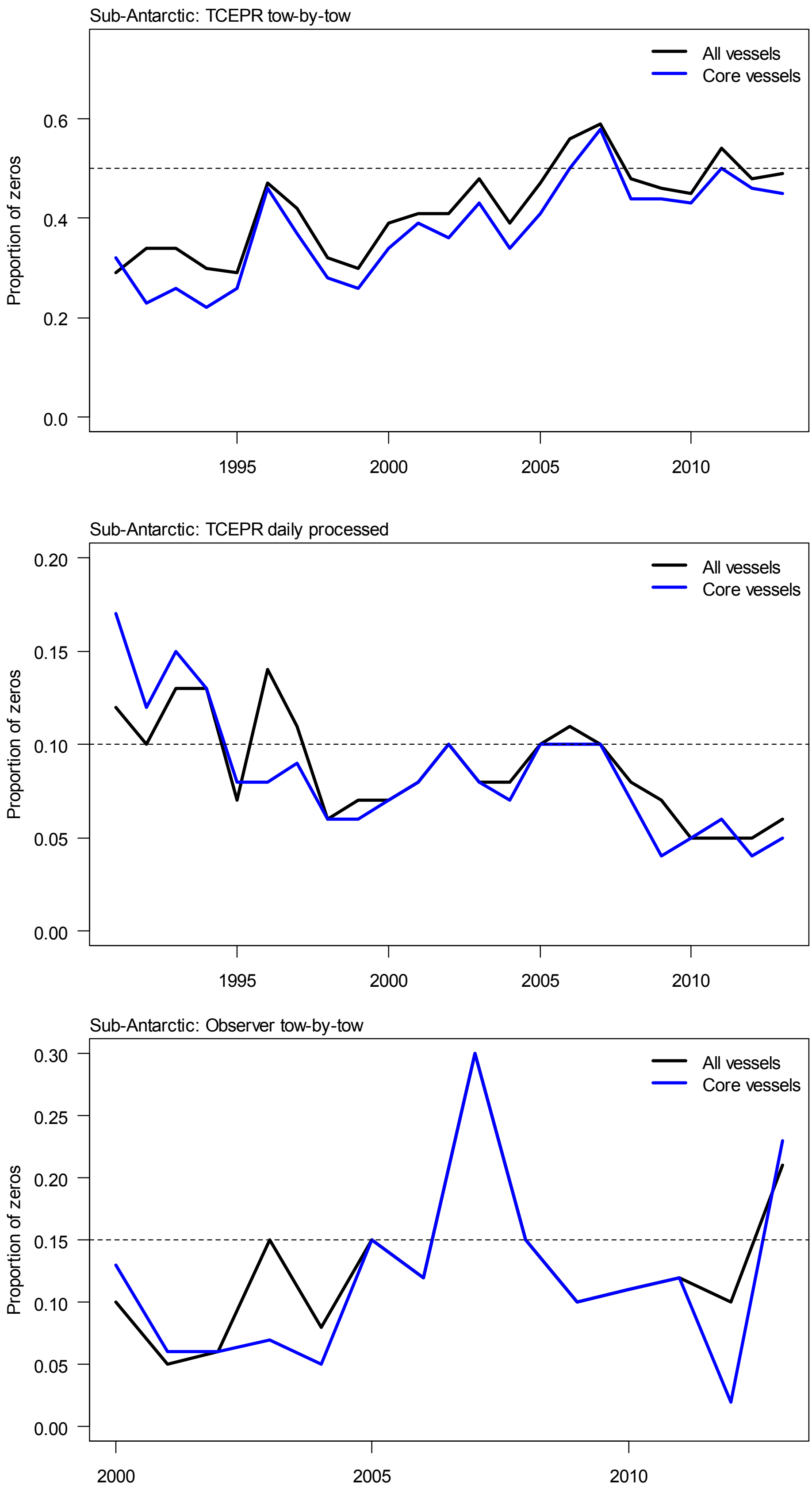


Figure 11a: Proportion of zeros for the Sub-Antarctic 'all vessel' and 'core vessel' datasets by year. Year is defined as September–August.

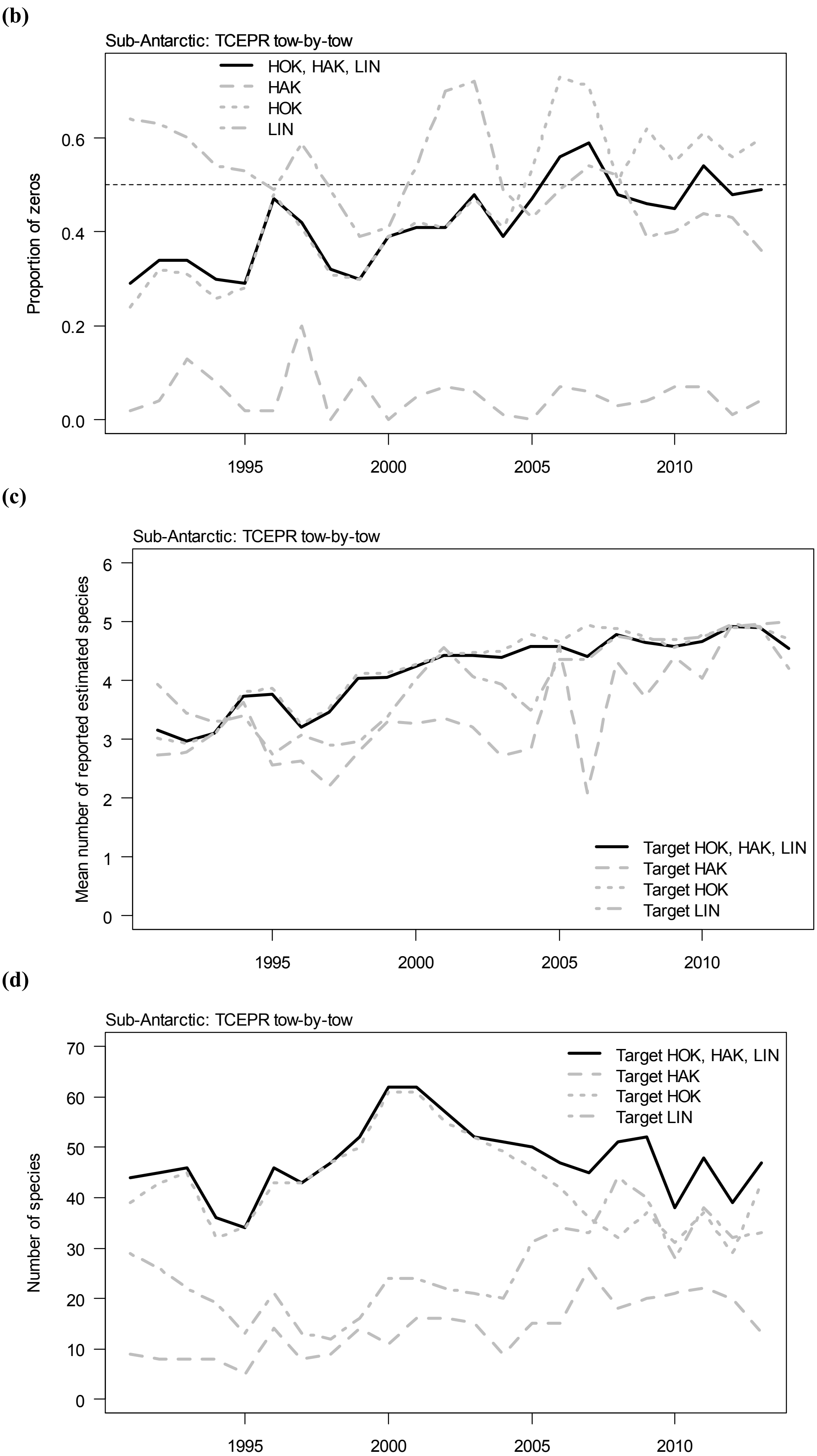


Figure 11: (b) Proportion of zeros for all Sub-Antarctic vessels by target species by year. (c) Mean number of estimated species by target species. (d) Overall number of estimated species by target species. Year is defined as September–August.

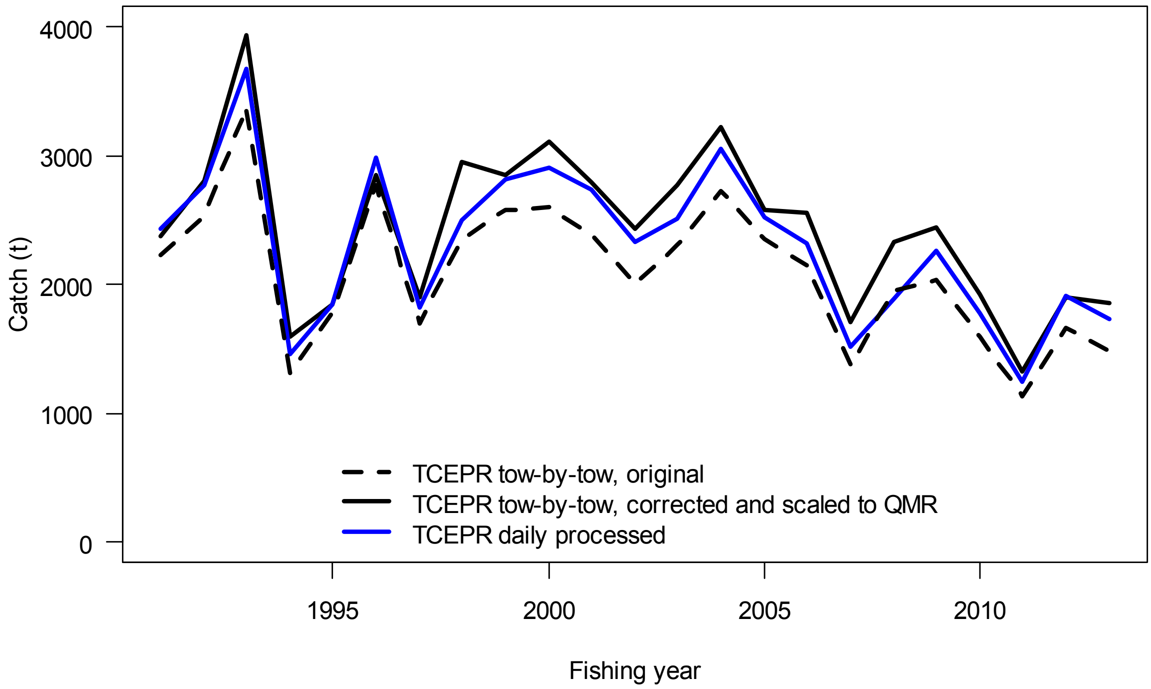
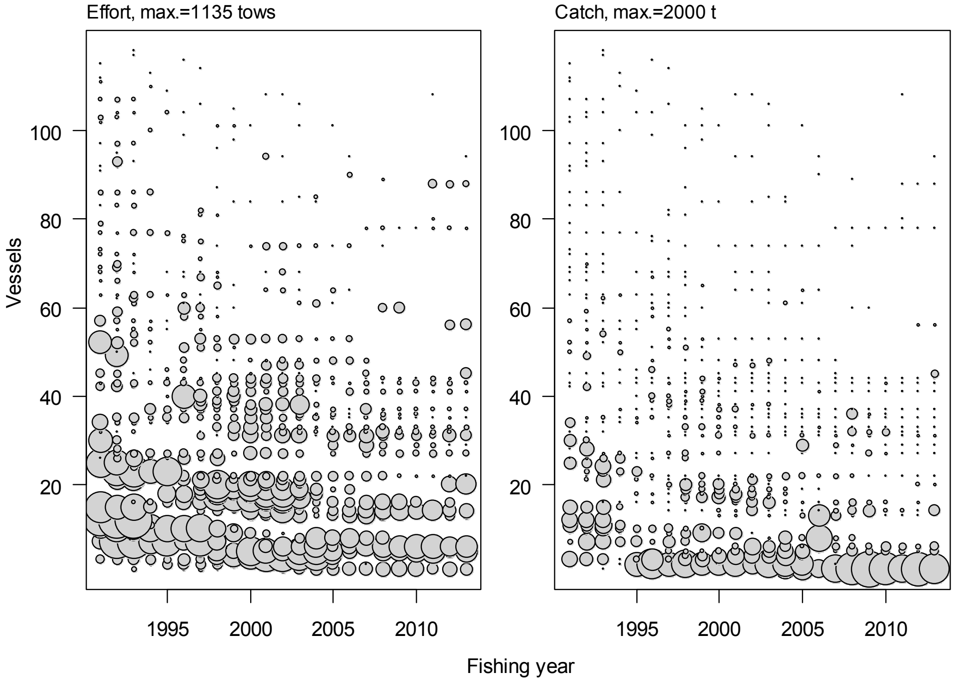


Figure 12: Sub-Antarctic TCEPR tow-by-tow and daily processed catch totals by fishing year. Year is defined as September–August.

All vessels



Core vessels

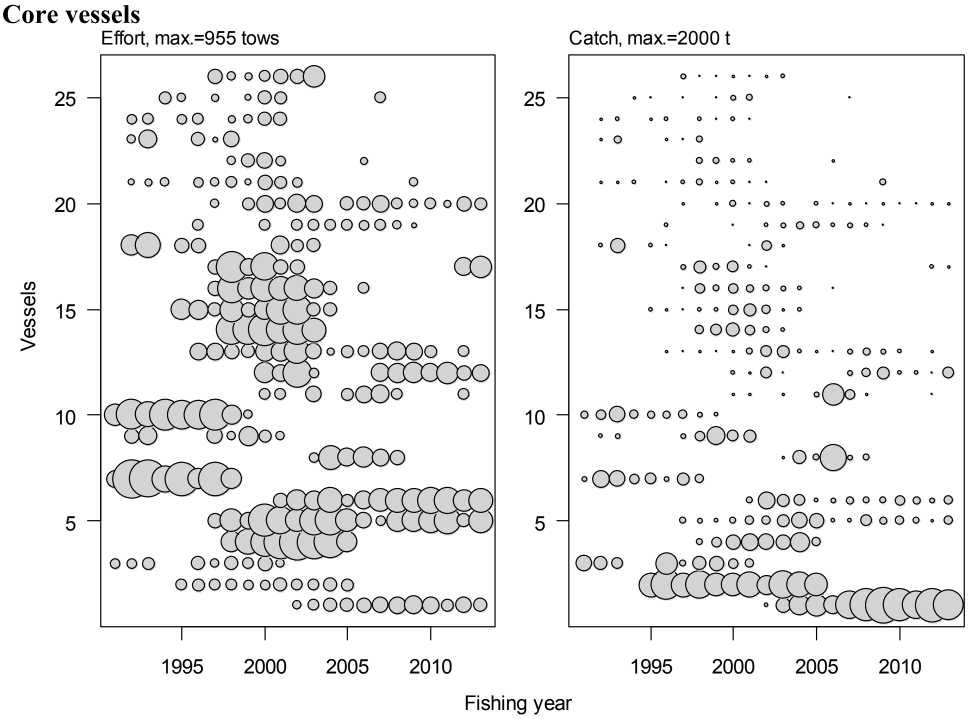
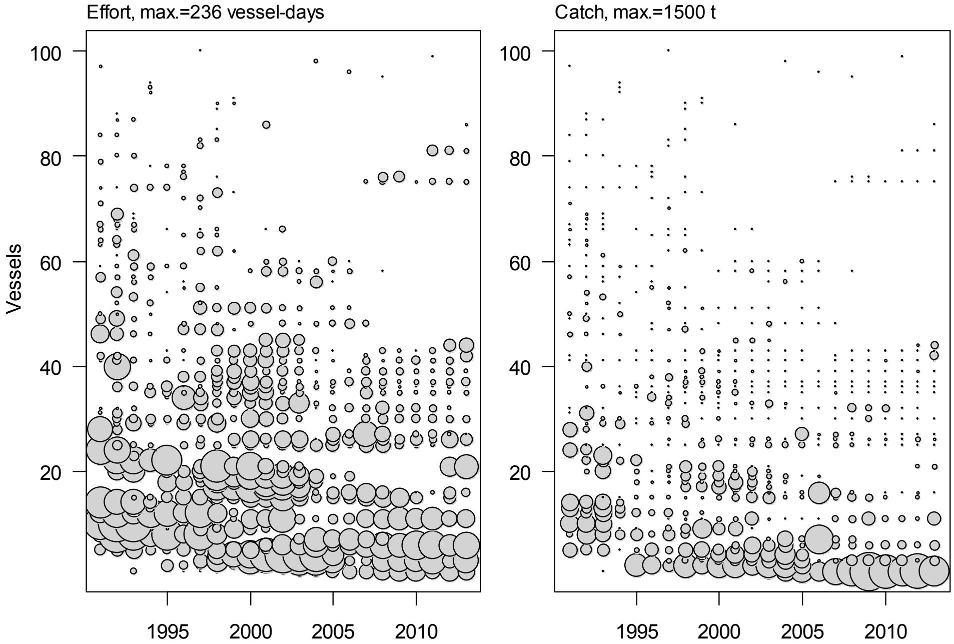


Figure 13a: Trawl fishing effort and catches (where circle area is proportional to the effort or catch) by fishing year (September–August) for individual vessels (denoted anonymously by number on the *y*-axis) in the Sub-Antarctic 'all' and 'core' CPUE analyses.

All vessels



Core vessels

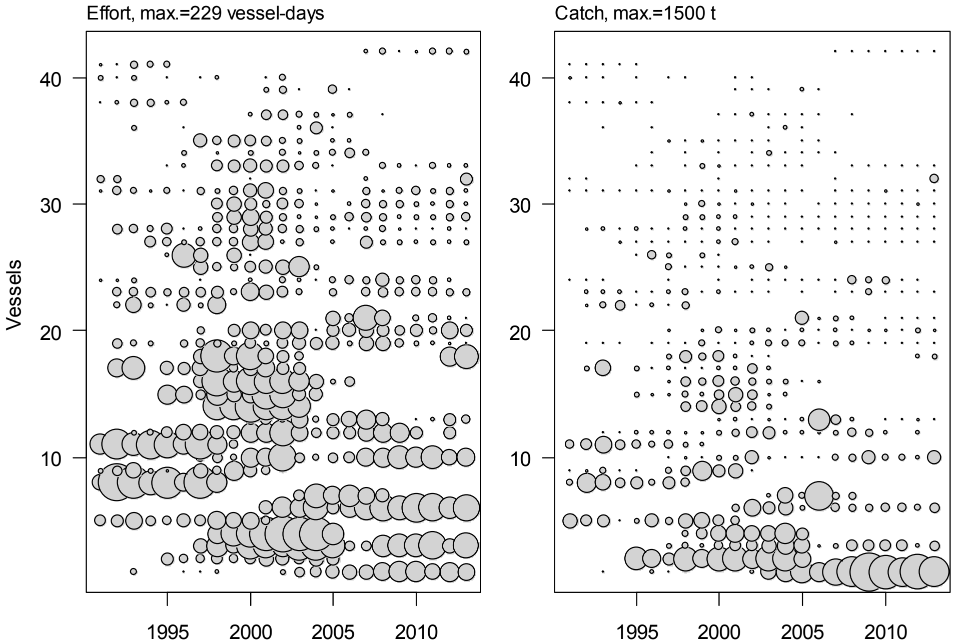
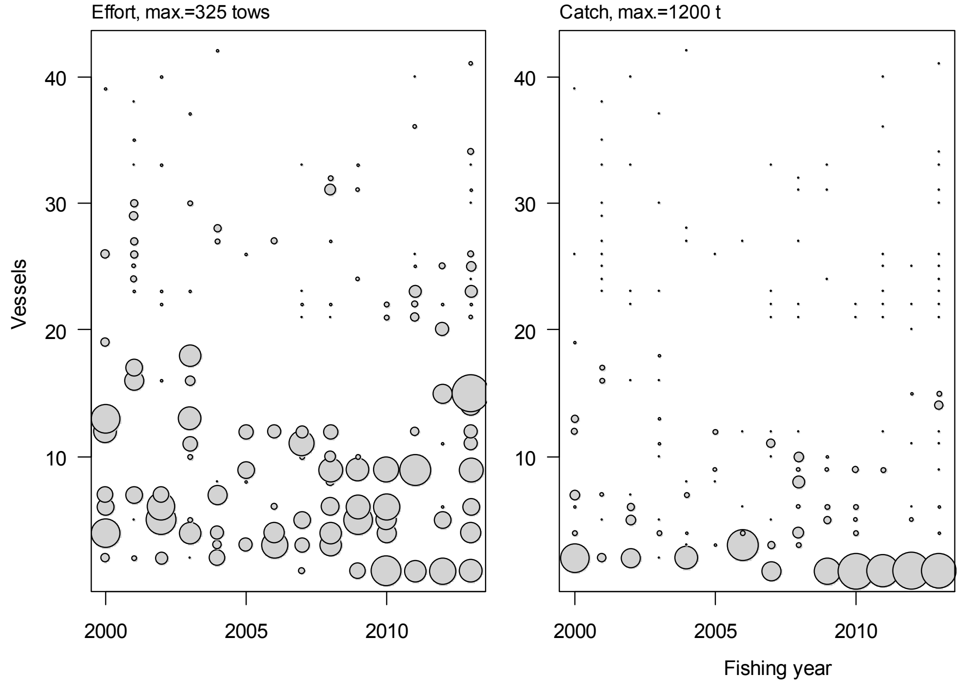


Figure 13b: Trawl fishing effort and catches (where circle area is proportional to the effort or catch) by fishing year (September–August) for individual vessels (denoted anonymously by number on the *y*-axis) in the Sub-Antarctic 'all' and 'core' CPUE analyses.

All vessels



Core vessels

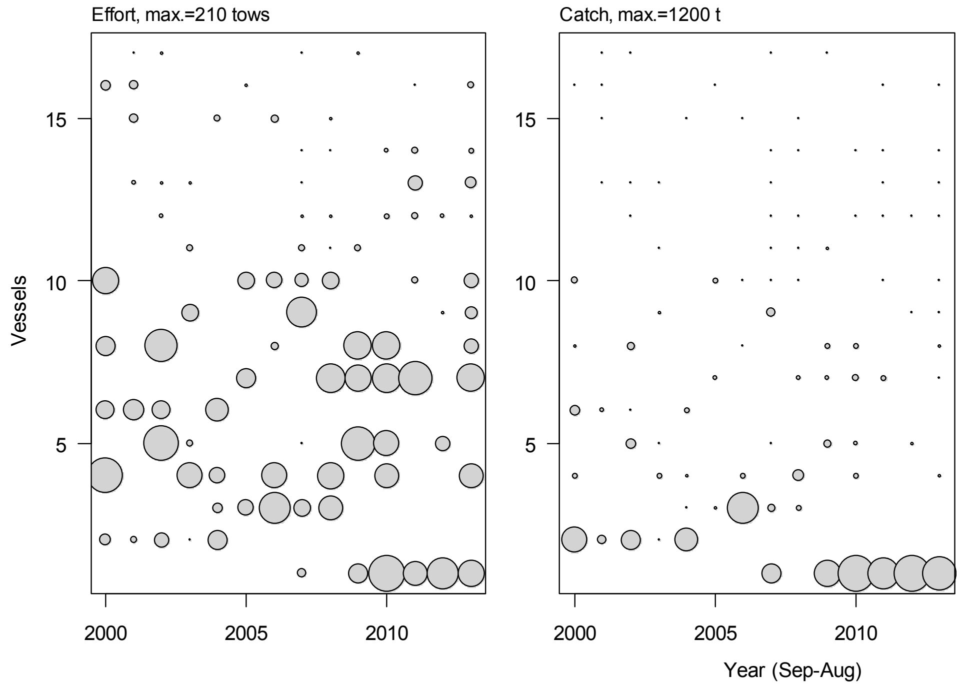


Figure 13c: Trawl fishing effort and catches (where circle area is proportional to the effort or catch) by fishing year (September–August) for individual vessels (denoted anonymously by number on the *y*-axis) in the Sub-Antarctic 'all' and 'core' CPUE analyses.

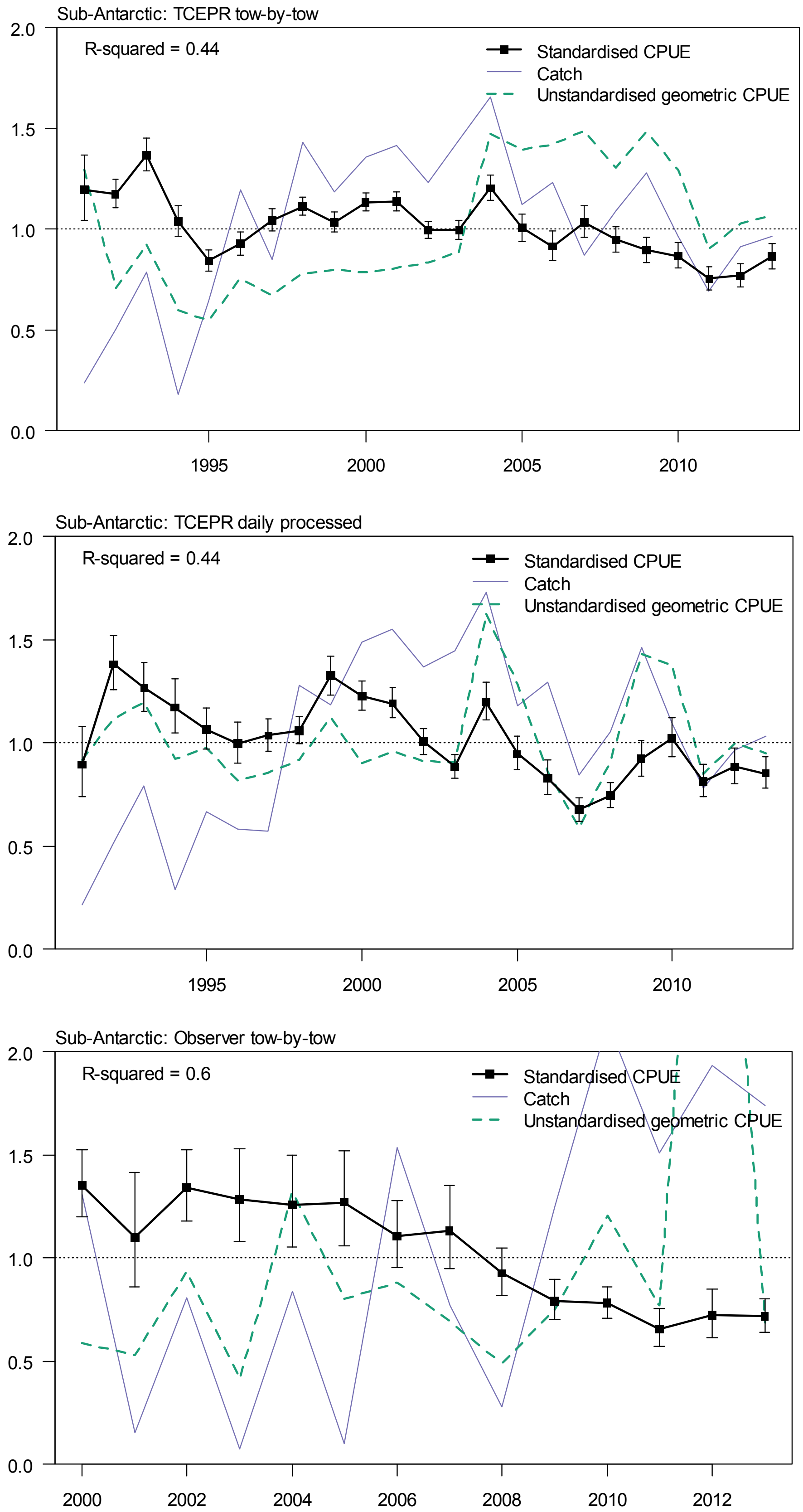


Figure 14: Standardised CPUE indices from the Sub-Antarctic lognormal model, 1991–2013 for TCEPR tow-by-tow and daily processed data and 2000–2013 for observer data. Bars indicate 95% confidence intervals. Year defined as September–August.

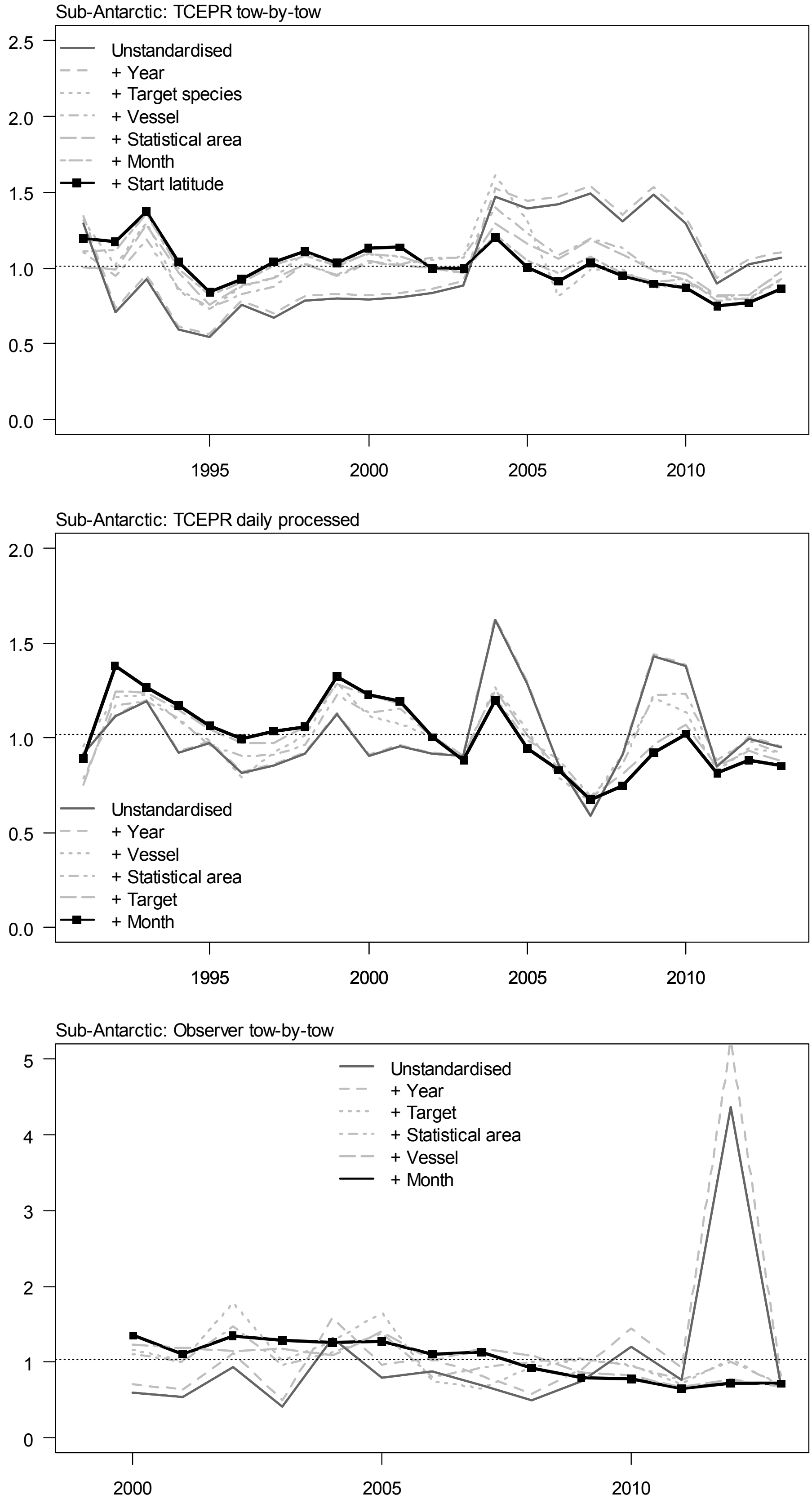


Figure 15: Standardised CPUE indices from the Sub-Antarctic lognormal model showing the effect of addition of variables, for TCEPR 1991–2013 tow-by-tow and daily processed data and observer tow-by-tow 2000–2013 data. Year defined as September–August.

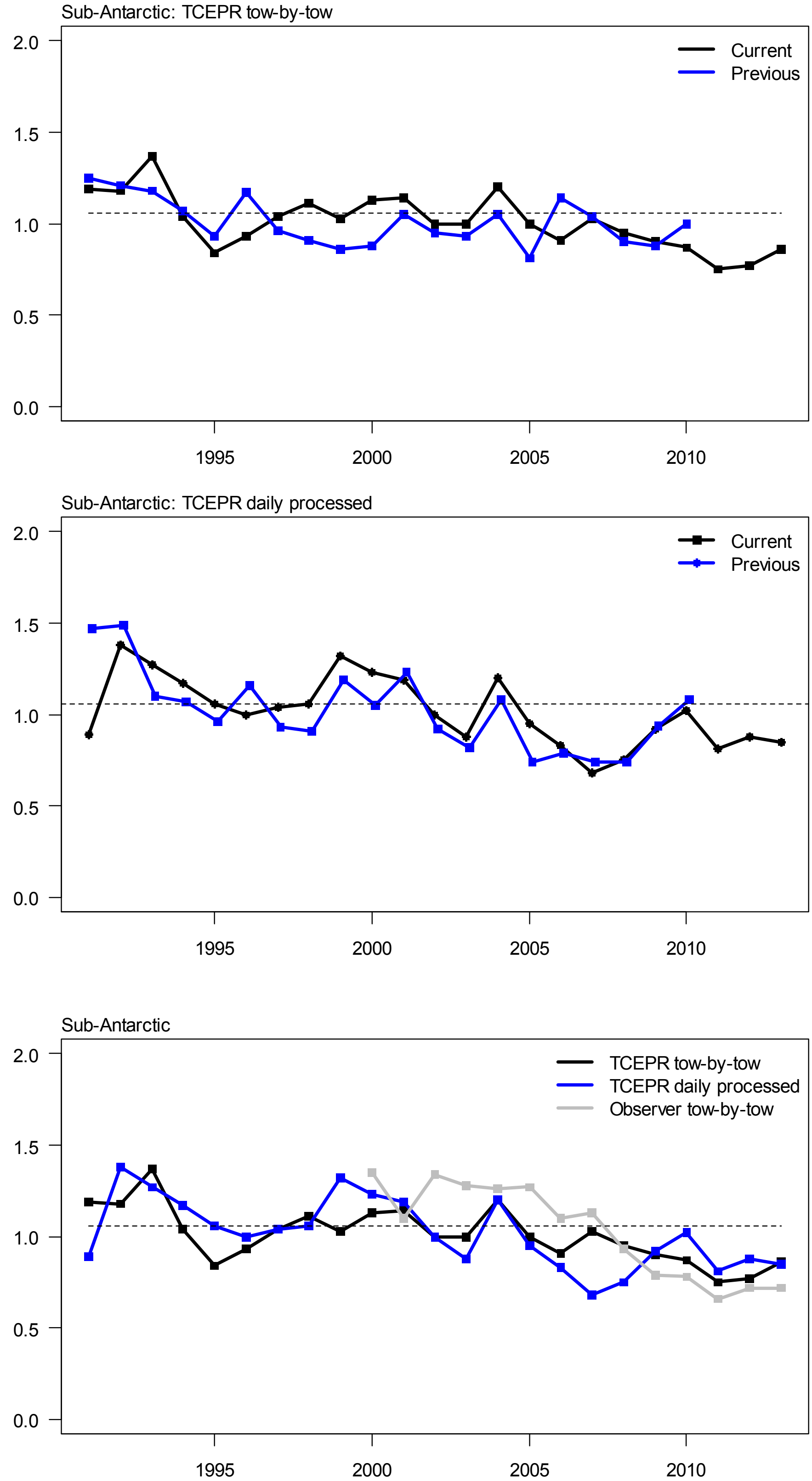


Figure 16: Comparison of CPUE indices for the Sub-Antarctic TCEPR lognormal models with the previous (Ballara 2012) results, and TCEPR and Observer models with each other. Year defined as September–August.

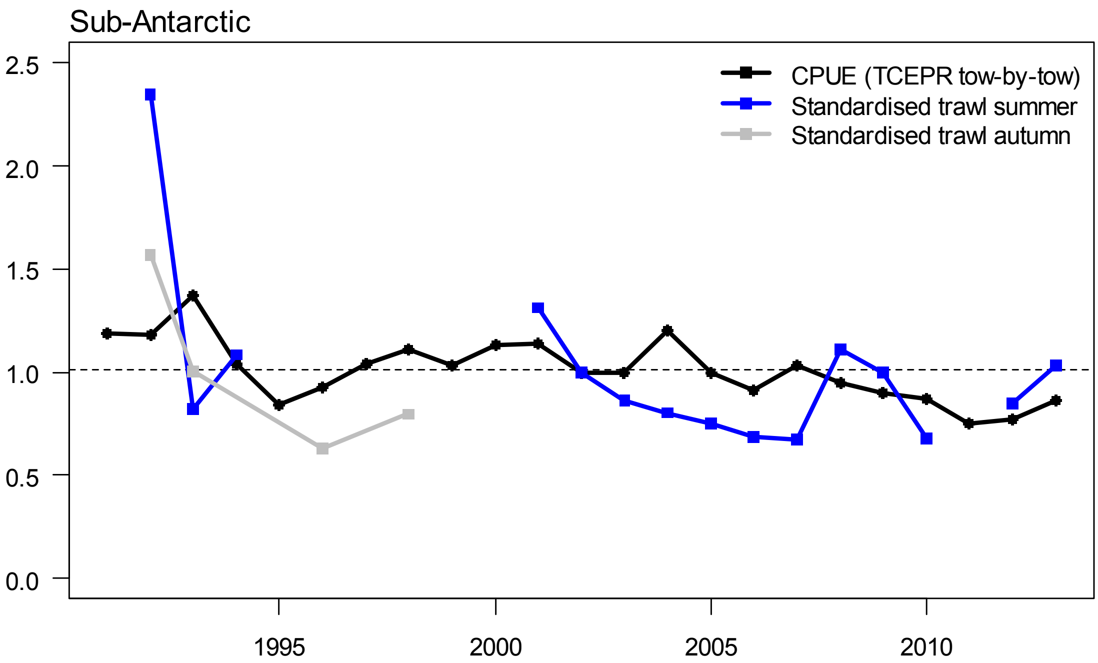


Figure 17: Comparison of Sub-Antarctic summer and autumn trawl survey hake biomass indices with CPUE from the Sub-Antarctic fishery (CPUE from TCEPR tow-by-tow data targeting hoki, hake, or ling 1991–2013). Indices in each series have been standardised to a mean of one.

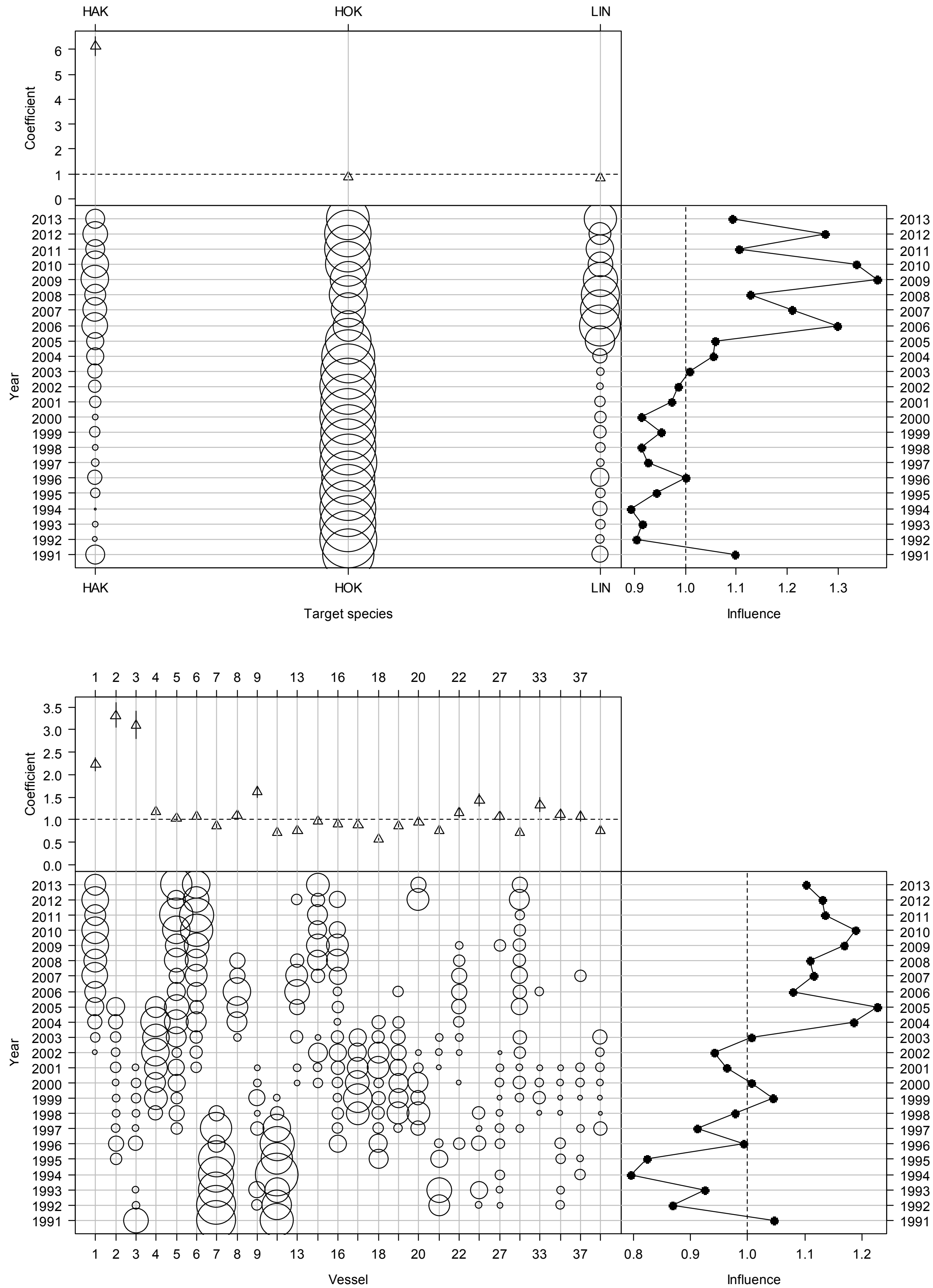
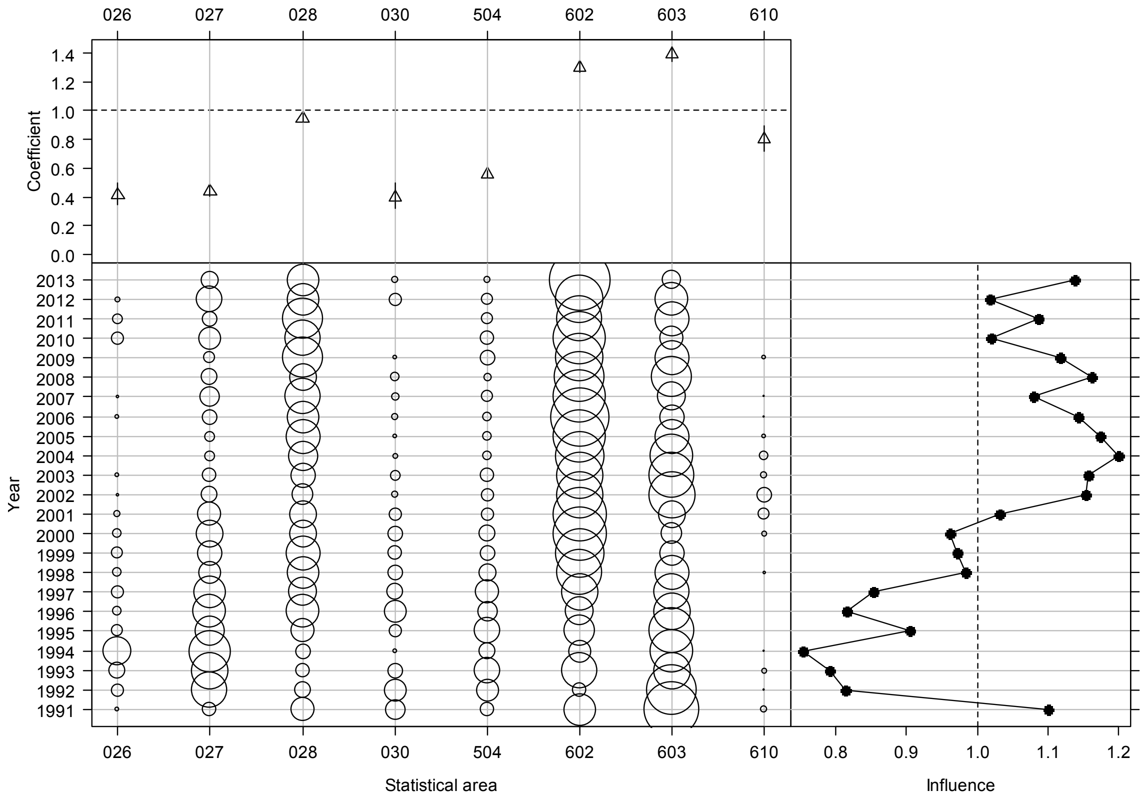


Figure 18a: Effect and influence of non-interaction term variables (target species, vessel) in the Sub-Antarctic TCEPR tow-by-tow core vessel lognormal model. Top: relative effect by level of each variable. Bottom left: relative distribution of each variable by fishing year. Bottom right: influence of variable on unstandardised CPUE by fishing year.



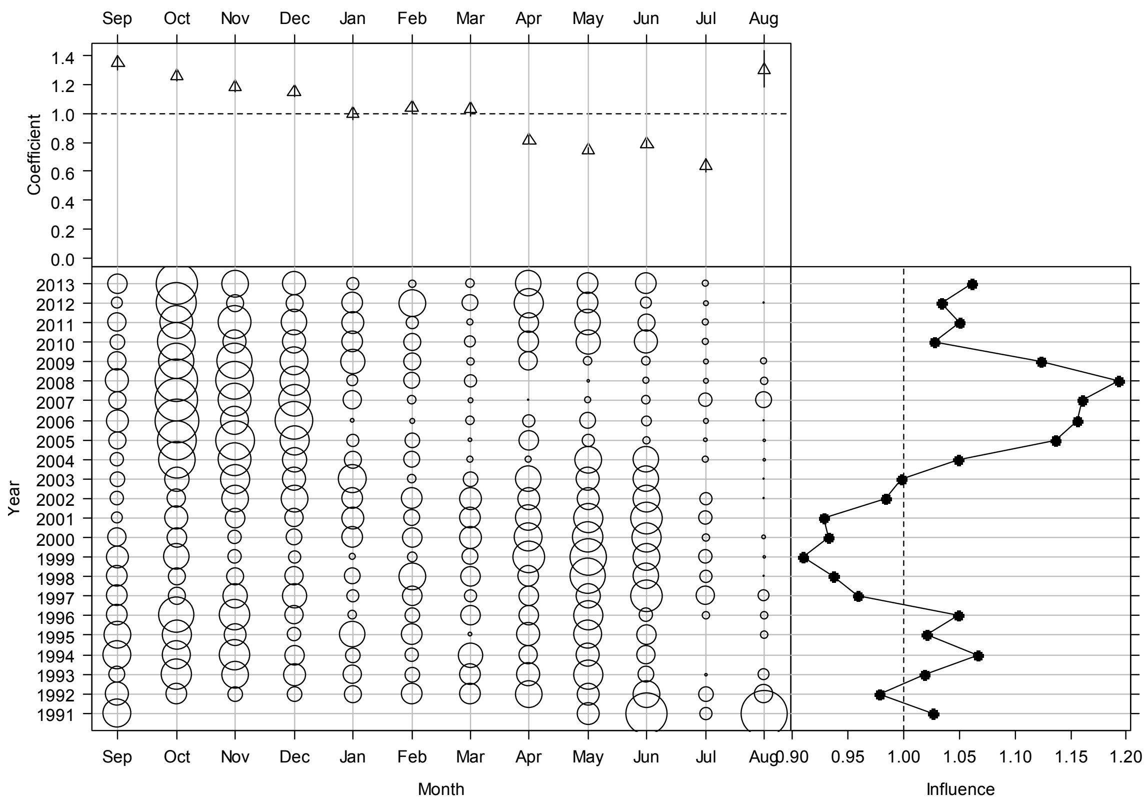


Figure 18a ctd.: Effect and influence of non-interaction term variables (statistical area, month) in the Sub-Antarctic TCEPR tow-by-tow core vessel lognormal model. Top: relative effect by level of each variable. Bottom left: relative distribution of each variable by fishing year. Bottom right: influence of variable on unstandardised CPUE by fishing year.

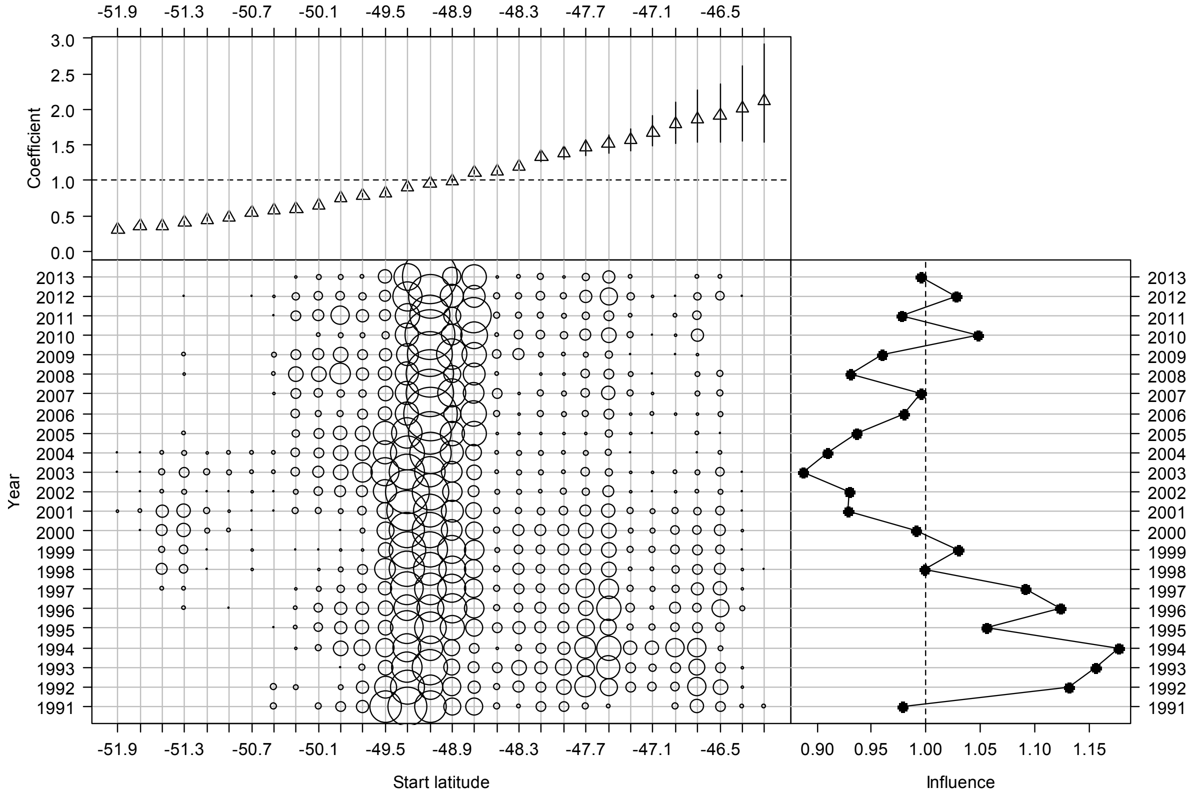
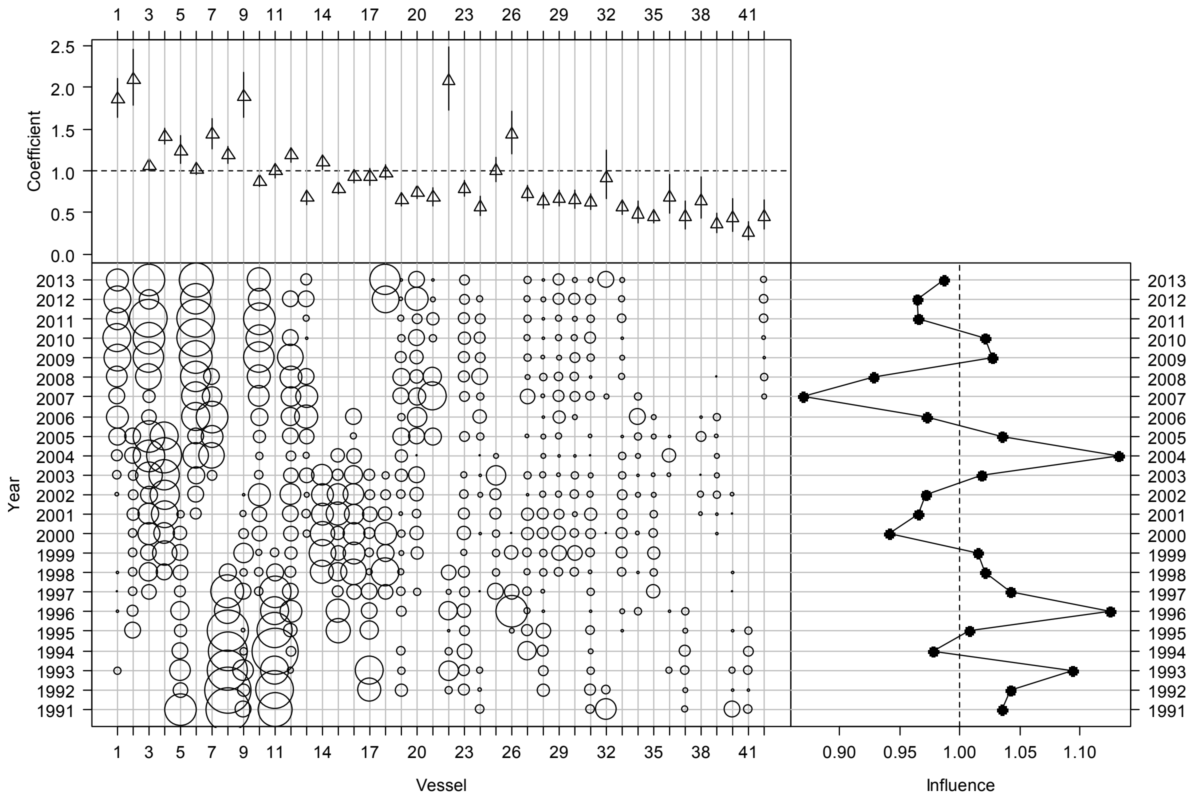


Figure 18a ctd.: Effect and influence of non-interaction term variables (start latitude) in the Sub-Antarctic TCEPR tow-by-tow core vessel lognormal model. Top: relative effect by level of each variable. Bottom left: relative distribution of each variable by fishing year. Bottom right: influence of variable on unstandardised CPUE by fishing year.



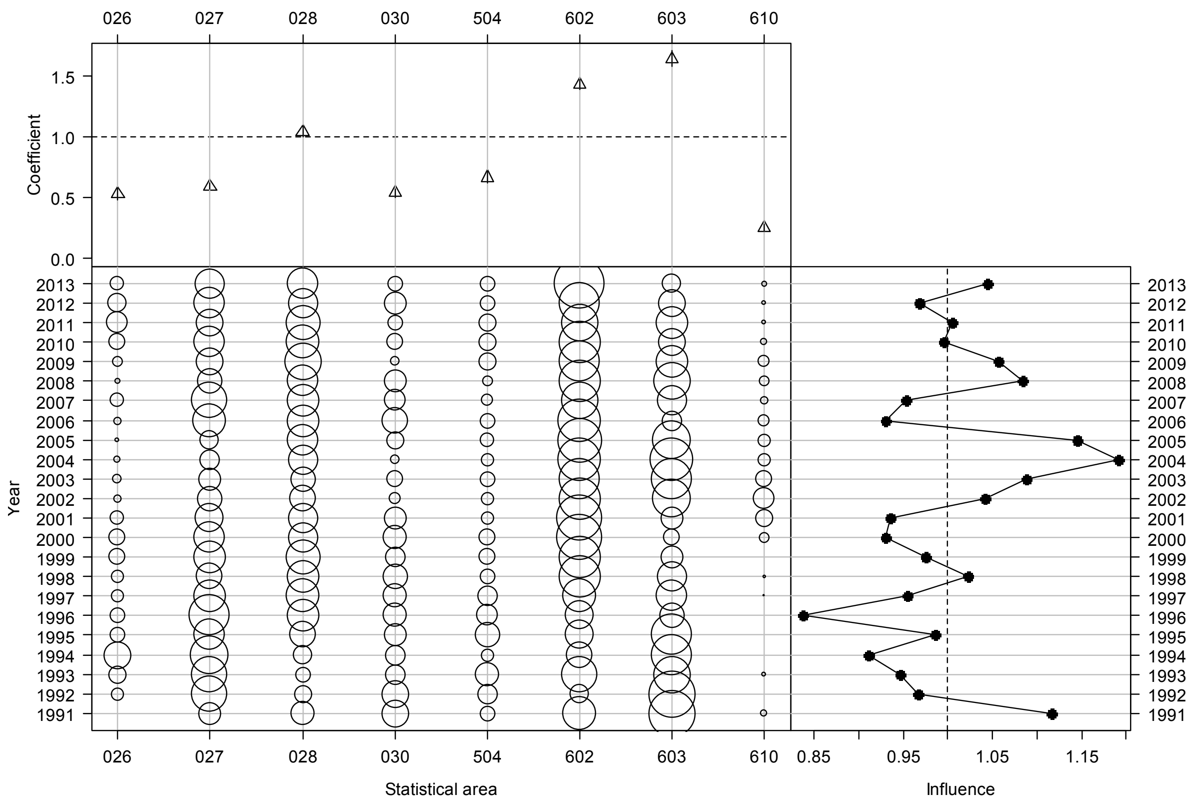
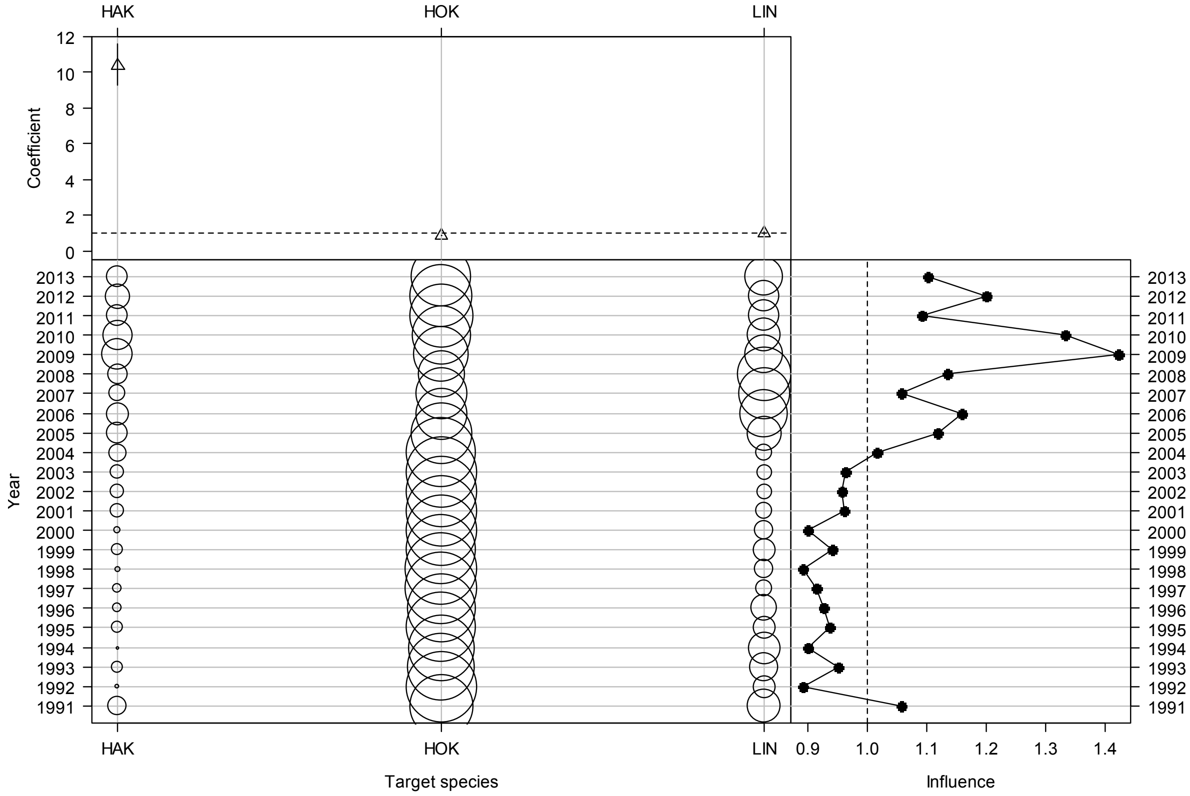


Figure 18b: Effect and influence of non-interaction term variables (vessel, statistical area) in the Sub-Antarctic TCEPR daily processed data core vessel lognormal model. Top: relative effect by level of each variable. Bottom left: relative distribution of each variable by fishing year. Bottom right: influence of variable on unstandardised CPUE by fishing year.



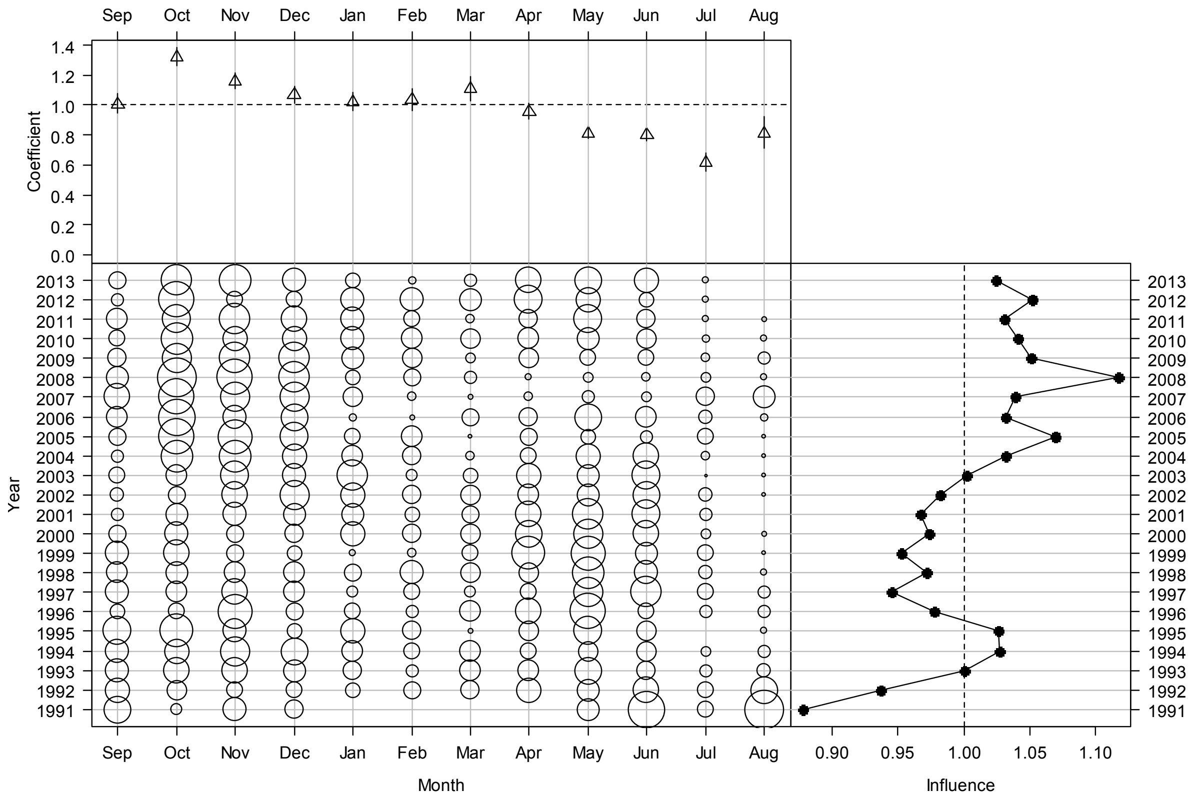


Figure 18b ctd.: Effect and influence of non-interaction term variables (target species, month) in the Sub-Antarctic TCEPR daily processed data core vessel lognormal model. Top: relative effect by level of each variable. Bottom left: relative distribution of each variable by fishing year. Bottom right: influence of variable on unstandardised CPUE by fishing year.

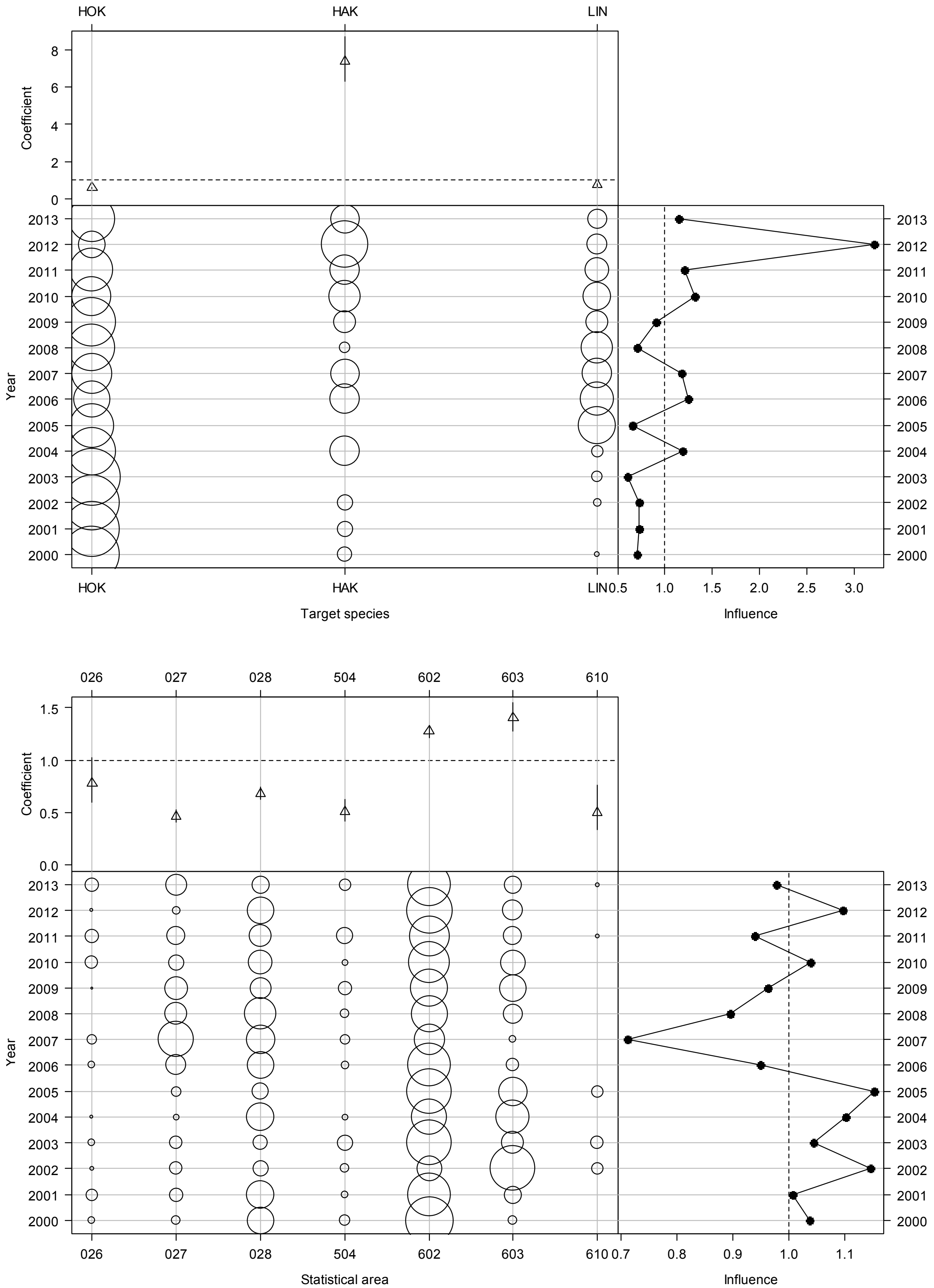
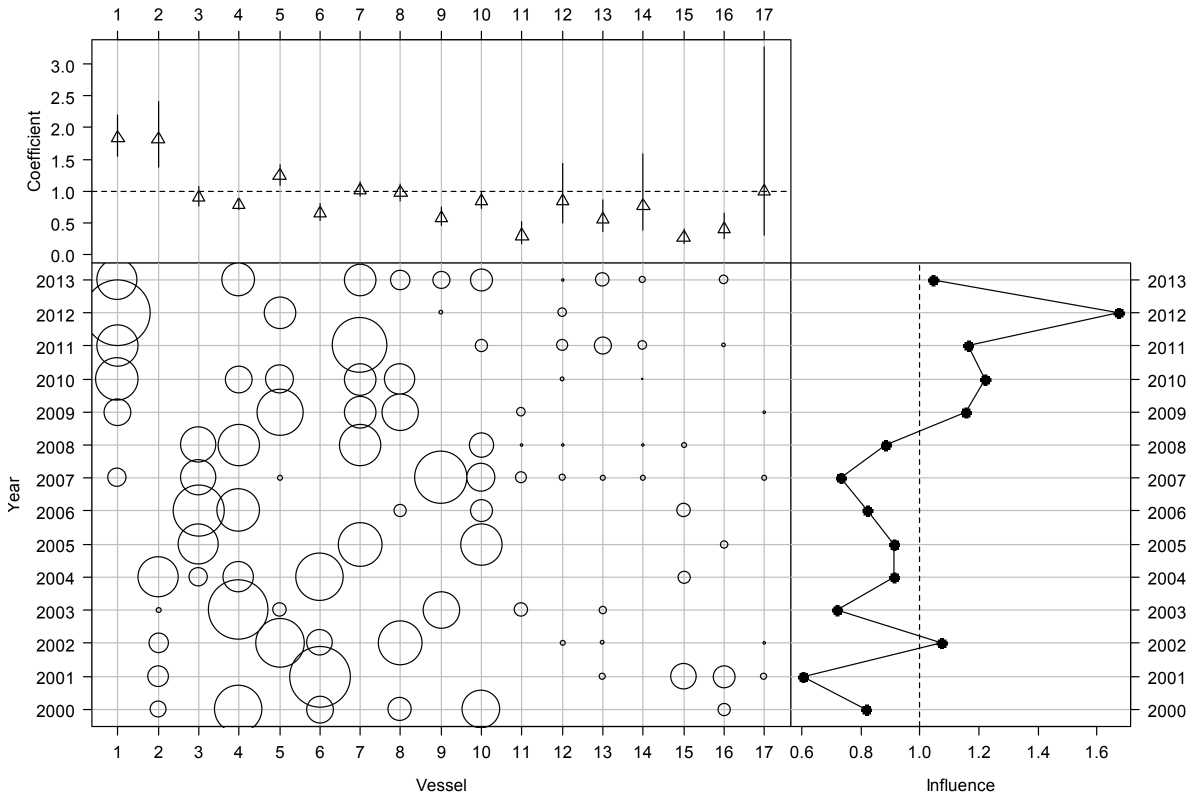


Figure 18c: Effect and influence of non-interaction term variables (target species, statistical area) in the Sub-Antarctic observer tow-by-tow data core vessel lognormal model. Top: relative effect by level of each variable. Bottom left: relative distribution of each variable by fishing year. Bottom right: influence of variable on unstandardised CPUE by fishing year.



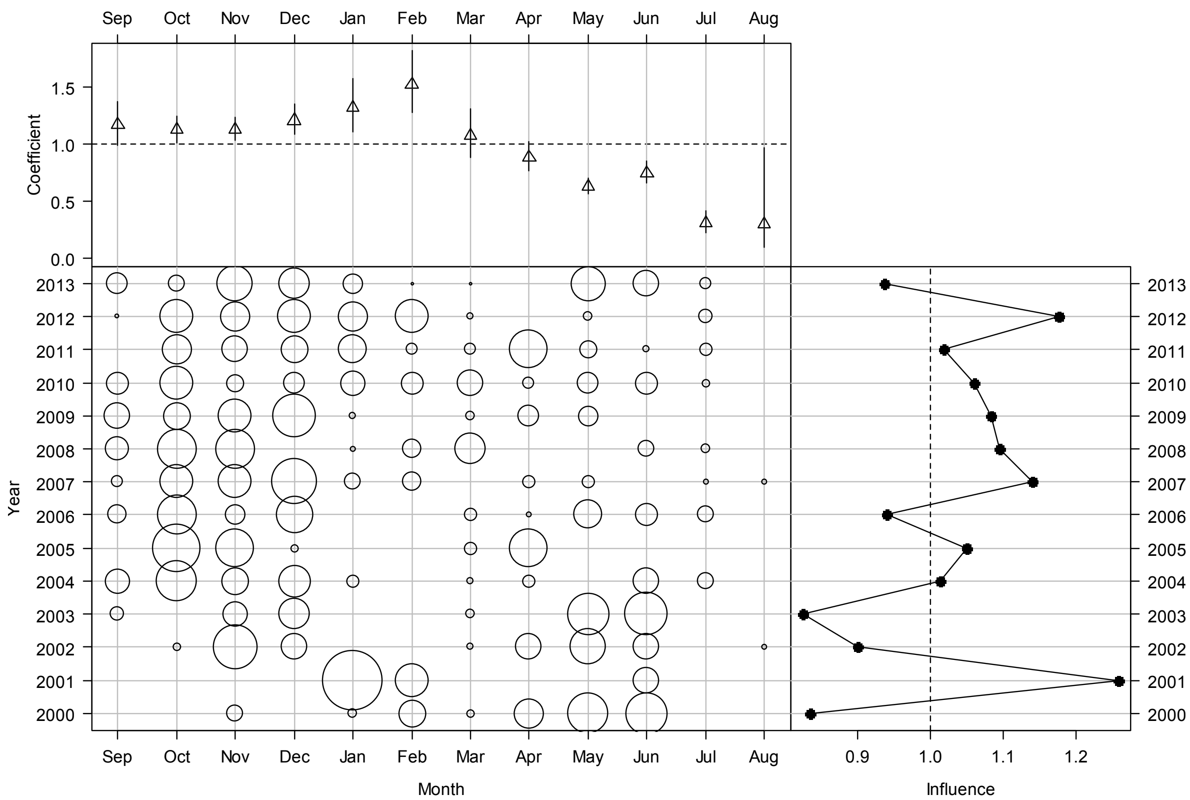


Figure 18c ctd.: Effect and influence of non-interaction term variables (vessel, month) in the Sub-Antarctic observer tow-by-tow data core vessel lognormal model. Top: relative effect by level of each variable. Bottom left: relative distribution of each variable by fishing year. Bottom right: influence of variable on unstandardised CPUE by fishing year.

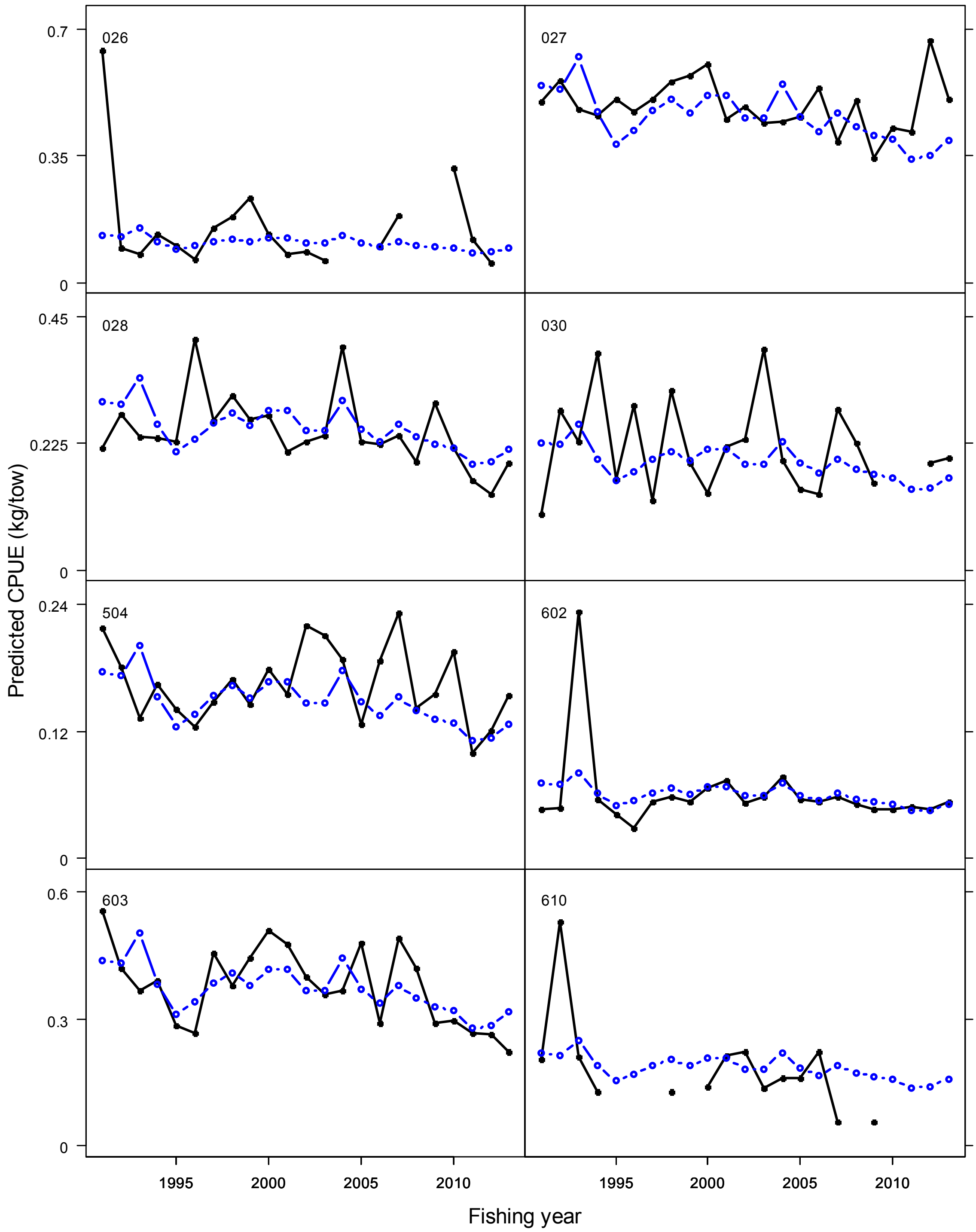


Figure 19: Predicted CPUE by statistical areas for the Sub-Antarctic TCEPR tow-by-tow core lognormal model with year-statistical area interaction (black) and without year-statistical area interaction (blue).

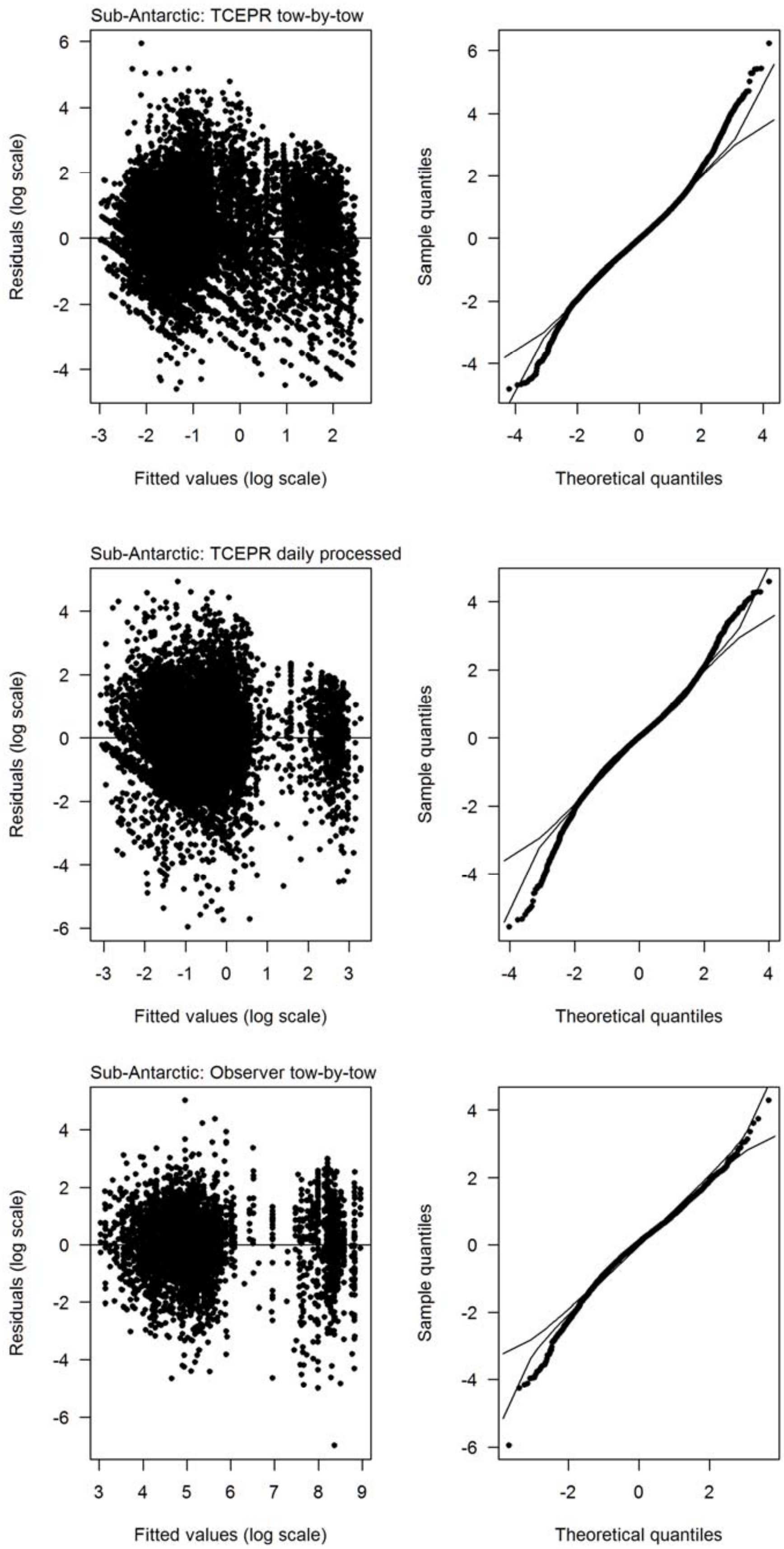


Figure 20: Diagnostic plots for the Sub-Antarctic CPUE models.