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Descriptive analysis of the fishery for hake (*Merluccius australis*) in HAK 1, 4 and 7 from 1989–90 to 2016–17, and a catch-per-unit-effort (CPUE) analysis for Sub-Antarctic hake

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EXECUTIVE SUMMARY

Ballara, S.L. (2018). Descriptive analysis of the fishery for hake (*Merluccius australis*) in HAK 1, 4 and 7 from 1989–90 to 2016–17, 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 west coast South Island (WCSI, HAK 7), Chatham Rise (HAK 4), and Sub-Antarctic (HAK 1) stocks for 1989–90 to 2016–17. 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 or hoki on any tow but did not process any hake were considered to be a zero catch day. A complete extract of data was undertaken and all variables were error groomed and interpreted in a similar manner.

The overall 2016–17 hake catch from the EEZ at 6144.7 t was higher than in 2015–16, but still markedly lower than those taken from 1995 to 2005. The largest current fishery is on the WCSI. 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. Formerly, it was primarily a target fishery for hake concentrating on spawning aggregations, but is now mostly caught as a bycatch of hoki targeting. 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 80% of the hake catch and were involved in the fishery for a minimum (varying) number of years. The r^2 values for the Sub-Antarctic CPUE models were relatively high (43–62%), and the retained variables exhibited many similarities, with *grid number* (a location variable) and *target species* accounting for most of the deviance explained. The variables included appeared logical and were similar to those selected in previous years. However, much of the underlying variability was not explained.

All three series produced here are similar, and are indicative of a slight overall decline in the 27 years covered by the analyses. There was good agreement between the Sub-Antarctic trawl survey biomass series and the CPUE series. Estimated CPUE indices follow a similar trend to summer trawl survey indices, although between 1992 and 1993 the survey indices show a large decrease not seen in CPUE indices. There is no way of establishing whether this analysis is likely to produce a reliable CPUE series.

1. INTRODUCTION

Hake are widely distributed throughout the middle depths, mainly from 250 to 800 m and primarily south of latitude 40° S (Anderson et al. 1998). 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 administrative 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). A comprehensive descriptive analysis of New Zealand hake fisheries was produced by Devine (2009) and the last published descriptive analysis of commercial catch and effort data for hake was an analysis by Ballara (2018) which included data to 2014–15. These reports showed how the hake fisheries in the New Zealand EEZ have evolved and operated, and defined seasonal and areal patterns of fish distribution. The work presented here updates the Ballara (2018) analysis, i.e., catch by area by method, to indicate whether any marked changes have occurred in the fisheries in recent years.

Hake are currently believed to consist of three biological stocks (Horn 2015), 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 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 (Colman 1998).

Commercial catch and effort data were analysed to produce catch-per-unit-effort (CPUE) indices for HAK 1 in 1998 (Kendrick 1998), and were updated, using the methodology of Gavaris (1980) and Vignaux (1994) in 1999 (Dunn et al. 2000), 2001 (Phillips & Livingston 2004), 2003 (Phillips 2005), 2005 (Dunn & Phillips 2006), 2007 (Devine & Dunn 2008), 2009 (Devine 2010), 2011 (Ballara & Horn 2011), 2012 (Ballara 2013), and 2013 (Ballara 2015). Evidence of misreporting of catch by a small number of vessels was detected during the 2001 update. Some 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 document reports on Specific Objective 1 and 2 of Project HAK201701, which has an Overall Objective "To carry out stock assessments of hake (*Merluccius australis*) in the sub-Antarctic (HAK 1) including estimating stock biomass and stock status". It includes a descriptive summary of catch and effort data, recorded on Trawl Catch Effort Processing Returns (TCEPRs) since 1989–90 and on TCERs since 2007–08, for HAK 1, 4, and 7. An analysis of the catch per unit of effort data for hake from the Sub-Antarctic stock for the years 1990–91 to 2016–17 is also presented. These fulfil Specific Objective 1 — "To carry out a descriptive analysis of the commercial catch and effort data for hake in the sub-Antarctic, and update the standardised catch and effort analyses". This objective requires that CPUE be updated only for the series used in the most recent stock assessment of the Sub-Antarctic stock.

2. DESCRIPTIVE ANALYSES

2.1 Methods

Catch-effort, daily processed, and landed data were extracted from the MPI catch-effort database "warehou" as extract 11384 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 from fishing years 1989–90 to 2016–17. This included all fishing recorded on Trawl Catch, Effort and Processing Returns (TCEPRs); Trawl Catch Effort returns (TCERs); Catch, Effort and Landing Returns (CELRs); LCER (Lining Catch Effort Return); LTCER (Lining Trip Catch Effort Return); NCELR (Netting Catch Effort Landing Return); and included high seas versions of these forms. Catch and effort data for hake from the MPI observer sampling programme (administered by NIWA in the *cod* database) were also extracted.

Data were checked for errors, using simple checking and imputation algorithms similar to those used by Ballara & O'Driscoll (2017). Data were also groomed for errors using simple checking and imputation algorithms developed in the statistical software package 'R' (R Development Core Team 2017). Individual tows 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). The tow-by-tow commercial and observed catches of hake were corrected for possible misreporting, using the method of Dunn (2003).

The Chatham Rise, WCSI, and Sub-Antarctic biological stock areas 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).

2.2 Results

2.2.1 All catch data

Estimated catches, reported landings, and TACC by stock from 1989–90 to 2016–17 are shown in Table 1 for the main hake stocks. Most hake catches since 1989–90 were reported on the TCEPR form (Table 2, Figure 3a). Other reporting forms were introduced in several years since 2003–04, but in 2016–17 most hake catch (98%) is still reported on TCEPRs, with TCERs (93.7 t, 2%) accounting for the second highest proportion. Significant catches were taken in all three biological stocks (Table 1), but with most catches taken in the WCSI and Sub-Antarctic since 2011–12. The largest fishery in 2016–17 was WCSI occurring primarily in Statistical Areas 034 and 035 (Table 1, Figures 3 and 4). Overall, hake were caught mainly by bottom trawlers targeting hake or hoki, and the proportion of hake caught in hoki target tows has been slowly decreasing since the mid 2000s (Figure 3a). Hake are caught all year around, but more commonly between June and December (Figure 3a). They are generally caught by mid-sized vessels, with Korean or Japanese vessels more likely to target hake.

2.2.2 Chatham Rise catch data

On the Chatham Rise, hake were caught mainly by bottom trawlers targeting hake or hoki (Table 3, Figure 3b). 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 a hake spawning aggregation on the northern Rise in Statistical Area 404 (Figures 3b and 4) (Devine 2010). However, catches from Area 404 since 2005–06 were low relative to early years, and negligible since 2009–10 (Figure 3b). The amount of hake caught in hoki target tows has been slowly decreasing since the late 1990s, although the proportion of hake over the last decade has been constant, and most of the Chatham Rise catch since 2011–12 was caught by target hoki fishing (Table 4, Figure 3b). 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 January (Table 4, Figure 3b). 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 4, Figure 3b) (Devine 2010). The reasons for the presence of this aggregation are not known, although periodic and minor aggregations of pre-mature and mature hake were found in that area in previous years and also in October–November 2008, and in Statistical Area 018 in October–November 2010 (Figure 3b). In 2016–17 most of the catch was taken from December to March along the northern Chatham Rise as a bycatch of hoki targeting.

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 4, Figure 3b). The catch since 2010 has been low; 187 t in 2014 was the lowest from all years since 1990, and in 2017 at 348 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 2004, and a decrease in speed since 2002 to 4.0–4.2 knots (Figure 5a), which can be attributed in part to the increased bottom tow catches since 2002 by smaller Korean vessels (Figure 3b). Mean hoki catch per tow has increased since 2004.

2.2.3 WCSI catch data

The WCSI hake fishery is mainly bycatch of the much larger hoki fishery (Table 5), but has undergone a number of changes in the last two decades (Devine 2010, Ballara 2015, Horn & Ballara 2018). 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. More of the hake catch since 2003 was from hake target tows, and the hake caught in hoki target tows has been relatively low since 2005 (Table 5, Figure 3c).

The timing of the catch on the WCSI has varied slightly between years, but most catch has been taken between June and September (Table 5, Figure 3c). Targeted hake catches were relatively high early in the fishing season in 1995, 1996, 1999, 2001, 2004, 2005, and 2007 (Ballara 2015). 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 (Ballara 2015). More than 2000 t of hake was taken during September in 1993 and 2006. In 2010 the total WCSI catch of 2282 t was the lowest in any year since 1990 (Table 6) and was taken mainly from July to September by mid-sized Korean vessels targeting hake with bottom trawl. In 2011–2015, catches increased and were taken mainly from July to

September. The 2015 catch at 5950 t was the highest since 2007. In 2016 there was a large decrease in catch to 2733 t, due to the reduction in fishing by Korean vessels (Figure 3b) and in 2017 catches increased to 4592 t, the highest catch since 2007. Catches were taken mainly in Statistical Areas 034 and 035, with most from sub-area North shallow since 2010 (Table 5, Figure 3c).

Mean duration, distance, and depth per tow were relatively high, and speed relatively low, from 2006–2009 (Figure 5b), which can be attributed in part to the increased activity of smaller Korean vessels. In 2015, relative to 2014, mean duration and distance towed were similar (Figure 5b) but with an increase in catches by midwater trawl on the bottom (Table 3c). In 2017, relative to 2016, there was an increase in mean duration, distance towed, depth of net and depth of bottom, and a corresponding decrease in mean hoki catch, effort width, and effort height (Figure 5b), again due to reduced fishing by Korean vessels. For hake target vessels in 2017, there was a levelling off of tow duration, effort width, and fishing speed, and a decrease in fishing distance, speed, fishing depth, and hoki catches (Figure 5c).

2.2.4 Sub-Antarctic data

Sub-Antarctic hake are caught mainly by bottom trawlers targeting hoki, hake, or ling (Table 7, Figure 3d). Significant targeting for hake occurs around the Norwegian Hole and at the southern end of the Snares shelf (Devine 2010). In general, hake are mainly caught 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. Most of the catch is taken from the Snares-Pukaki sub-area (Figures 3d and 4). Since 2000, 1000–2000 t of targeted hake were caught annually, and since 2005 hake caught in hoki target tows has been decreasing (Table 7, Figure 3d). 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 (Table 8, Figure 3d). 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, December to February from 2006 to 2012, and October to January from 2013 to 2017. In December 2005, 2000 t of hake was taken (Figure 3d) 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 2017, most of the catch was taken from October to January on the southern Snares shelf and from the Norwegian Hole (Figures 3d and 4).

For vessels targeting hoki or hake, bottom tows showed a decrease in mean distance, speed, and depth of net and bottom since 2002 (Figure 5d), which can be attributed in part to the increased bottom tow catches by smaller Korean vessels. Mean depth of net, depth of bottom, and mean hoki catches decreased in the early 2000s, but have since increased.

2.3 Descriptive analysis summary

In summary, the overall 2016–17 hake catch from the EEZ at 6144.7 t was higher than in 2015–16, but still markedly lower than those taken from 1995 to 2005. The largest current fishery is on the WCSI. 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 Chatham Rise fishery is concentrated on the northern and western Rise, mainly from September to February. It used to be primarily a target fishery for hake in spawning aggregations, but is now mostly caught as a bycatch of hoki targeting. The WCSI fishery is of short duration (June–September), with hake mainly caught as target catch, but some also caught as bycatch in the hoki fishery. 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 November–February from the mid-2000s, and October–January from 2013.

3. ESTIMATION OF CPUE

This section 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 this fishery were most recently reported by Ballara (2015). These CPUE series are used as inputs into stock assessments reported elsewhere.

3.1 Methods

3.1.1 Data grooming

Data grooming was carried out as described in section 2.1.

3.1.2 Variables

Variables used in the CPUE analysis are described in Table 9 and are generally similar to those used in previous analyses (e.g., Ballara 2018). CPUE indices were calculated using catch per tow (in kilograms) for TCEPR and observer tow-by-tow data, or catch per vessel-day for daily processed data, with tow *duration* offered as an explanatory variable. Hake are caught on the Sub-Antarctic all year around, but more commonly between September and February (Figure 3b), so *year* was defined as September–August, and was a categorical variable. Season variables *month* and *day of year* were offered to the model. Gear width was not used as an explanatory variable as this field in the TCEPR variously contained wingspread and doorspread measurements, and hence, *headline height* was the only trawl gear dimension variable offered to the model. Individual vessel details were checked for consistency each year. Tow records with no vessel identification data were excluded from further analyses. *Vessel* was incorporated into the CPUE standardisation to allow for differences in fishing power between vessels. For the estimated catch-by-tow run, all variables were included. For the daily processed catch run, *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*. *Grid number*, defined as the 0.5° latitude/longitude square where the catch was taken (V. McGregor, NIWA, pers. comm.) was included in all runs (Figure 6).

3.1.3 Data selection

The data used for each CPUE analysis consisted of all records from core vessels that targeted hoki, hake, or ling. Vessels not involved in the fishery for at least two years were excluded because they provided little information for the standardisations, which could result in model over-fitting (Francis 2001). Data were 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 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. 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 10). Catches believed to be misreported were excluded. Core vessel analyses were run for TCEPR tow-by-tow and daily processed data, and for observer tow-by-tow data.

The use of daily processed catch from the TCEPR processing summaries to estimate catch and derive CPUE indices was developed to account for changes over time in the recording of the top five species on the top of the TCEPR by Phillips (2005), and have been produced for analyses since then (Phillips 2005, Dunn & Phillips 2006, Devine & Dunn 2008, Devine 2010, Ballara & Horn 2011, Ballara 2012, 2013, 2015, 2018). CPUE indices were derived from daily processed catch reported on the TCEPR processing summaries as done in the past (e.g., Ballara 2015). Total daily processed catch was calculated from the daily processing summaries of the TCEPR forms and merged with the combined tow-by-tow data. Tow-by-tow commercial catches of hake were combined into vessel-day summary records. 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. The variable vessel-day from the combined tow-by-tow data and the daily processing summary was used to link the data for various variables. 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. 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, hoki or ling on any tow but did not process any hake were considered to be a zero day. Hake, hoki and ling target tows were selected, as hake form a significant and important bycatch of these fisheries.

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), and there are no daily processed summaries for TCER data.

3.1.4 The model

Annual unstandardised (raw) CPUE indices were calculated as the mean of catch per tow (kg) for TCEPR or observer tow-by-tow data, or catch (kg) per vessel-day for daily processed data. All series used the lognormal distribution for the positive catch model. A binomial model based on the presence/absence of hake in each data set was also calculated, with the two models combined using the delta-lognormal method to provide the final series (Vignaux 1994). 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 2017) 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.

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). For the binomial component, model fits were investigated visually using randomised quantile residuals (Dunn & Smyth 1996). Randomised quantile residuals are based on the idea of inverting the estimated distribution function for each observation to obtain exactly standard normal residuals. For discrete distributions, such as the binomial, some randomisation was introduced to produce continuous normal residuals.

Predictor variables were either categorical or continuous. 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 of the data series. Year indices were standardised to the mean and were presented in canonical form (Francis 1999). Variables were either categorical or continuous.

Potential continuous variables were modelled as third-order polynomials, although a fourth-order polynomial was also offered for duration. *Vessel* was incorporated into the CPUE standardisation to allow for differences in fishing ability between vessels. *Grid number* was also incorporated to allow for differences in fishing area (Figure 6). Model runs with *grid number* included all cells, top cell (cell with the highest overall catch), the top 4–6 cells (cells with the highest catches), and complement of the top cells (all cells not in top cells model run). The index CVs represent the ratio of the standard error to the index. The 95% confidence intervals were also calculated for each index.

Unstandardised CPUE was also derived for each year from the available datasets. The annual indices were calculated as the mean of the individual daily catch (kg) for trawl processed data, or catch per tow (kg) for tow-by-tow data.

The model predictors for each selected variable were plotted, with all other model predictors fixed. These fixed values were chosen to be 'typical' values (see Francis (2001) for further discussion of this method). If different fixed values were chosen, the absolute values on the plotted *y*-axis would change but the trend would be unchanged.

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).

3.2 Results

CPUE series for trawl-caught hake for the Sub-Antarctic are presented here. For each standardised CPUE analysis, the estimated catch of hake, number of tows (tow-by-tow data) or vessel-days (daily processed data), proportion of zero catches, the number of vessels involved, and unstandardised CPUE by year for the initial and core datasets are given in Table 11, with variables retained in each model listed in Table 12 and the CPUE indices by fishing year given for each model in Table 13. For each CPUE analysis, catch and effort data for individual vessels (Figure 7), proportion of zeros (Figure 8), [proportion of zeros, mean number of reported estimated species, and number of species by target species for the tow-by-tow dataset are also in Figure 8], unstandardised and standardised CPUE trajectories (Figure 9), the effects of adding additional variables (Figure 10), comparisons of lognormal, binomial, and delta lognormal trajectories (Figure 11) are also presented. Model runs are compared in Figure 12. Diagnostics for each CPUE series comprise effect and influence plots (Figure 13), expected binomial variable effects (Figure 14), and residual plots (Figures 15 and 16).

3.2.1 CPUE indices for Sub-Antarctic

TCEPR tow-by-tow

TCEPR tow-by-tow commercial data from bottom trawl vessels targeting hoki, hake or ling were analysed to produce a CPUE series, using the combined model. Overall a total of 120 unique vessels caught 43 256 t from 90 212 tows, and from these, 32 vessels were selected as core vessels (range 5–20 per year) which caught an estimated 37 624 t of hake from 70 580 tows (Table 11, Figure 7). Although there were 6 core vessels that fished in only four years, there were 17 core vessels in the fishery for 10 or more years (with the maximum being 21 years). The proportion of zero catch tows (i.e., tows where either hoki, hake, or ling was targeted, but no hake was caught) for core vessels ranged between 0.22 and 0.59, and showed an increasing trend for both core and all vessels (Figure 8a), although the trend flattened off from 2006, with overall 27 627 (39%) of tows with no reported hake catch (Table 11). The proportion of zero tows in target hake data was low with no trend, i.e., generally less than 4% (Figure 8b). Overall the mean number of species reported on the TCEPR tow-by-tow estimated part of the form increased from 1991 to 2017 (Figure 8c), however the overall number of species was higher in 1999–2005 and then decreased (Figure 8d) indicating that since 2005 some vessels may not be filling out the estimated part of the form with all top five species (Ballara 2015).

For the tow-by-tow core data analysis, five variables were selected into the lognormal model, resulting in a total r^2 of 43.5%, with *target species* explaining 29% of the residual deviance; for the binomial model, *year* explained about 2.8% of the variance, with the final model explaining 15% (Table 12). The standardised year effects from the lognormal model (Table 13, Figure 9) index showed an overall slight decrease. Unstandardised indices 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* (Figure 10). The binomial series showed a decreasing trend, and the combined indices are similar to the lognormal model, although they are higher for earlier years and lower for later years (Figure 11). A combined model run for the Snares-Pukaki box showed similar trends, as did top cell, top cells or complement of top cells lognormal runs, although higher values were seen for earlier years for top cell and top cells runs (Figure 12). Estimated CPUE indices follow a similar trend to summer trawl survey indices, although between 1992 and 1993 the survey indices show a large decrease not seen in CPUE indices, except for the top cell analysis (Figure 12).

Influence plots (Figures 13a) show that fleet dynamics and behaviour have changed: for all variables there is a negative trend in influence until about 2005 when there is a positive shift in influence. Influence of target species shows that there is a positive influence on CPUE when hake or ling are targeted, especially in 2006, 2009, 2010, 2012, and 2016, and expected catch rates were higher for target hake catches. Vessel has a large positive influence on CPUE from 2004–2012, and again in 2017, suggesting a change in fleet dynamics. Vessels with more overall catch tended to have higher expected catches and lower variability. Expected catch varied between grid number; it was highest around the Norwegian Hole and along the Snares Shelf (Statistical Areas 602, 603, and 604) with the influence of latitude on CPUE more positive in the north (see Figure 6) and from August to December. The probability of a zero hake catch varied markedly with *grid number* and *vessel* (Figure 14a).

TCEPR daily processed

Vessels targeting hake, hoki, or ling fished for 24 602 vessel-days, averaging 911 days per year since 1991 (Table 11). Thirty-eight core vessels (range 9–28 per year) which caught an estimated 31 984 t of hake from 20 423 vessel-days were included (Table 11, Figure 7). Four of these vessels had been observed in only six years, although 22 had been observed in 10 or more years (with the maximum being 26 years). The proportion of zero catch days per year (i.e., days fished where hoki, hake, or ling was targeted (Table 11, Figure 7b), but no hake was processed) for core vessels was much lower than for tow-by-tow data, and ranged between 0.03 and 0.21; it was higher in earlier years of the fishery, and overall 1555 (7.6%) of vessel-days had no reported hake catch (Table 11). 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 7). Another core vessel strongly dominated the catch from 2007 to 2017, although it had been fishing consistently since 2003.

For the tow-by-tow daily processed core data analysis, five variables were selected into the lognormal model, resulting in a total r^2 of 46.6%, with *grid number* explaining 30.5% of the residual deviance; for the binomial model, *year* explained about 2.2% of the variance, with the final model explaining 26.5% (Table 12). The standardised year effects from the lognormal model (Table 13, Figure 9) index showed an overall decrease. Unstandardised indices 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 *grid number* (Figure 10). The binomial series showed a slight increasing trend, and the combined indices are similar to the lognormal model (Figure 11). The lognormal and combined models showed similar trends to the TCEPR tow-by-tow models, although the combined model showed a flatter declining trend and the lognormal showed a steeper declining trend compared to the tow-by-tow models (Fgure 12). As for the TCEPR tow-by-tow models, top cell, top cells or complement of top cells lognormal runs were similar to daily processed runs with higher values seen for earlier years (Figure 12). Estimated CPUE indices follow a similar decreasing trend to summer trawl survey indices, except for the marked decline between 1992 and 1993 in the survey indices (Figure 12).

Influence plots for the daily processed lognormal model all showed a positive influence on target species, grid number, and month in later years (Figure 13b). Influence from most variables was small, however, as most values were between 0.9 and 1.1. 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 effort levels around October were higher, and higher catch rates were expected from October to March. Vessels with more overall catch tended to have higher expected catches and lower variability. The probability of a zero hake catch was lowest for tows that were deeper, for longer durations, and for more northerly fishing (Figure 14b).

Observer tow-by-tow

Tow-by-tow data collected by observers from the target hoki, hake and ling trawl fishery in the Sub-Antarctic were analysed to produce a CPUE series, using the combined model. A total of 43 observed vessels (range 5–18 vessels each year) targeting hake, hoki, or ling caught an estimated 10 758 t of hake since 2000, from 8375 tows (Table 11c). Data from 19 vessels (range 3–15 per year) were included in the core dataset (Table 11, Figure 7). Although 7 of these vessels had been observed in only five years, 7 had been observed in 8 or more years. There were 6435 tows in the data set, of which 873 (13.6%) reported no hake catch, and the proportion of zero tows showed no trend (Table 11, Figure 8a).

The lognormal model explained 62.7% of total variance, with *year* and *target species* explaining about 54%; in the binomial model, *year* explained about 3.5% of the variance, with the final model explaining 21.6% (Table 12). The standardised year effects from the lognormal model produced a series that is spiky, and declines from 2002 to 2017 (Table 13, Figure 9). This index did not match the unstandardised index well for most of the series (Figure 10). The binomial series is flat, and the combined indices are similar to the lognormal model (Figure 11). Estimated CPUE indices decline as for TCEPR tow-by-tow and daily processed indices, and as for the *Tangaroa* trawl survey indices (Figure 12).

Influence plots (Figures 13c) show that fleet behaviour has changed. The influence on CPUE of target species, duration and grid number has had a positive trend over time, so these variables have a large overall influence on observed CPUE from year to year. For target species, there was a large positive shift in 2004 and 2012; for grid number, a large negative shift in 2001, and a large positive shift in 2005, 2010 and 2012; and for month, a large positive shift in 2001. Expected catches tended to be higher when hake was targeted, for longer tows, and in December–February (Figure 14c). Vessel has a smaller influence on CPUE, with large positive shifts in 2004 and 2012. The probability of a zero hake catch was highest for tows that were shallower, for tows targeting hoki or ling, and for tows that started at night (Figure 14c). *Duration* has a relatively weak effect on the probability of a zero hake catch, unless the tow was very short or long.

3.3 CPUE summary

A combined TCEPR tow-by-tow model using QMS data from the Sub-Antarctic hoki, hake and ling target trawl fishery was updated. There is a large volume of data used in the analysis, and the tow-by-tow estimated catch and daily processed, and observer tow-by-tow indices exhibit an overall decrease over the 27 years covered by the analyses. 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 grid number or target species (Figure 10). All three series produced here appear fairly stable (similar results to previous analyses). Estimated CPUE indices follow a similar trend to summer Sub-Antarctic trawl survey indices, although between 1992 and 1993 the survey indices show a large decrease not seen in CPUE indices (Figure 12). There is no way of establishing whether this CPUE analysis is likely to produce a reliable index series.

It is assumed that there is a proportional relationship between CPUE and fish 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. 2000). Big catches occurred when spawning aggregations were targeted, and this could easily have biased the data, producing CPUE series that do not track abundance. However there was reasonable agreement between the Sub-Antarctic trawl survey biomass series and the CPUE series, so credence may be given to these indices.

Daily processed data was used as a sensitivity analysis for the tow-by-tow analyses as processing data includes most species in a daily summary, and has low proportions of zero hake days as catches from several tows are likely to be amalgamated in a daily summary. Although there has been a trend of more species being reported on the TCEPR tow-by-tow estimated catch part of the form, there is evidence from recent years that some vessels may not be filling out all hake catches in hoki target tows. 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. Daily processed data may not capture changes in conversion factors. Daily processed data also may not capture as much detail in the data, for example for each fishing day a “main target species” must be selected, and only the daily medians of variables such as latitude, longitude, and depths must be used. The observer tow-by-tow data was also used as a sensitivity analysis, and although this dataset should be free of biases, there were only 18 years of data used in this analysis, and there were low numbers of tows in some years.

The trend in zero tows for the TCEPR tow-by-tow data means that the binomial results are influential in the combined model, resulting in a steeper decline in the indices. Adding zero tows does not change the overall trends of either the daily processed or observer CPUE series, implying that little was gained by using the combined model for these two analyses.

The r^2 values for the Sub-Antarctic CPUE models were relatively high (43–62%), and the retained variables exhibited many similarities across models, with most of the explanatory power from the first two or three variables. Grid number (location) or target species was the most important variable in all analyses. There was a reasonably strong vessel effect in all analyses except for the observer tow-by-tow analysis, and month was also retained in most analyses. In the binomial models, grid number and vessel were retained in all models, and sometimes duration, depth, or time of day. and the combined models explained 15–26% of the variance. 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 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 if included might have resulted in an increase in the overall deviance explained.

Influence plots for the lognormal tow-by-tow models show that for most variables there is a negative trend in influence until about 2005 when there is a positive shift in influence. All models show a positive influence of target species when hake are targeted.Vessel has a large positive influence on CPUE in the more recent years, suggesting a change in fleet dynamics. Vessels with more overall catch tended to have higher expected catch rates and lower variability. All models show that the influence of location (grid number) is important; catches were 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. There was little influence from other variables as most values were between 0.9 and 1.1.

The diagnostic plots for all lognormal models were unable to capture the extremes in catch rates observed in the fishery and tended to underestimate the lower or higher catch rates (Figure 15). 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.The diagnostics for the binomial models were good and the quantile-quantile plots indicated very little 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 well modelled (Figure 16).

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6. TABLES

Table 1: 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 and by biological stock area (see Figure 1) from fishing years 1989–90 to 2016–17. 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	2 592	726	6 175	2 603	743	6 148	2 610	1 000	3 310
1991–92	3 156	2 013	3 027	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	1 783	2 579	3 005	1 803	2 587	2 974	3 501	3 500	6 835
1994–95	2 217	2 841	9 744	2 572	3 369	8 841	3 632	3 500	6 835
1995–96	3 834	3 075	9 081	3 956	3 466	8 678	3 632	3 500	6 835
1996–97	3 300	3 190	6 848	3 534	3 524	6 118	3 632	3 500	6 835
1997–98	3 659	3 060	7 858	3 809	3 523	7 416	3 632	3 500	6 835
1998–99	3 703	2 879	8 650	3 845	3 324	8 165	3 632	3 500	6 835
1999–00	3 781	2 756	7 042	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
2013–14	1 883	168	3 620	1 883	168	3 642	3 701	1 800	7 700
2014–15	1 721	304	6 175	1 725	304	6 219	3 701	1 800	7 700
2015–16	1 581	274	2 864	1 584	274	2 864	3 701	1 800	7 700
2016–17	1 175	268	4 701	1 175	268	4 701	3 701	1 800	7 700

Table 1 ctd.

	Estimated catch by biological stock		
Year	CHAT	SUBA	WCSI
1989–90	951	1 927	4 903
1990–91	931	2 370	6 175
1991–92	2 418	2 751	3 027
1992–93	2 799	3 269	7 155
1993–94	2 924	1 453	2 987
1994–95	3 287	1 771	9 744
1995–96	4 028	2 884	9 076
1996–97	4 233	2 263	6 840
1997–98	4 074	2 607	7 851
1998–99	3 808	2 797	8 618
1999–00	3 517	3 020	7 039
2000–01	2 963	2 791	8 348
2001–02	1 774	2 510	7 499
2002–03	1 402	2 738	7 405
2003–04	2 467	3 245	7 939
2004–05	3 520	2 540	7 298
2005–06	491	2 557	6 896
2006–07	1 087	1 818	7 660
2007–08	1 109	2 202	2 611
2008–09	1 836	2 427	5 944
2009–10	412	1 958	2 333
2010–11	976	1 288	3 534
2011–12	216	1 894	4 427
2012–13	373	1 864	5 422
2013–14	219	1 832	3 620
2014–15	390	1 635	6 174
2015–16	355	1 501	2 863
2016–17	406	1 037	4 701

Table 2: 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	9 474.2	-	19.7	-	-	-	9 493.9
1991–92	8 187.5	-	8.1	-	-	-	8 195.6
1992–93	13 188.4	-	36.1	-	-	-	13 224.5
1993–94	7 361.8	-	4.7	-	-	-	7 366.4
1994–95	14 797.0	-	5.2	-	-	-	14 802.2
1995–96	15 984.8	-	4.6	-	-	-	15 989.3
1996–97	13 334.3	-	2.4	-	-	-	13 336.7
1997–98	14 572.7	-	3.9	-	-	-	14 576.6
1998–99	15 223.3	-	8.4	-	-	-	15 231.7
1999–00	13 569.8	-	9.2	-	-	-	13 579.0
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	7 377.7	211.9	-	5.7	63.5	0.6	7 659.4
2013–14	5 403.8	186.3	0.1	10.6	69.3	1.0	5 671.3
2014–15	7 951.5	196.0	0.1	4.9	46.7	0.5	8 199.6
2015–16	4 562.6	116.8	0.3	4.2	33.7	1.8	4 719.4
2016–17	6 006.0	93.7	2.2	3.6	38.6	0.6	6 144.7

Table 3: Chatham Rise hake TCEPR catch by target species and fishing method, 1989–90 to 2016–17. 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	778	72	6	15	0	20	12	0
1992–93	1 630	829	54	4	9	0	236	35	1
1993–94	856	365	65	22	33	0	1 501	78	2
1994–95	781	752	60	230	31	0	1 200	230	1
1995–96	2 611	929	105	7	40	0	71	264	0
1996–97	2 060	1 401	78	–	65	0	404	223	1
1997–98	1 984	1 158	255	0	64	0	360	250	0
1998–99	2 410	1 006	152	–	25	0	46	167	1
1999–00	1 274	924	243	382	33	0	540	120	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	291	0	157	139	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
2013–14	0	168	8	1	5	1	2	1	0
2014–15	89	239	19	0	17	0	–	2	2
2015–16	5	277	16	0	11	0	0	2	0
2016–17	–	350	14	1	15	1	–	4	0

Table 4: Chatham Rise estimated hake TCEPR catch (t) by month from 1989–90 to 2016–17. 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	56	45	54	119	588	2 418
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	362	2 922
1994–95	913	1 072	632	61	39	13	13	51	102	39	48	302	3 285
1995–96	299	1 074	986	659	57	22	44	93	144	172	157	318	4 027
1996–97	626	267	1 484	133	72	112	82	101	84	700	4	568	4 232
1997–98	302	469	284	95	65	173	107	112	175	208	1	2 082	4 073
1998–99	327	610	624	349	73	278	46	36	492	208	1	764	3 807
1999–00	1 204	373	299	107	71	122	57	28	592	131	1	531	3 517
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	20	28	6	21	7	3	1	10	344
2013–14	2	8	20	66	41	13	13	6	2	1	1	14	187
2014–15	10	13	56	55	10	14	15	15	10	5	2	168	371
2015–16	33	10	12	36	73	33	17	22	37	0	4	56	332
2016–17	33	22	90	37	58	50	24	29	11	1	1	34	389

Table 5: WCSI hake TCEPR catch (t) by target species and fishing method, 1989–90 to 2016–17. 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	4 627	2	5	1 246	44
1991–92	1 224	355	74	45	837	1	249	232	2
1992–93	536	607	21	962	1 024	0	2 548	1 409	15
1993–94	53	638	20	175	943	3	762	386	4
1994–95	0	583	92	785	4 785	19	1 724	1 739	13
1995–96	232	1 206	78	1 187	4 360	24	215	1 724	49
1996–97	56	1 072	45	511	3 119	46	280	1 572	70
1997–98	58	840	5	276	4 334	20	297	2 009	1
1998–99	370	1 430	10	1 115	3 252	7	1 205	1 209	0
1999–00	286	1 891	36	400	2 316	2	587	1 501	0
2000–01	333	1 547	15	2 164	1 578	0	1 172	1 536	0
2001–02	427	2 886	20	234	1 810	0	143	1 978	1
2002–03	2 158	1 984	7	434	996	0	528	1 296	1
2003–04	2 706	1 564	2	224	584	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	438	0	915	60	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
2013–14	2 103	578	1	2	176	0	63	463	0
2014–15	4 509	582	9	4	187	0	335	324	0
2015–16	1 409	733	4	–	136	0	0	450	0
2016–17	2 729	1 347	8	1	142	0	7	352	0

Table 6: WCSI estimated hake TCEPR catch (t) by month from 1989–90 to 2016–17. 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	192	771	172	1 884	3 019
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	886	1 240	385	474	2 985
1994–95	12	0	2	0	0	2	1	22	3 285	2 535	3 456	424	9 741
1995–96	168	0	0	0	0	1	0	1	2 506	2 599	2 719	1 080	9 074
1996–97	56	0	0	0	0	0	0	0	942	2 450	2 033	1 358	6 840
1997–98	64	31	0	0	0	0	2	15	1 751	3 339	2 155	492	7 849
1998–99	48	332	15	0	0	4	1	30	3 191	3 476	1 153	361	8 611
1999–00	151	0	–	–	0	2	1	44	1 776	3 586	835	637	7 032
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
2013–14	–	–	0	0	0	0	0	58	774	1 109	879	567	3 387
2014–15	8	0	0	2	0	0	0	204	1 159	1 424	2 795	359	5 950
2015–16	0	–	–	2	–	0	1	20	917	922	409	462	2 733
2016–17	0	–	–	4	2	0	0	18	518	1 760	1 632	658	4 592

Table 7: Sub-Antarctic hake TCEPR catch (t) by target species and fishing method, 1989–90 to 2016–17. 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	–	152	9	–	50	1
1995–96	1 203	460	1 071	–	87	0	–	62	0
1996–97	555	954	590	–	155	6	–	0	1
1997–98	738	1 198	658	–	6	3	–	0	2
1998–99	946	1 141	645	0	36	3	0	22	2
1999–00	906	1 460	252	0	357	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	6	0	4	16
2006–07	1 029	278	480	0	0	10	0	3	18
2007–08	1 558	188	436	–	0	6	–	–	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
2013–14	1 361	155	303	–	0	7	–	0	3
2014–15	1 351	129	133	–	1	1	–	0	14
2015–16	1 156	137	197	–	0	0	–	0	6
2016–17	725	155	137	–	0	1	–	0	5

Table 8: Sub-Antarctic estimated hake TCEPR catch (t) by month from 1989–90 to 2016–17. 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	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
2013–14	440	431	338	510	20	8	28	22	19	0	5	10	1 830
2014–15	179	554	248	532	14	17	15	14	11	3	3	40	1 630
2015–16	314	179	272	468	170	2	5	9	3	1	1	74	1 497
2016–17	172	141	382	187	5	12	34	21	1	2	2	65	1 024

Table 9: Description of variables used in the Sub-Antarctic CPUE analysis for the estimated TCEPR and observer 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.

(a) Tow-by-tow data

Variable	Type	Description
Year	Categorical	Year Sep-Aug)
Vessel	Categorical	Unique (encrypted) vessel identification number
Statistical area	Categorical	Statistical area
Effort	Continuous	-
Tow duration	Continuous	Duration of tow (hrs)
Catch	Continuous	Estimated green weight of hake (t) caught for a given tow
CPUE	Continuous	Hake catch (t) per tow
Target species	Categorical	Target species for a tow
Date	Continuous	Start date of the tow
Month	Categorical	Month of the year
Dayofyear	Continuous	Day of the year, starting at 1 January
Time start	Continuous	Start time of tow, 24 hour clock
Time mid	Continuous	Time at the midpoint of the tow, 24 hour clock
Method	Categorical	Fishing method for a tow (BT is bottom trawl; MB is midwater trawl within 5 m of the seabed; MW is midwater trawl)
Tow distance	Continuous	Distance of tow
Distance2	Continuous	Distance (as speed in knots *duration)
Headline height	Continuous	Headline height (m) of the net for a tow
Bottom depth	Continuous	Seabed depth (m) for a tow
Net depth	Continuous	Net depth (m) for a tow (depth of ground rope)
Speed	Continuous	Vessel speed (knots) for a tow
Vessel experience	Continuous	Number of years the vessel has been involved in the fishery
Twin trawl tow	Categorical	T/F variable for a vessel that has used twin trawl for a tow
Subarea	Categorical	Defined by fishing effort distribution and depth for a tow
Longitude	Continuous	Longitude of the vessel for a tow
Latitude	Continuous	Latitude of the vessel for a tow
Grid number	Categorical	0.5 degree square based on start latitude and longitude (TCEPR only)

(b) Daily processed data

Variable	Type	Description
Year	Categorical	Year (Sep-Aug)
Vessel	Categorical	Unique (encrypted) vessel identification number
Statistical area	Categorical	Statistical area
Effort	Continuous	Number of tows for a given day
Tow duration	Continuous	Duration of all tows on a given day (hrs)
Catch	Continuous	Estimated green weight of hake (t) caught for a given day
CPUE	Continuous	Hake catch (t) per day
Target species	Categorical	Main target species for a given day
Date	Continuous	Date the fish were processed
Month	Categorical	Month of the year
Dayofyear	Continuous	Day of the year, starting at 1 January
Method	Categorical	Fishing method for a given day (BT is bottom trawl; MB is midwater trawl
Tow distance	Continuous	Distance of all tows on a given day
Distance2	Continuous	Distance (as speed × duration) of all tows on a given day
Headline height	Continuous	Median headline height (m) of the net on a given day
Bottom depth	Continuous	Median seabed depth (m) on a given day
Net depth	Continuous	Median net depth (m) on a given day (depth of ground rope)
Speed	Continuous	Median vessel speed (knots) on a given day
Vessel experience	Continuous	Number of years the vessel has been involved in the fishery
Twin trawl tow	Categorical	T/F variable for a vessel that has used twin trawl on a given day
Longitude	Continuous	Median longitude of the vessel for a given day
Latitude	Continuous	Median latitude of the vessel for a given day
Subarea	Categorical	Defined by fishing effort distribution and depth for a given day
Grid number	Categorical	0.5 degree square based on start latitude and longitude

Table 10: CPUE data constraints for each target hoki, hake or ling bottom trawl dataset for fishing years 1991–2017 for TCEPR data and 2000–2017 for observer data. Fishing year defined as September–August.

	Dataset		
	TCEPR tow-by-tow	TCEPR daily processed	Observer tow-by-tow
Fisheries	Auckland Island; Campbell Island; Puysegur; Snares-Pukaki	Auckland Island; Campbell Island; Puysegur; Snares-Pukaki	
Statistical Areas	026–028, 030, 504, 602, 603, 604, 610, 618	026–028, 030, 504, 602, 603, 610, 618	026–028, 504, 602, 603, 610
Catch	< 50 t	< 80 t	< 50 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 One vessel removed (odd catch values)	Exclude days with misreported tows One vessel removed (odd catch values)	
Core vessel selection	Approx. 80% of catch, ≥ 4 years vessel participation and number of tows per year ≥ 20	Approx. 80% of catch, ≥ 6 years vessel participation	Approx. 80% of catch, ≥ 5 years vessel participation

Table 11: Summary of data for all and core vessels included in the CPUE datasets, by year. Data include: number of unique vessels fishing (No. 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 (Prop. zeros), estimated catch, and unstandardised CPUE (CPUE).

TCEPR tow-by-tow

	All vessels					**Core vessels**				
Fishing year	**No. vessels**	**Catch**	**Effort**	**Prop. zeros**	**CPUE**	**No. vessels**	**Catch**	**Effort**	**Prop. zeros**	**CPUE**
1991	38	2 123.1	3 281	0.30	0.65	6	1 019.4	1 151	0.25	0.89
1992	45	2 626.5	4 499	0.34	0.58	11	1 405.3	2 531	0.29	0.56
1993	40	3 107.1	3 818	0.34	0.81	11	2 268.7	2 804	0.29	0.81
1994	26	889.6	1 711	0.30	0.52	7	626.8	1 542	0.22	0.41
1995	25	594.9	2 082	0.29	0.29	7	486.8	1 974	0.22	0.25
1996	30	1 224.4	1 614	0.48	0.76	11	898.9	1 119	0.47	0.80
1997	39	918.3	2 260	0.42	0.41	15	737.4	1 806	0.37	0.41
1998	42	1 616.1	3 338	0.32	0.48	19	1 535.2	3 182	0.28	0.48
1999	33	1 660.0	2 547	0.30	0.65	19	1 526.5	2 337	0.26	0.65
2000	30	1 747.9	3 645	0.42	0.48	20	1 729.0	3 567	0.39	0.48
2001	33	1 624.8	3 190	0.44	0.51	20	1 565.6	2 979	0.42	0.53
2002	34	1 746.9	3 480	0.43	0.50	15	1 678.1	3 264	0.39	0.51
2003	36	1 573.7	2 359	0.52	0.67	16	1 495.5	2 244	0.49	0.67
2004	26	2 062.5	1 848	0.45	1.12	9	2 025.9	1 759	0.40	1.15
2005	26	1 289.1	1 016	0.51	1.27	9	1 020.1	869	0.45	1.17
2006	23	2 153.9	826	0.56	2.61	11	2 137.7	766	0.50	2.79
2007	21	1 372.7	912	0.59	1.51	10	1 315.3	747	0.59	1.76
2008	23	1 968.2	1 201	0.48	1.64	9	1 648.3	1 011	0.44	1.63
2009	19	2 239.7	998	0.46	2.24	8	2 144.9	904	0.44	2.37
2010	19	1 663.8	952	0.46	1.75	6	1 523.8	857	0.43	1.78
2011	20	1 067.6	806	0.55	1.32	5	1 033.6	725	0.50	1.43
2012	21	1 458.3	859	0.48	1.70	8	1 417.1	715	0.46	1.98
2013	21	1 444.7	1 002	0.51	1.44	7	1 420.1	950	0.44	1.49
2014	17	1 536.6	1 030	0.59	1.49	7	1 515.9	966	0.53	1.57
2015	19	1 282.5	926	0.58	1.38	8	1 262.1	857	0.51	1.47
2016	18	1 266.7	762	0.52	1.66	8	1 205.9	679	0.43	1.78
2017	19	996.4	719	0.60	1.39	5	980.6	648	0.53	1.51

Table 11 ctd.

TCEPR daily processed

Fishing year	All vessels No. vessels	Catch	Effort	Prop. zeros	CPUE	Core vessels No. vessels	Catch	Effort	Prop. zeros	CPUE
1991	31	1 757.4	941	0.12	1.87	9	312.0	118	0.21	2.64
1992	40	2 234.2	1 556	0.10	1.44	14	739.5	580	0.11	1.27
1993	33	2 613.6	1 187	0.13	2.20	15	1 145.9	568	0.14	2.02
1994	24	722.4	531	0.13	1.36	12	415.5	353	0.12	1.18
1995	24	529.8	655	0.08	0.81	15	390.3	484	0.08	0.81
1996	27	565.3	543	0.14	1.04	16	414.9	378	0.10	1.10
1997	38	817.1	916	0.11	0.89	23	655.4	776	0.09	0.84
1998	39	1 330.2	1 293	0.06	1.03	27	1 245.0	1 193	0.06	1.04
1999	30	1 384.0	944	0.06	1.47	23	1 323.0	873	0.06	1.52
2000	28	1 545.7	1 520	0.07	1.02	27	1 545.7	1 519	0.07	1.02
2001	31	1 623.4	1 412	0.09	1.15	26	1 588.9	1 349	0.09	1.18
2002	32	1 632.2	1 463	0.10	1.12	28	1 596.9	1 411	0.10	1.13
2003	33	1 497.6	1 234	0.08	1.21	27	1 487.3	1 208	0.08	1.23
2004	24	1 845.6	852	0.08	2.17	21	1 820.0	820	0.07	2.22
2005	24	1 213.9	559	0.10	2.17	22	1 193.5	545	0.10	2.19
2006	21	1 791.7	430	0.11	4.17	17	1 777.3	410	0.10	4.33
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	2 024.5	530	0.07	3.82	16	2 023.2	507	0.04	3.99
2010	18	1 576.0	504	0.05	3.13	18	1 576.0	504	0.05	3.13
2011	19	1 039.6	505	0.06	2.06	17	1 037.2	481	0.06	2.16
2012	21	1 316.0	497	0.05	2.65	20	1 315.7	482	0.05	2.73
2013	21	1 466.5	600	0.06	2.44	19	1 466.4	593	0.05	2.47
2014	17	1 325.7	744	0.05	1.78	15	1 321.9	722	0.03	1.83
2015	19	1 102.1	679	0.04	1.62	16	1 092.5	636	0.03	1.72
2016	18	923.7	506	0.05	1.83	14	915.8	468	0.04	1.96
2017	18	851.2	561	0.03	1.52	13	846.5	542	0.03	1.56

Observer tow-by-tow

Fishing year	All vessels No. vessels	Catch	Tows	Prop. zeros	CPUE	Core vessels No. vessels	Catch	Tows	Prop. zeros	CPUE
2000	9	500.3	639	0.11	0.78	5	337.8	365	0.15	0.93
2001	15	145.1	330	0.06	0.44	7	68.7	38	0.21	1.81
2002	10	390.3	463	0.07	0.84	7	384.0	401	0.08	0.96
2003	12	73.0	392	0.15	0.19	6	42.4	172	0.09	0.25
2004	9	407.2	222	0.09	1.83	3	380.4	114	0.10	3.34
2005	5	54.9	147	0.16	0.37	4	54.8	145	0.16	0.38
2006	5	813.4	323	0.14	2.52	4	812.7	312	0.14	2.60
2007	10	372.6	202	0.29	1.84	10	372.6	202	0.29	1.84
2008	11	233.5	403	0.16	0.58	8	155.8	384	0.17	0.41
2009	8	687.5	477	0.09	1.44	8	687.5	477	0.09	1.44
2010	8	1 177.8	618	0.11	1.91	8	1 177.8	618	0.11	1.91
2011	8	661.0	315	0.12	2.10	7	660.8	311	0.12	2.12
2012	9	1 027.3	321	0.10	3.20	6	1 011.6	215	0.03	4.71
2013	18	923.6	795	0.21	1.16	15	825.3	418	0.25	1.97
2014	12	1 182.0	592	0.14	2	11	1 179.3	551	0.12	2.14
2015	12	926.0	406	0.16	2.28	9	919.2	333	0.15	2.76
2016	11	713.7	342	0.12	2.09	6	698.3	281	0.08	2.49
2017	10	469.3	256	0.10	1.83	6	465.6	224	0.10	2.08

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

TCEPR tow-by-tow

Lognormal

Variable	R-squared
Year	5.14
Target species	28.74
Grid number	36.99
Vessel	41.63
Month	43.47

Binomial

Variable	R-squared
Year	2.83
Grid number	13.44
Vessel	15.40

TCEPR daily processed

Lognormal

Variable	R-squared
Year	2.49
Grid number	30.45
Target species	43.30
Vessel	45.06
Month	46.58

Binomial

Variable	R-squared
Year	2.24
Grid number	17.02
Depth of bottom	20.33
Month	23.03
Duration	24.81
Vessel	26.53

Observer tow-by-tow

Lognormal

Variable	R-squared
Year	6.28
Target species	54.45
Grid number	59.96
Month	61.58
Duration	62.67

Binomial

Variable	R-squared
Year	3.56
Grid number	14.51
Target species	16.52
Depth of net	17.99
Month	19.17
Duration	20.29
Mid time of tow	21.63

Table 13: Lognormal, binomial, and delta lognormal (combined) standardised CPUE indices (with CVs to 2 decimal places).

TCEPR tow-by-tow

	Lognormal		Binomial		Delta lognormal	
Year	**Index**	**CV**	**Index**	**CV**	**Index**	**CV**
1991	1.18	0.04	0.92	0.00	1.28	0.04
1992	1.18	0.03	0.97	0.00	1.35	0.03
1993	1.36	0.03	0.96	0.00	1.55	0.03
1994	1.14	0.03	1.00	0.00	1.35	0.03
1995	0.85	0.03	0.99	0.00	1.00	0.03
1996	0.83	0.03	0.82	0.00	0.80	0.03
1997	1.05	0.03	0.88	0.00	1.09	0.03
1998	1.13	0.02	0.96	0.00	1.28	0.02
1999	1.09	0.02	0.97	0.00	1.25	0.02
2000	1.17	0.02	0.92	0.00	1.27	0.02
2001	1.19	0.02	0.89	0.00	1.25	0.02
2002	1.06	0.02	0.85	0.00	1.07	0.02
2003	1.10	0.02	0.80	0.00	1.04	0.02
2004	1.40	0.03	0.84	0.00	1.38	0.03
2005	1.13	0.04	0.73	0.00	0.98	0.04
2006	1.00	0.04	0.65	0.00	0.77	0.04
2007	1.06	0.04	0.58	0.00	0.73	0.04
2008	1.02	0.03	0.75	0.00	0.90	0.03
2009	0.91	0.03	0.79	0.00	0.85	0.03
2010	0.89	0.04	0.80	0.00	0.84	0.04
2011	0.83	0.04	0.76	0.00	0.75	0.04
2012	0.79	0.04	0.79	0.00	0.73	0.04
2013	1.03	0.03	0.78	0.00	0.95	0.03
2014	0.72	0.03	0.68	0.00	0.58	0.03
2015	0.63	0.04	0.70	0.00	0.53	0.04
2016	0.76	0.04	0.75	0.00	0.67	0.04
2017	0.98	0.04	0.67	0.00	0.77	0.04

Table 13: ctd.

TCEPR daily processed

	Lognormal		Binomial		Delta lognormal	
Year	**Index**	**CV**	**Index**	**CV**	**Index**	**CV**
1991	1.23	0.10	0.89	0.00	1.09	0.10
1992	1.57	0.05	0.94	0.00	1.48	0.05
1993	1.50	0.05	0.87	0.00	1.31	0.05
1994	1.36	0.06	0.93	0.00	1.27	0.06
1995	1.13	0.05	0.95	0.00	1.07	0.05
1996	1.01	0.05	0.94	0.00	0.95	0.05
1997	1.18	0.04	0.95	0.00	1.12	0.04
1998	1.16	0.03	0.98	0.00	1.13	0.03
1999	1.52	0.04	0.98	0.00	1.49	0.04
2000	1.36	0.03	0.97	0.00	1.32	0.03
2001	1.37	0.03	0.97	0.00	1.33	0.03
2002	1.11	0.03	0.95	0.00	1.06	0.03
2003	1.05	0.03	0.96	0.00	1.01	0.03
2004	1.34	0.04	0.95	0.00	1.28	0.04
2005	0.99	0.04	0.94	0.00	0.94	0.04
2006	0.84	0.05	0.96	0.00	0.81	0.05
2007	0.69	0.04	0.96	0.00	0.67	0.04
2008	0.78	0.04	0.98	0.00	0.76	0.04
2009	0.92	0.05	0.99	0.00	0.92	0.05
2010	1.01	0.05	0.99	0.00	1.00	0.05
2011	0.85	0.05	0.99	0.00	0.84	0.05
2012	0.88	0.05	0.99	0.00	0.88	0.05
2013	0.89	0.04	0.98	0.00	0.88	0.04
2014	0.61	0.04	0.99	0.00	0.61	0.04
2015	0.56	0.04	1.00	0.00	0.56	0.04
2016	0.68	0.05	0.99	0.00	0.67	0.05
2017	0.57	0.04	1.00	0.00	0.57	0.04

Observer tow-by-tow

	Lognormal		Binomial		Delta lognormal	
Year	**Index**	**CV**	**Index**	**CV**	**Index**	**CV**
2000	1.41	0.07	0.95	0.00	1.38	0.07
2001	1.07	0.16	1.00	0.00	1.11	0.16
2002	1.78	0.06	0.96	0.00	1.77	0.06
2003	1.19	0.08	1.00	0.00	1.23	0.08
2004	1.34	0.09	0.95	0.00	1.32	0.09
2005	1.09	0.09	0.84	0.00	0.95	0.09
2006	1.07	0.06	0.95	0.00	1.05	0.06
2007	0.87	0.07	0.81	0.00	0.73	0.07
2008	0.90	0.06	0.90	0.00	0.84	0.06
2009	1.08	0.05	0.98	0.00	1.10	0.05
2010	0.98	0.04	0.92	0.00	0.94	0.04
2011	0.75	0.06	0.96	0.00	0.74	0.06
2012	1.02	0.07	1.00	0.00	1.06	0.07
2013	0.76	0.05	0.83	0.00	0.65	0.05
2014	1.05	0.05	0.94	0.00	1.02	0.05
2015	0.67	0.06	0.89	0.00	0.62	0.06
2016	0.80	0.06	0.96	0.00	0.79	0.06
2017	0.74	0.07	0.93	0.00	0.71	0.07

7. FIGURES

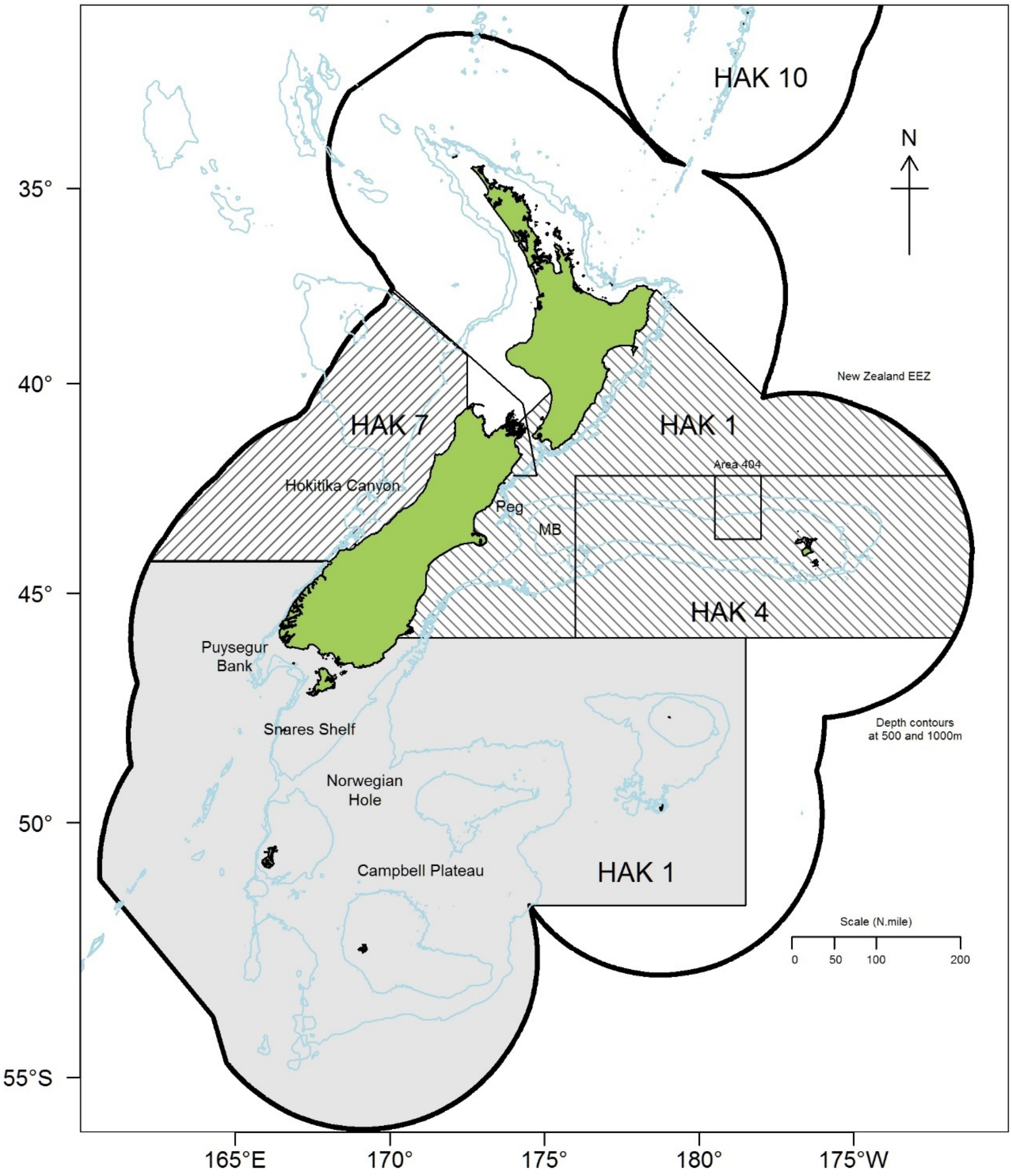


Figure 1: Quota Management Areas (QMAs) HAK 1, 4, 7, and 10, and hake biological stock boundaries, as assumed in this report: West coast South Island (dark stripes over HAK 7), Chatham Rise (light stripes over HAK 1 and HAK 4), and Sub-Antarctic (grey shading over HAK 1). Place names referred to in the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

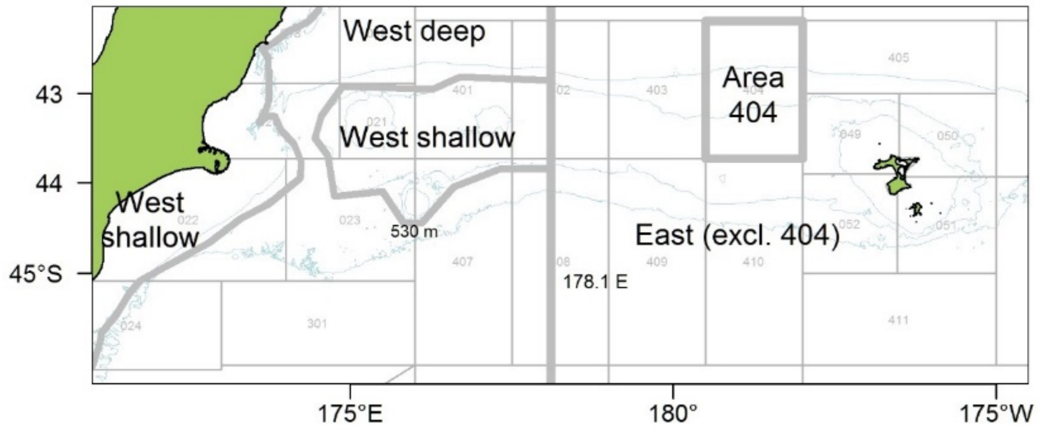


Figure 2a: Location and boundaries of the four Chatham Rise sub-areas used in this analysis: West deep (at least 530 m deep); West shallow (less than 530 m deep); East, excluding Statistical Area 404; and Statistical Area 404.

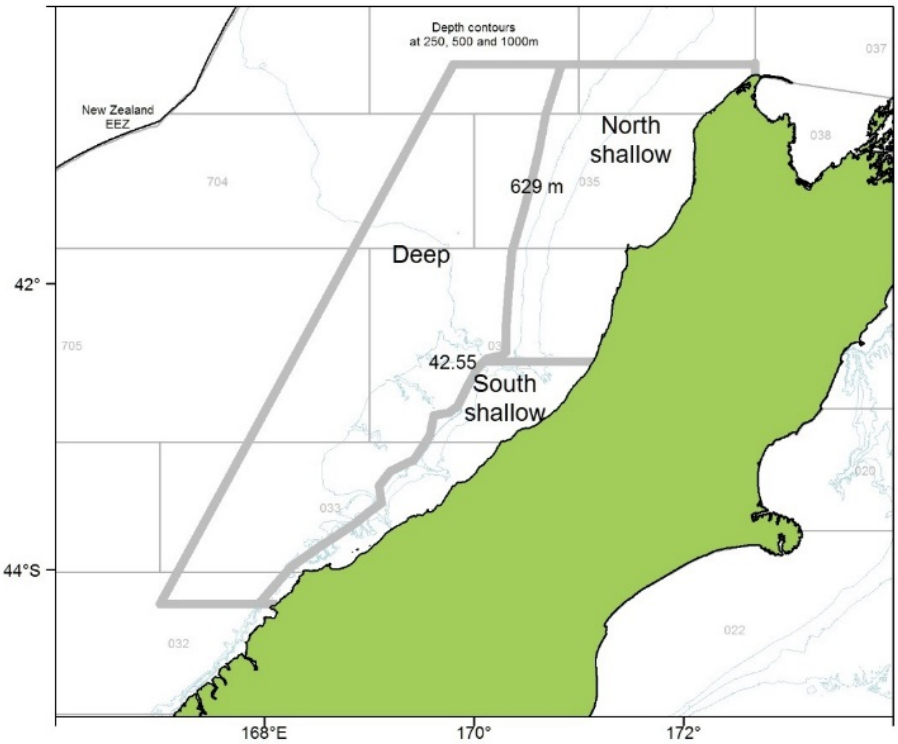


Figure 2b: Location and boundaries of the three WCSI sub-areas used in this analysis: Deep (at least 530 m deep); North shallow (less than 530 m deep, north of 42.55° S); South shallow (less than 530 m deep, south of 42.55° S).

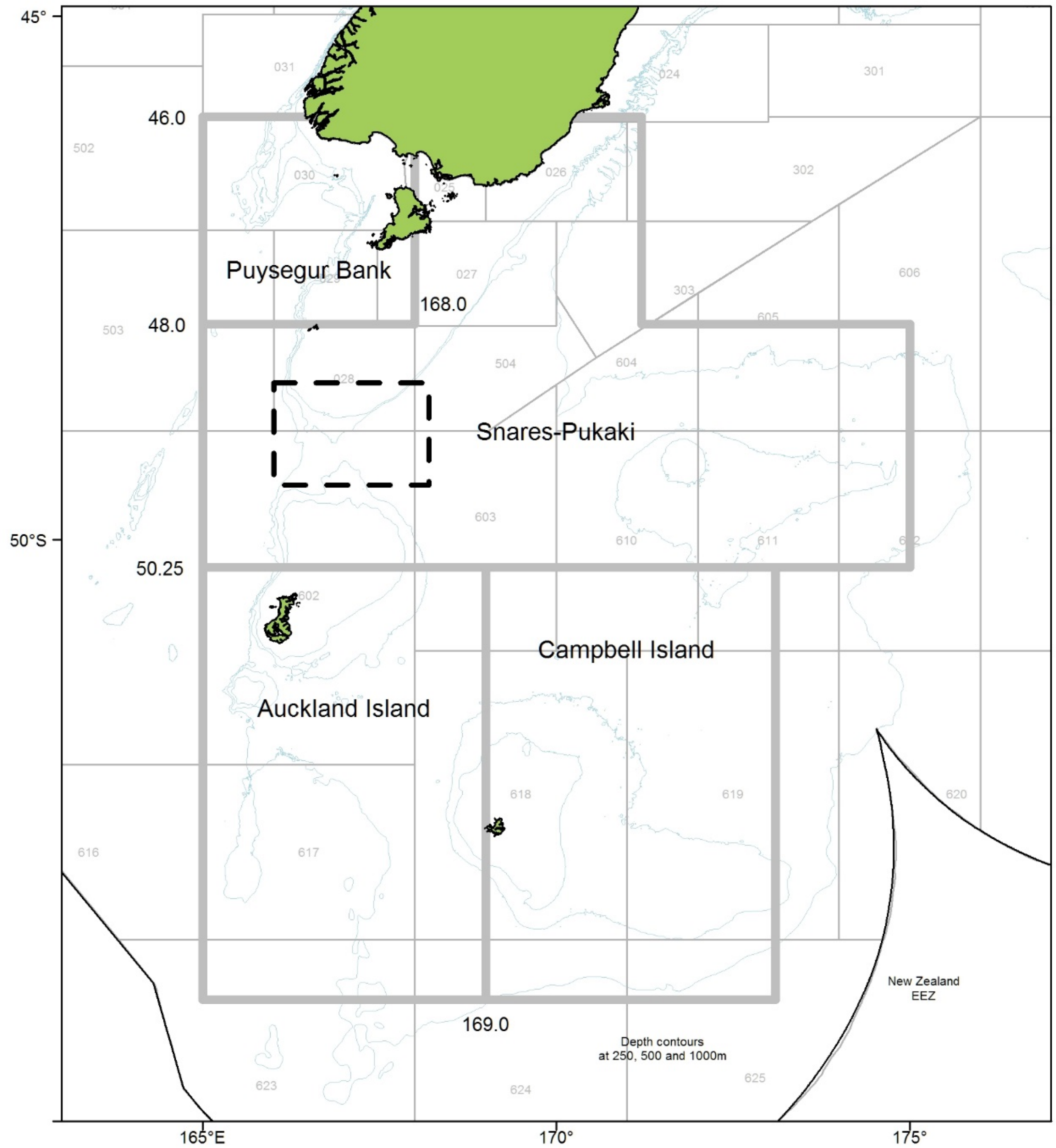


Figure 2c: Location and boundaries of the four Sub-Antarctic sub-areas: Puysegur Bank; Snares-Pukaki; Auckland Island; and Campbell Island. Dashed lines show the Snares-Pukaki box used in the CPUE analysis. SA (north) and SA (south) are any Sub-Antarctic positions to the north and south of 49º S not in these four main areas.

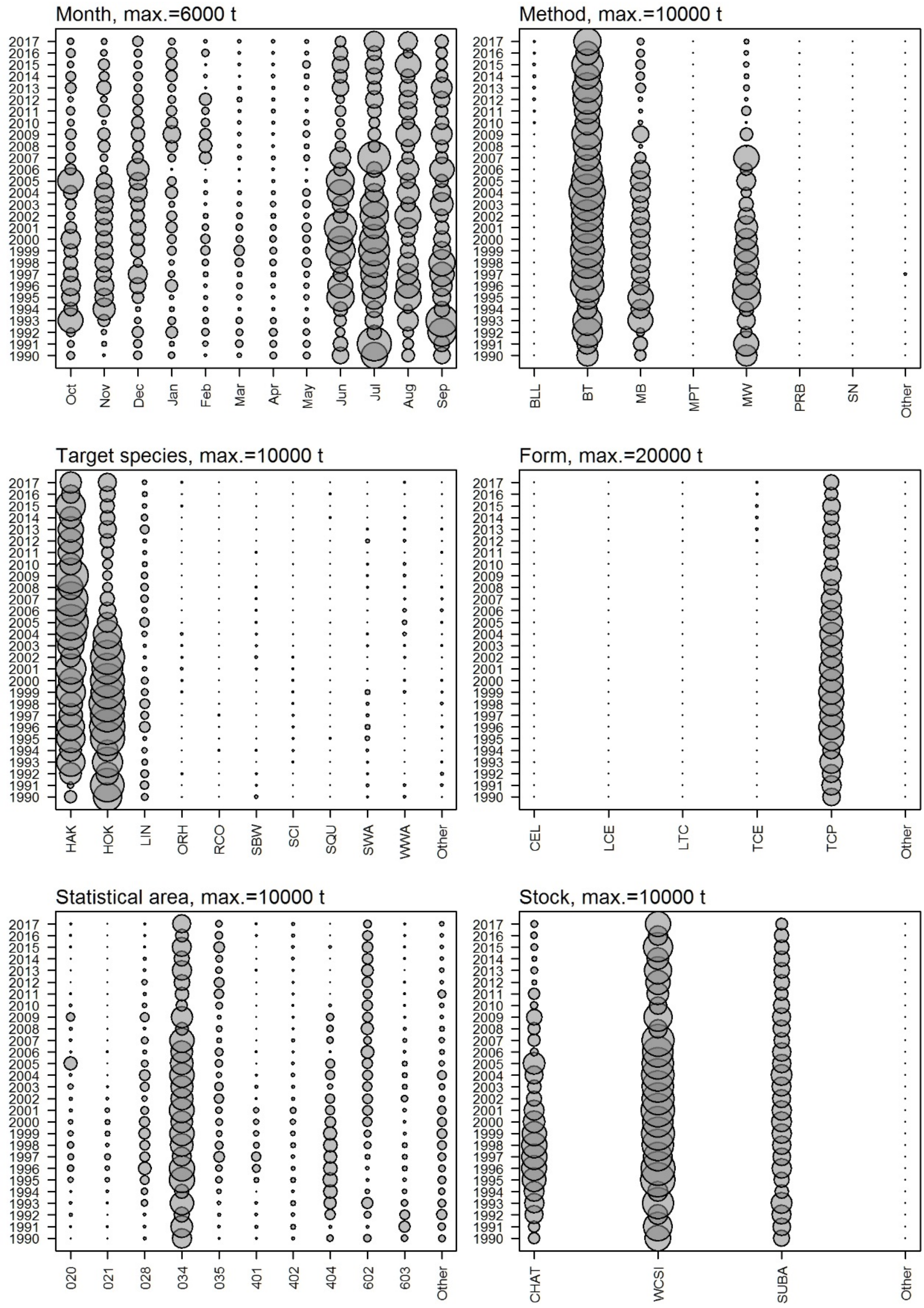


Figure 3a: Distribution of overall hake catch by month, statistical area, method, target species, form type, and area by fishing year since 1989–90 (1990). Circle size is proportional to catch; maximum circle size is indicated on the top of each plot. Statistical areas and sub-areas are defined in Figure 2. Form types: CEL is Catch, Effort, Landing Return; LCE is Lining Catch Effort Return; 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; PRB, bottom trawl precision seafood harvesting; SN, set net. Species codes: HAK, hake; HOK, hoki; LIN, ling; ORH, orange roughy; RCO, red cod; SBW, southern blue whiting; SCI, scampi; SQU, arrow squid; SWA, silver warehou; WWA, white warehou.

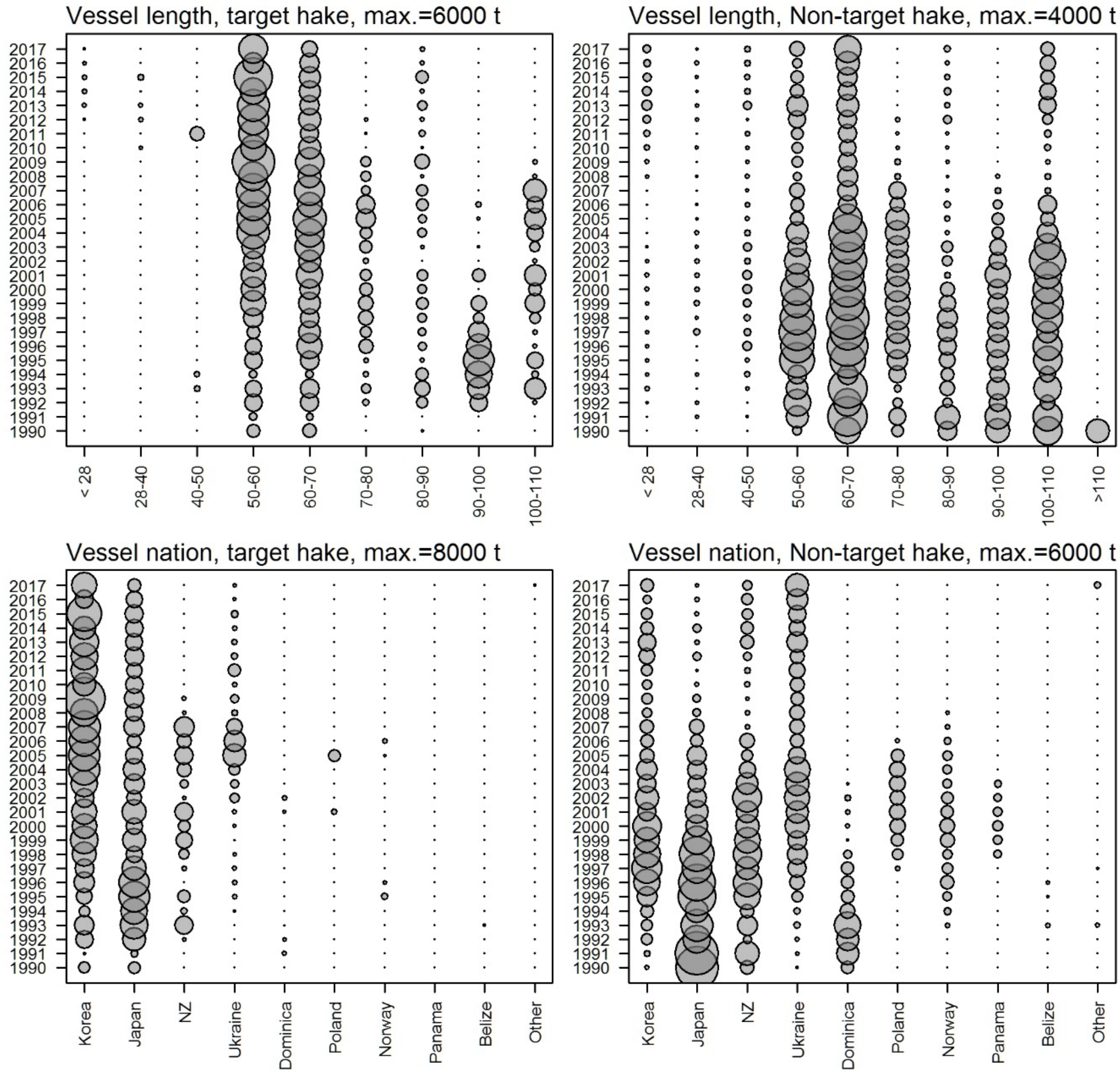


Figure 3a: continued. Distribution of overall target and non-target hake catch by vessel length and nationality by fishing year since 1989–90 (1990). Circle size is proportional to catch; maximum circle size is indicated on the top of each plot.

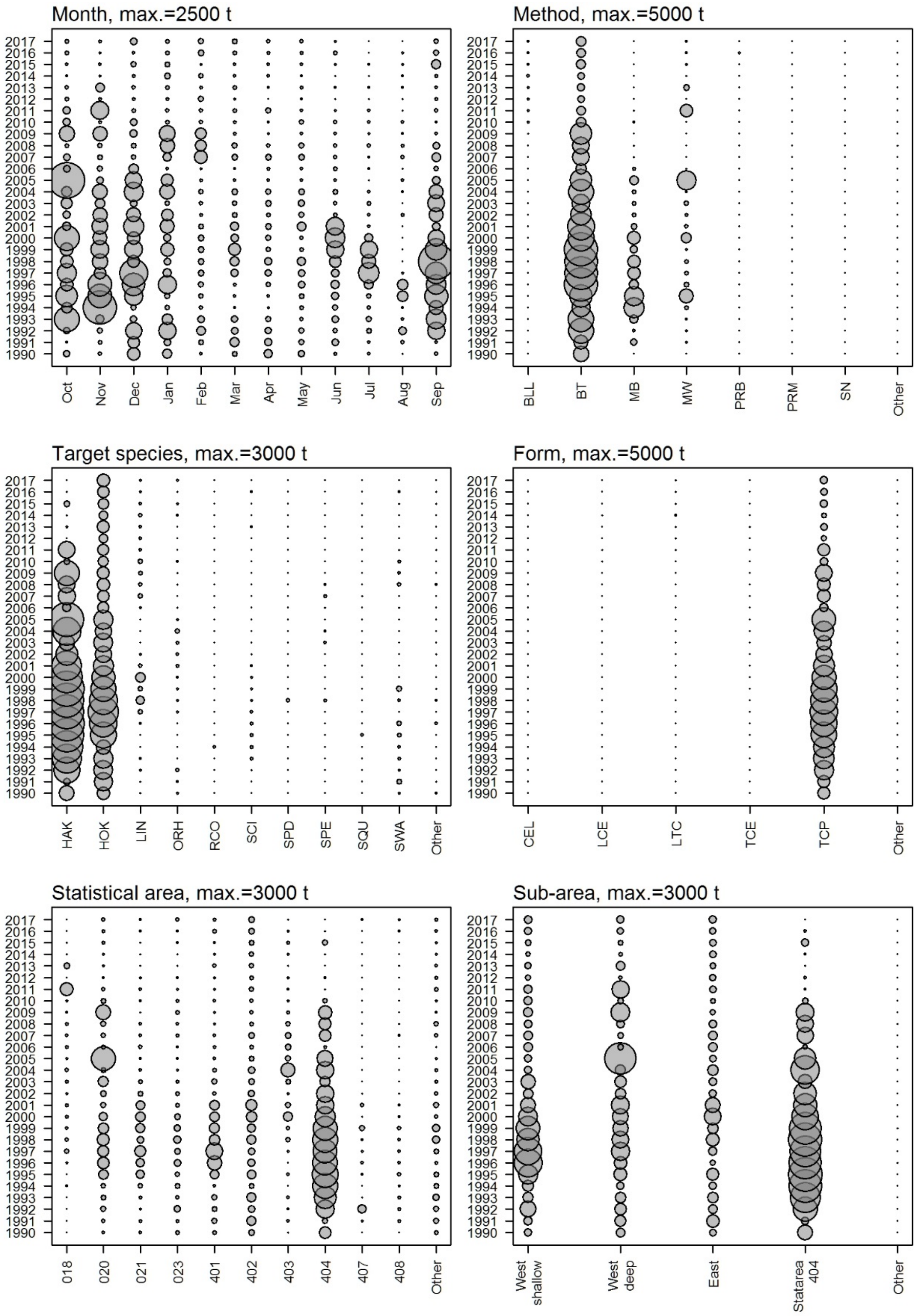


Figure 3b: Distribution of Chatham Rise hake catch by month, statistical area, method, target species, form type, and sub-area by fishing year since 1989–90 (1990). Circle size is proportional to catch; maximum circle size is indicated on the top of each plot. Statistical areas and sub-areas are defined in Figure 2. Form types: CEL is Catch, Effort, Landing Return; LCE is Lining Catch Effort Return; 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; MW, midwater trawl; PRB is precision harvesting bottom trawl; PRM is precision harvesting midwater trawl; SN, set net. 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.

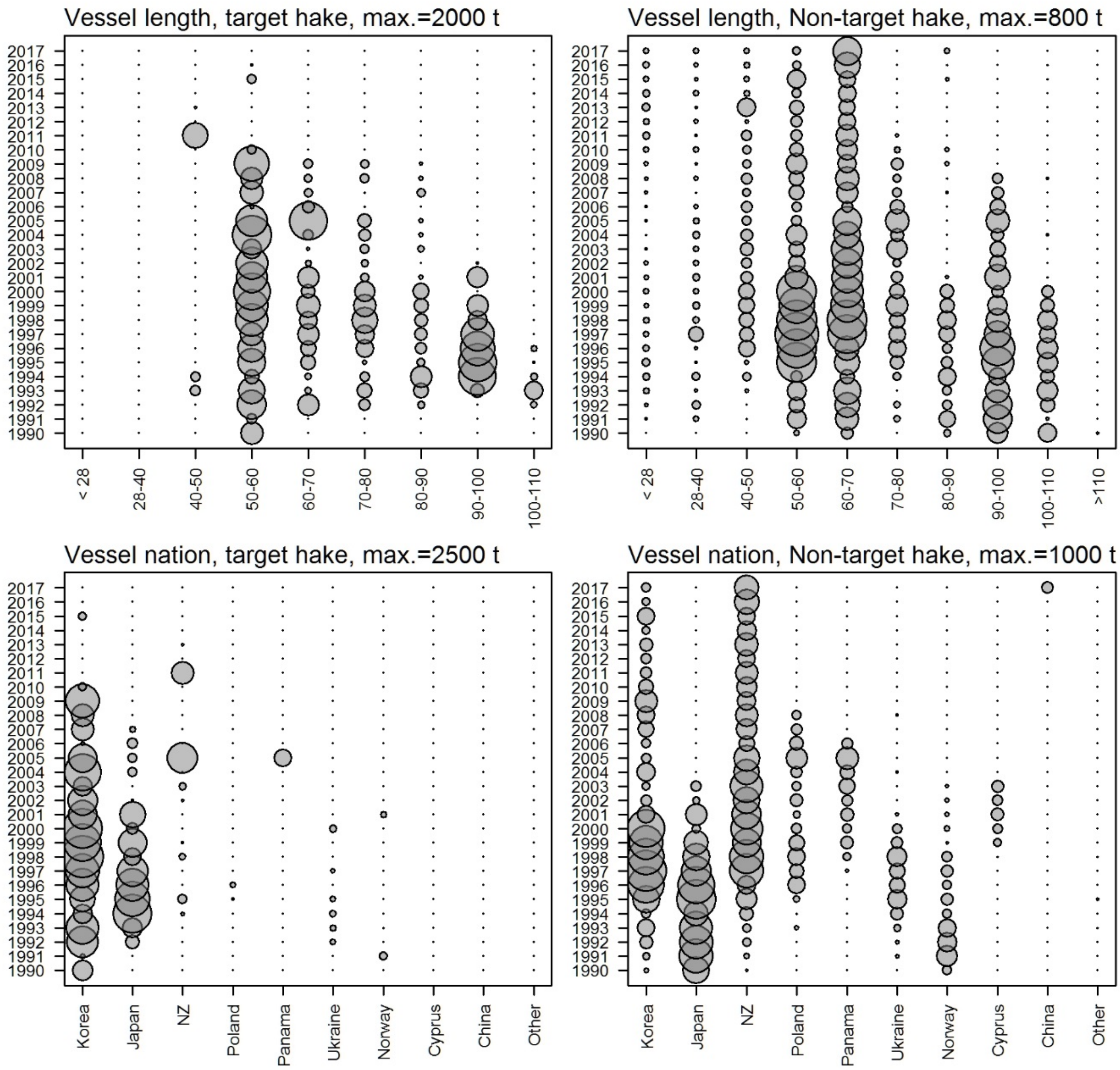


Figure 3b: continued. Distribution of Chatham Rise target and non-target hake catch by vessel length and nationality by fishing year since 1989–90 (1990). Circle size is proportional to catch; maximum circle size is indicated on the top of each plot.

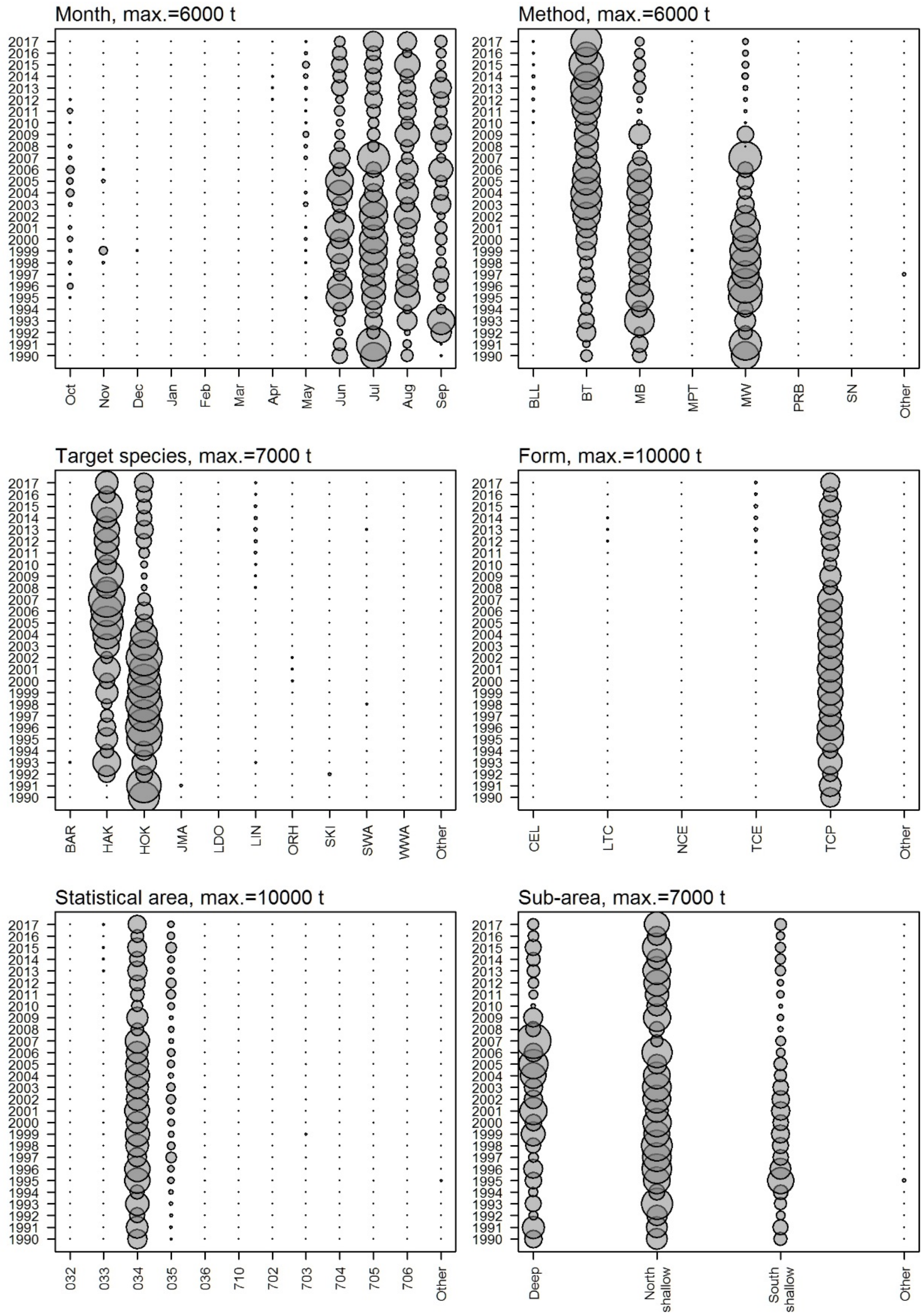


Figure 3c: Distribution of WCSI TCEPR tow-by-tow hake trawl catch by month, statistical area, method, target species, form type, and sub-area by fishing year since 1989–90 (1990). Circle size is proportional to catch; maximum circle size is indicated on the top of each plot. Statistical areas and sub-areas are defined in Figure 2. Form types: CEL is Catch, Effort, Landing Return; LTC is Lining Trip Catch, Effort return; NCE is Netting 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; PRB is precision harvesting bottom trawl; SN, set net. Species codes: BAR, barracouta; HAK, hake; HOK, hoki; JMA, jack mackerels; LDO, lookdown dory; LIN, ling; ORH, orange roughy; SKI, gemfish; SWA, silver warehou; WWA, white warehou.

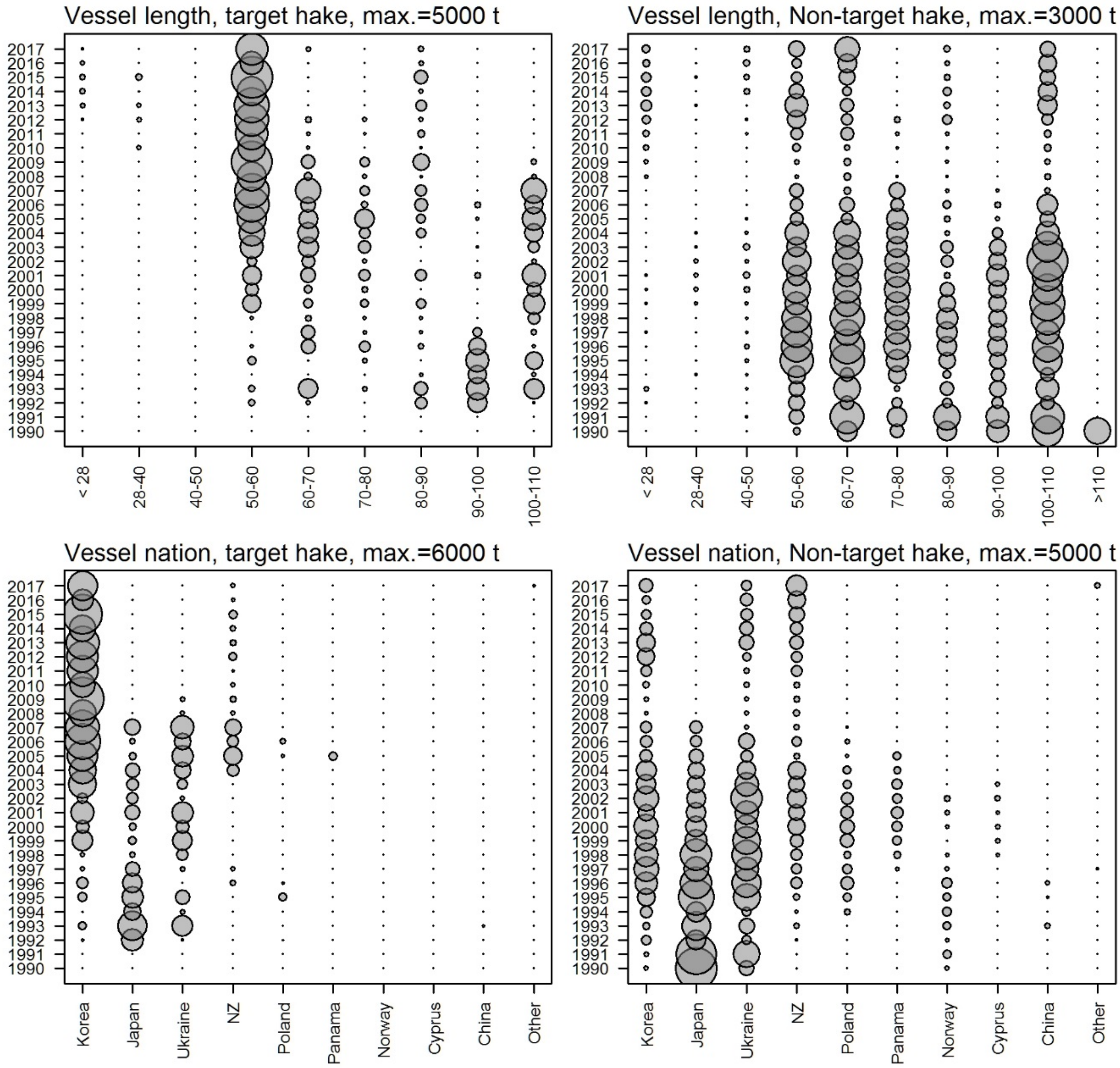


Figure 3c: continued. Distribution of WCSI target and non-target hake catch by vessel length and nationality by fishing year since 1989–90 (1990). Circle size is proportional to catch; maximum circle size is indicated on the top of each plot.

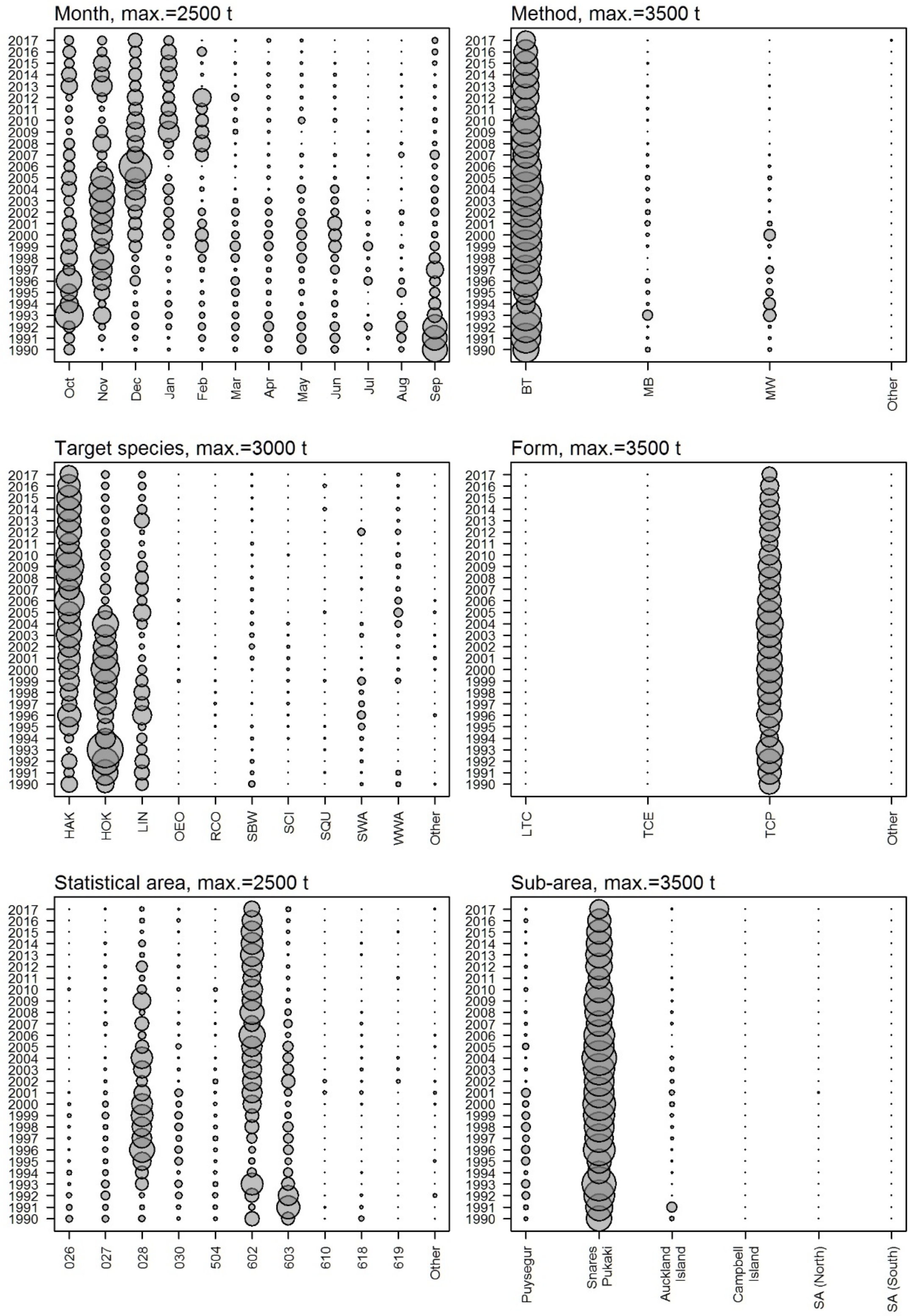


Figure 3d: Distribution of Sub-Antarctic hake catch by month, statistical area, method, target species, form type, and sub-area by fishing year since 1989–90 (1990). Circle size is proportional to catch; maximum circle size is indicated on the top of each plot. Statistical areas and sub-areas are defined 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: 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; RCO, red cod; SBW, southern blue whiting; SCI, scampi; SQU, arrow squid; SWA, silver warehou; WWA, white warehou.

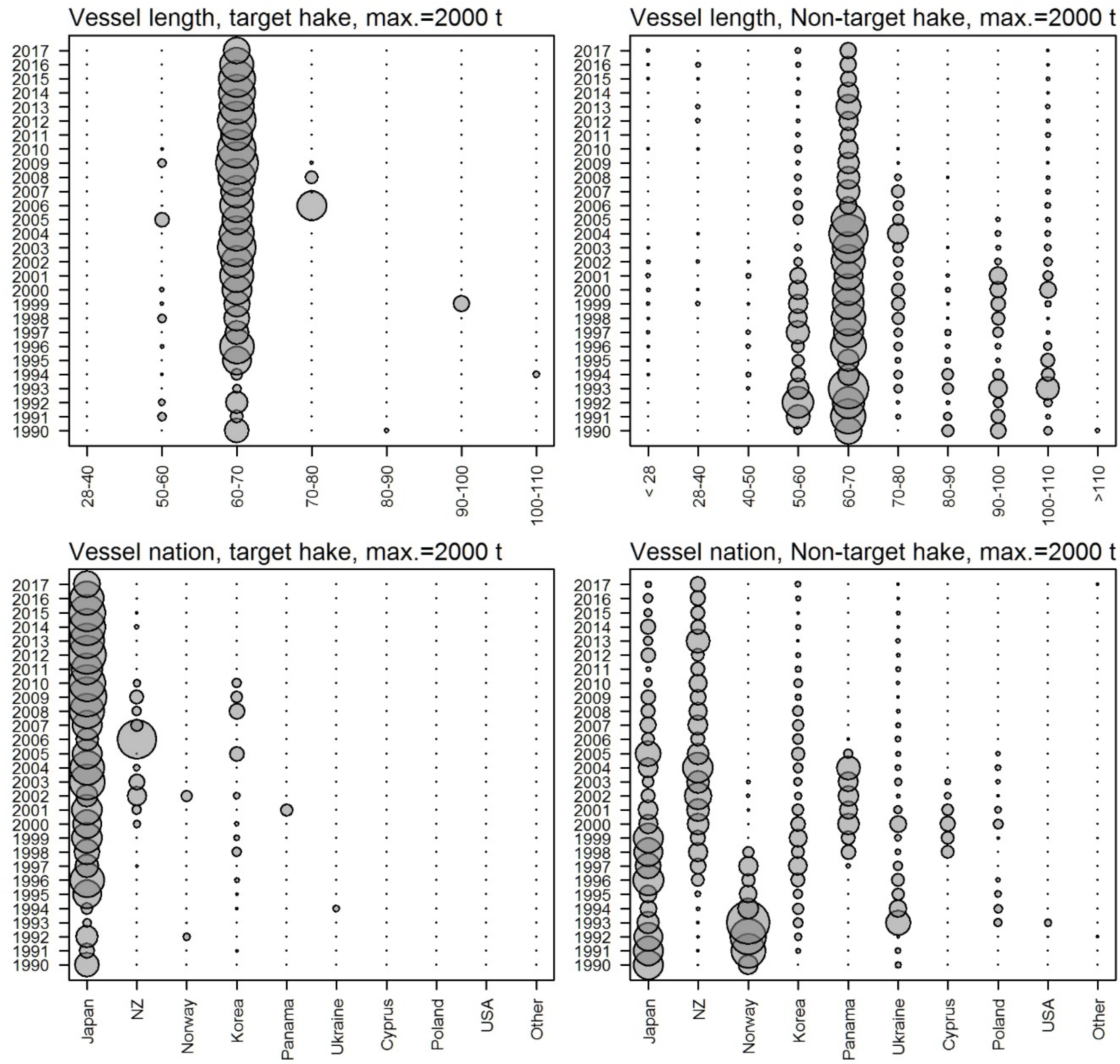


Figure 3d: continued. Distribution of Sub-Antarctic target and non-target hake catch by vessel length and nationality by fishing year since 1989–90 (1990). Circle size is proportional to catch; maximum circle size is indicated on the top of each plot.

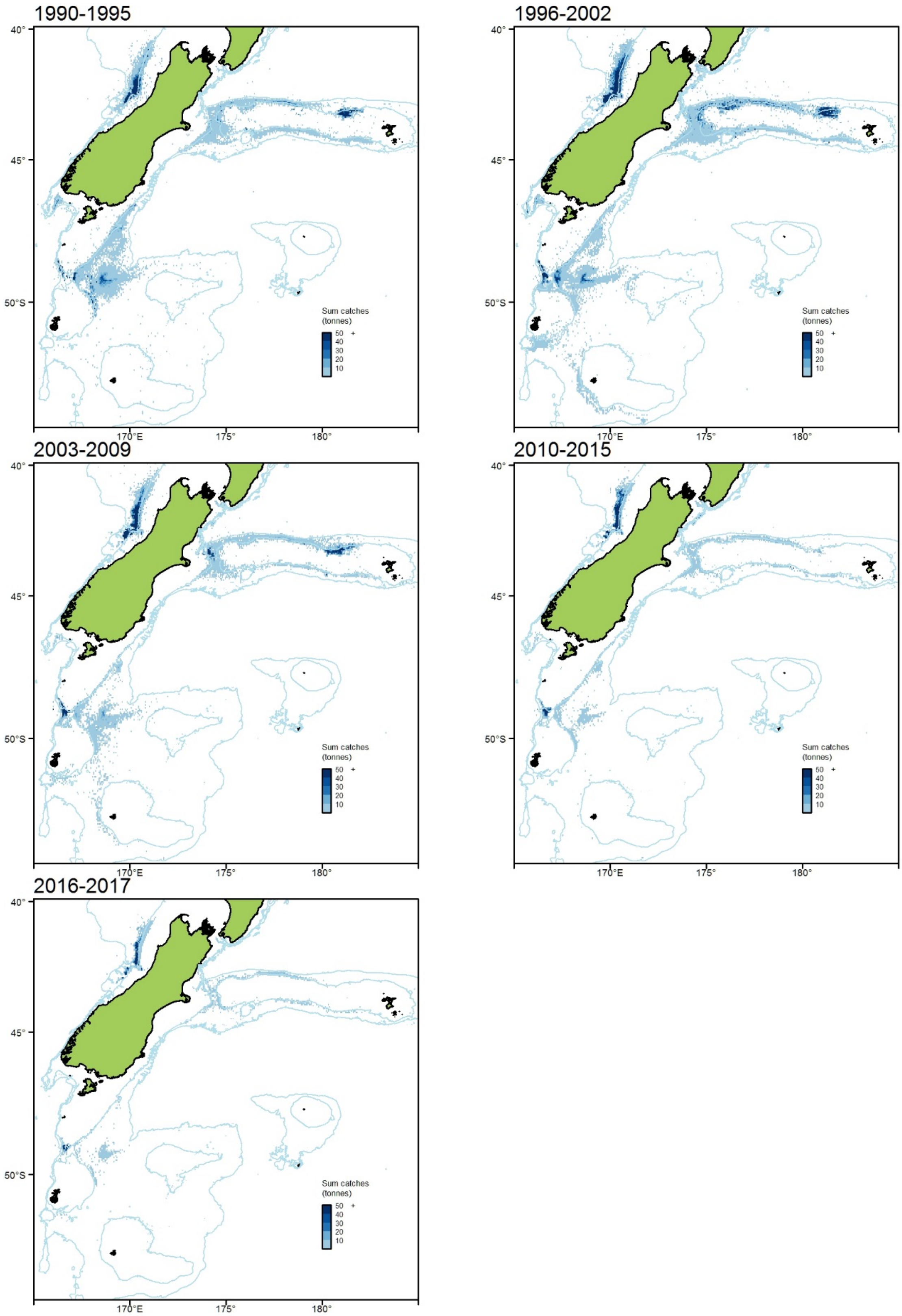


Figure 4: Density plots of commercial hake catches from TCEPR tow-by-tow records for target hake and hoki tows for fishing year combined blocks.

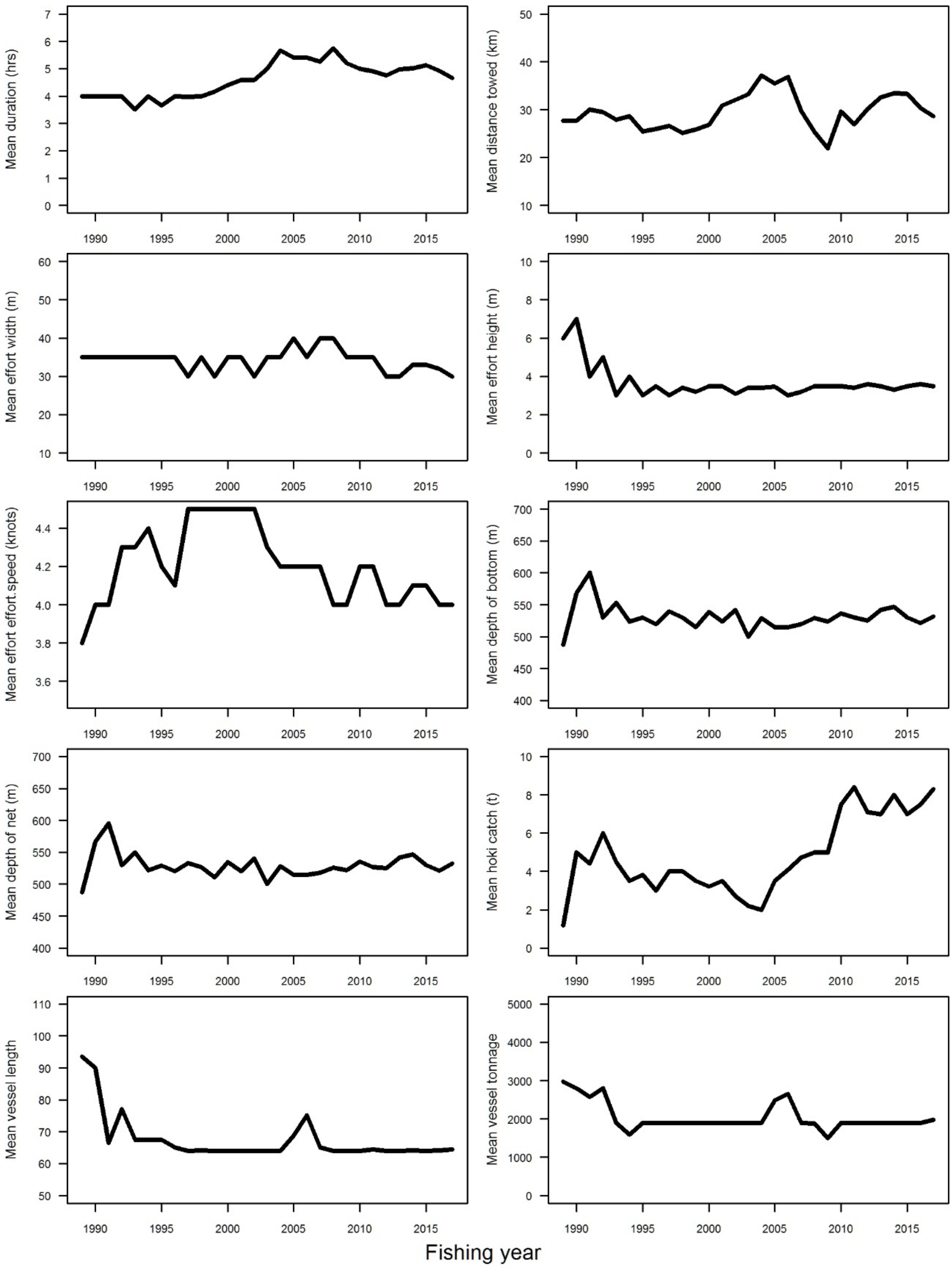


Figure 5a: Means of effort variables by fishing year for Chatham Rise vessels using bottom trawl targeting hake or hoki.

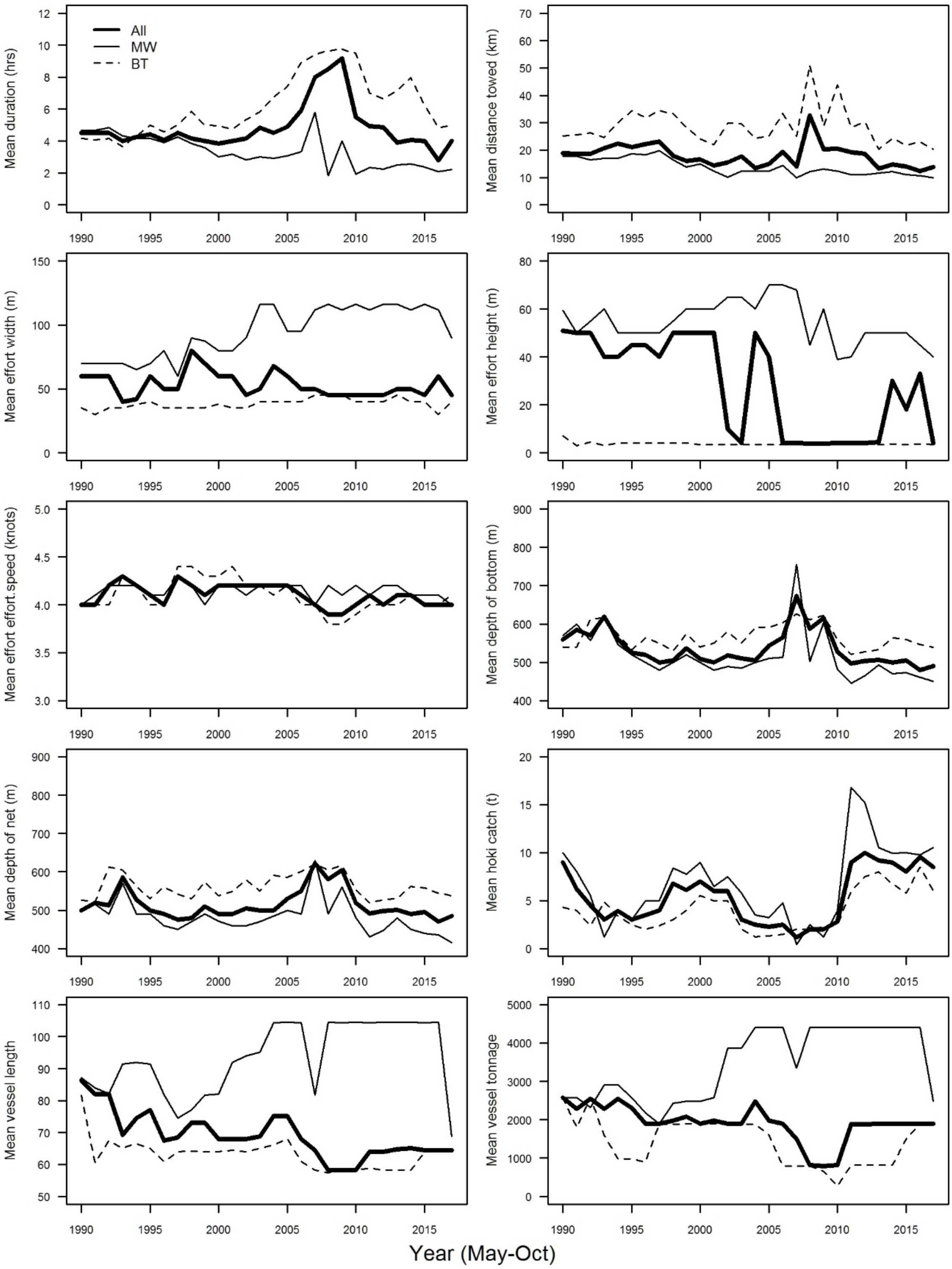


Figure 5b: Means of effort variables by fishing year for WCSI vessels targeting hake or hoki, for all tows (All), bottom tows (BT), and midwater tows (MW).

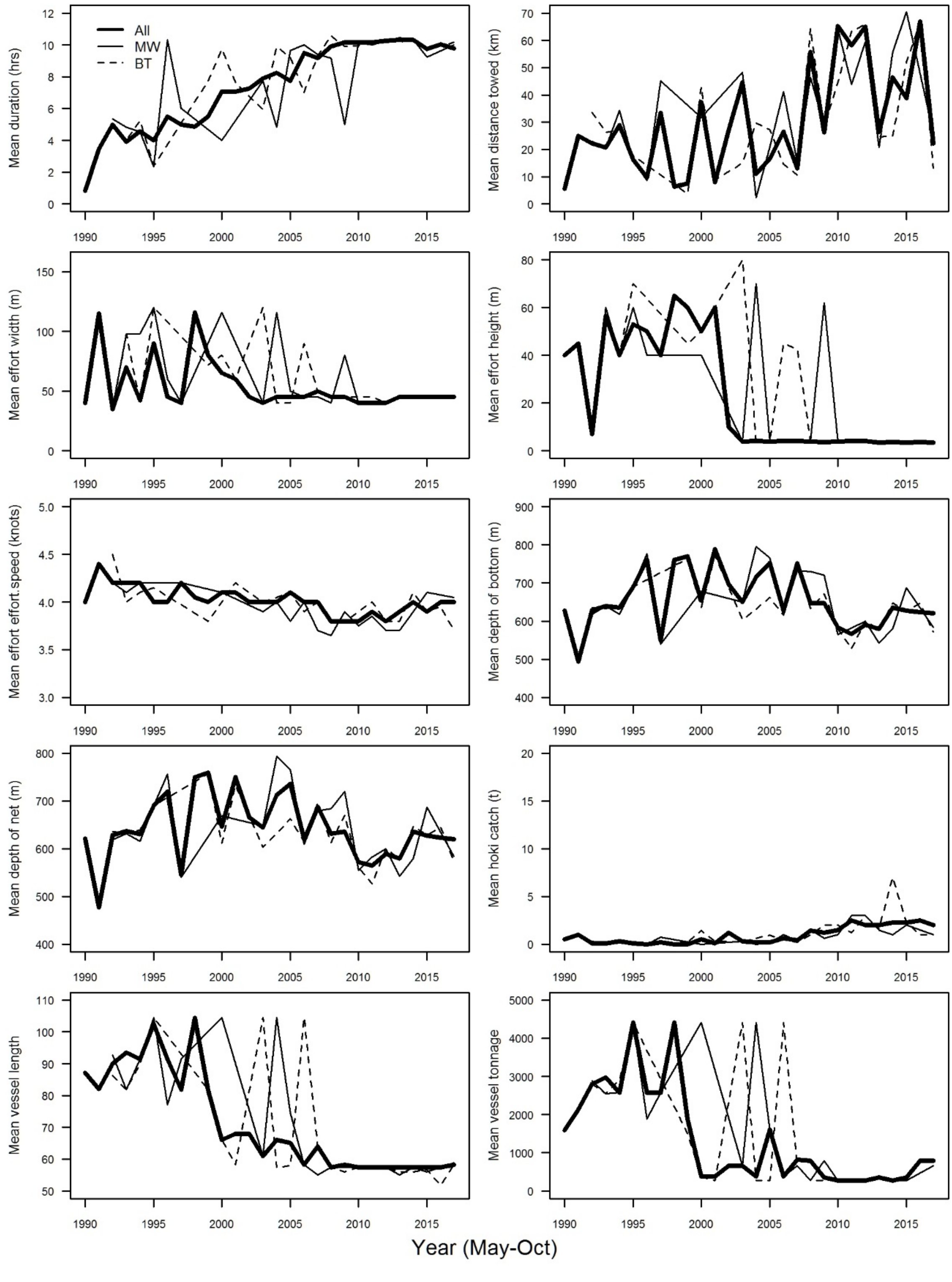


Figure 5c: Means of effort variables by fishing year for WCSI vessels targeting hake, for all tows (All), bottom tows (BT), and midwater tows (MW).

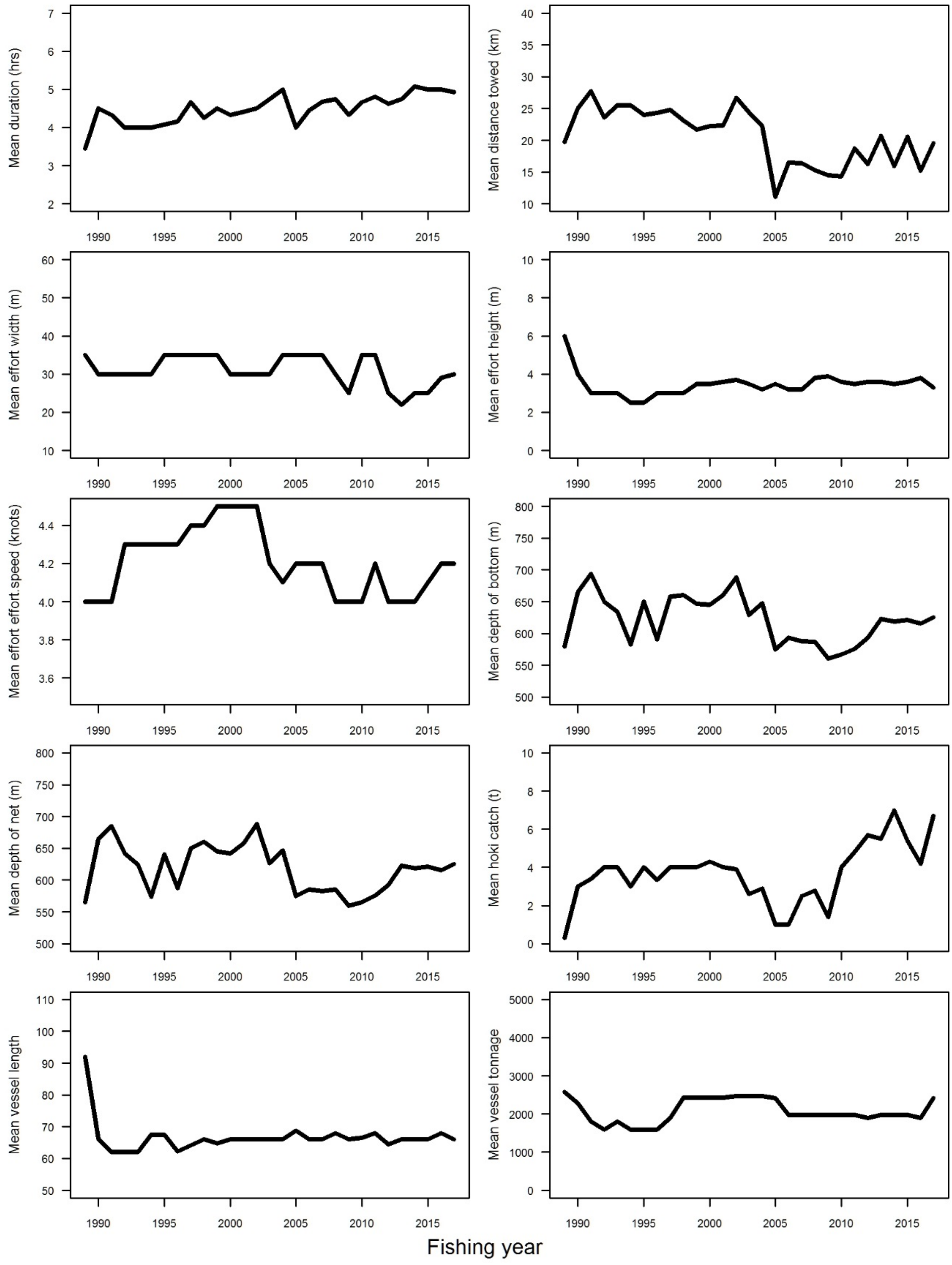
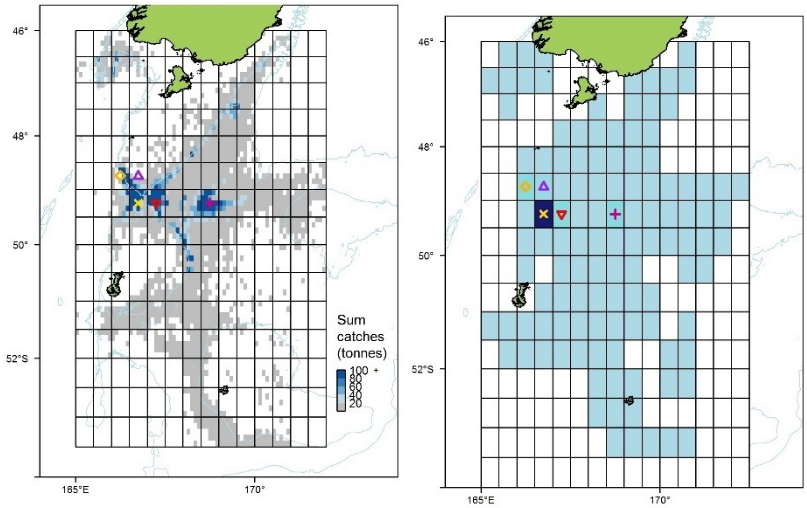
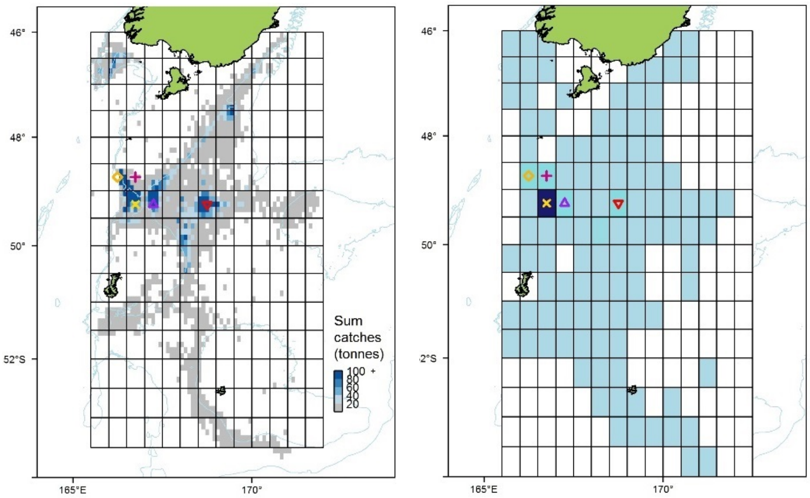


Figure 5d: Means of effort variables by fishing year for Sub-Antarctic vessels using bottom trawl targeting hake or hoki.

TCEPR tow-by-tow



TCEPR daily processed



Observer tow-by-tow

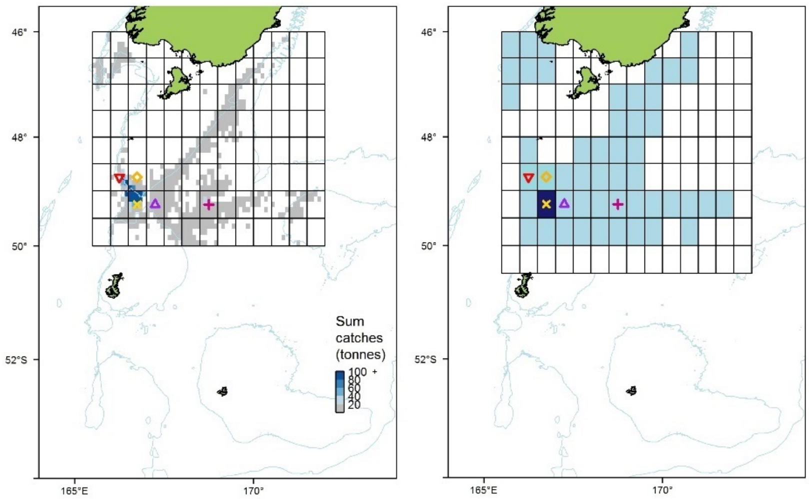
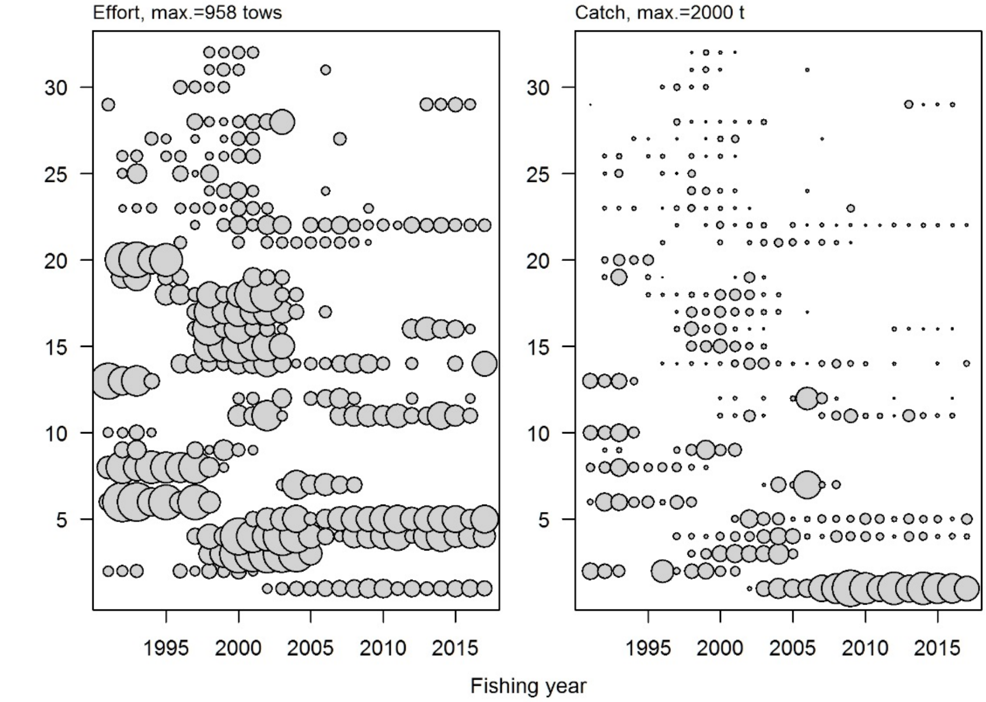


Figure 6: Density plots (latitude and longitude, and 0.5° grid cells) of commercial hake catches from TCEPR tow-by-tow, TCEPR daily processed and observer tow-by-tow datasets for records for target hake and hoki tows by for all fishing years combined showing grid cells with top cells marked (1: gold cross; 2: orange diamond; 3: red triangle; 4: red cross; 5: purple triangle).

TCEPR tow-by-tow



TCEPR daily processed

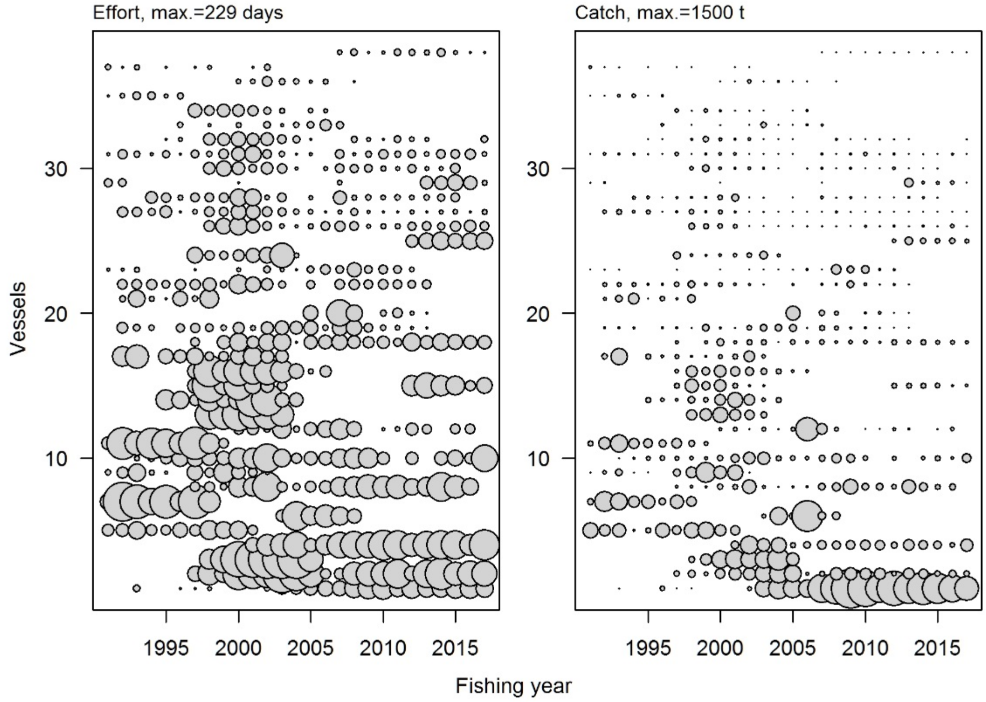


Figure 7: Trawl fishing effort and catches (where circle area is proportional to the effort or catch) by fishing year (September–August) for individual vessels (denoted anonymously by number on the *y*-axis) in the Sub-Antarctic 'core' CPUE analyses.

Observer tow-by-tow

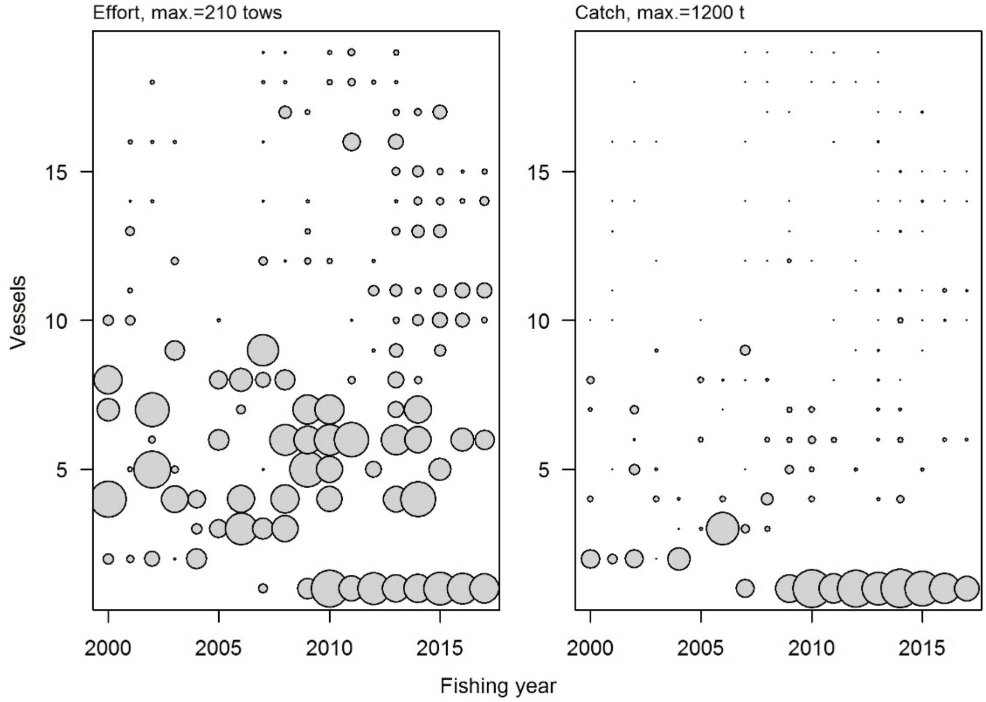


Figure 7: ctd.

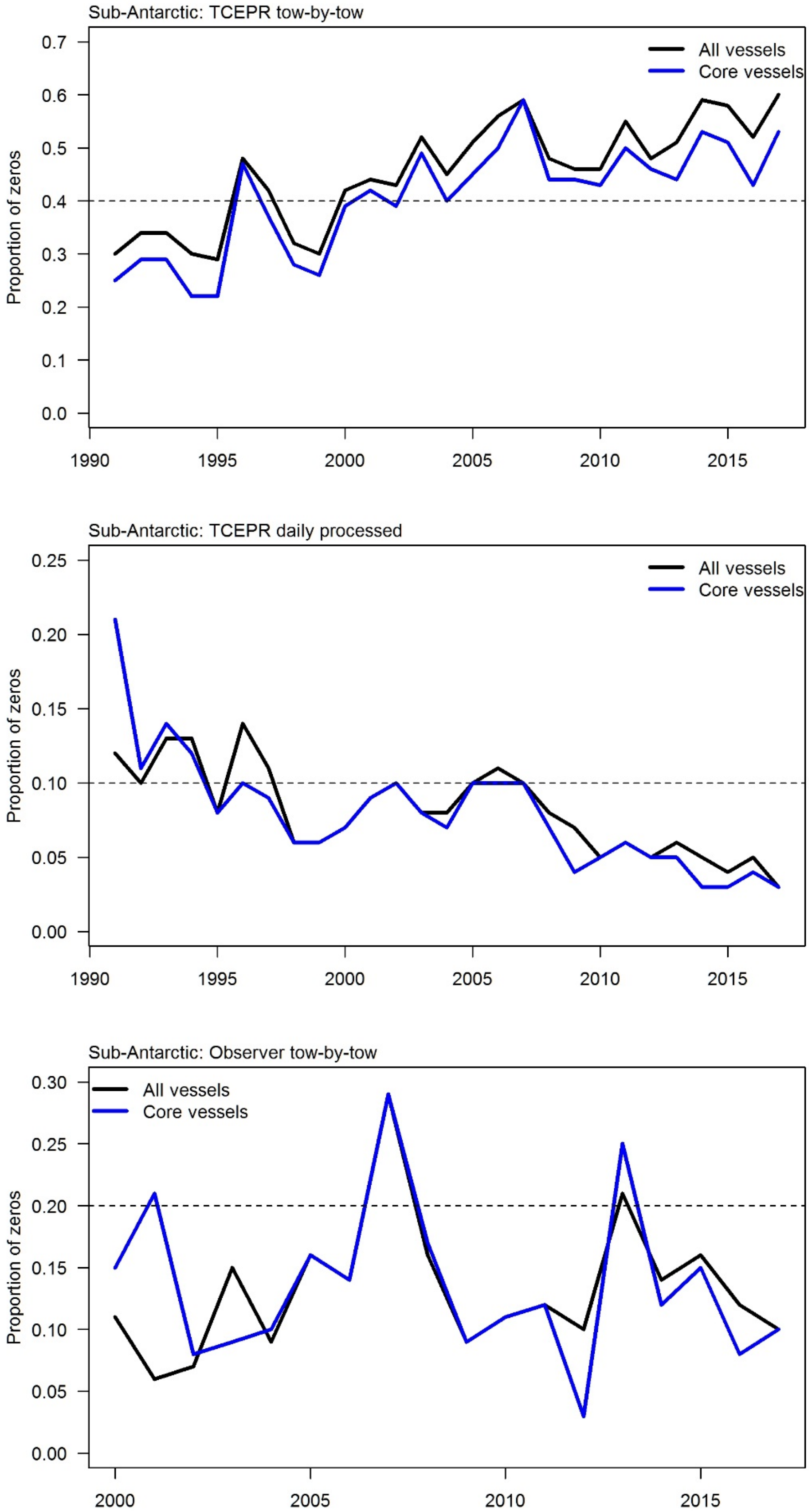
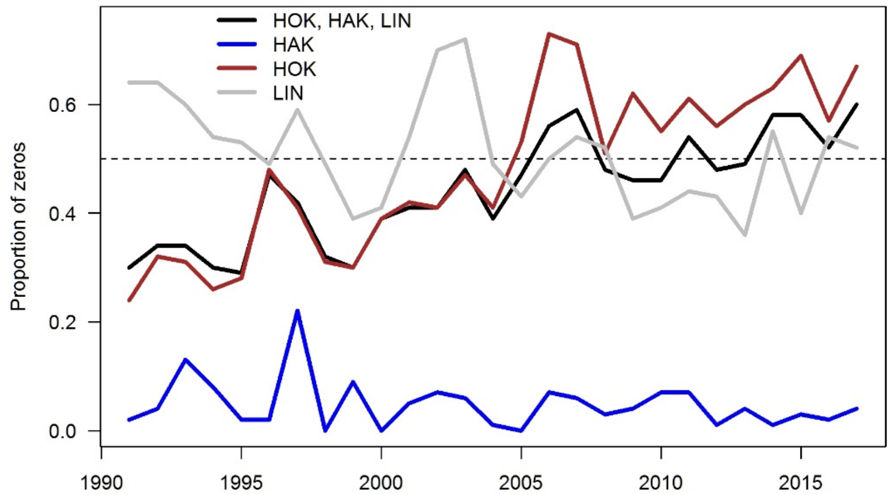
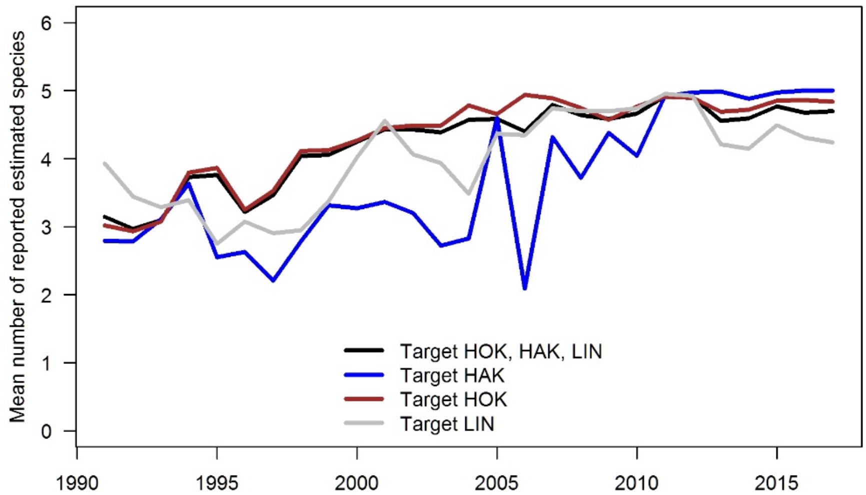


Figure 8a: Proportion of zeros for the Sub-Antarctic 'all vessel' and 'core vessel' datasets by year. Year is defined as September–August.

(b)



(c)



(d)

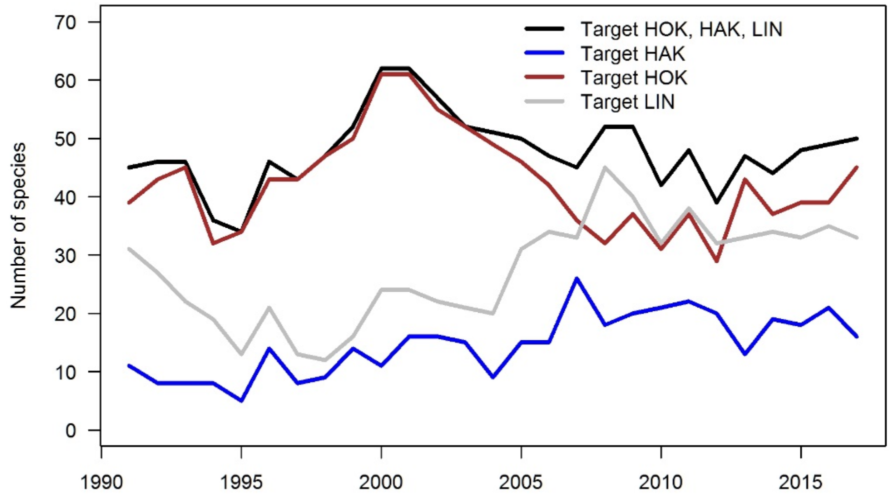
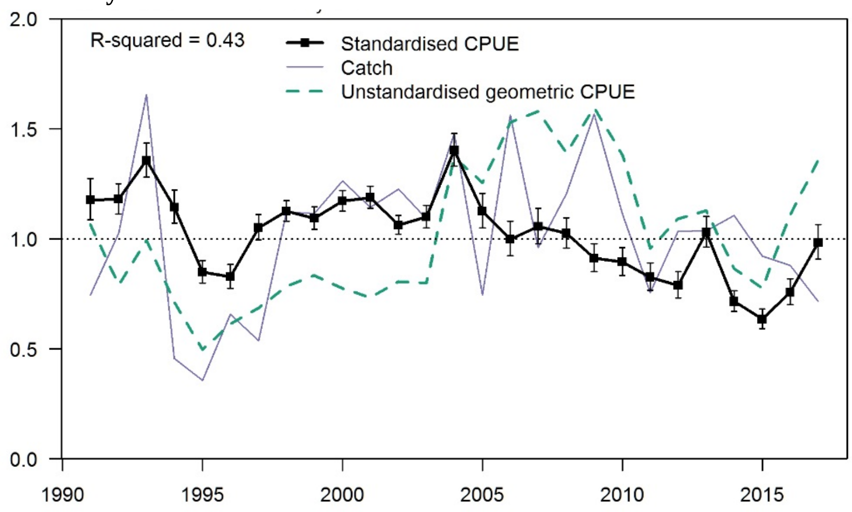
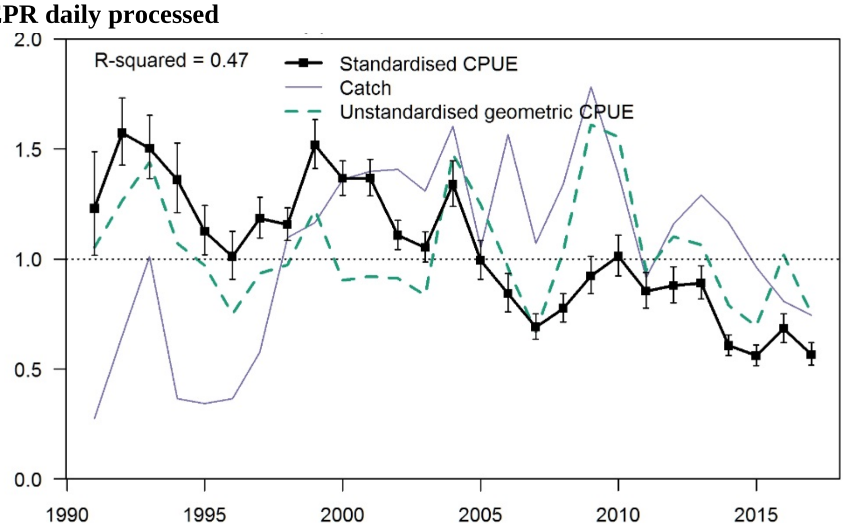


Figure 8: (b) Proportion of zeros for all Sub-Antarctic vessels by target species by year. (c) Mean number of species for which estimated catches are reported, by main target species. (d) Overall number of species for which estimated catches are reported, by main target species. Year is defined as September–August.

TCEPR tow-by-tow



TCEPR daily processed



Observer tow-by-tow

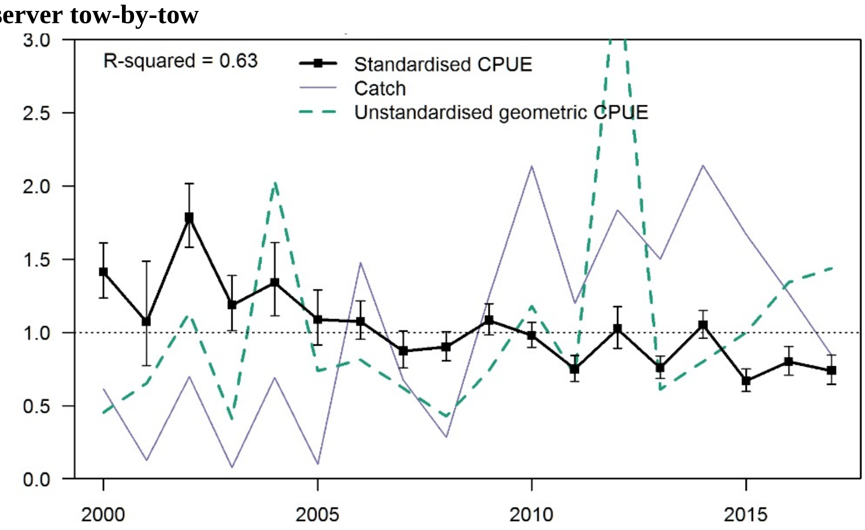
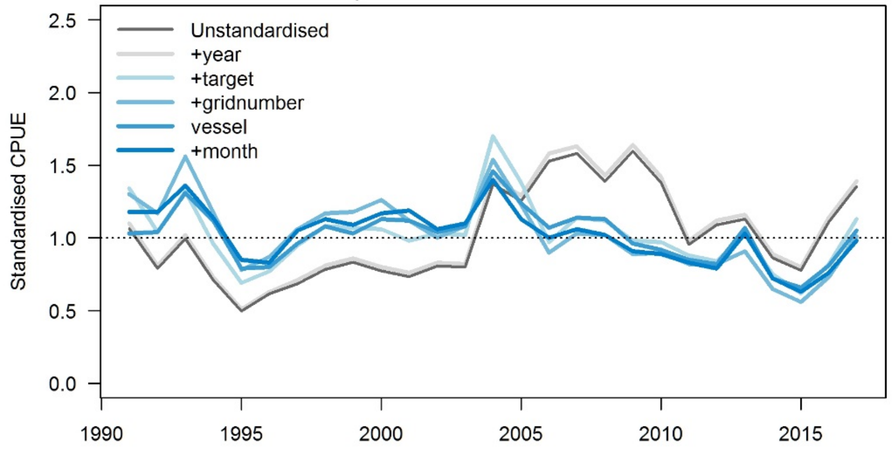
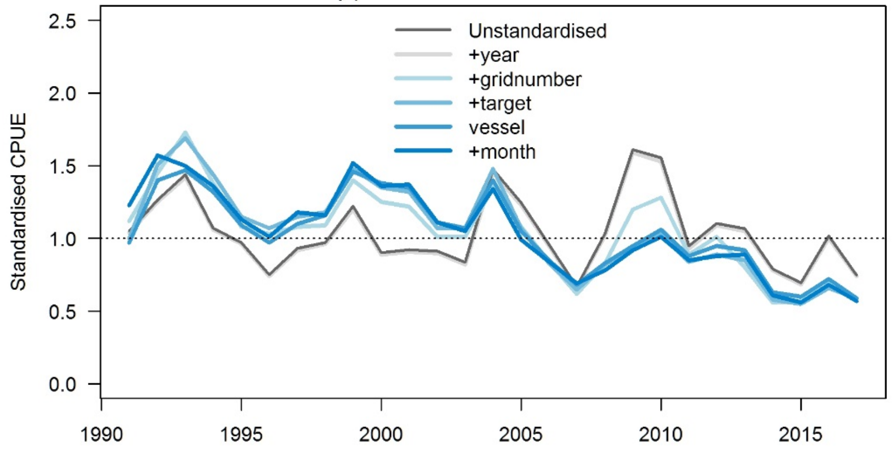


Figure 9: Standardised CPUE indices from the Sub-Antarctic lognormal models. Bars indicate 95% confidence intervals. Year defined as September–August.

TCEPR tow-by-tow



TCEPR daily processed



Observer tow-by-tow

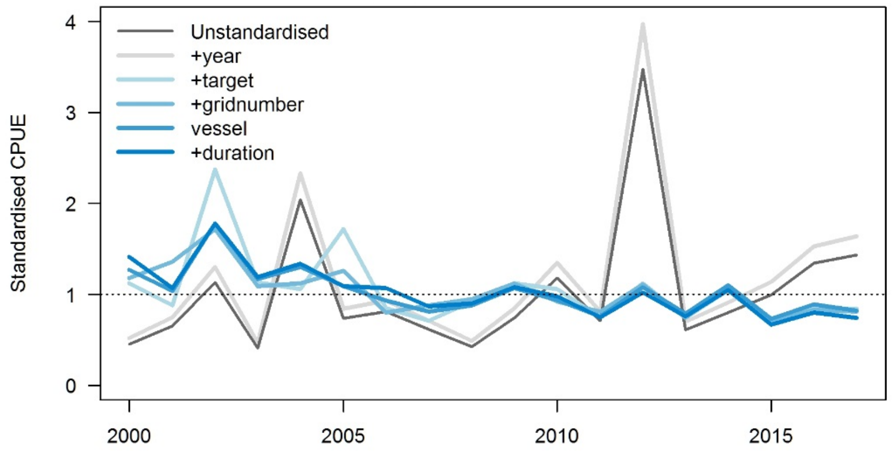
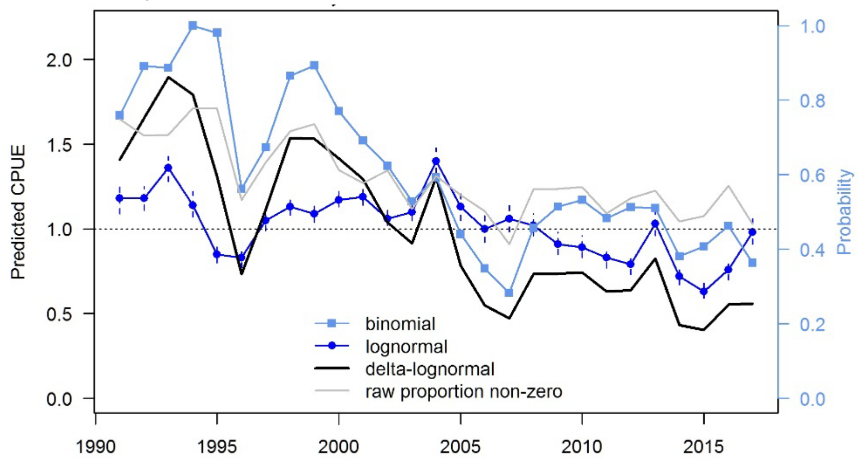
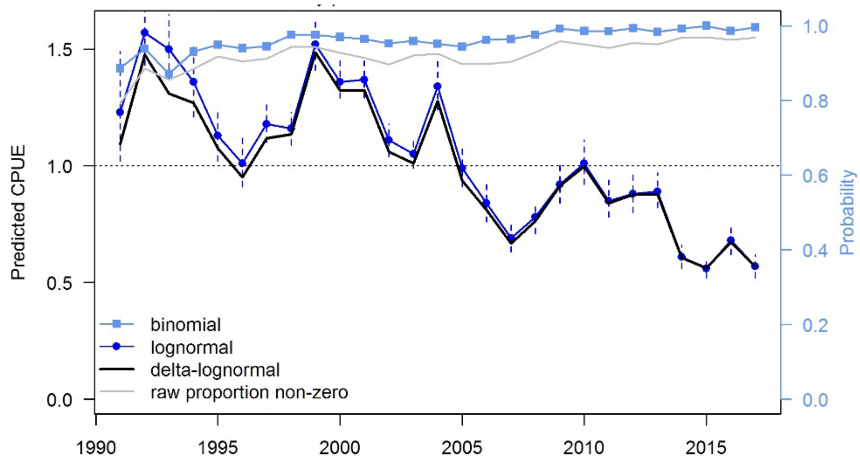


Figure 10: Standardised CPUE indices from the Sub-Antarctic lognormal model showing the effect of addition of variables. Year defined as September–August.

TCEPR tow-by-tow



TCEPR daily processed



Observer tow-by-tow

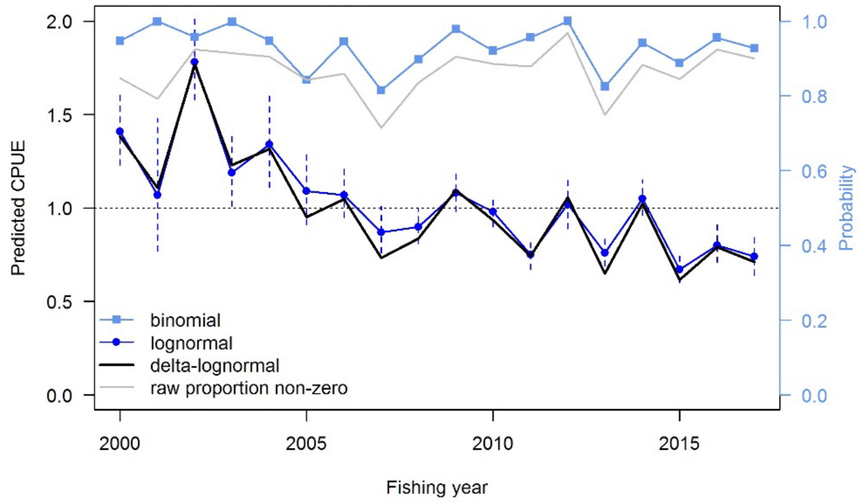
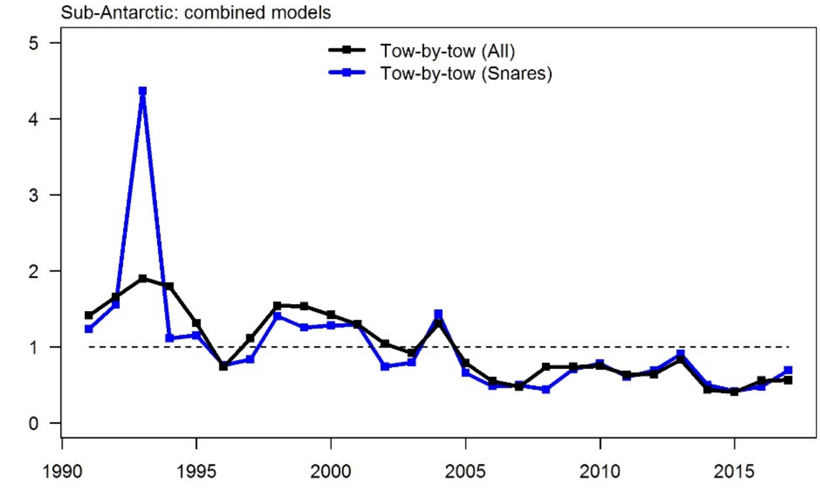
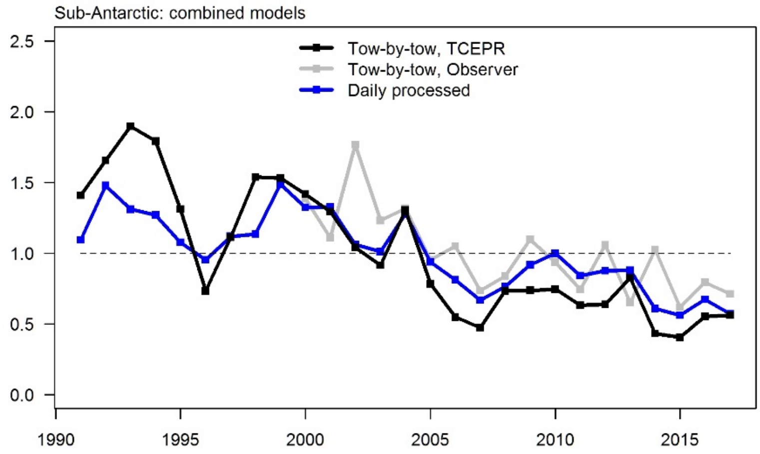


Figure 11: Standardised CPUE indices from the lognormal, binomial and combined model for each fishery. Bars indicate 95% confidence intervals. Year defined as September–August. The horizontal dotted line shows the mean of the combined series. The probability scale relates to the binomial and raw proportion non-zero series.





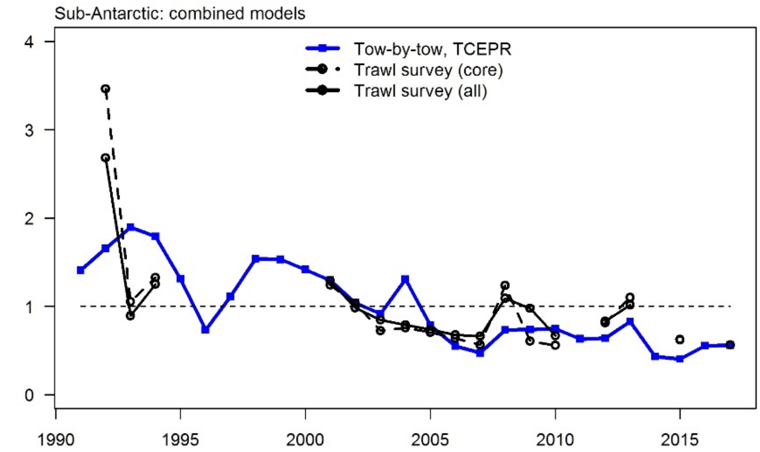
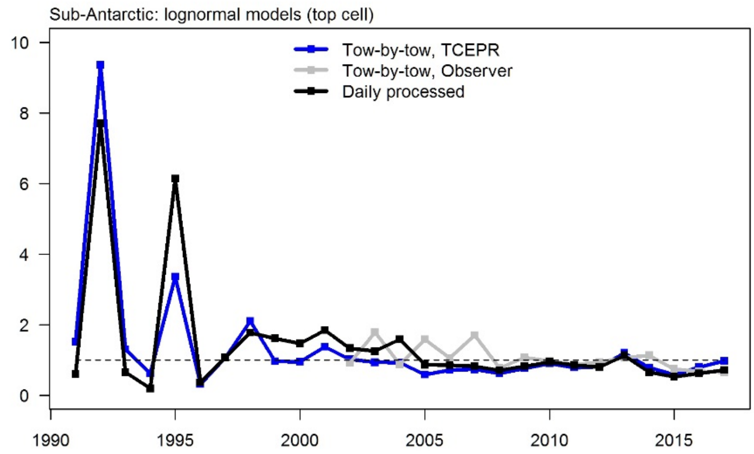
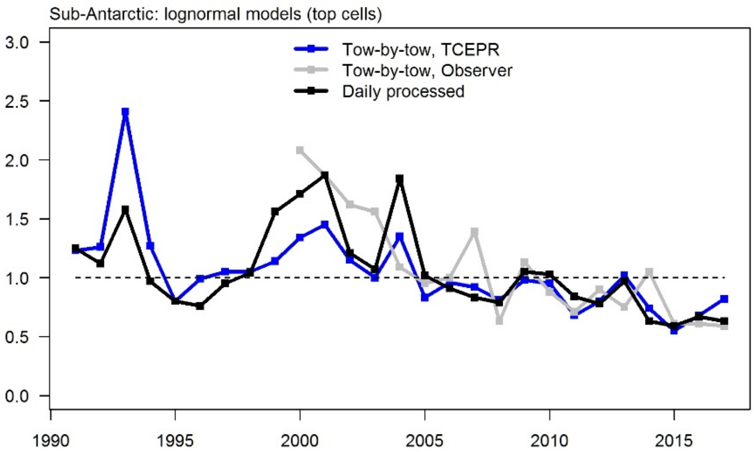


Figure 12: Comparison of combined hake indices. Trawl survey hake biomass indices have been standardised to a mean of one. Sub-Antarctic trawl survey indices are for core strata (300–800 m), and all strata (300–1000 m).





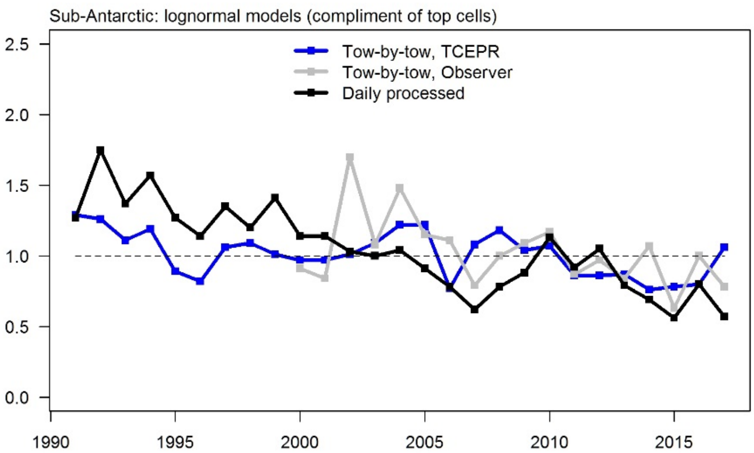


Figure 12: Continued

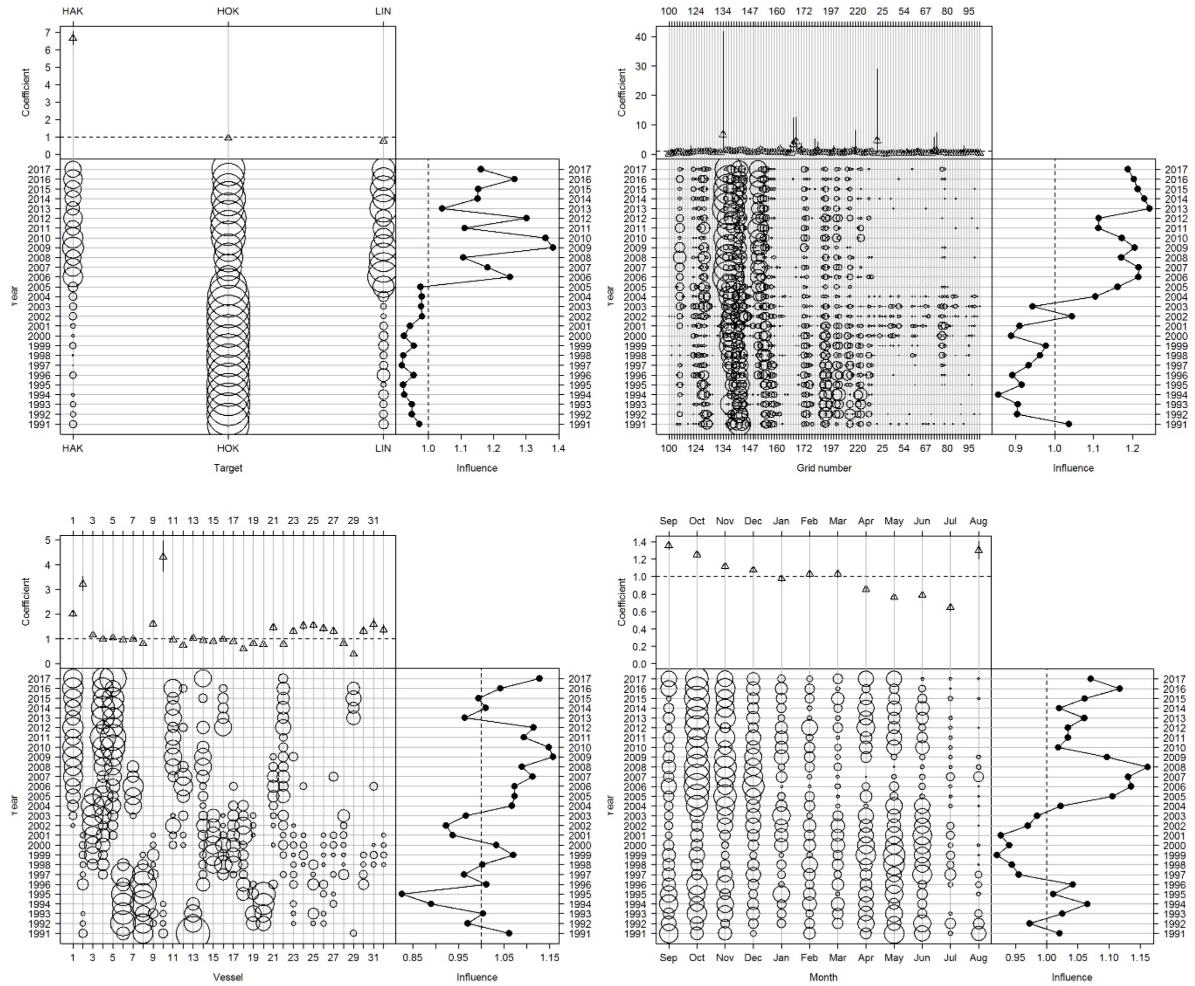


Figure 13a: Effect and influence of non-interaction term variables in the Sub-Antarctic tow-by-tow core vessel lognormal CPUE model. Top: relative effect by level of each variable. Bottom left: relative distribution of each variable by fishing year. Bottom right: influence of variable on unstandardised CPUE by fishing year.

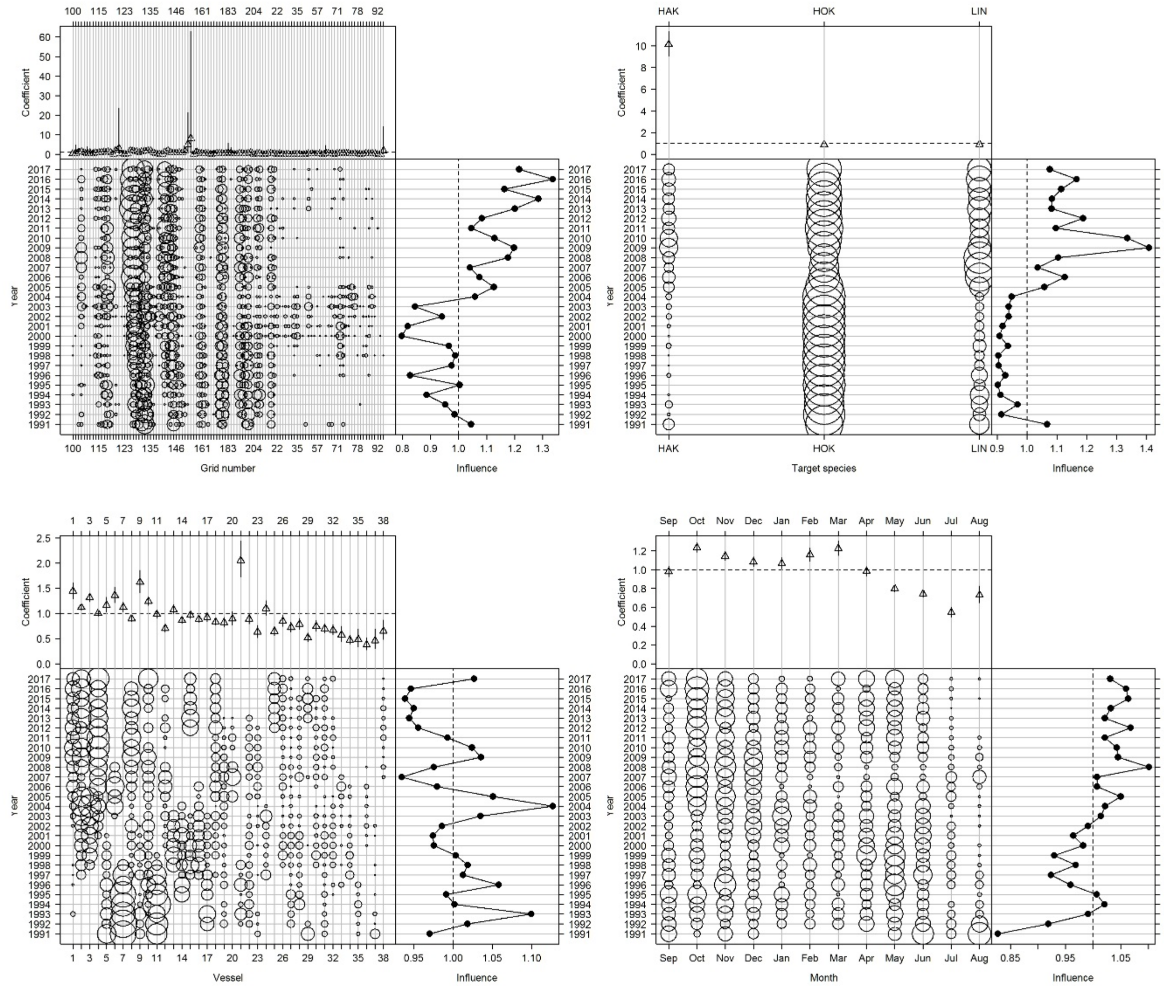


Figure 13b: Effect and influence of non-interaction term variables in the Sub-Antarctic daily processed core vessel lognormal CPUE model. Top: relative effect by level of each variable. Bottom left: relative distribution of each variable by fishing year. Bottom right: influence of variable on unstandardised CPUE by fishing year.

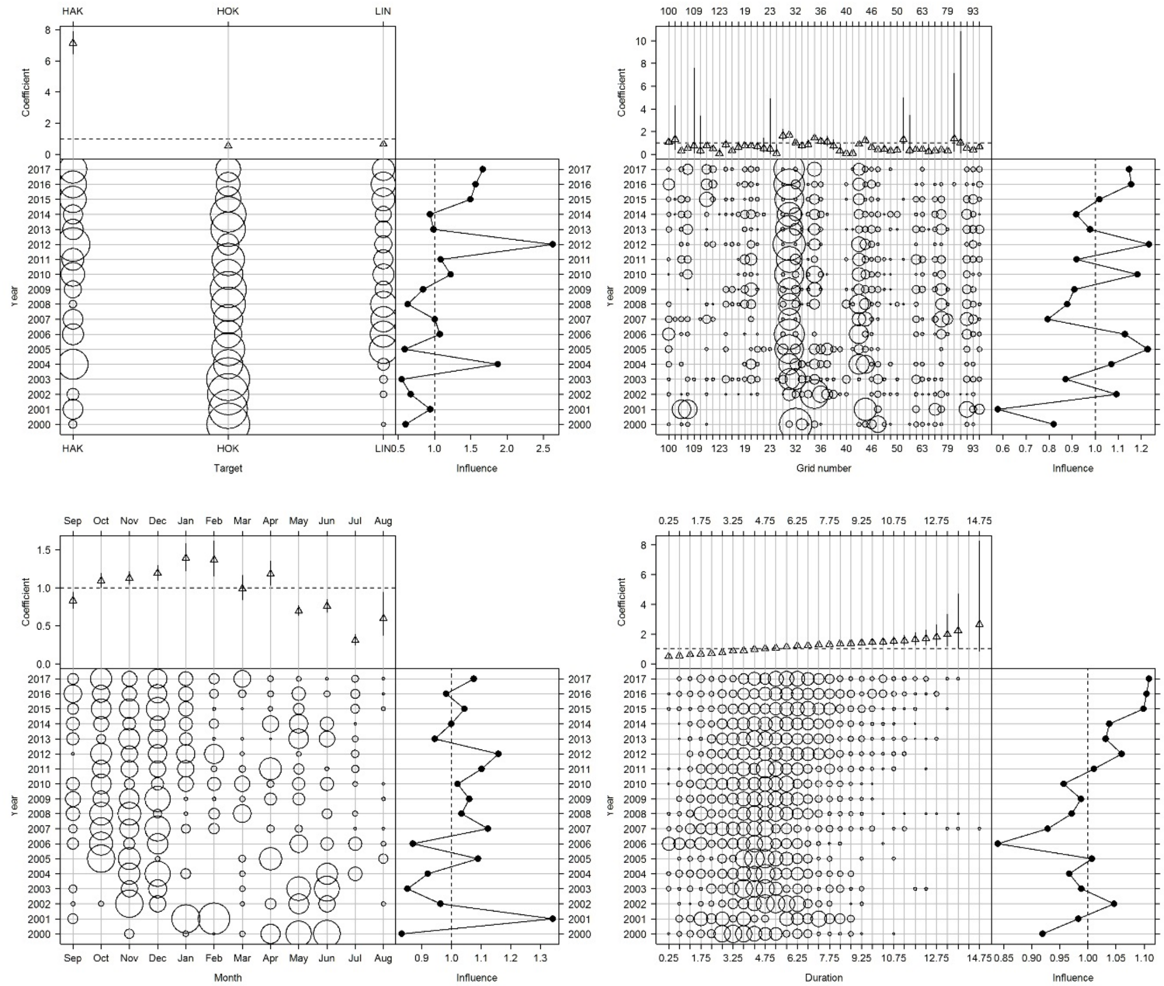


Figure 13c: Effect and influence of non-interaction term variables in the Sub-Antarctic observer tow-by-tow vessel lognormal CPUE model. Top: relative effect by level of each variable. Bottom left: relative distribution of each variable by fishing year. Bottom right: influence of variable on unstandardised CPUE by fishing year.

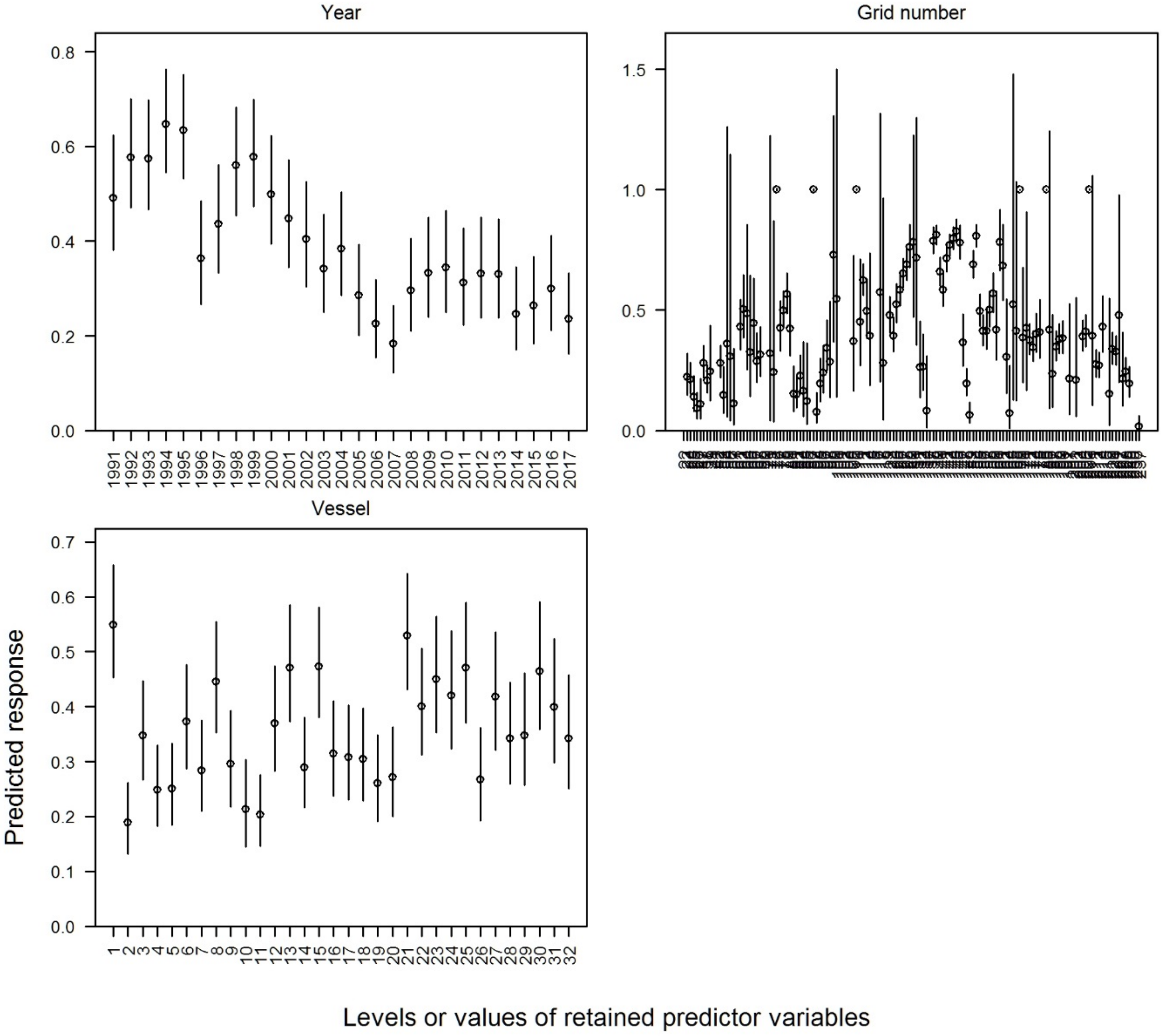


Figure 14a: Expected variable effects for variables selected into the CPUE binomial model for the Sub-Antarctic TCEPR tow-by-tow core vessel fishery, 1991–2017. The 95% confidence intervals are shown as bars for categorical variables and as upper and lower lines for continuous variables.

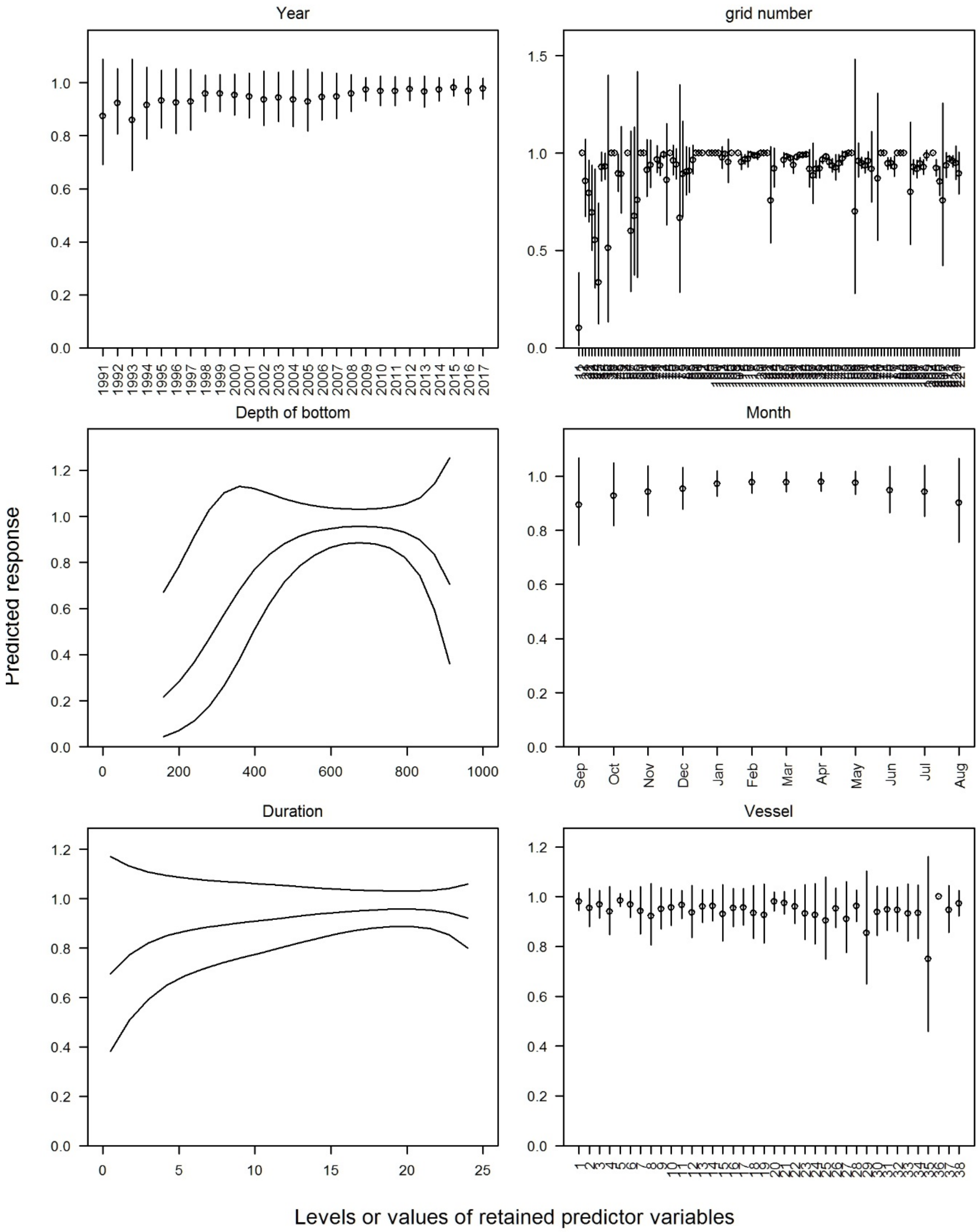


Figure 14b: Expected variable effects for variables selected into the CPUE binomial model for the Sub-Antarctic TCEPR daily processed core vessel fishery, 1991–2017. The 95% confidence intervals are shown as bars for categorical variables and as upper and lower lines for continuous variables.

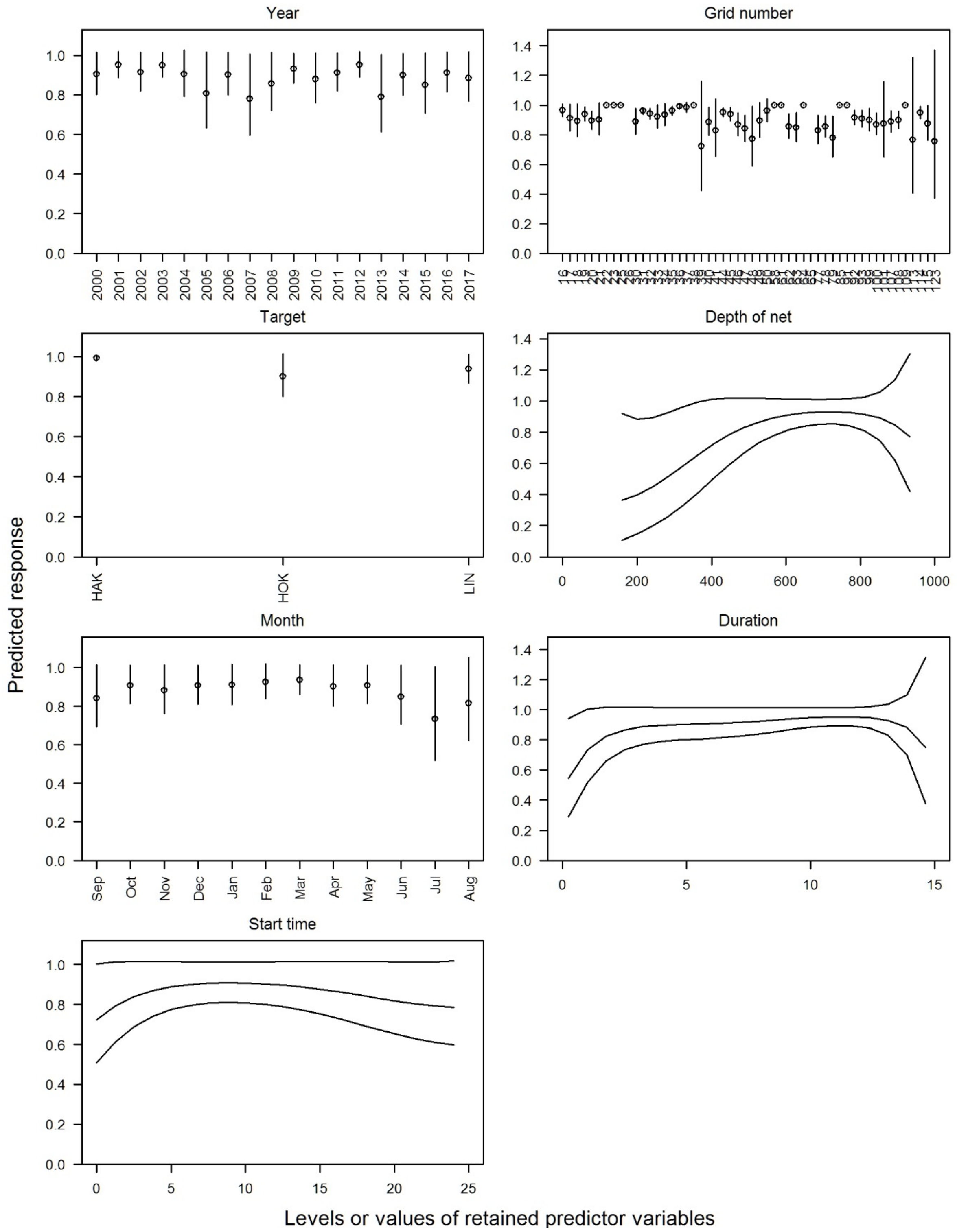
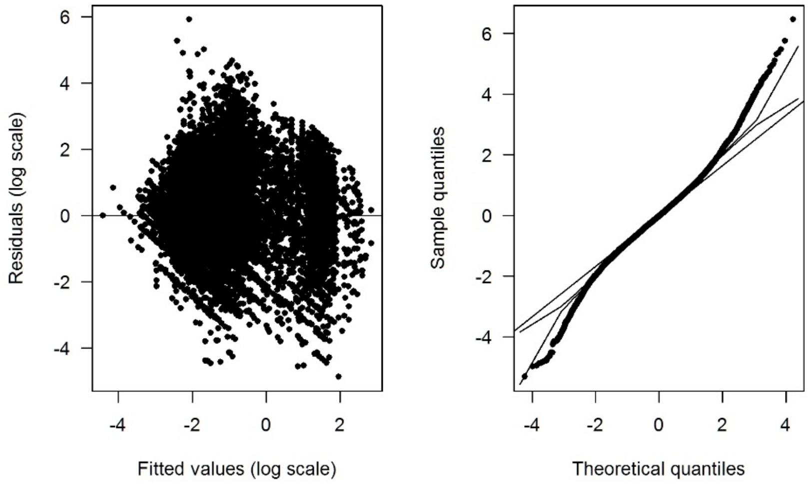
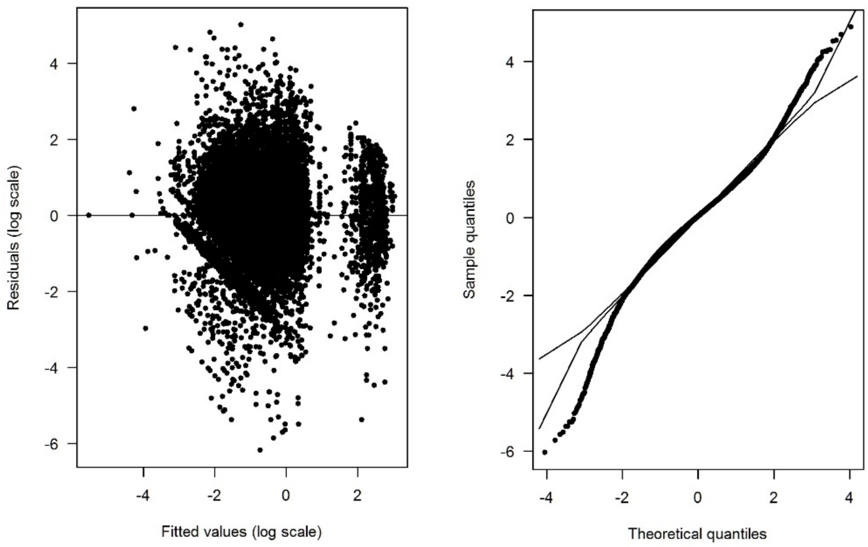


Figure 14c: Expected variable effects for variables selected into the CPUE binomial model for the Sub-Antarctic observer tow-by-tow vessel fishery, 2001–2017. The 95% confidence intervals are shown as bars for categorical variables and as upper and lower lines for continuous variables.

TCEPR tow-by-tow



TCEPR daily processed



Observer tow-by-tow

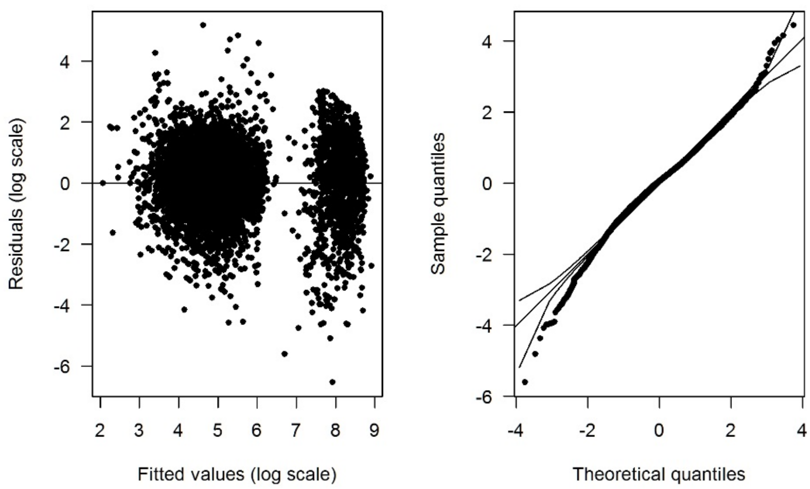


Figure 15: Diagnostic plots for the lognormal CPUE models.

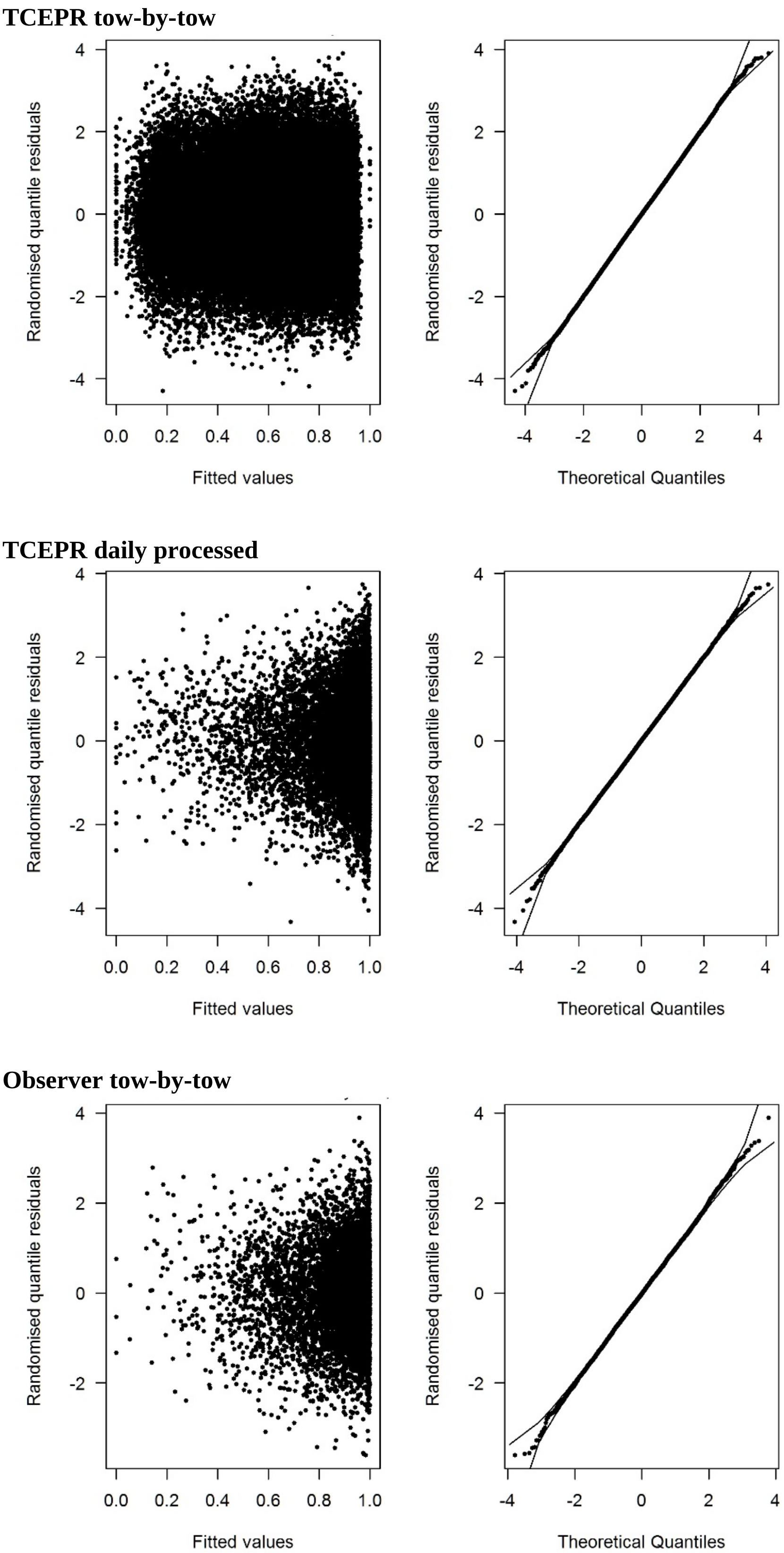


Figure 16: Diagnostic plots for the binomial CPUE models.