Descriptive analysis of the fishery for hake (*Merluccius australis*) in HAK 1, 4 and 7 from 1989–90 to 2009–10, and a catch-per-unit-effort (CPUE) analysis for Sub-Antarctic hake

S.L. Ballara

NIWA
Private Bag 14901
Wellington 6241

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EXECUTIVE SUMMARY

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This report provides a descriptive analysis of the catch and effort data for hake from the WCSI (HAK 7), Chatham Rise (HAK 4), and Sub-Antarctic (HAK 1) stocks for 1989–90 to 2009–10. An updated CPUE series for Sub-Antarctic hake is 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, so this analysis captures the latest data available, and all variables were error groomed and interpreted in a similar manner.

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

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

The explained residual deviances for the Sub-Antarctic CPUE lognormal models were relatively high (34–39%), with *vessel* and *statistical area* accounting for most of the deviance explained. The variables included appeared logical, and were generally consistent between the models and were similar to those previously calculated. However, a large proportion of the underlying variability was not explained.

The Sub-Antarctic hake tow-by-tow estimated and processed CPUE series are indicative of a slight overall decline in the 20 years covered by the analyses. The tow-by-tow estimated catch lognormal index declined slightly from 1991 to about 1999, and then stabilised, with minor fluctuations, through to 2010. The daily processed catch declined from 1991 to about 1995, was then stable with minor fluctuations to 2004, followed by a further decline to 2008, and subsequent recovery to 2010. The estimated tow-by-tow series does not look markedly different to the processed series, although the processed series is slightly higher in earlier years and generally lower in later years. There was reasonable agreement between the two Sub-Antarctic trawl survey biomass series and CPUE indices.

The lognormal models were unable to capture the extremes in catch rates observed and tended to underestimate the lower catch rate, suggesting that other CPUE models may usefully be investigated.

1. INTRODUCTION

Hake are widely distributed throughout the middle depths, mainly from 250 to 800 m and primarily south of latitude 40° S (Colman 1995). Adults have been found as deep as 1200 m and juveniles (0+) are often found in shallower inshore regions (less than 250 m depth) (Hurst et al. 2000). Hake within the New Zealand Economic Exclusion Zone (EEZ) are managed as three separate Fishstocks: the Challenger Plateau and west coast of the South Island (HAK 7), the eastern Chatham Rise (HAK 4), and the remainder of the EEZ (HAK 1), which includes waters around the North Island, east coast of the South Island and Sub-Antarctic, and excludes the Kermadec area (Figure 1). A comprehensive descriptive analysis of New Zealand hake fisheries was produced by Devine (2009).

Hake are currently believed to consist of three biological stocks (Colman 1998), i.e., West coast South Island (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, three known spawning areas exist: the west coast of the South Island (WCSI), west of the Chatham Islands, and on the Campbell Plateau (Dunn 1998).

Commercial catch and effort data were analysed to produce catch-per-unit-effort (CPUE) indices for HAK 1 and 4 in 1998 (Kendrick 1998), and were updated, using the methodology of Gavaris (1980) and Vignaux (1994), in 1999 (Dunn et al. 2000a), 2001 (Phillips & Livingston 2004), 2003 (Phillips 2005), 2005 (Dunn & Phillips 2006), 2007 (Devine & Dunn 2008), 2009 (Devine 2010), and 2011 (Ballara & Horn in press). Evidence of misreporting of catch by a small number of vessels was detected during the 2001 update. Hake caught in HAK 7 were misreported as catch on the Chatham Rise and Sub-Antarctic in HAK 4 and HAK 1 (Dunn 2003).

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

This report 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. This fulfils Objective 1 of Project DEE201002HAKA — "To carry out a descriptive analysis of the commercial catch and effort data for hake from HAK 1, 4, and 7".

An analysis of the catch and effort data for hake from the Sub-Antarctic stock (HAK 1) for the years 1989–90 to 2009–10 is also presented. This report fulfils Objective 2 of Project DEE201002HAKA — "To update the standardised analysis of the commercial catch and effort data for HAK 1, 4, and 7". This objective requires that CPUE be updated only for the stock(s) to be fully investigated using a stock assessment model.

2. METHODS

2.1 Data selection and variable description

Catch and effort data were requested from the Ministry of Fisheries catch-effort database "warehou" as extract 7922A which consisted of all fishing and landing events associated with a set of fishing trips that reported a positive catch or landing of hake, hoki, or ling between 1 October 1989 and 30 December 2010. Catch and effort data forms included the total estimated catch from the catch effort and landing return (CELR), lining catch effort return

(LCER), net catch effort and landing return (NCELR), trawl catch effort return (TCER), lining trip catch effort return (LTCER), tuna long lining catch effort return (TLCER), and trawl catch effort and processing return (TCEPR) forms.

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

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

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

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

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

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

Catch-effort data often contain significant errors, most commonly invalid codes and missing or implausible values. Data were checked for errors, using simple checking and imputation algorithms described below and similar to those used by Dunn & Phillips (2006), Devine & Dunn (2008), Devine (2010), and Ballara & Horn in press.

Individual tow locations were investigated and, where possible, errors were corrected using median imputation; that is, all tows for each vessel on each fishing day where the start/finish latitude was more than one degree different from the median start/finish latitude were replaced with the median start/finish latitude. This error check was then repeated for longitude. If the median value could not be determined or the tow locations appeared invalid, the tow record was excluded from any further analysis. Tow speed, net depth, bottom depth,

duration, wingspread, and headline height were also corrected by method subsets using median imputation. If the median values could not be determined for these variables or appeared invalid, the tow record was excluded from the analysis. Range checks were defined for the remaining attributes to identify outliers in the data. The outliers were checked and corrected if possible, or the record was removed from the data set. Individual vessel details were checked for consistency each year as it was apparent that more than one vessel can have the same vessel identification number. Where there was more than one set of values for an individual vessel, the data were examined and corrected. Tow records with no vessel identification data were excluded from further analyses.

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

Sub-areas on the WCSI were based on a tree regression analyses of mean fish length (by sex) in the catches sampled by MFish observers (Horn & Sutton 2010), and 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 2a).

Sub-areas on the Chatham Rise were based on a tree regression analysis of mean fish length (by sex) in the catches sampled by MFish observers (Horn & Dunn 2007). These 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 2b). However, for this analysis sub-areas were combined to West (West Chatham Rise deep and West Chatham Rise shallow) and East (East Chatham Rise and Area 404) Chatham Rise based on areas used in the latest stock assessment (Horn & Francis 2010).

Sub-areas for the Sub-Antarctic stock were also based on tree regression analyses of mean fish length (by sex) in the catches sampled by MFish observers (Horn 2008), and were defined as Puysegur, Snares-Pukaki, Auckland Islands, and Campbell Island (Figure 2c). Data from areas on the Sub-Antarctic that were outside these sub-areas were excluded from the CPUE analyses.

2.2 Catch per unit effort analysis

The analysis of CPUE for the Sub-Antarctic hake fishery is updated here. Annual unstandardised (raw) CPUE indices were calculated as the mean of the catch per tow (kg).

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 2011) 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. Interaction terms were ignored. A stopping rule of 1% change in residual deviance was used as this results in a relatively parsimonious model with moderate explanatory power. Alternative stopping rules or error structures were not investigated.

The variable *year* was treated as a categorical value so that the regression coefficients of each year could vary independently within the model. The relative year effects calculated from the regression coefficients represent the change in CPUE through time, all other effects having been taken into account. Hence, it represents a possible index of abundance. Year was standardised to the first year. Year indices were standardised to the mean and were presented in canonical form (Francis 1999).

Categorical and continuous variables offered to the model are listed in Table 1. Fits to continuous variables were modelled as third-order polynomials, although a fourth-order

polynomial was also offered to the models for *duration*. In each analysis *statistical area* and *start latitude* or *start longitude* were not allowed to enter the same model at the same time as they were correlated. For the estimated catch runs all variables were included. For the processed catch runs, *date*, *start time*, *start longitude* or *start latitude* were not included as they were redundant. Date was included in the processed catch runs as *year* and *month*, and *latitude* and *longitude* were included as *statistical area*. Of course, the potential exists that factors that drive hake CPUE are not available in the processed catch models.

A vessel variable was incorporated into the CPUE standardisation to allow for differences in fishing power between vessels. Vessels not involved in the fishery for at least three consecutive years were excluded because they provided little information for the standardisations, which could result in model over-fitting (Francis 2001). Thus, CPUE analyses were undertaken for "core" vessels that reported at least 80% of the hake catch and were involved in the fishery for at least three consecutive years.

Model fits to the model were investigated using standard residual diagnostics.

The data used for each CPUE analysis consisted of all records from core vessels that targeted hake, hoki or ling. For this analysis of Sub-Antarctic catch and effort data, lognormal CPUE models were run for two datasets: hake processed catch by vessel-day, and hake tow-by-tow estimated data. These two datasets included data from the TCEPR form only for core vessels targeting hake, hoki, or ling from 1991 to 2010, with year defined as September to August. Misreported catches from tows or vessel-days were excluded.

3. RESULT

3.1 Descriptive analyses

Estimated catches, reported landings, and TACC by stock from 1989–90 to 2009–10 are shown in Table 2 and Figure 3 for the main hake stocks. Most hake catches since 1989–90 have been reported on the TCEPR form (Table 3). New reporting forms have been introduced in several years since 2003–04, but in 2009–10 most hake catch (98.4%) is still reported in TCEPRs, with TCERs (36 t, 0.8%) accounting for the second highest proportion. The distribution and density of the catch recorded on these two form types in 2009–10 is shown in Figure 4.

3.1.1 WCSI

The WCSI hake fishery is mainly bycatch in the much larger hoki fishery (Table 4), but has undergone a number of changes during the last decade (Devine 2010). These include changes in TACCs for both hake and hoki, and changes in fishing practices such as the gear used, tow duration, and strategies to limit hake bycatch. Most of the hake catches are from hake or hoki target tows, although the hake caught in hoki target tows has decreased steadily since 2005 (Figure 5a, Table 4).

The timing of the catch on the WCSI has varied slightly between years, but most catch has been taken between June and September (Figure 5a, Table 5). Targeted catches of hake were relatively high early in the fishing season in 1995, 1996, 1999, 2001, 2004 and 2005 (Figure 6). 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 (Table 5, Figure 6). More than 2000 t of hake was taken during September 1993 and 2006. In 2010, catches were the lowest in any year since 1990 (Table 5) and were taken mainly from July to September by mid-sized Korean vessels targeting hake with bottom trawl (Figure 5). In the last 4 years few large vessels have been catching hake (Figure 5). Catches are taken mainly in Statistical Areas 034 and 035, but from all 3 subareas (Figure 5). In 2010, most of the catch was taken immediately north of the Hokitika Canyon in the North Shallow subarea (Figures 5 and 7).

Mean duration, distance, and depth per tow increased, and speed decreased in the last few years (Figure 8a), which can be attributed in part to the increased bottom tow catches since 2002 by smaller Korean vessels, and changes in midwater and bottom tow vessels. In 2010 there was little midwater catch, a decrease in mean duration and depth, and an increase in mean hoki catches (Figure 8a). For hake target vessels, there were very low hoki catches, increases in duration per tow for both midwater and bottom tows in recent years, and a

decrease in fishing speed (Figure 8b). Target hake catches also show discrete fishing by timing and location, especially earlier years (Figure 9).

3.1.2 Chatham Rise

On the Chatham Rise, hake have been caught mainly by bottom trawlers targeting hake or hoki (Table 6, Figure 10a). Generally, hake are caught on the northern edge of the Chatham Rise and in the deep channel along the western part of the Chatham Rise, but with most of the catch taken from Statistical Area 404 (Figure 11), where vessels target the hake spawning aggregation (Devine 2010). However, catches from Area 404 since 2006 have been low relative to the previous 14 years (Figure 10). Hake caught in hoki target tows has been slowly decreasing since the late 1990s (Table 6, Figure 10a). More than 99% of the Chatham Rise catch is reported on the TCEPR form.

Hake are caught on the Chatham Rise all year around, but more commonly between September and February (Figure 12, Table 7). In October 2004, a large aggregation of possibly mature or maturing hake was fished on the western Chatham Rise, west of the Mernoo Bank (see figure 7 of Devine 2010) with approximately 2000 t of hake caught over a four week period. The reasons for the presence of this aggregation are not known, although periodic and minor aggregations of pre-mature and mature hake have been found in that area in previous years and also in 2009 (Figure 10a). In 2006, very little catch was taken from all areas. 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 7, Figure 10). The catch in 2010 was lower than all years since 1990, and was split approximately equally between New Zealand and Korean vessels targeting hoki and hake with bottom trawl (Figure 10).

For target hoki and hake vessels, bottom tows have shown an overall slight increase in mean duration, and decrease in speed since 2002 (Figure 13), which can be attributed in part to the increased bottom tow catches from 2002 by smaller Korean vessels. Mean hoki catch per tow has increased since 2004.

3.1.3 Sub-Antarctic

Sub-Antarctic hake are caught mainly by bottom trawlers targeting hoki or hake (Table 8, Figure 14a). Significant targeting for hake occurs around the Norwegian Hole and at the southern end of the Snares shelf (Devine 2010). The majority of the catch is taken from the Snares-Pukaki sub-area (Figures 14a and 15). Since 2000, 1000–2000 t of targeted hake have been caught annually, but since 2005 hake caught in hoki target tows has been decreasing (Table 8, Figure 14a). More than 99% of the hake catch on the Sub-Antarctic is reported on the TCEPR form.

The timing of the catch in the Sub-Antarctic shifted over the years (Figure 16, Table 9). Most catch was taken from September to November in the early 1990s, October to December in the late 1990s, November to January during the early 2000s, and December to February from 2006. In December 2005, 2000 t of hake was taken (Figure 16) 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 2010, most of the catch was taken from December to February on the southern Snares shelf by mid-sized Japanese, New Zealand and Korean vessels (Figures 14 and 15). In general, hake were caught mostly along the edge of the Stewart-Snares shelf, in the Norwegian Hole, and, in smaller amounts, on the northern Campbell Plateau, southern Auckland Island shelf, and Puysegur Bank (Figure 15).

For vessels targeting hoki and hake, bottom tows showed a decrease in mean distance, speed, and depth of net and bottom since 2002 (Figure 17), which can be attributed in part to the increased bottom tow catches from 2002 by smaller Korean vessels. Mean hoki catches decreased from 2001, and have since increased.

3.2 CPUE indices for Sub-Antarctic hake

A total of 119 unique vessels (range 19–45 vessels each year) targeting hake, hoki, and ling caught an estimated 45 300 t of hake since 1991, from 75 172 tows (Table 10a). Sixteen core vessels (range 5–10 per year) caught an estimated 35 700 t of hake, representing 79% of the total catch. Estimated hake catches for core vessels targeting hake, hoki or ling ranged from 500–2800 t annually (Table 10a).

All vessels targeting hake, hoki, and ling fished some 23 159 vessel-days, averaging 1158 days per year since 1991 (Table 10b). The 22 core vessels fished over 14 500 vessel-days and took 85% of the total hake catch, averaging 729 vessel-days per year. The percentage of zero days for core vessels ranged between 2 and 10%.

The number of all vessels has declined steadily since its peak in the 1990s (Table 10a). One core vessel took most of the hake catch from 1995 to 2005 with relatively little effort (Figure 18). Another core vessel strongly dominated the catch from 2007 to 2010, although it had been fishing consistently since 2003.

For the tow-by-tow estimated core data analysis, four variables were selected into the lognormal model, resulting in a total r^2 of 39%, with *vessel* explaining 26% of the residual deviance (Table 11). The other variables selected were *statistical area*, *month*, and *start latitude*. For the processed core data analysis, the same four variables as in the estimated core analysis were selected into the lognormal model, resulting in a total r^2 of 34%, with *vessel* explaining 15% of the residual deviance (Table 11).

CPUE series from the lognormal models are presented in Table 12 and Figure 19. The tow-by-tow estimated catch index declined slightly from 1991 to about 1999, and then stabilised, with minor fluctuations, through to 2010. The daily processed catch declined from 1991 to about 1995, was then stable with minor fluctuations to 2004, followed by a further decline to 2008, and subsequent recovery to 2010. However, when plotted together, the two series do not look markedly different, and are indicative of a slight overall decline in the 20 years covered by the analyses (Figure 20). The standardised processed catch index matches the unstandardised index well (Figure 19). However, the unstandardized estimated catch index exhibits an overall increase, while the standardised index is relatively constant (Figure 19). Both standardised series are very similar to those previously produced using data up to 2009 (Figure 19). The CPUE indices are also similar to the research survey biomass indices from the summer and autumn trawl survey series (Figure 20).

The effects of the selected variables on the expected catch rates of hake in the lognormal tow-by-tow estimated catch model are shown in Figure 21. Catch rates were highest from August to December, and at more northerly latitudes. Expected catch varied markedly between statistical areas; they were highest around the Norwegian Hole and along the Snares Shelf. Variable effects for the daily processed catch model (Figure 22) were generally similar to those for the estimated catch model, although highest catches were from September to March and there was a plateau in the relationship between expected catch and latitude.

The diagnostics for both models were poor and the quantile-quantile plots indicated a deviation from the normal distribution of the residuals at both the lower and upper ends, i.e., very small and very large catch rates were not well modelled (Figures 23 and 24).

4. SUMMARY

The data used in the analyses were groomed to correct where catch may have been misreported, and where incorrect data were recorded or punched. Although some errors may still be present, they would have had only a negligible effect on the CPUE analysis due to the large size of the data sets used (e.g., Dunn & Harley 1999). Also, unlike Devine (2010), a complete extract of data was undertaken, so this analysis captures the latest data available, and all variables were error groomed and interpreted in a similar manner.

The hake catches from fisheries in all three areas are a consequence of direct targeting for the species and a bycatch of targeting for hoki. The WCSI fishery is of short duration (June–September), with hake mainly a bycatch of hoki, but with some targeting occurring generally before or after the main hoki season. The Chatham Rise fishery is concentrated on the

northern and western Rise, mainly from September to February, with targeting for hake concentrating on spawning aggregations. The Sub-Antarctic fishery is concentrated off the south and east of the Snares shelf out to the Pukaki Rise; target fishing here also concentrates on spawning aggregations. The timing of the peak Sub-Antarctic fishery has shifted over time, from September–November in the early 1990s to December–February since the mid 2000s.

The CPUE analysis by Phillips (2005) indicated that low or zero catches may have been inconsistently recorded over time, and there may have also been some problems due to hake not being one of the top five species recorded on the TCEPR tow by tow data. However, the Sub-Antarctic analyses presented above using the daily processed summaries for hake may not be superior to a tow-by-tow analysis (even though they account for those days when catches were not recorded on the tow-by-tow summaries), as estimated and processed indices generally showed similar trends, and estimated and processed catches are of a similar order. However, this may not be true of species that are rarely recorded as one of the top five on the TCEPR form. Ballara & Horn (in press) showed strong similarities between daily processed and tow-by-tow CPUE for WCSI hake, and also found that trends in the combined and lognormal indices were similar, implying that little was gained by adding tow data from zero catches into that analysis.

Here we have assumed a proportional relationship between CPUE and abundance. However, there are specific areas and times (e.g., Statistical Area 404 on the Chatham Rise during the spawning season) when hake were more available and hence targeted, therefore the indices from this area may have a hyperstable CPUE/abundance relationship (Dunn et al. 2000b). There was reasonable agreement between the two Sub-Antarctic trawl survey biomass and the CPUE series.

The r^2 values for the Sub-Antarctic CPUE models were relatively high (34–39%), with *vessel* and *statistical area* accounting for most of the deviance explained. However, a large proportion of the underlying variability was not explained. While this is not unusual for CPUE analyses (e.g., Vignaux 1994, Punt et al. 2000), it may be a reflection of a lack of explanatory information available to the models to explain catch rates. For example, individual skippers' experience was not available, even though the number of years the vessel has been in the fishery was included as a variable. There were almost certainly different skippers over the time period. Other effects on catching ability, such as improvements or changes in net and bottom rig design, and electronic equipment could not be quantified and may result in an increase in the overall deviance explained. The data held by the Ministry of Fisheries now has a new variable, indicating whether a vessel was a twin trawler. These data were offered to the models but the variable was not selected, and models excluding twin trawl vessels were little different to those including them.

The diagnostic plots for the CPUE analyses shown that the lognormal model was unable to capture the extremes in catch rates observed in the fishery and tended to underestimate the lower catch rate. Clumping of residuals is also apparent, probably due to the different catch rates for each target species and subarea. 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).

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

Variable	Type	Estimated	Processed
Year	Categorical	Year (Sep–Aug)	Year (Sep–Aug)
Vessel	Categorical	Unique (encrypted) vessel identification number	Unique (encrypted) vessel identification number
Subarea	Categorical	Defined by fishing effort distribution and depth for a tow	Defined by fishing effort distribution and depth for a given day
Statarea	Continuous	Statistical area	Statistical area
Effort	Continuous	–	Number of tows for a given day
Tow duration	Continuous	Duration of tow (hrs)	Duration of all tows (hrs) on a given day
Headline height	Continuous	Headline height (m) of the net for a tow	Median headline height (m) of the net on a given day
Bottom depth	Continuous	Seabed depth (m) for a tow	Median seabed depth (m) on a given day
Speed	Continuous	Vessel speed (knots) for a tow	Median vessel speed (knots) on a given day
Wingspread	Continuous	Wingspread (m) of the net for a tow	Median wingspread (m) of the net on a given day
Vessel experience	Continuous	Number of years the vessel has been involved in the fishery	Number of years the vessel has been involved in the fishery
Twin trawl vessel	Categorical	T/F variable for a vessel that has used a twin trawl	T/F variable for a vessel that has used a twin trawl
Month	Categorical	Month of the year	Month of the year
Catch	Continuous	Estimated green weight of hake (t) caught from a tow	Estimated green weight of hake (t) caught on a given day
Longitude	Continuous	Longitude of the vessel for a tow	Median longitude of the vessel on a given day
Latitude	Continuous	Latitude of the vessel for a tow	Median latitude of the vessel on a given day
Date	Continuous	Date of the tow	Date the fish were processed

Table 2: Estimated hake catch (t) (TCEPR and CELR were scaled to reported QMR or MHR catch totals and adjusted for misreporting), reported landings (t) from QMR records, and TACC (t) by QMA from 1989–90 to 2009–10. 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 landings			TACC		
Year	HAK1	HAK4	HAK7	HAK1	HAK4	HAK7	HAK1	HAK4	HAK7
1989–90	2 115	763	4 903	2 115	763	4 903	2 610	1 000	3 310
1990–91	2 593	726	6 175	2 603	743	6 148	2 610	1 000	3 310
1991–92	3 156	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	1 787	2 587	2 990	1 803	2 587	2 974	3 501	3 500	6 835
1994–95	2 346	2 896	9 538	2 572	3 369	8 841	3 632	3 500	6 835
1995–96	3 828	3 070	9 089	3 956	3 466	8 678	3 632	3 500	6 835
1996–97	3 300	3 190	6 846	3 534	3 524	6 118	3 632	3 500	6 835
1997–98	3 659	3 239	7 683	3 809	3 523	7 416	3 632	3 500	6 835
1998–99	3 703	2 740	8 786	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

Table 3: Hake estimated catches by form type and fishing year.

	Catches (t)						
Year	TCEPR	TCER	CELR	LCER	NCELR	LTCER	Total
1989–90	7 780.1	–	1.0	–	–	–	7 781.1
1990–91	9 474.1	–	19.7	–	–	–	9 493.9
1991–92	8 187.5	–	8.1	–	–	–	8 195.6
1992–93	13 188.4	–	36.1	–	–	–	13 224.5
1993–94	7 358.9	–	4.7	–	–	–	7 363.6
1994–95	14 774.3	–	5.2	–	–	–	14 779.5
1995–96	15 982.8	–	4.6	–	–	–	15 987.4
1996–97	13 334.2	–	2.4	–	–	–	13 336.6
1997–98	14 577.3	–	3.9	–	–	–	14 581.3
1998–99	15 220.0	–	8.4	–	–	–	15 228.3
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	13 355.0	–	0.5	1.9	–	–	13 357.4
2005–06	9 938.0	–	5.2	0.8	–	–	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	1.8	11.5	5 922.5
2008–09	10 164.5	20.8	0.0	6.4	2.3	14.0	10 208.0
2009–10	4 631.0	36.4	0.0	9.6	1.9	25.1	4 703.9
Total	239 044.8	76.8	127.9	26.8	6.9	50.6	239 333.8

Table 4: WCSI hake TCEPR catch (t) by target species and fishing method, 1989–90 to 2009–10. Values have been rounded to the nearest tonne unless catch was less than 1 t, so '0' denotes catches from 1 to 49 kg, and '–' denotes zero catch.

Method	Bottom trawl			Midwater trawl			Midwater, on bottom		
Target species	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	1 223	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	173	934	2	761	386	3
1994–95	0	631	97	851	4 329	20	1 870	1 722	14
1995–96	221	1 204	79	1 198	4 348	25	217	1 740	49
1996–97	57	1 072	45	511	3 119	45	281	1 572	70
1997–98	58	792	5	213	4 271	20	297	2 009	1
1998–99	370	1 381	10	1 191	3 283	7	1 229	1 242	15
1999–00	286	1 891	36	400	2 319	2	587	1 499	0
2000–01	333	1 547	15	2 180	1 592	0	1 157	1 523	0
2001–02	427	2 886	20	234	1 820	0	143	1 967	1
2002–03	2 158	1 984	7	434	1 007	0	528	1 285	1
2003–04	2 706	1 564	2	225	589	2	1 273	1 576	2
2004–05	2 675	743	3	848	456	1	2 117	455	0
2005–06	2 576	674	15	714	413	0	1 927	573	1
2006–07	1 591	373	10	4 292	437	0	889	60	7
2007–08	2 322	127	3	3	7	0	69	50	0
2008–09	2 504	122	4	1 209	6	0	1 999	69	0
2009–10	1 948	159	9	10	11	0	67	77	0

Table 5: WCSI estimated hake TCEPR catch (t) by month from 1989–90 to 2009–10. Values have been rounded to the nearest tonne unless catch was less than 1 t, so '0' denotes catches from 1 to 49 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	0.1	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	0.6	556	1 383	1 832	3 343	7 122
1993–94	0	0	0	0	0	0.6	0	0	885	1 234	381	470	2 971
1994–95	14	0.1	2	0.2	0.1	3	1	24	3 193	2 325	3 655	318	9 535
1995–96	85	0	0	0	0	0.9	0	0.8	2 530	2 625	2 748	1 092	9 082
1996–97	57	0	0	0	0	0	0	0.2	941	2 450	2 033	1 358	6 838
1997–98	65	3	0	0	0	0	2	15	1 588	3 328	2 154	492	7 674
1998–99	48	332	15	0.3	0.5	4	0.8	31	3 315	3 483	1 153	361	8 742
1999–00	151	0.1	–	–	0	2	1	44	1 776	3 586	835	637	7 031
2000–01	71	0	0	–	0	–	3	17	3 607	2 308	1 675	665	8 346
2001–02	0	2	0	0.1	–	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	–	0.1	–	39	2 850	1 548	2 249	972	7 939
2004–05	192	64	0	–	0	0.1	0.1	4	3 373	2 014	1 031	620	7 298
2005–06	275	19	0	0	0	0	0	0.1	774	1 092	2 185	2 547	6 892
2006–07	61	0	0	0.4	0	0	0	73	1 919	4 602	637	367	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	–	–	–	–	–	15	209	517	716	813	2 282

Table 6: Chatham Rise hake TCEPR catch by target species and fishing method, 1989–90 to 2009–10. Values have been rounded to the nearest tonne unless catch was less than 1 t, so '0' denotes catches from 1 to 49 kg, and '–' denotes zero catch.

Method	Bottom trawl			Midwater trawl			Midwater, on bottom		
Target species	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	1 629	829	53	4	9	0	237	35	1
1993–94	856	365	65	23	43	0	1 501	78	1
1994–95	808	777	55	230	56	0	1 241	219	1
1995–96	2 638	949	85	7	40	0	72	237	0
1996–97	2 061	402	78	–	65	1	404	223	0
1997–98	2 139	182	255	0	64	0	360	250	0
1998–99	2 302	975	152	–	25	1	46	167	0
1999–00	1 274	924	243	382	36	0	540	118	0
2000–01	1 787	901	69	38	15	0	120	32	0
2001–02	1 111	515	36	0	45	0	2	60	0
2002–03	532	671	43	0	91	0	1	63	0
2003–04	1 782	542	59	–	12	0	–	70	0
2004–05	1 376	436	15	1 110	292	0	158	140	0
2005–06	173	243	29	0	5	0	–	39	0
2006–07	695	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

Table 7: Chatham Rise estimated hake TCEPR catch (t) recorded by month, 1989–90 to 2009–10. Values have been rounded to the nearest tonne, so '0' denotes catches from 1 to 499 kg.

	Month												
Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1989–90	82	30	304	167	15	50	144	88	24	17	3	26	950
1990–91	7	37	268	99	48	177	114	63	62	14	29	14	931
1991–92	78	59	520	572	146	99	83	56	45	54	119	587	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	39	26	8	11	32	43	25	6	374	2 934
1994–95	948	1 110	656	64	41	14	14	53	109	42	61	276	3 387
1995–96	242	1 079	997	669	59	23	45	96	151	175	160	330	4 028
1996–97	625	267	1 484	133	72	112	82	101	83	701	4	569	4 234
1997–98	302	469	284	95	65	173	107	112	175	386	1	2083	4 252
1998–99	327	610	623	349	73	278	46	37	264	297	1	764	3 669
1999–00	1 204	373	299	107	71	122	57	28	592	131	1	531	3 517
2000–01	138	493	772	385	51	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	41	24	45	71	85	30	31	2	561	1 401
2003–04	197	446	694	421	44	68	65	70	53	14	7	384	2 465
2004–05	2 401	91	552	281	18	13	15	17	15	3	15	105	3 526
2005–06	68	61	203	15	10	8	20	14	40	7	4	39	489
2006–07	98	51	46	133	330	76	73	75	24	8	8	160	1 081
2007–08	37	40	47	418	248	58	27	63	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

Table 8: Sub-Antarctic hake TCEPR catch (t) by target species and fishing method, 1989–90 to 2009–10. Values have been rounded to the nearest tonne unless catch was less than 1 t, so '0' denotes catches from 1 to 49 kg, and '–' denotes zero catch.

Method	Bottom trawl			Midwater trawl			Midwater, on bottom		
Target species	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	885	444	301	–	160	8	–	54	1
1995–96	1 251	440	1 077	–	68	0	–	37	0
1996–97	555	954	590	–	155	6	–	0	1
1997–98	738	1 198	658	–	7	4	–	0	2
1998–99	946	1 141	645	0	36	3	0	22	2
1999–00	906	1 460	253	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	63
2002–03	1 498	1 015	152	–	16	8	–	11	38
2003–04	1 224	1 537	426	–	8	15	–	12	23
2004–05	1 074	449	903	41	1	5	12	13	34
2005–06	2 078	112	336	2	6	6	0	2	17
2006–07	1 029	277	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

Table 9: Sub-Antarctic estimated hake TCEPR catch (t) recorded by month, 1990 to 2009. Values have been rounded to the nearest tonne, so '0' denotes catches from 1 to 499 kg.

	Month												
Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1990	222	11	18	22	26	45	79	156	107	8	64	1 169	1 927
1991	230	82	57	16	91	84	106	167	187	25	166	1 159	2 370
1992	272	92	78	75	106	127	200	139	171	125	265	1 100	2 750
1993	1515	570	103	89	72	95	112	118	39	9	120	427	3 269
1994	648	126	53	78	66	48	45	23	78	1	3	284	1 453
1995	611	535	27	40	37	132	56	77	35	0	161	141	1 852
1996	1 147	705	219	24	15	152	62	54	36	145	78	236	2 873
1997	294	791	120	66	50	19	50	71	158	46	16	582	2 262
1998	554	1 024	83	44	122	136	88	195	101	21	7	230	2 606
1999	478	427	305	35	339	196	174	149	320	163	37	172	2 796
2000	295	851	435	253	322	120	142	194	307	14	4	84	3 020
2001	413	825	343	190	147	60	100	207	378	39	33	55	2 790
2002	177	1 007	391	191	106	124	96	97	120	28	54	121	2 510
2003	210	1 190	804	135	10	54	84	57	111	0	0	82	2 738
2004	432	1 246	862	254	39	6	12	137	143	4	5	105	3 245
2005	445	976	880	83	26	2	30	14	19	8	3	44	2 531
2006	163	189	2 083	1	1	11	22	15	8	1	4	60	2 557
2007	268	194	536	164	343	9	13	36	21	10	57	167	1 818
2008	227	609	509	214	560	11	8	3	2	3	14	40	2 202
2009	72	294	727	876	345	49	23	5	5	7	2	22	2 427
2010	109	84	586	619	303	41	32	93	33	3	3	53	1 958

Table 10: Summary of Sub-Antarctic data used in the analyses of estimated and processed CPUE for all vessels and for core vessels for each fishing year (defined as September-August). Vessels, number of unique vessels fishing; tows, number of tow records; Zeros, proportion of tows (estimated) or days (processed) that caught zero catch; Catch, estimated or processed (green weight) catch; CPUE, unstandardised CPUE from the tow-by-tow data (estimated) or daily catch records (processed); Days, number of vessel days fished.

(a) Estimated data targeting hake, hoki, and ling for September–August, excluding misreported tows.

	All vessels					Core vessels				
Year	Vessels	Tows	Zeros	Catch (t)	CPUE	Vessels	Tows	Zeros	Catch (t)	CPUE
1991	38	4 630	0.30	2 210.9	0.68	7	1 682	0.27	1 453.5	0.86
1992	45	6 807	0.34	2 597.4	0.58	7	2 628	0.25	1 610.9	0.61
1993	40	5 781	0.34	3 156.8	0.83	9	2 473	0.30	1 998.1	0.81
1994	27	2 451	0.30	891.0	0.52	8	1 122	0.26	508.4	0.45
1995	29	3 055	0.29	1 508.0	0.70	6	1 125	0.29	1 218.2	1.08
1996	32	2 976	0.49	2 433.3	1.60	6	712	0.41	2 153.2	3.02
1997	44	4 069	0.43	1 752.4	0.75	8	1 317	0.38	1 342.1	1.02
1998	44	5 069	0.32	2 715.1	0.78	10	1 699	0.24	1 882.5	1.11
1999	34	3 715	0.30	2 368.2	0.91	8	1 421	0.25	1 852.1	1.30
2000	31	5 780	0.39	2 585.4	0.73	8	1 762	0.33	1 833.1	1.04
2001	34	5 393	0.41	2 567.0	0.81	10	1 691	0.33	2 024.1	1.20
2002	35	5 803	0.41	2 256.6	0.66	9	1 783	0.34	1 630.5	0.91
2003	37	4 385	0.48	2 632.8	1.15	9	1 508	0.42	2 350.1	1.56
2004	27	3 174	0.40	2 971.9	1.55	8	1 580	0.36	2 794.8	1.77
2005	27	2 110	0.47	2 264.7	2.01	8	827	0.42	1 897.9	2.29
2006	25	1 771	0.56	2 368.7	3.04	7	567	0.49	2 293.1	4.04
2007	22	2 266	0.59	1 598.9	1.73	7	562	0.54	1 423.0	2.53
2008	23	2 329	0.48	2 268.3	1.86	6	792	0.43	1 798.7	2.27
2009	19	1 853	0.46	2 352.7	2.35	5	654	0.44	1 952.2	2.99
2010	19	1 755	0.46	1 841.8	1.93	5	729	0.39	1 658.5	2.28
Total	119	75 172		45 342.0		16	40 355		35 674.9	

(b) Processed data targeting hake, hoki, and ling for September–August, excluding days with misreported tows.

	All vessels					Core vessels				
Year	Vessels	Days	Zeros	Catch (t)	CPUE	Vessels	Days	Zeros	Catch (t)	CPUE
1991	34	1 217	0.12	2 234.6	1.99	7	610	0.07	1 471.9	2.59
1992	41	1 872	0.11	2 571.4	1.41	9	1 007	0.07	1 623.4	1.73
1993	35	1 538	0.15	2 800.6	1.93	11	995	0.09	2 059.5	2.27
1994	26	690	0.16	776.5	0.89	9	405	0.09	453.5	1.24
1995	26	832	0.10	1 354.4	1.40	9	515	0.07	1 141.2	2.38
1996	29	897	0.16	2 485.3	2.43	9	476	0.07	2 214.8	4.99
1997	41	1 225	0.14	1 734.2	1.25	14	753	0.10	1 378.0	2.02
1998	41	1 563	0.07	2 277.4	1.35	15	918	0.04	1 742.6	1.98
1999	32	1 189	0.08	2 292.0	1.64	13	701	0.05	1 927.2	2.89
2000	30	1 753	0.08	2 396.1	1.15	13	1 048	0.05	2 024.1	2.04
2001	33	1 667	0.10	2 496.6	1.25	15	1 080	0.06	2 281.4	2.24
2002	34	1 755	0.13	2 135.6	1.00	14	1 203	0.05	1 982.0	1.73
2003	34	1 422	0.12	2 315.9	1.26	14	934	0.05	2 136.0	2.40
2004	25	1 054	0.11	2 842.2	1.85	12	862	0.04	2 792.9	3.37
2005	25	779	0.14	2 274.8	2.40	11	553	0.06	2 005.0	3.86
2006	24	653	0.12	2 137.6	2.38	10	446	0.10	2 069.4	5.13
2007	22	918	0.11	1 440.6	1.30	9	542	0.08	1 333.8	2.68
2008	22	851	0.08	1 834.3	1.76	8	581	0.04	1 673.4	2.99
2009	17	667	0.07	2 206.1	2.12	6	494	0.02	2 059.3	4.27
2010	18	617	0.07	1 664.8	1.68	7	448	0.02	1 526.3	3.49
Total	106	23 159		42 270.7		22	14571		35 895.8	

Table 11: Variables retained in order of decreasing explanatory value by each Sub-Antarctic lognormal model and the corresponding total R^2 value.

Data set	Variable	R^2
Estimated core (target hake, hoki, or ling)	Year	4.6
	Vessel	31.0
	Statistical area	35.6
	Month	38.2
	Latitude start	39.3
Processed core (target hake, hoki, or ling)	Year	2.0
	Vessel	16.9
	Statistical area	29.3
	Month	32.3
	Latitude start	34.4

Table 12: Sub-Antarctic lognormal CPUE core indices (target hake, hoki, and ling) by fishing year (defined as September-August), with 95% confidence intervals and c.v.s.

	Estimated			Processed		
Year	Index	95% CI	c.v.	Index	95% CI	c.v.
1991	1.25	1.15–1.35	0.04	1.47	1.31–1.65	0.06
1992	1.21	1.13–1.29	0.03	1.49	1.36–1.62	0.04
1993	1.18	1.11–1.26	0.03	1.10	1.01–1.19	0.04
1994	1.07	0.99–1.15	0.04	1.07	0.96–1.20	0.06
1995	0.93	0.87–1.00	0.04	0.96	0.87–1.06	0.05
1996	1.17	1.08–1.27	0.04	1.16	1.05–1.28	0.05
1997	0.96	0.90–1.02	0.03	0.93	0.86–1.01	0.04
1998	0.91	0.86–0.96	0.03	0.91	0.85–0.98	0.04
1999	0.86	0.81–0.91	0.03	1.19	1.10–1.29	0.04
2000	0.88	0.83–0.93	0.03	1.05	0.99–1.13	0.03
2001	1.05	0.99–1.11	0.03	1.23	1.15–1.32	0.03
2002	0.95	0.90–1.01	0.03	0.92	0.87–0.99	0.03
2003	0.93	0.88–0.98	0.03	0.82	0.77–0.89	0.04
2004	1.05	0.99–1.11	0.03	1.08	1.00–1.16	0.04
2005	0.81	0.75–0.87	0.04	0.74	0.67–0.81	0.05
2006	1.14	1.04–1.25	0.05	0.79	0.71–0.87	0.05
2007	1.04	0.95–1.13	0.05	0.74	0.67–0.82	0.05
2008	0.90	0.83–0.97	0.04	0.74	0.67–0.81	0.05
2009	0.88	0.81–0.95	0.04	0.94	0.86–1.04	0.05
2010	1.00	0.93–1.09	0.04	1.08	0.97–1.20	0.05

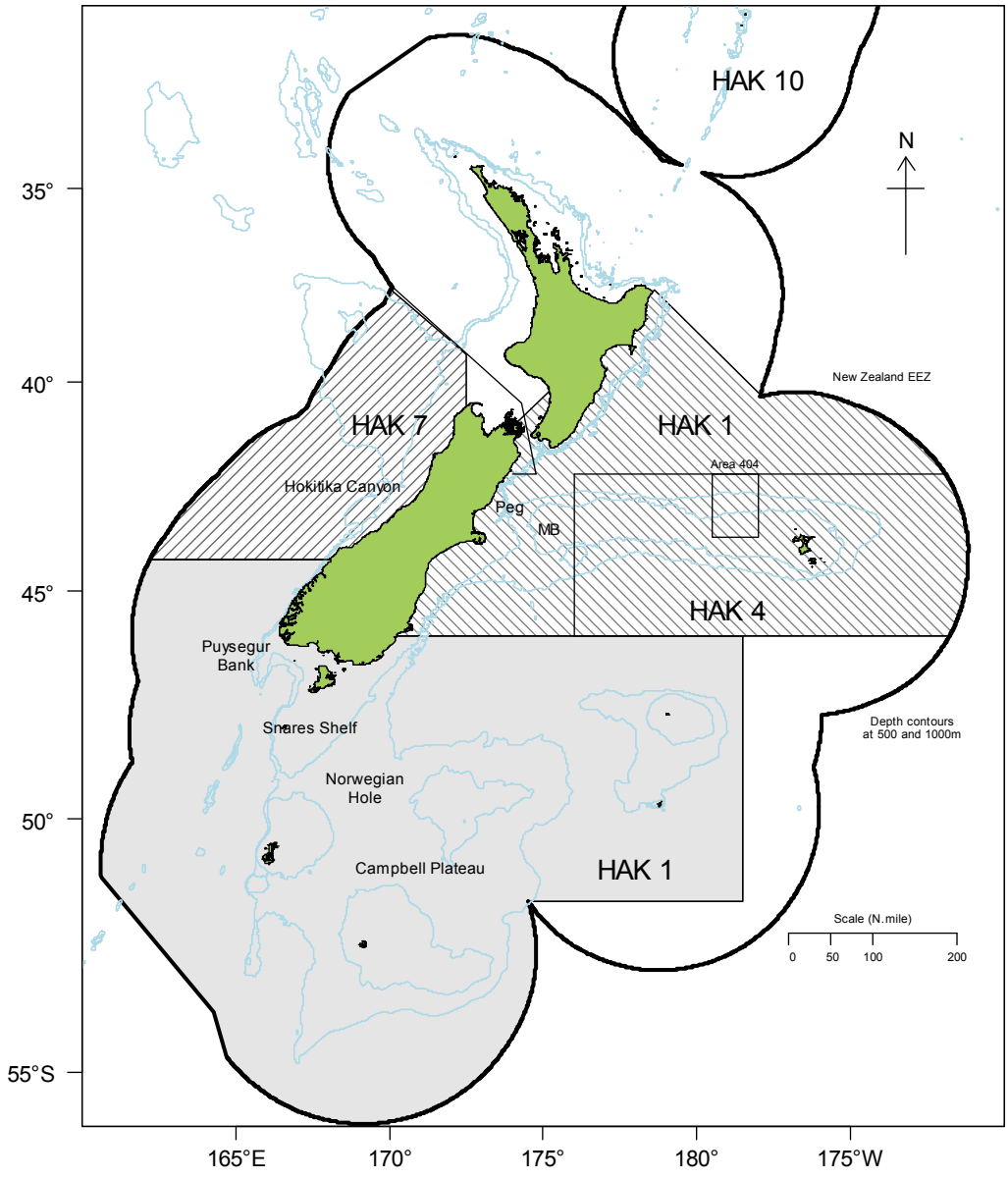


Figure 1: Quota Management Areas (QMAs) HAK 1, 4, 7, & 10, and hake stock boundaries, as assumed in this report: West coast South Island (dark stripes over HAK7), Chatham Rise (light stripes over HAK1 and HAK4), and Sub-Antarctic (grey shading over HAK1). Place names referred to in the text are also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

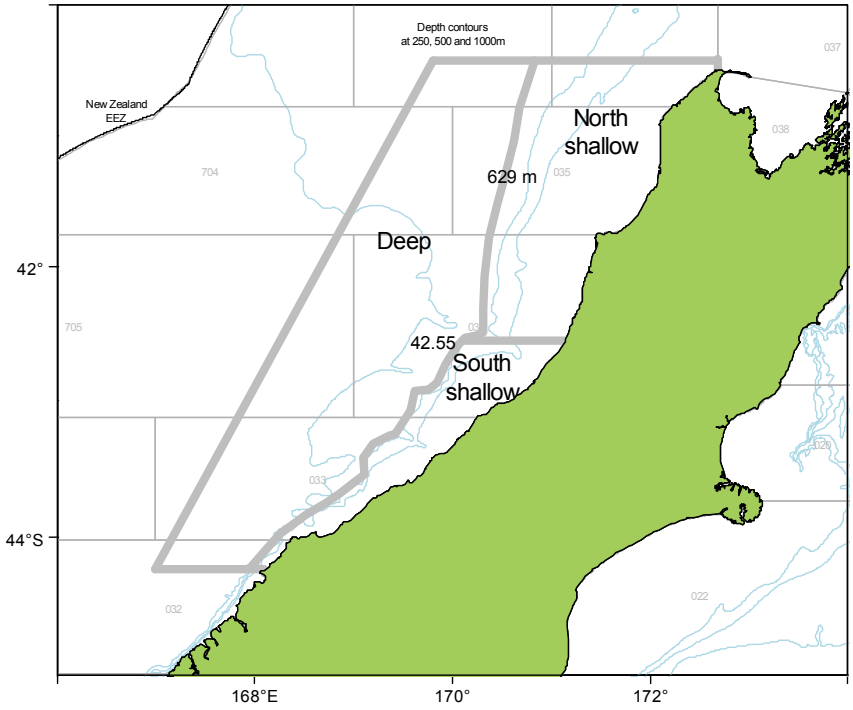


Figure 2a: Location and boundaries of the three WCSI sub-areas used in this analysis: Deep (≥ 530 m depth); North shallow (< 530 m depth, < 42.55° S); South shallow (< 530 m depth, ≥ 42.55° S).

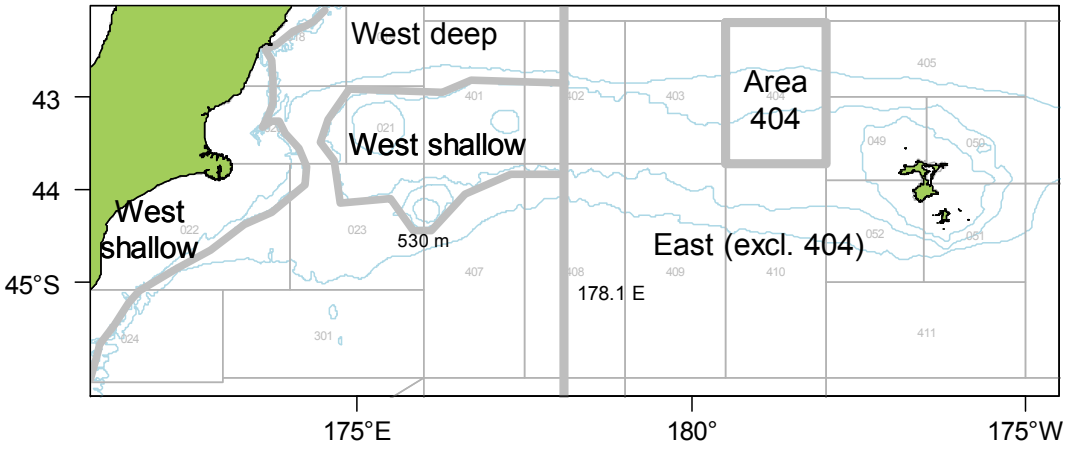


Figure 2b: Location and boundaries of the four Chatham Rise sub-areas used in this analysis: West deep (≥ 530 m depth); West shallow (< 530 m depth); East, excluding Statistical Area 404; and Statistical Area 404.

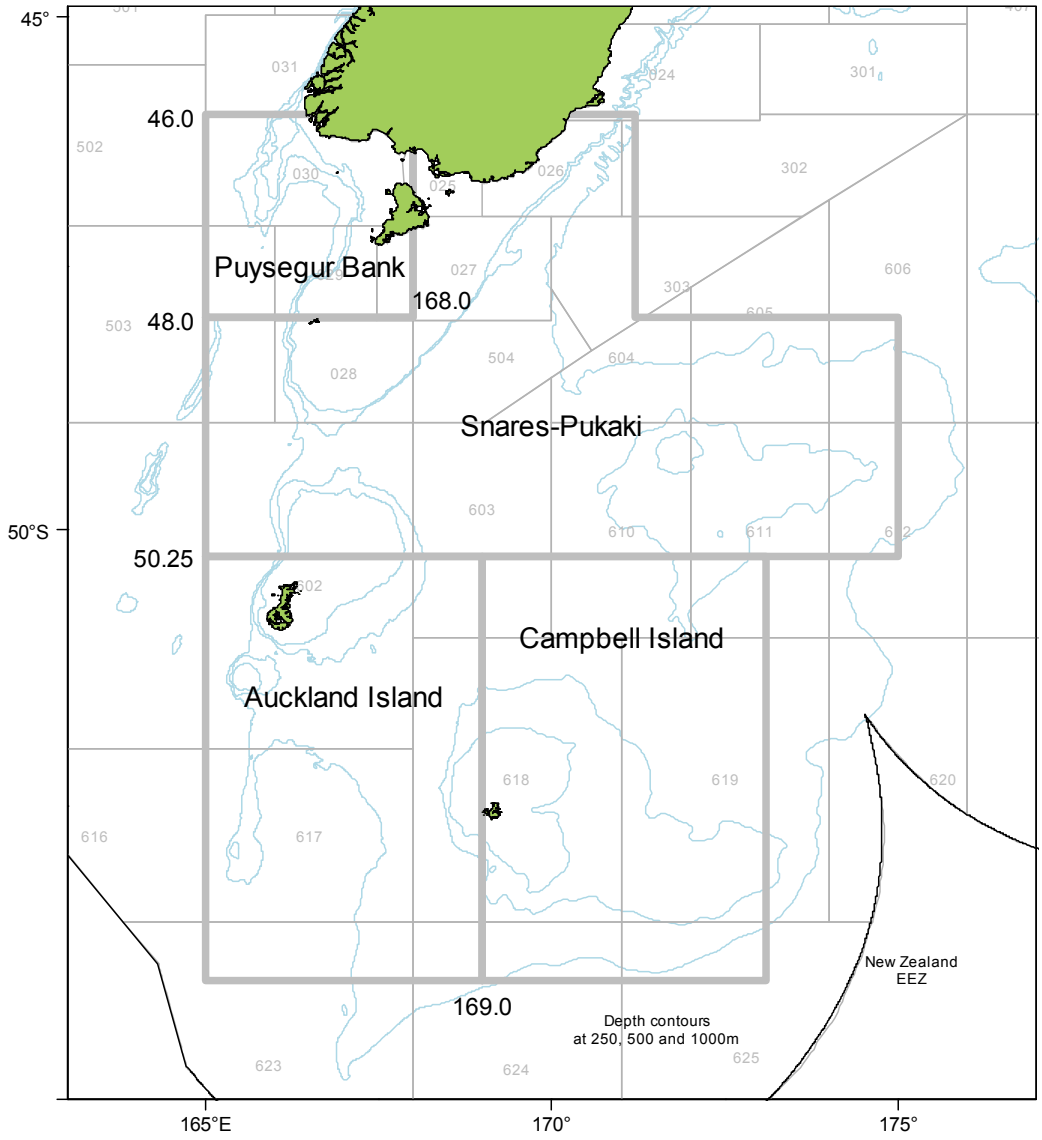


Figure 2c: Location and boundaries of the four Sub-Antarctic sub-areas used in this analysis: Puysegur Bank; Snares-Pukaki; Auckland Island; and Campbell Island.

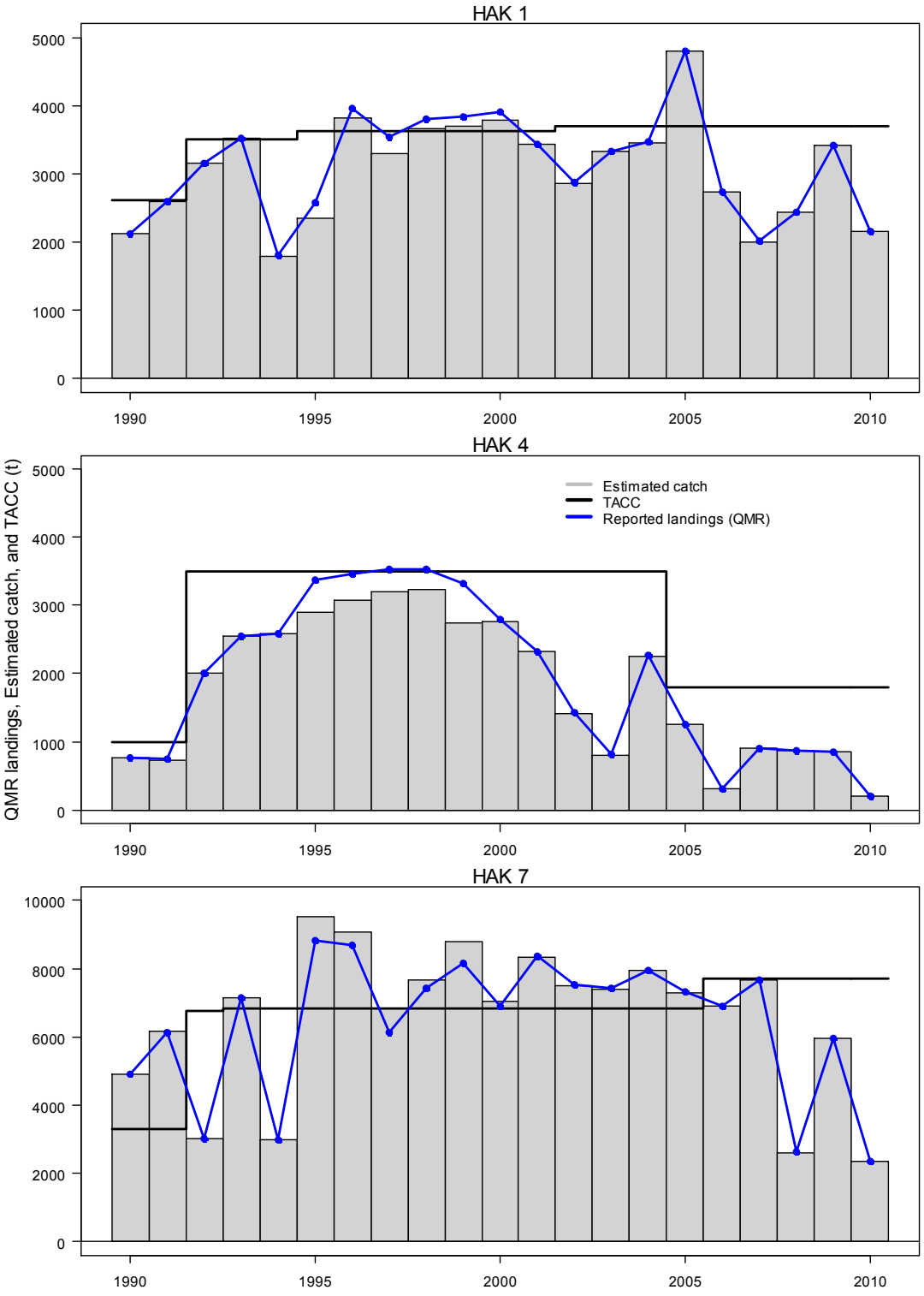


Figure 3: The QMR landings (line with dots), scaled estimated catch corrected for misreporting (shaded bars), and TACC (solid line) for HAK1, HAK4, and HAK7, for the fishing years 1989–90 (1990) to 2009–10 (2010).

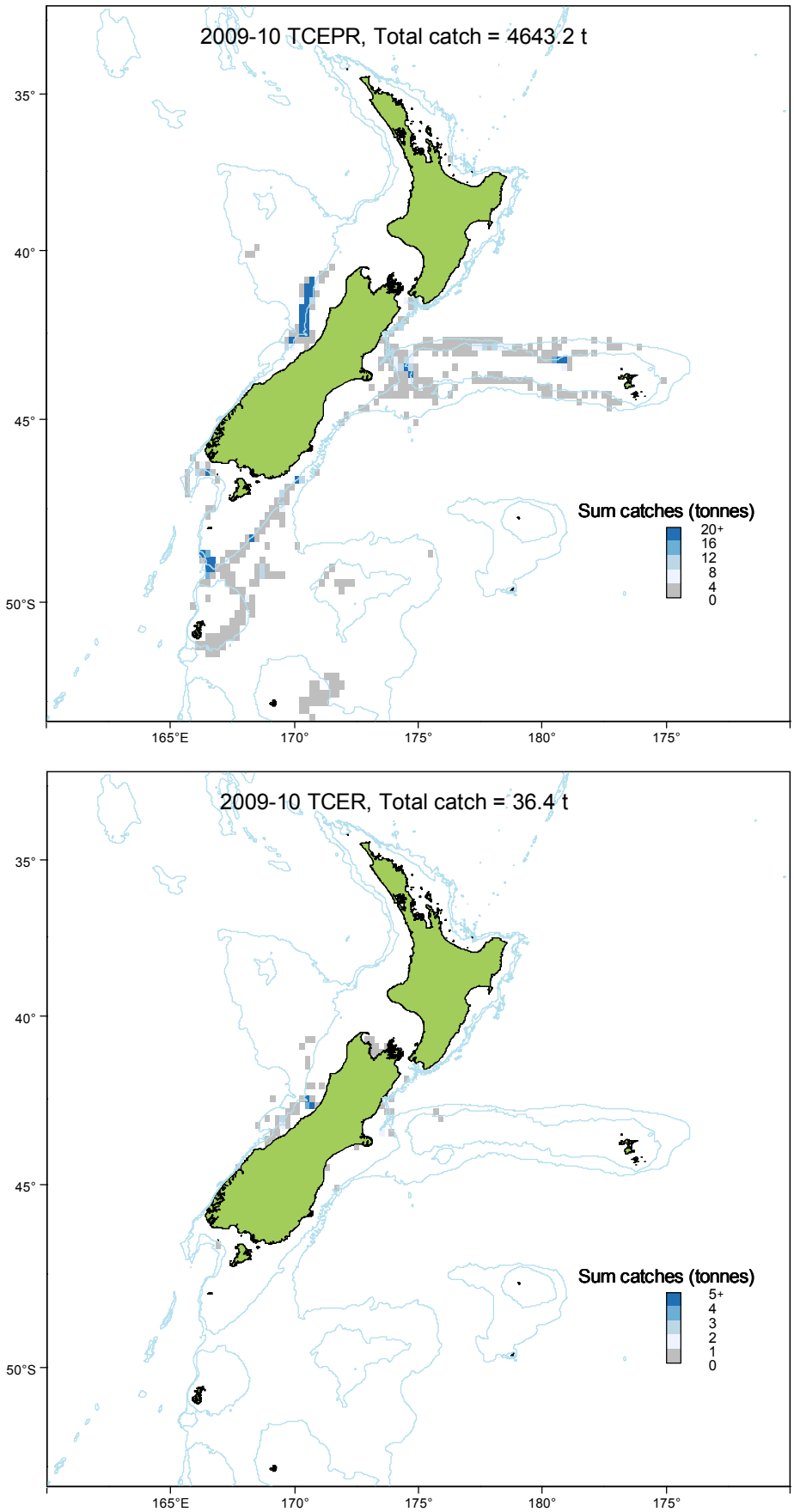


Figure 4: Density plots of all commercial TCEPR and TCER trawls where hake was caught in the 2009–10 fishing year.

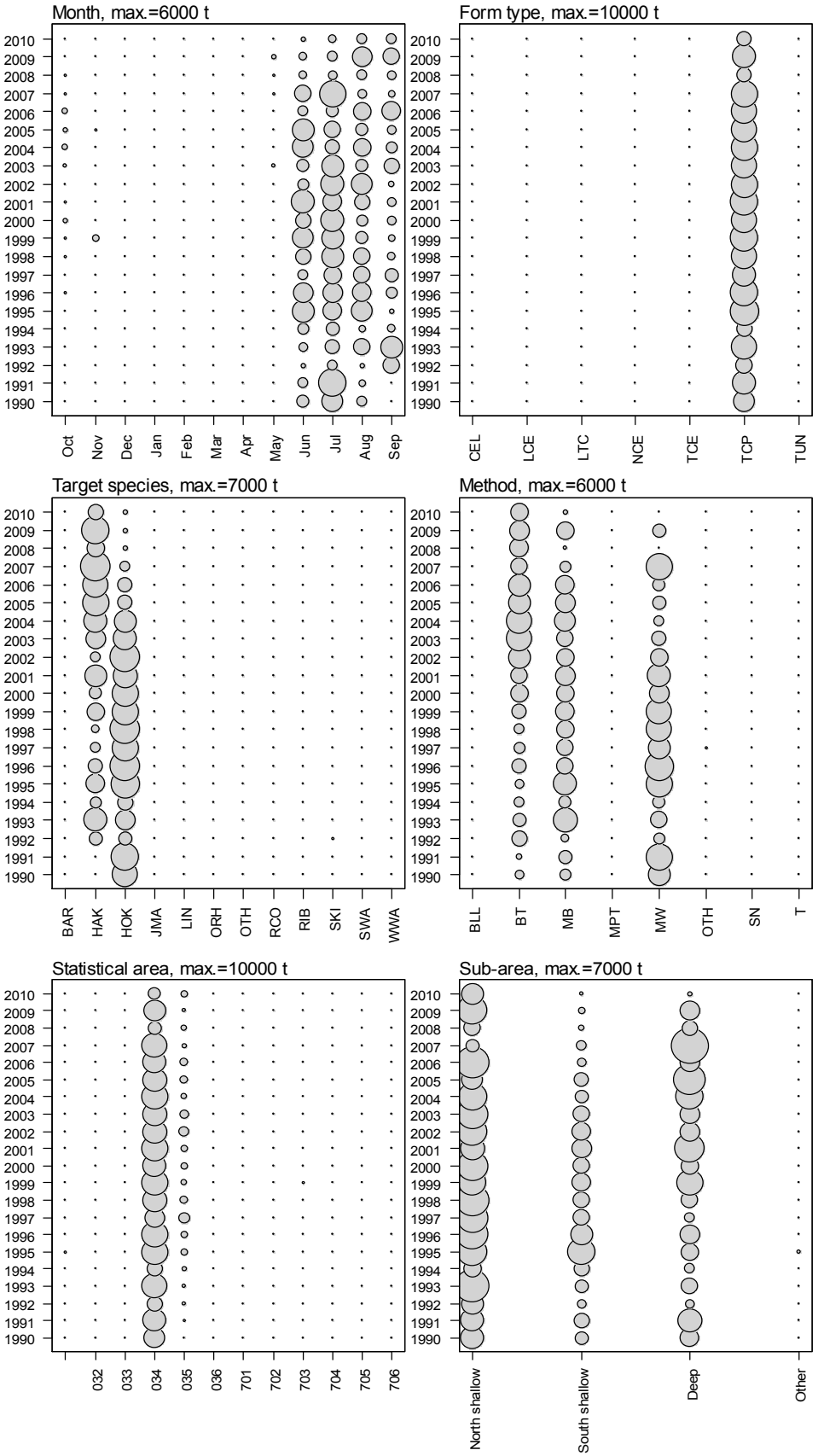


Figure 5a: Distribution of WCSI hake catch by month, target species, form type, subarea, method, and statistical area for the 1989–90 (1990) to 2009–10 (2010) fishing years. Circle size is proportional to catch; maximum circle size is indicated in the label of each plot. See Figure 2 for fishery sub-areas; Method definitions: BT, bottom tow; MB, midwater tow on the bottom, and MW, midwater tow. Form types: CEL (CELR), LCE (LCER), LTC (LTCER), NCE (NCELR), TUN (TLCER), TCP (TCEPR), and TCE (TCER).

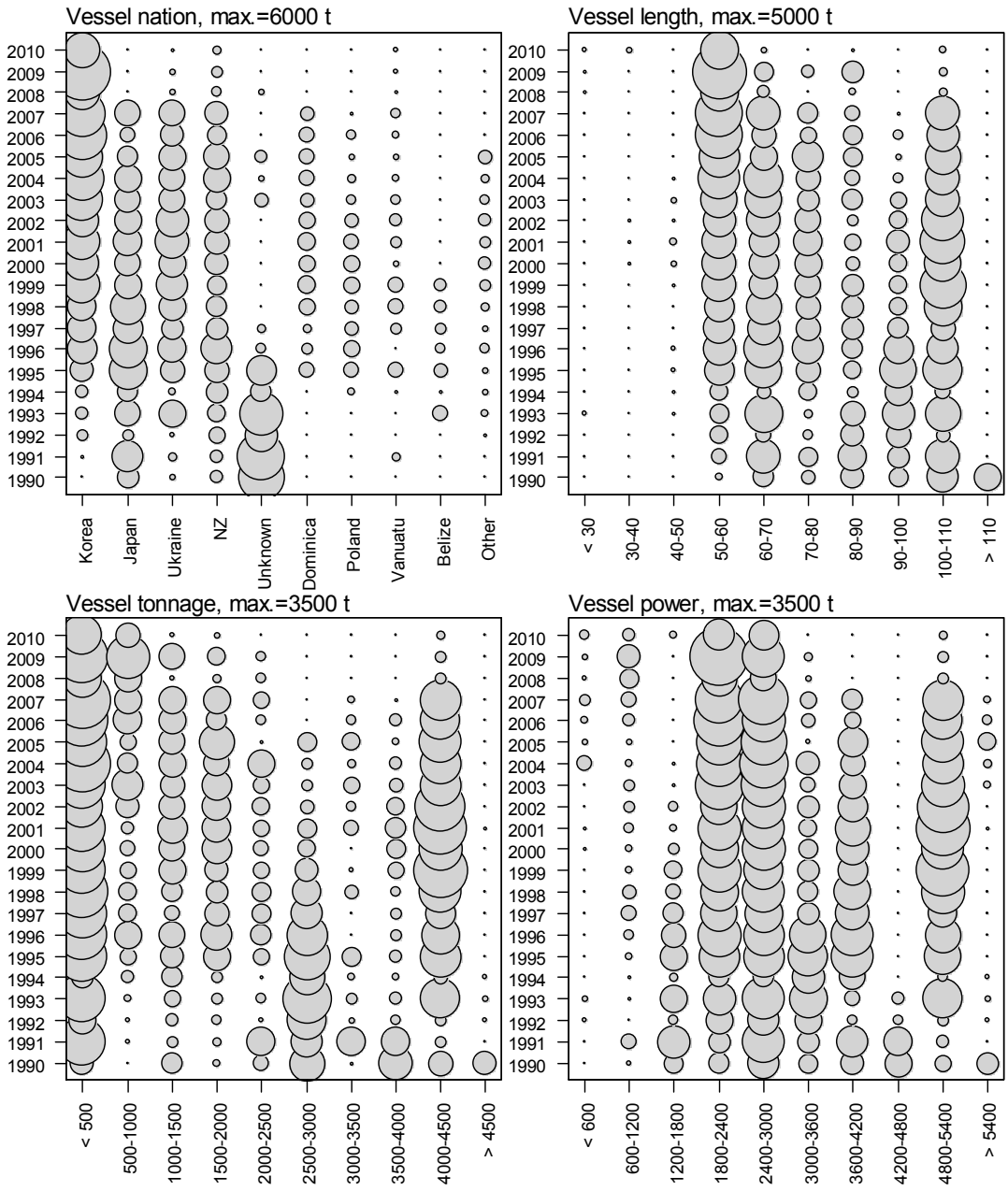


Figure 5b: Distribution of WCSI hake catch by nationality, vessel power, gross tonnage, and length (m) for fishing years 1989–90 (1990) to 2009–10 (2010). Circle size is proportional to catch; maximum circle size is indicated in the label of each plot.

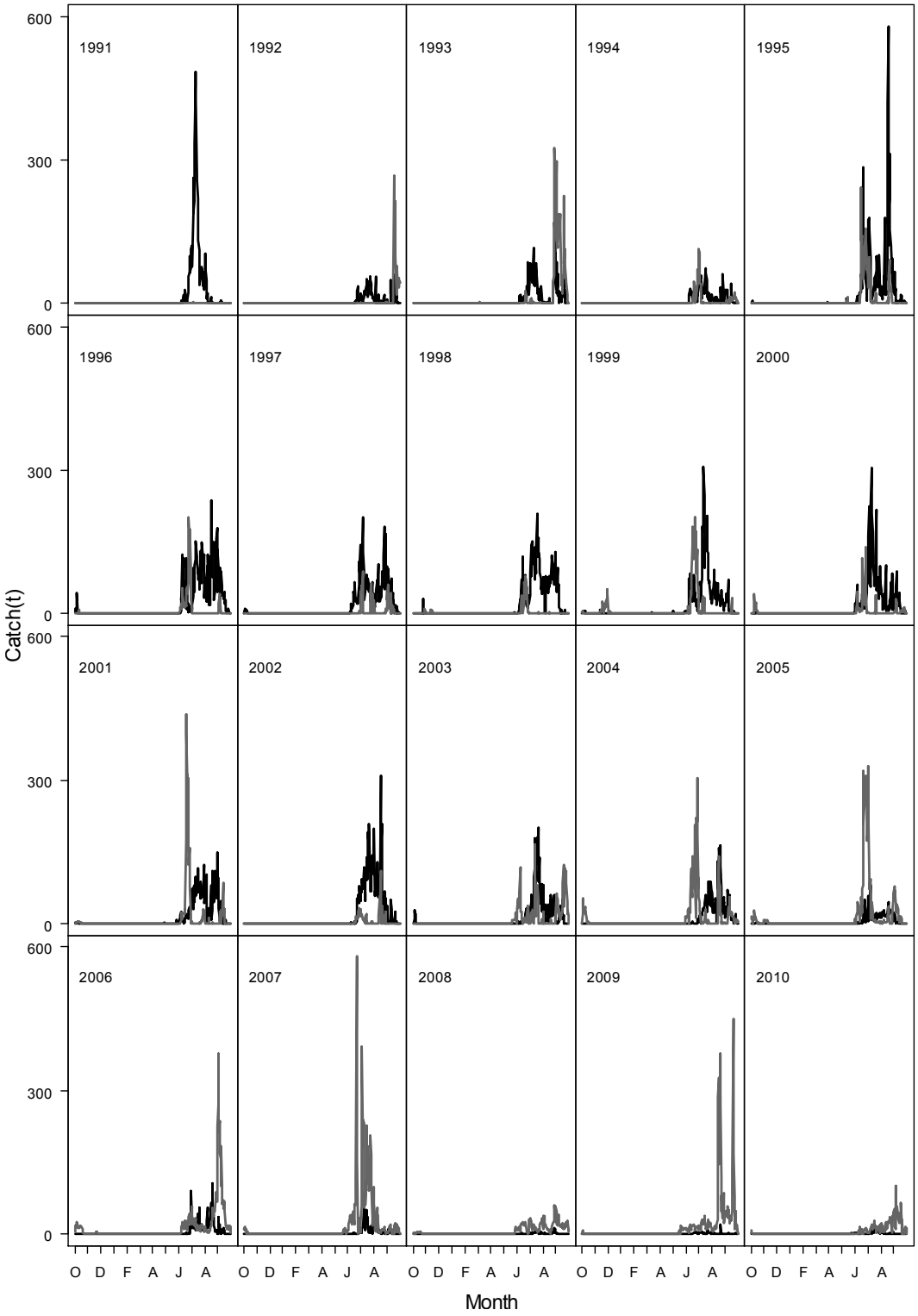
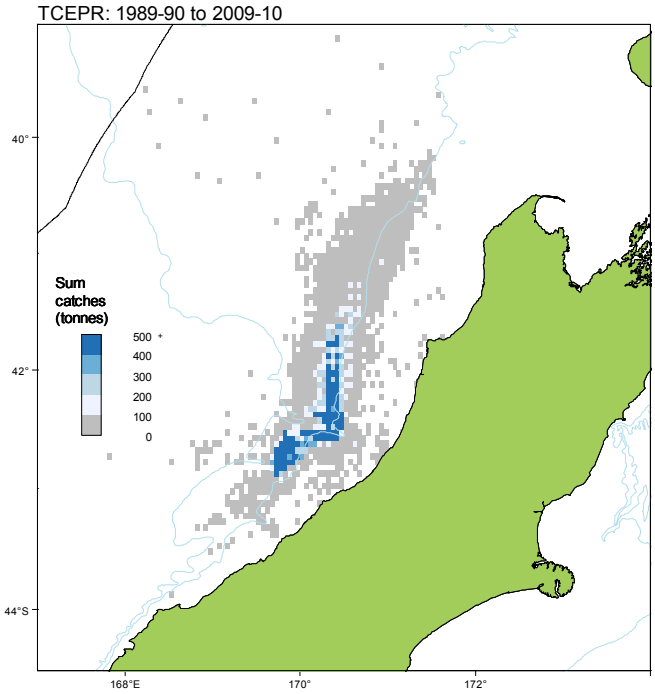


Figure 6: Daily catch by fishing year 1990–91 (1991) to 2009–10 (2010). Grey lines, hake catches from target hake tows; black lines, hake catches from target hoki tows.



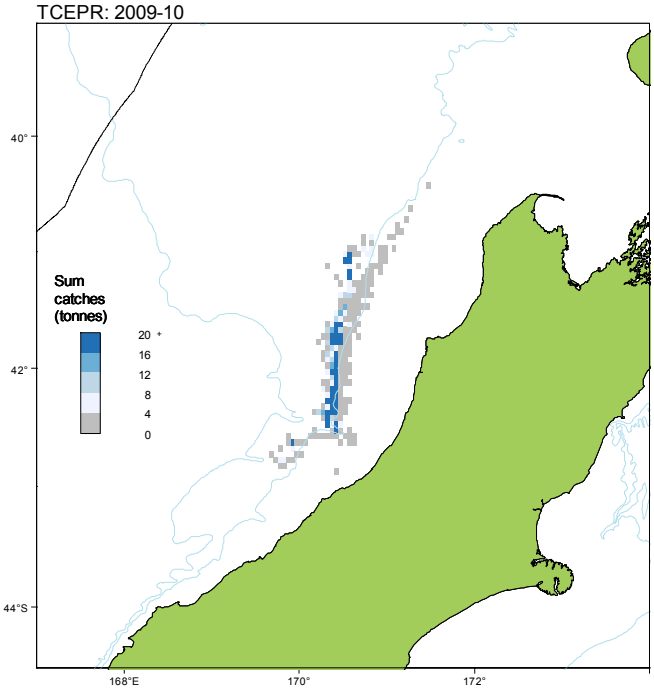


Figure 7: Density (in tonnes) of WCSI commercial hake catches from TCEPR records by fishing year (1 October to 30 September) for all fishing years combined (1989–90 to 2009–10), and for the 2009–10 fishing year.

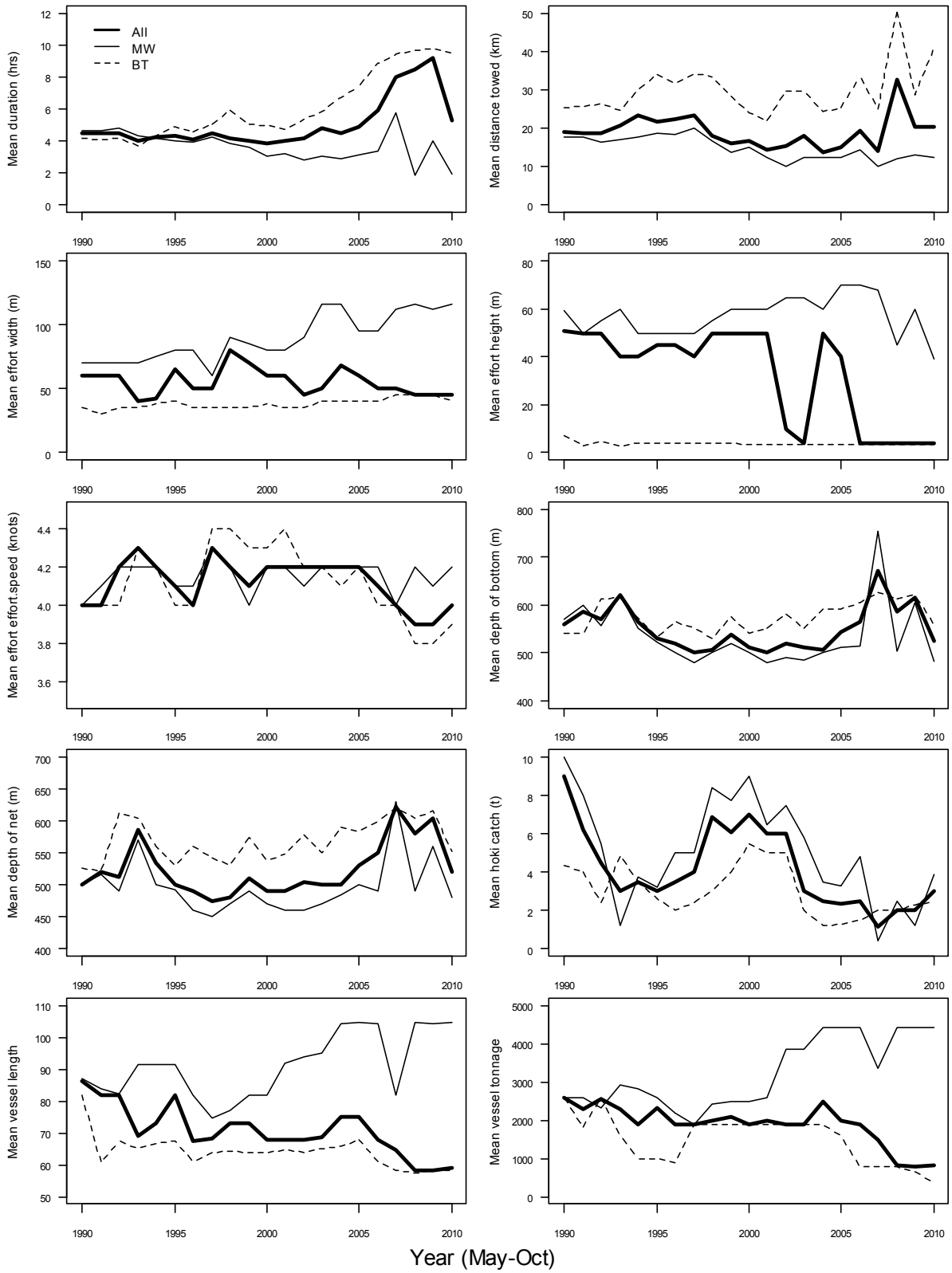


Figure 8a: Mean of some available variables by method for WCSI vessels targeting hake, hoki, and ling by year, for all tows (All), bottom tows (BT), and midwater tows (MW).

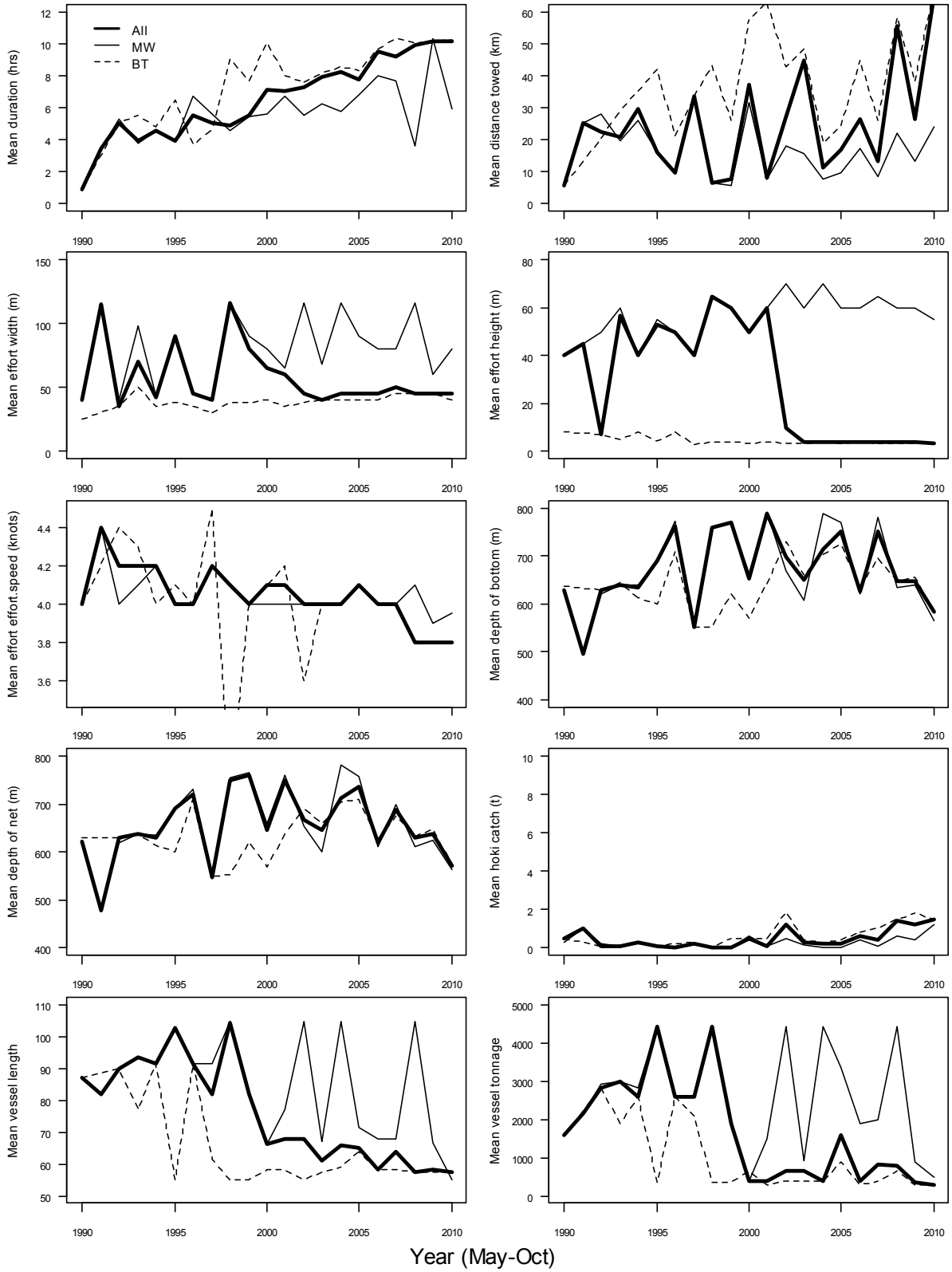


Figure 8b: Mean of some available variables by method for WCSI vessels targeting hake by year, for all tows (All), bottom tows (BT), and midwater tows (MW).

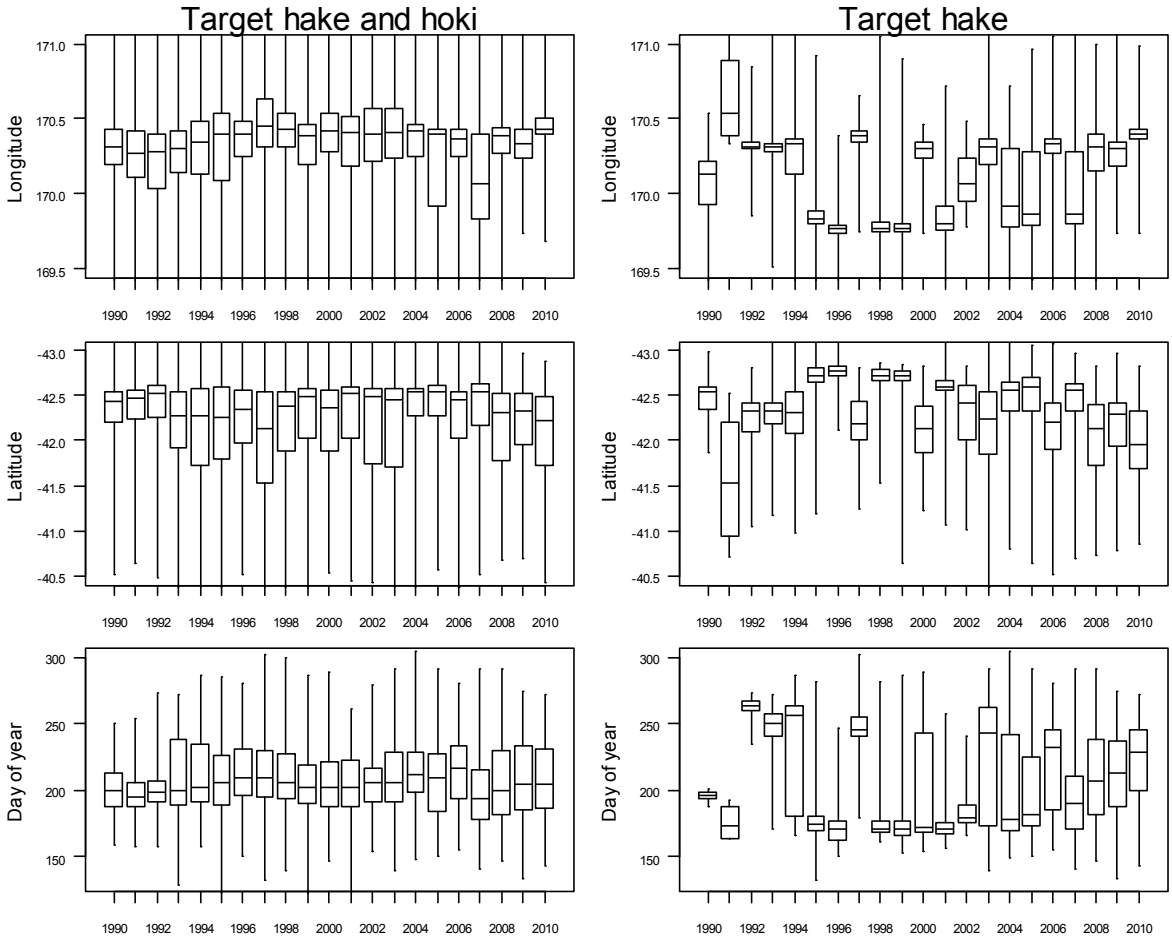


Figure 9: Box and whisker plots of longitude, latitude, and day of year for WCSI vessels targeting hake and hoki, or targeting hake. The plots show medians and lower and upper quartiles in the box, and whiskers extending up to 1.5x the interquartile range.

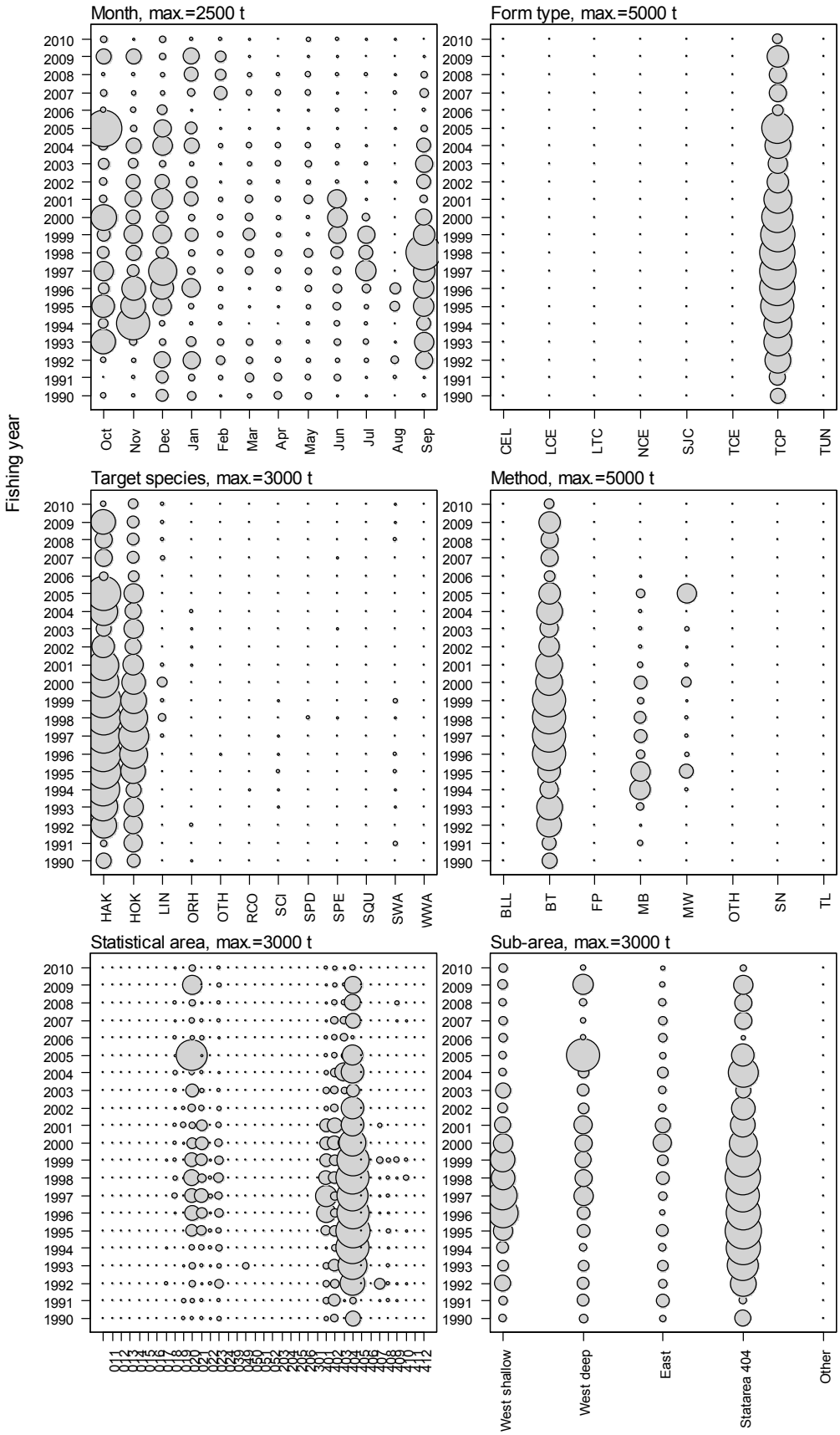


Figure 10a: Distribution of Chatham Rise hake catch by month, target species, form type, fishery, method, and hoki catch for the 1989–90 (1990) to 2009–10 (2010) fishing years. Circle size is proportional to catch; maximum circle size is indicated in the label of each plot. See Figure 2 for fishery sub-areas; Method definitions: BT, bottom tow; MB, midwater tow on the bottom, and MW, midwater tow. Form types: CEL (CELR), LCE (LCER), LTC (LTCER), NCE (NCELR), TUN (TLCER), TCP (TCEPR), and TCE (TCER).

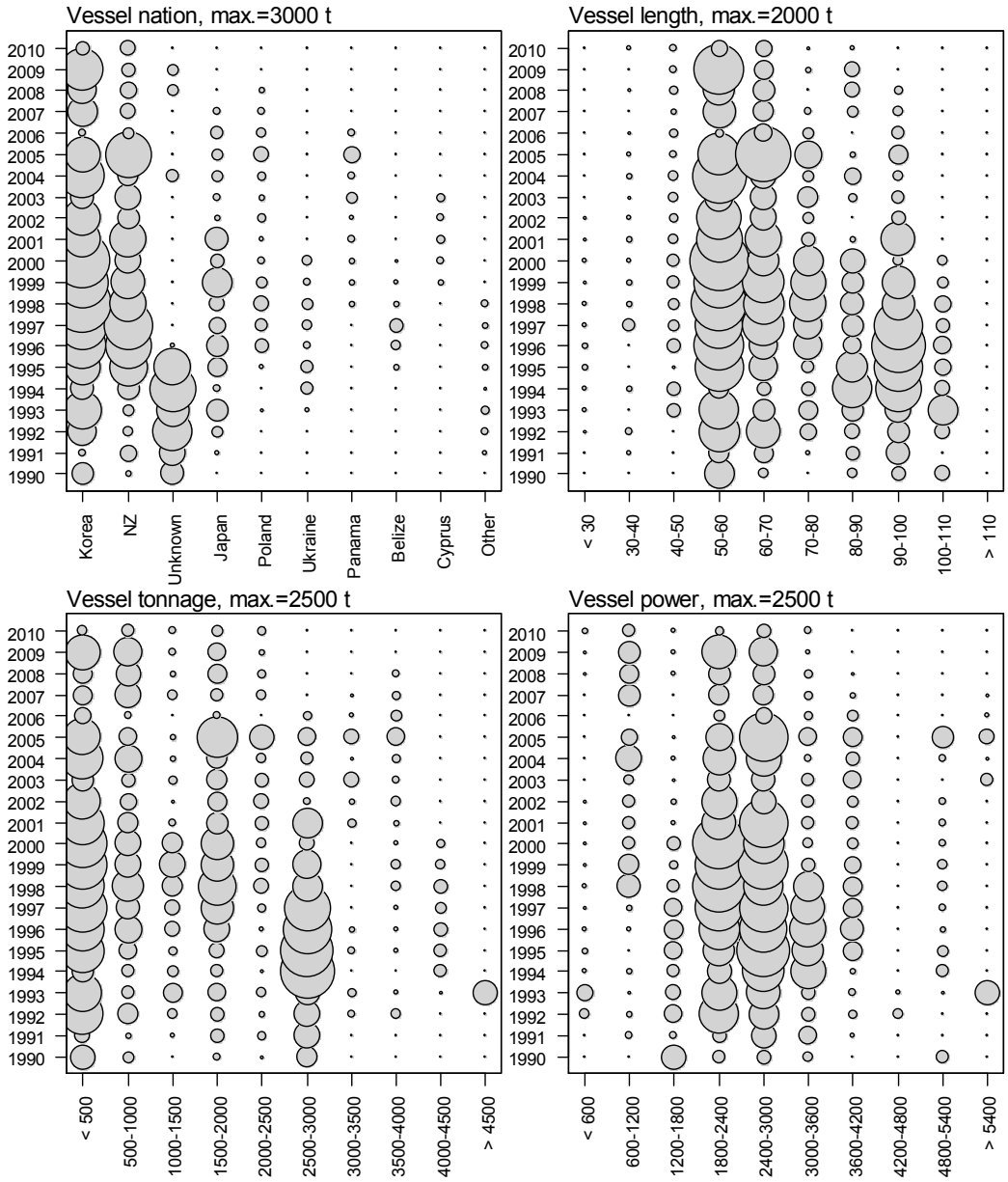


Figure 10b: Distribution of hake catch for the Chatham Rise nationality, vessel power, gross tonnage, and length (m) for fishing years 1989–90 (1990) to 2009–10 (2010). Circle size is proportional to catch; maximum circle size is indicated in the label of each plot.

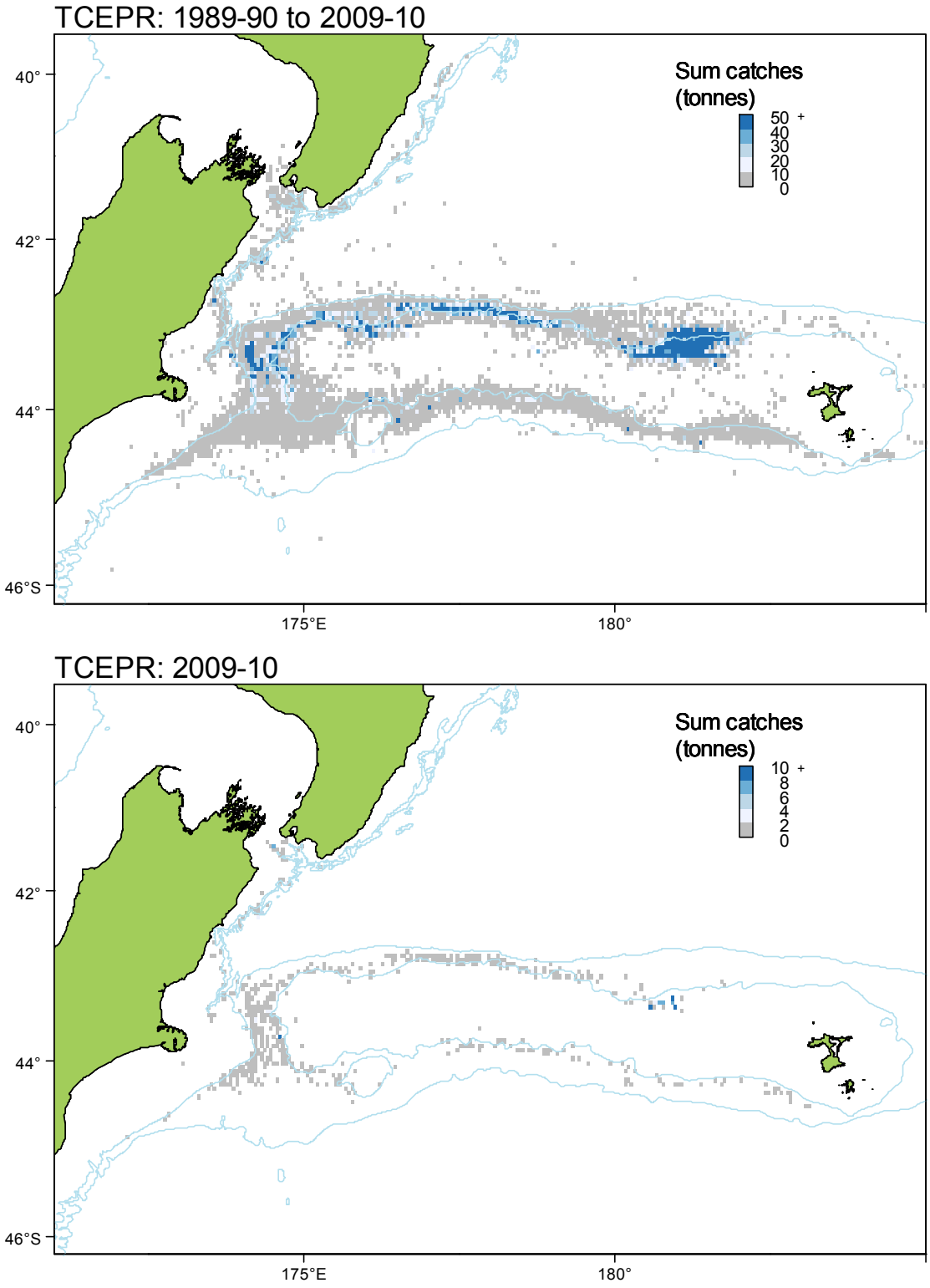


Figure 11: Density (in tonnes) of Chatham Rise commercial hake catches from TCEPR records by fishing year (1 October to 30 September) for all fishing years combined (1989–90 to 2009–10), and for the 2009–10 fishing year.

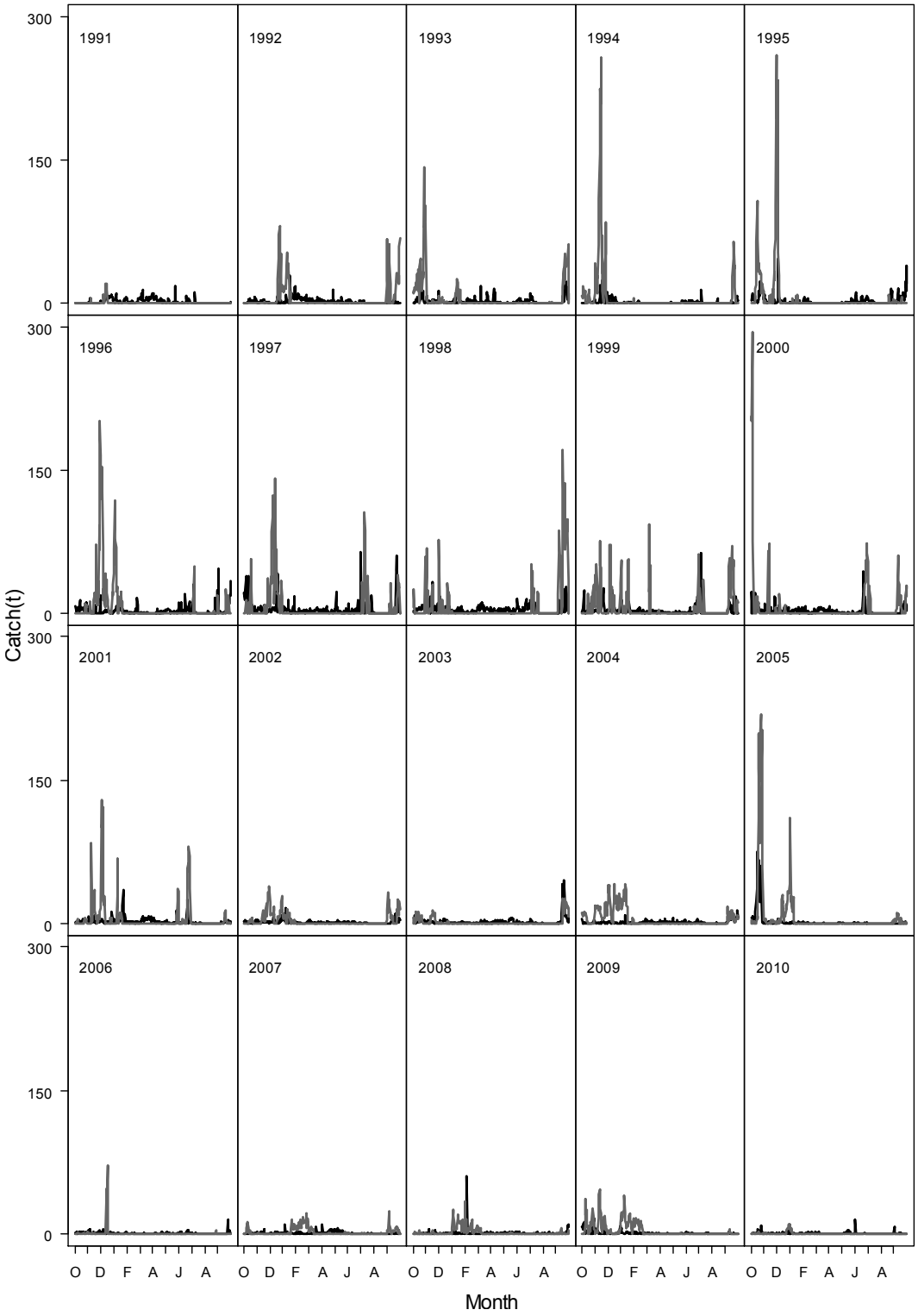


Figure 12: Daily Chatham Rise hake catch by fishing year 1990–91 (1991) to 2009–10 (2010). Grey lines, hake catches from target hake tows; black lines, hake catches from target hoki tows.

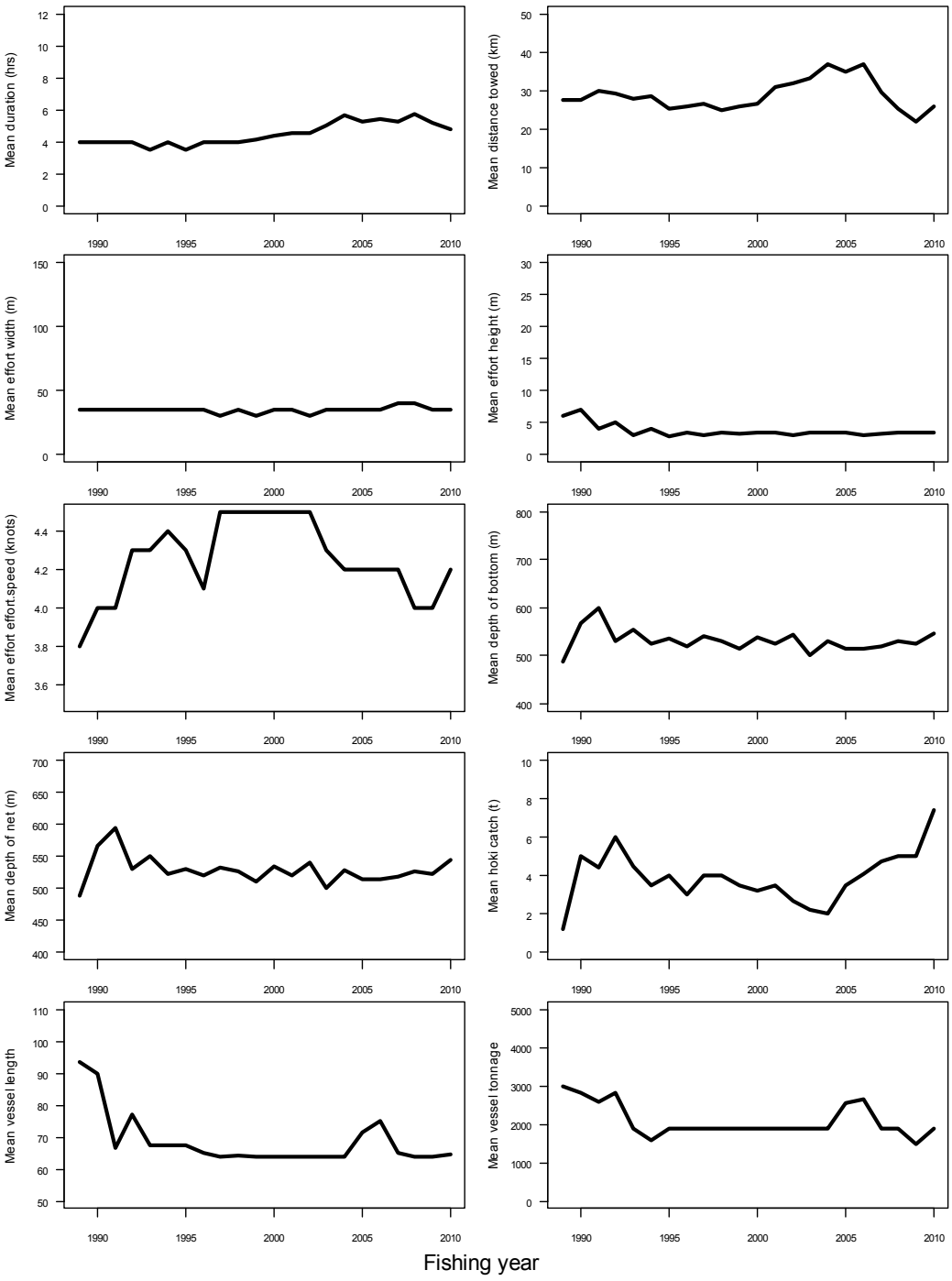


Figure 13: Mean of some available variables by method for Chatham Rise vessels using bottom tows targeting hake, hoki and ling by fishing year.

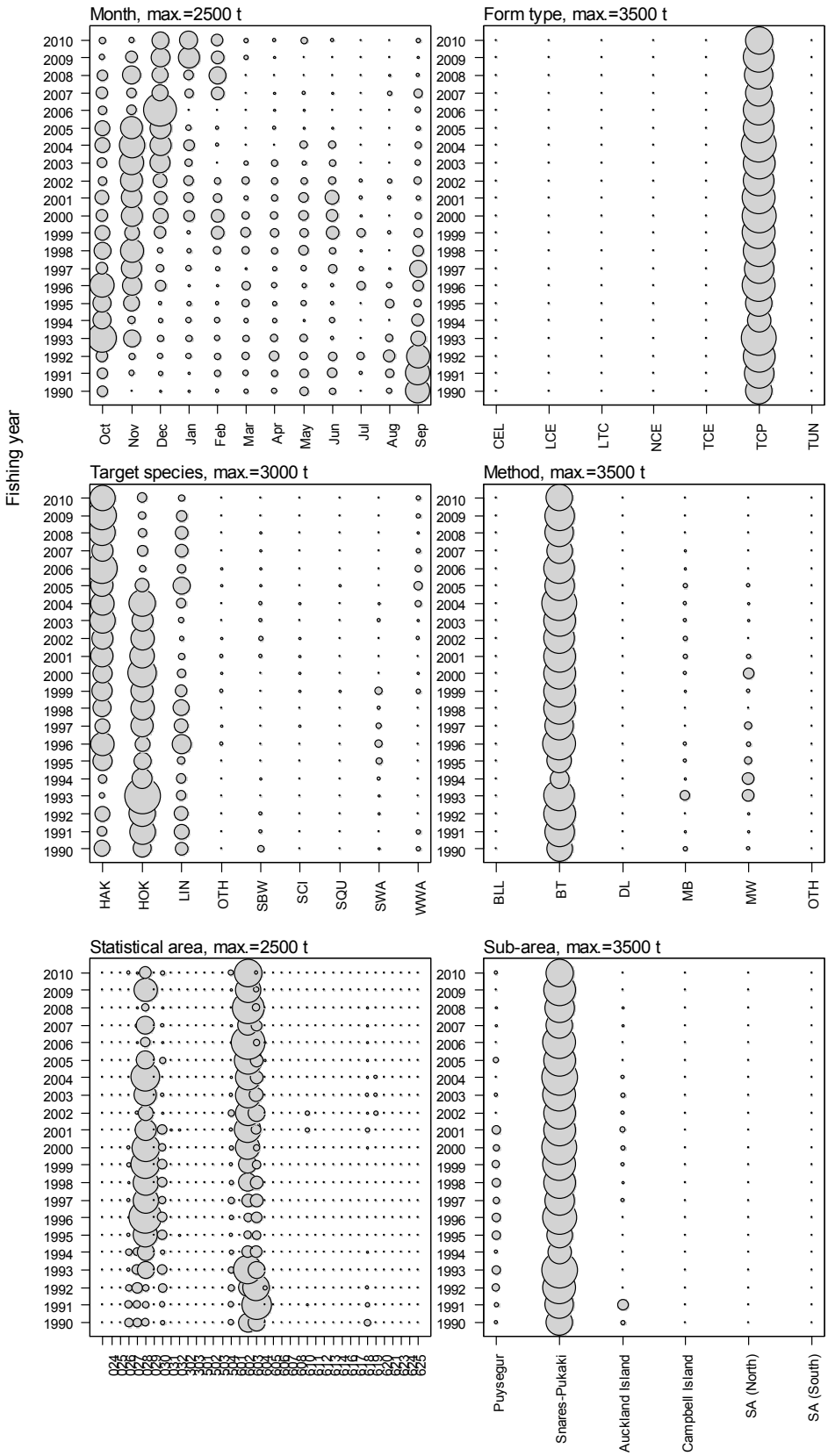


Figure 14a: Distribution of Sub-Antarctic hake catch by month, target species, form type, fishery, method, and statistical area for the 1989–90 (1990) to 2009–10 (2010) fishing years. Circle size is proportional to catch; maximum circle size is indicated in the label of each plot. See Figure 2 for fishery sub-areas; Method definitions: BT, bottom tow; MB, midwater tow on the bottom, and MW, midwater tow. Form types: CEL (CELR), LCE (LCER), LTC (LTCER), NCE (NCELR), TUN (TLCER), TCP (TCEPR), and TCE (TCER).

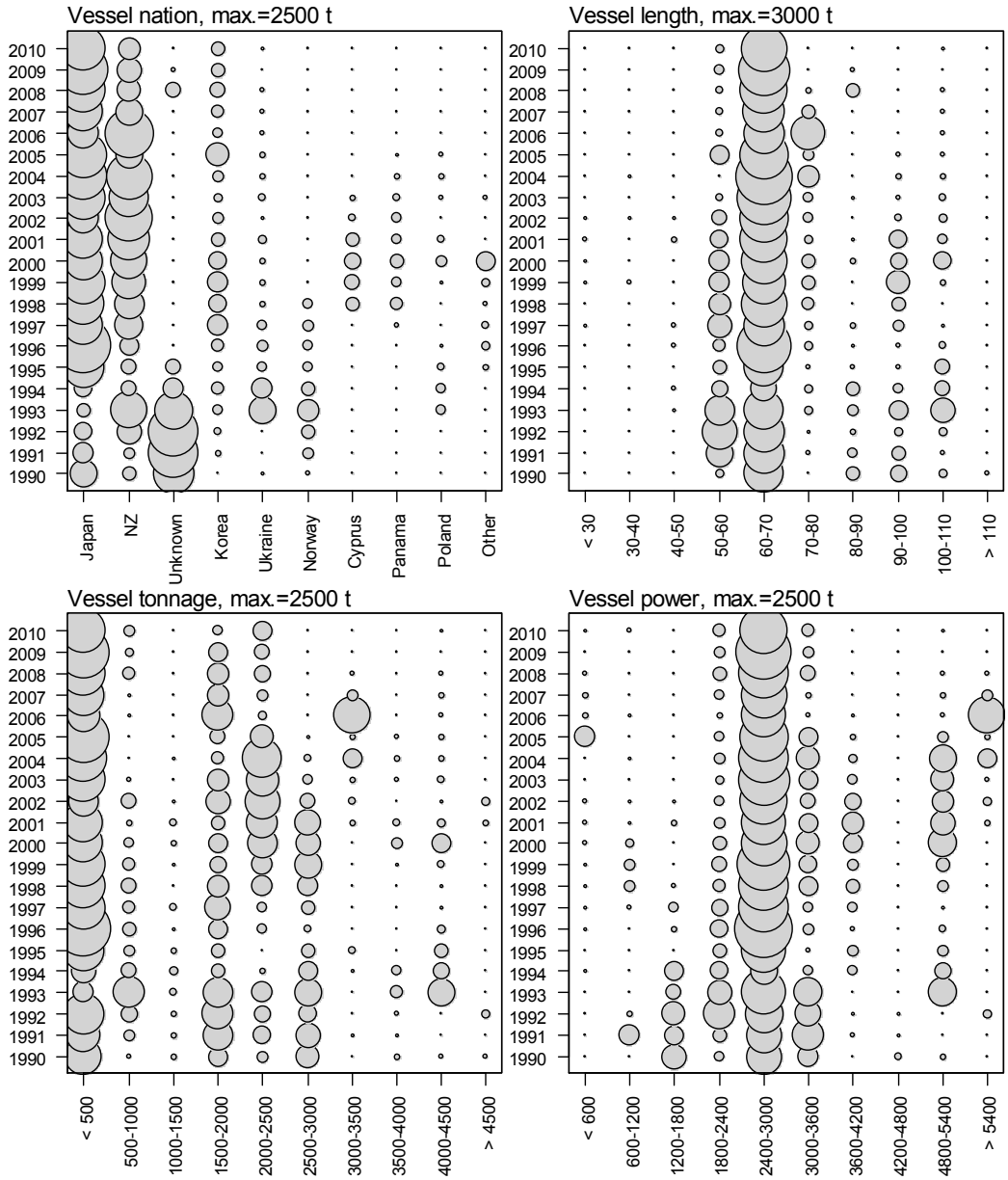


Figure 14b: Distribution of hake catch for the Sub-Antarctic by nationality, vessel power, gross tonnage, and length (m) for fishing years 1989–90 (1990) to 2009–10 (2010). Circle size is proportional to catch; maximum circle size is indicated in the label of each plot.

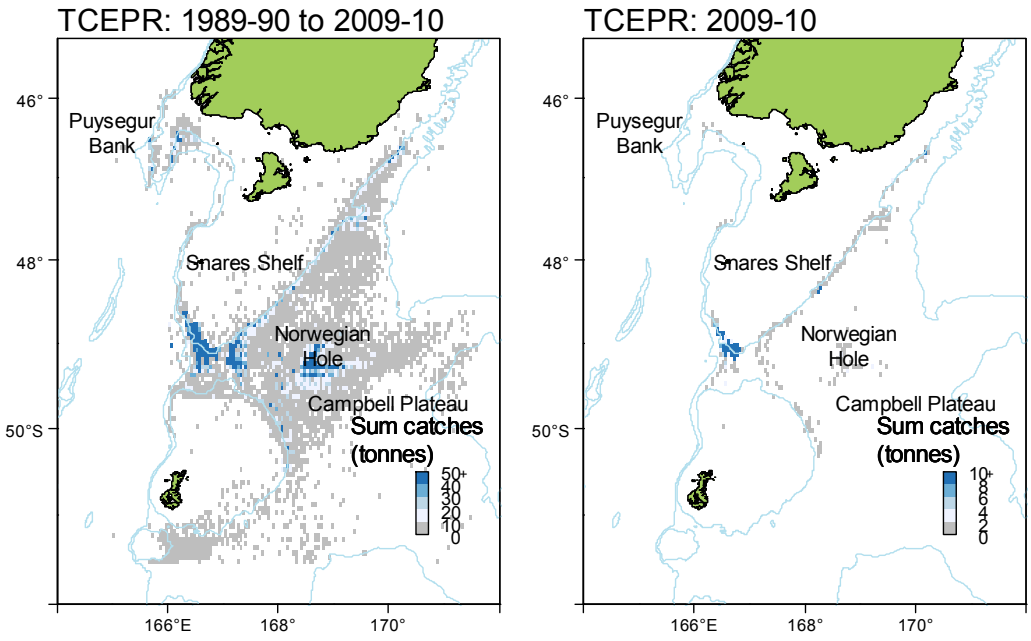


Figure 15: Density (in tonnes) of Sub-Antarctic commercial hake catches from TCEPR estimated records by fishing year (1 October to 30 September) for all fishing years combined (1989–90 to 2009–10), and for the 2009–10 fishing year.

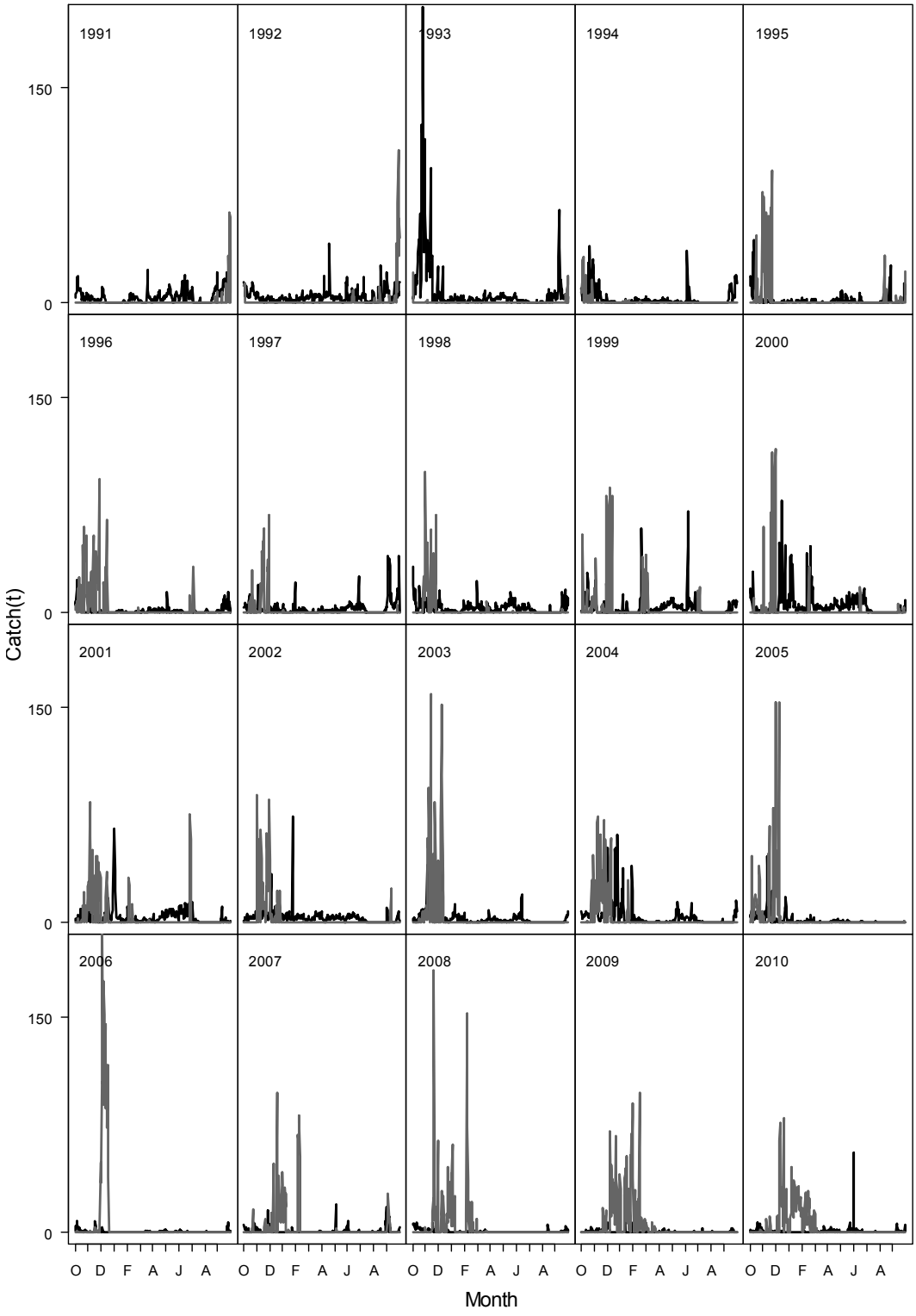


Figure 16: Daily Sub-Antarctic catch by fishing year 1990–91 (1991) to 2009–10 (2010). Grey lines, hake catches from target hake tows; black lines, hake catches from target hoki tows.

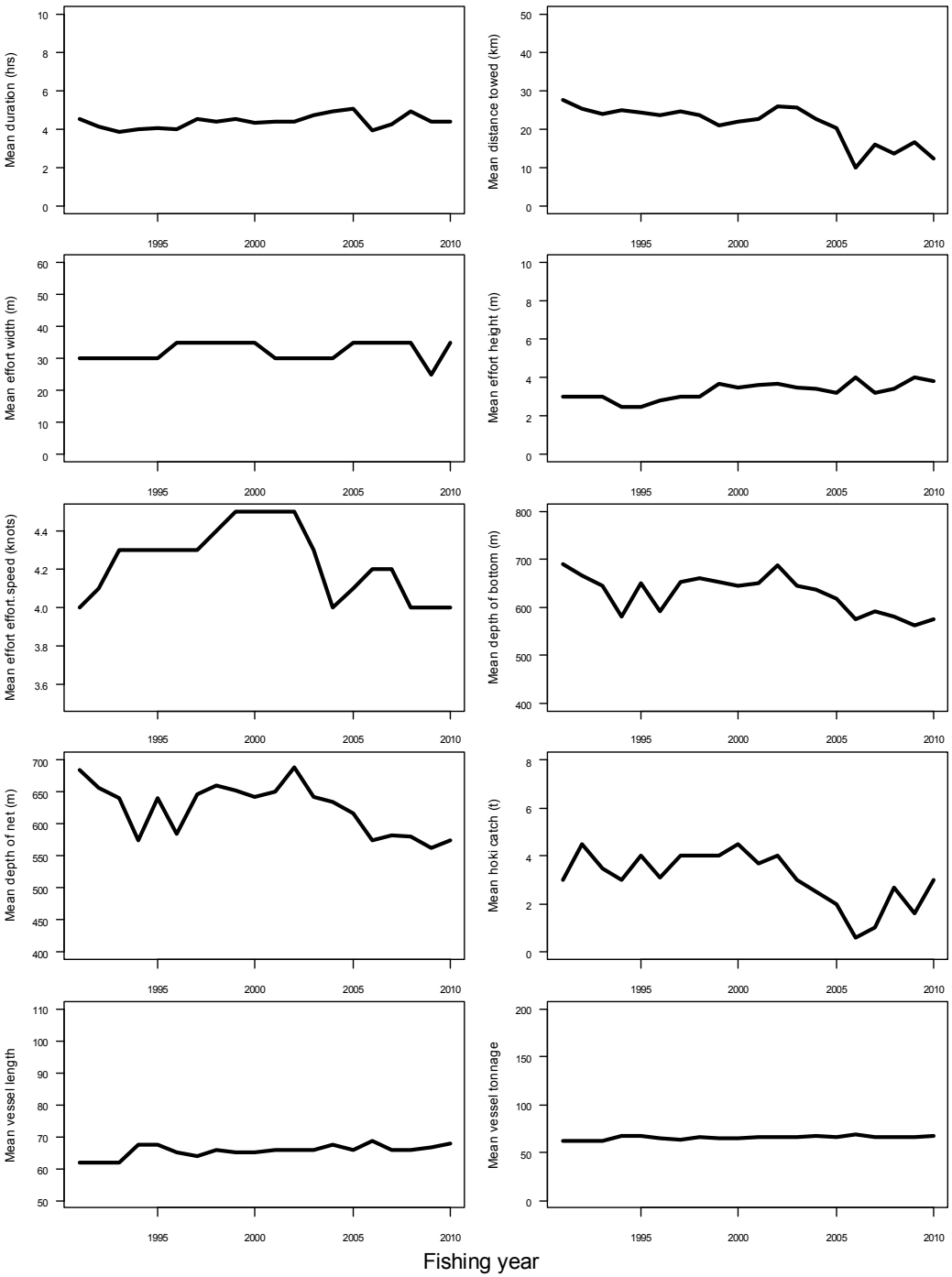
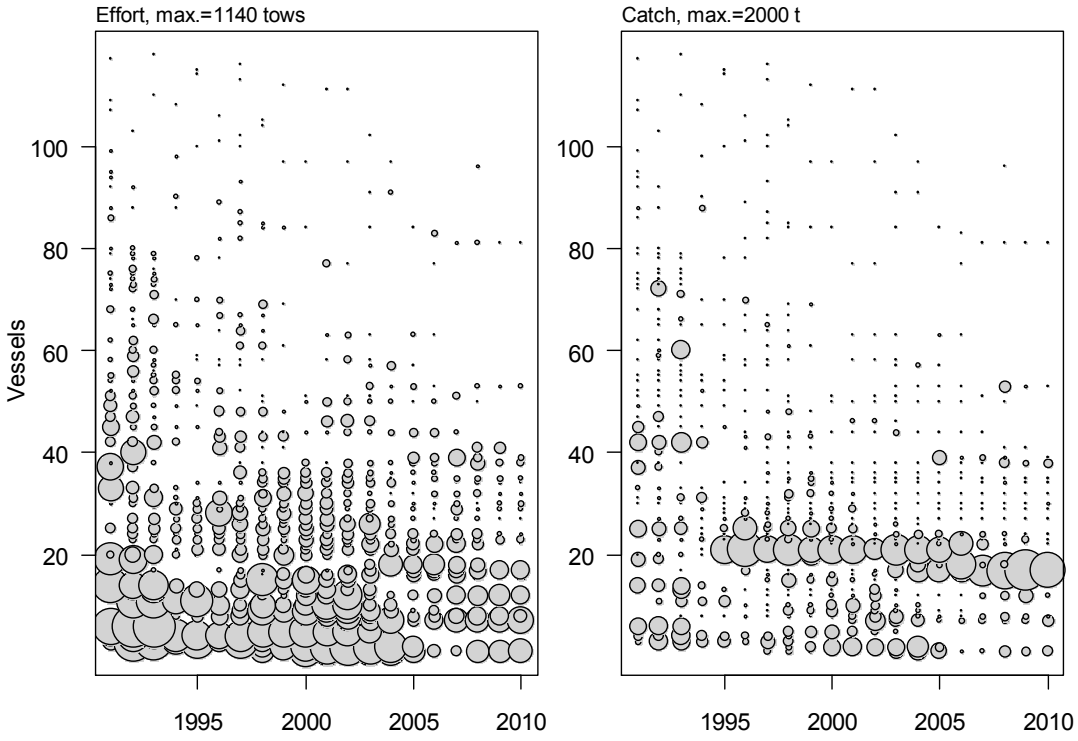


Figure 17: Mean of some available variables for Sub-Antarctic vessels using bottom tows targeting hake, hoki, and ling by fishing year.

(a) All vessels



(b) Core vessels

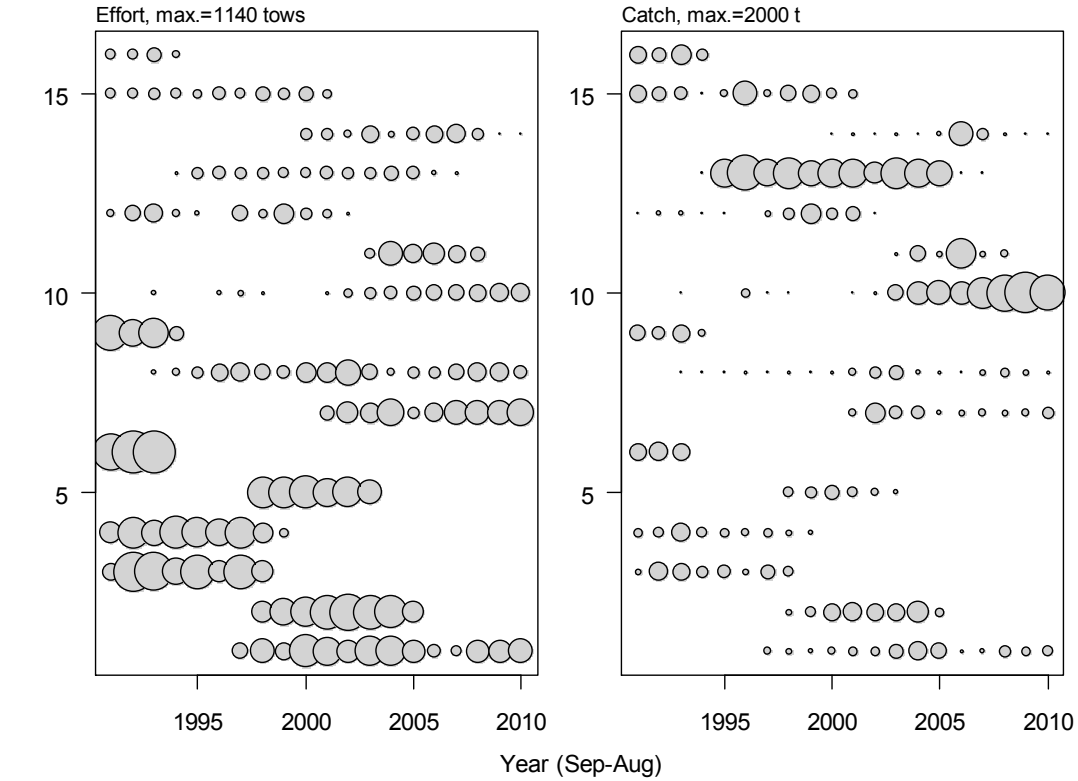


Figure 18: Sub-Antarctic — summary of effort (number of tows) and estimated catch (excluding misreported catch) for target hake, hoki, and ling days by September–August year (1991–2010) from (a) all and (b) core vessels. Symbol area is proportional to either number of tows or annual catch, and maximum circle size is shown in the label of the plot.

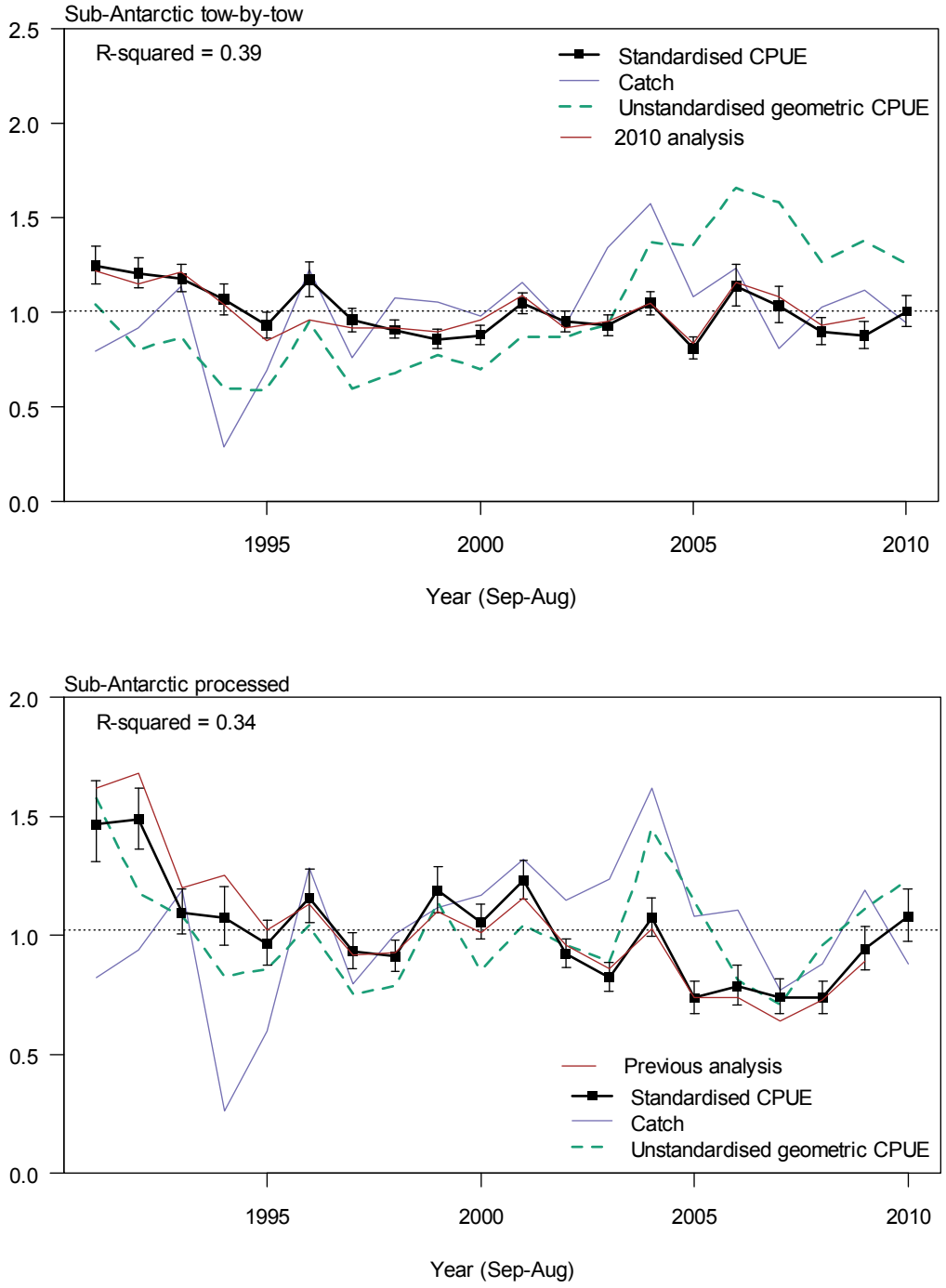
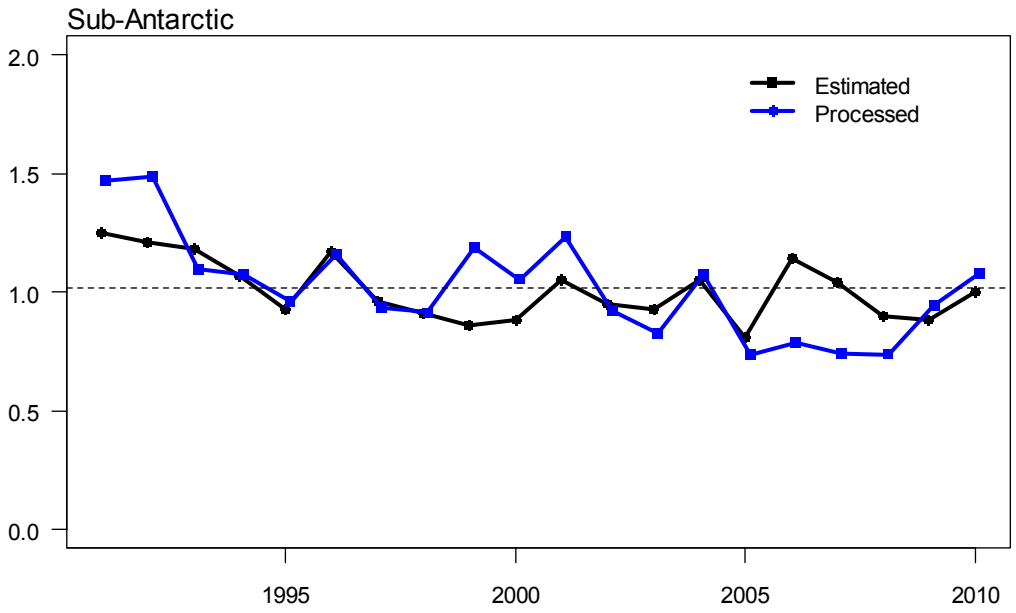


Figure 19: Sub-Antarctic CPUE, 1991–2010, showing catches (scaled to same mean as indices), and lognormal standardised (current and previous analyses) and un-standardised indices. Bars indicate 95% confidence intervals.

(a)



(b)

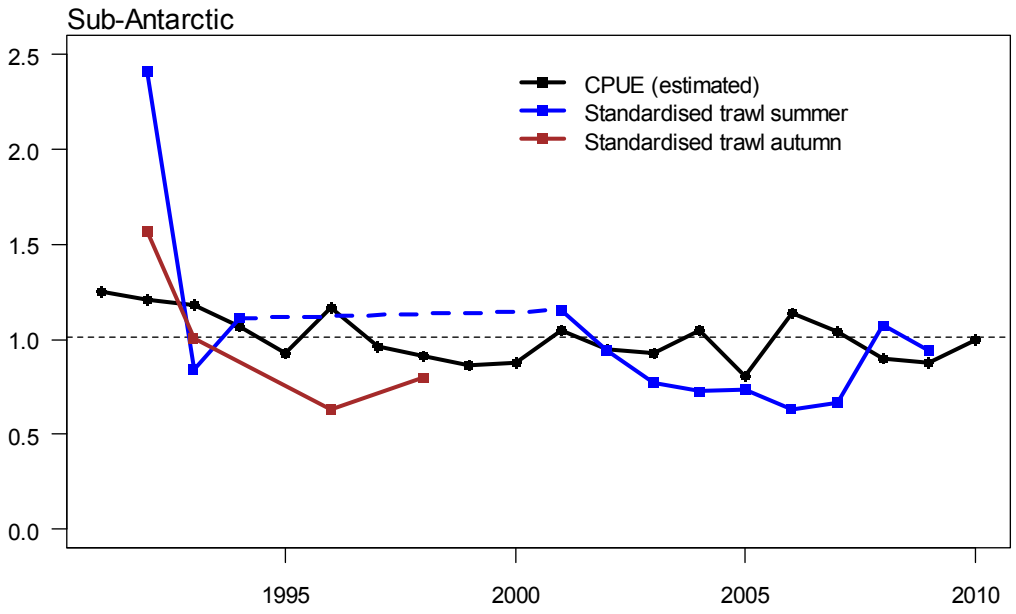


Figure 20: (a) Comparison of Sub-Antarctic indices for the tow-by-tow estimated and daily processed datasets for 1991–2010 (fishing year defined as September–August). (b) Comparison of the Sub-Antarctic trawl survey (summer and autumn) hake biomass indices and combined CPUE indices from the Sub-Antarctic fishery targeting hake, hoki, and ling, 1990–2010. Indices have been standardised to have a mean of one.

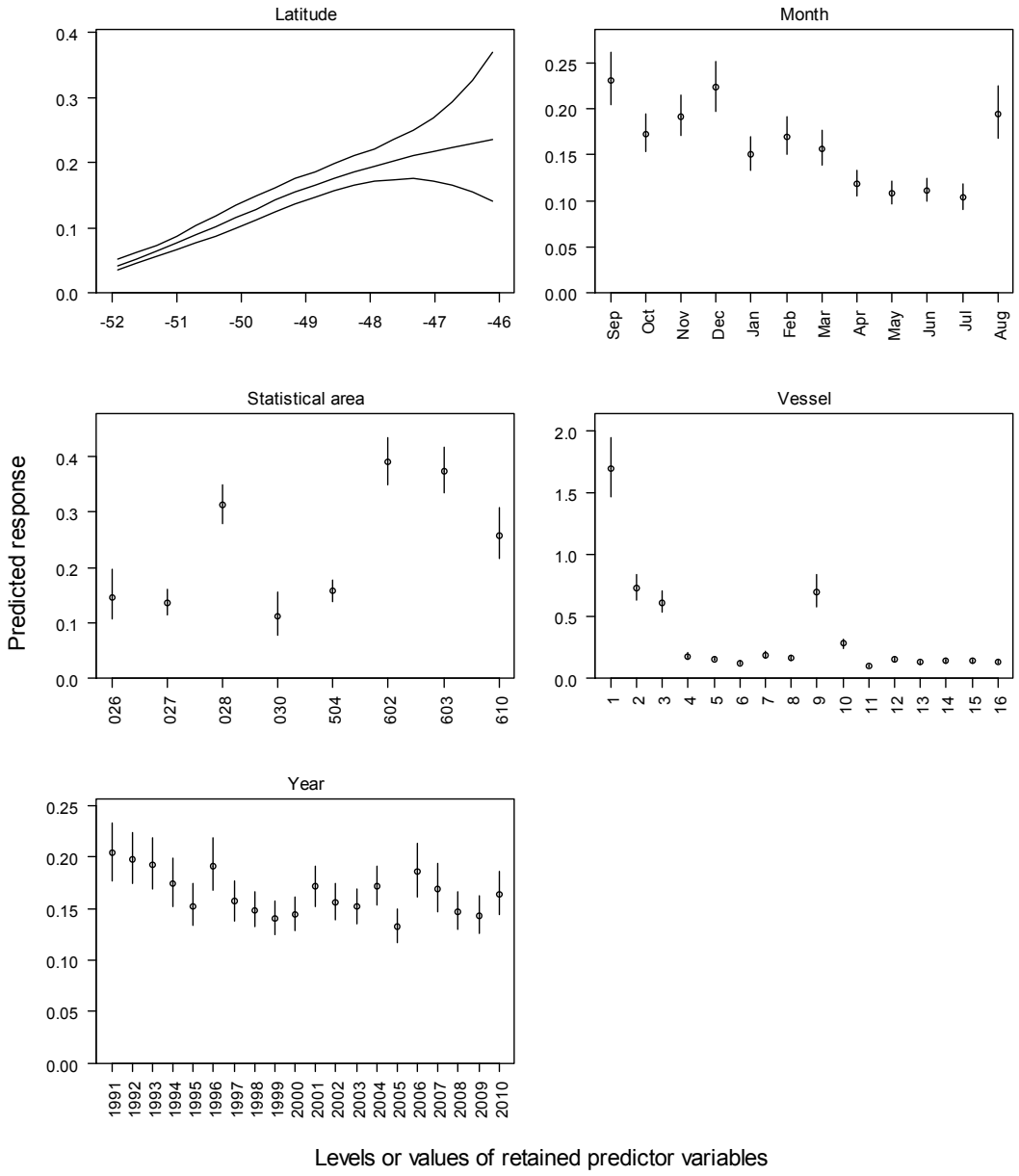


Figure 21: Effects of selected variables in the lognormal model for the Sub-Antarctic estimated catch for core vessels targeting hake, hoki, and ling, 1991–2010. Bars indicate 95% confidence interval.

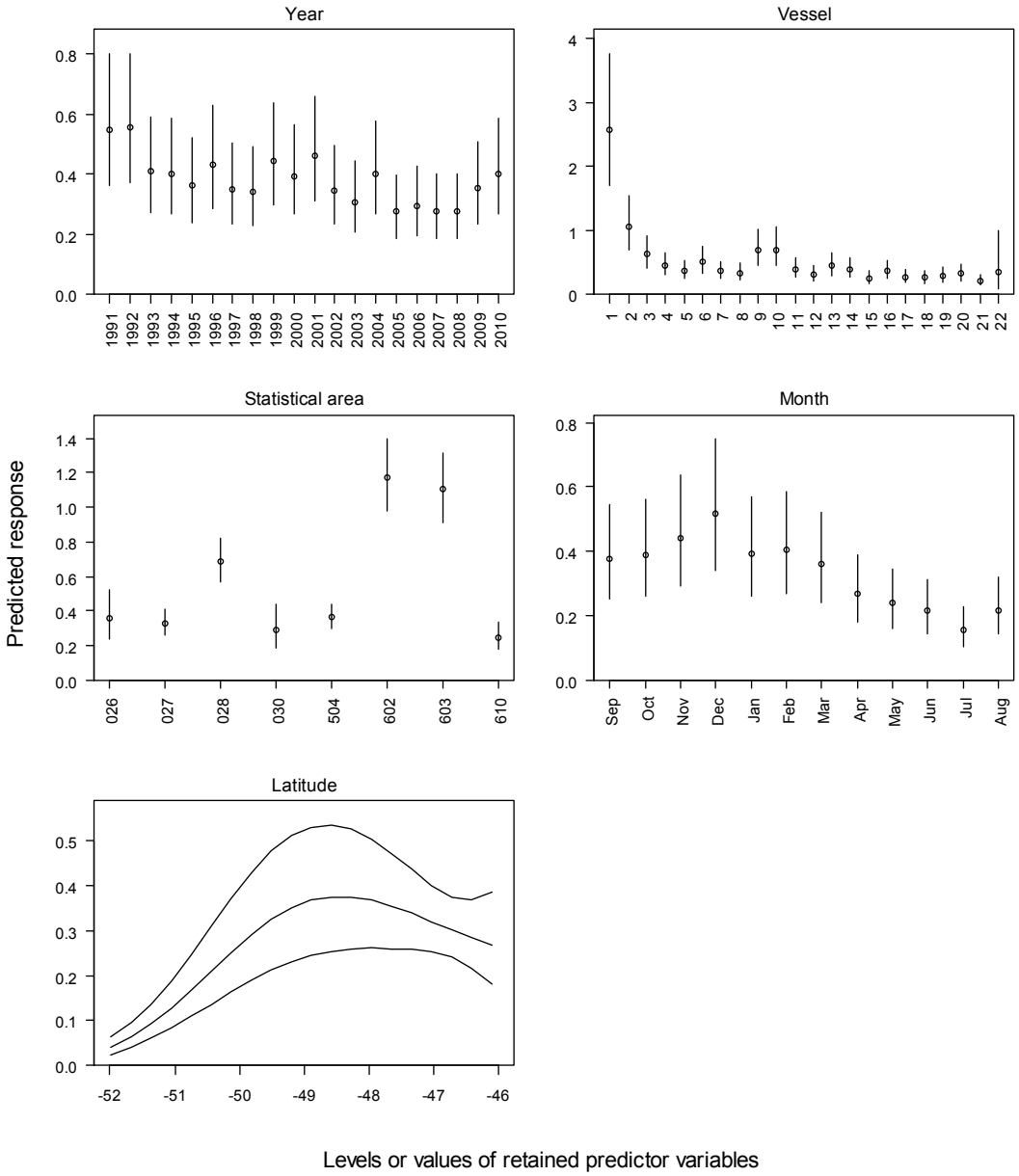


Figure 22: Effects of selected variables in the lognormal model for the Sub-Antarctic daily processed catch for core vessels targeting hake, hoki, or ling, 1991–2010. Bars indicate 95% confidence interval.

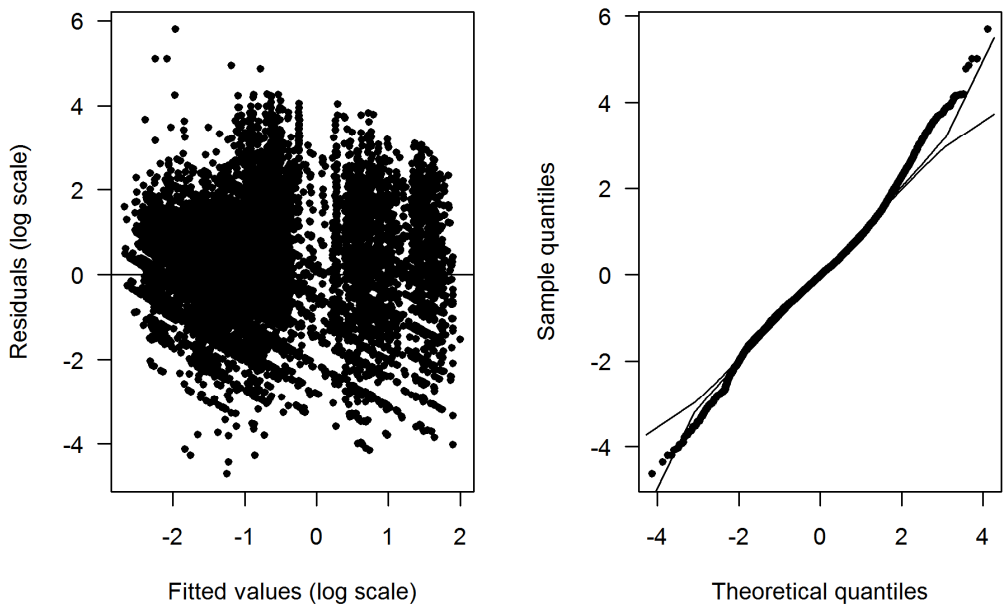


Figure 23: Sub-Antarctic lognormal model (estimated tow-by-tow data when targeting hake, hoki, or ling, for core vessels); distribution of the standardised residuals against fitted values (left) and quantile-quantile plot of the residuals (right).

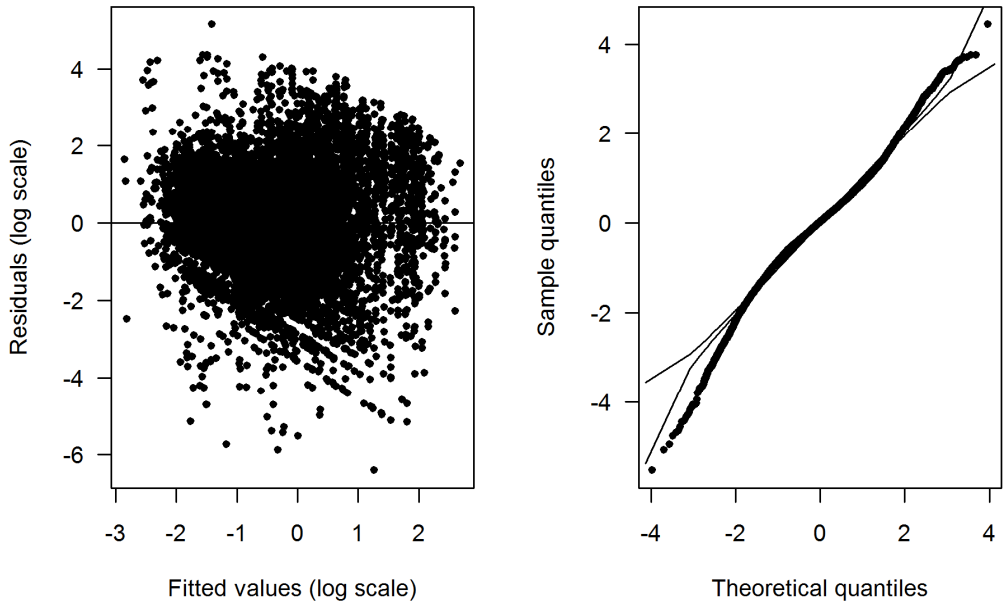


Figure 24: Sub-Antarctic lognormal model (processed daily catch when targeting hake, hoki, or ling, for core vessels); distribution of the standardised residuals against fitted values (left) and quantile-quantile plot of the residuals (right).