Fisheries New Zealand
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Descriptive analysis of the fishery for hake (*Merluccius australis*) in HAK 1, 4 and 7 from 1989–90 to 2014–15, and a catch-per-unit-effort (CPUE) analysis for Chatham Rise and WCSI hake

New Zealand Fisheries Assessment Report 2018/55

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ISSN 1179-5352 (online)
ISBN 978-1-98-857137-9 (online)

December 2018

New Zealand Government

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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 2014–15, and a catch-per-unit-effort (CPUE) analysis for Chatham Rise and WCSI hake.

***New Zealand Fisheries Assessment Report 2018/55*. 57 p.**

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 2014–15. Updated CPUE series for Chatham Rise and WCSI 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 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 or hake; core vessels were those that together reported 80% of the hake catch and were each involved in the fishery for a set number of years. The r^2 values for the Chatham Rise East CPUE modes was very high (69%), with *vessel* and *statistical area* accounting for most of the deviance explained, while the r^2 values for the WCSI CPUE model was relatively high (59%), with *target species* and area variables (*latitude* and *longitude*) generally 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.

The relationship between the survey biomass indices from the eastern Chatham Rise and the TCEPR daily processed CPUE indices for that area were strong, suggesting that those CPUE indices were reasonably reliable as an index of relative abundance. For WCSI, the available fishery-independent indices of abundance are sparse. The CPUE indices from observer tow-by-tow estimated catch from 2001 to 2015 were used in hake assessment modelling as this part of the series was considered most likely to be accurate. Data before 2001 were believed to be influenced by changes in fishing behaviour and reporting.

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 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, but excludes the Kermadec area (Figure 1). A comprehensive descriptive analysis of New Zealand hake fisheries was produced by Devine (2009) and the last descriptive analysis of commercial catch and effort data for hake was an analysis by Ballara (2015) which included data to 2012–13. 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 (2015) 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 and 4 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), and 2012 (Ballara 2013). Evidence of misreporting of catch by a small number of vessels was detected during the 2001 update. Hake caught in HAK 7 were misreported as catch on the Chatham Rise and Sub-Antarctic in HAK 4 and HAK 1 (Dunn 2003).

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

This document reports on Specific Objective 1 and 2 of Project DEE201609, which has an Overall Objective "To carry out assesments of hake (*Merluccius australis*) on the Chatham Rise (HAK 4) and west coast South Island (HAK 7) including estimating stock biomass and sustainable yields". 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. This fulfils Specific Objective 1 — "To carry out a descriptive analysis of the commercial catch and effort data for hake on the Chatham Rise and the west coast South Island (WCSI) in preparation for the quantitative stock assessment". An analysis of the catch and effort data for hake from the Chatham Rise and WCSI stocks for the years 1989–90 to 2014–15 is also presented, and it fulfils Specific Objective 2 — "To update the standardised analysis of the commercial catch and effort data for HAK 4 and 7". This objective

requires that CPUE be updated only for the series used in the most recent previous stock assessments of the Chatham Rise and WCSI stocks.

2. DESCRIPTIVE ANALYSES

2.1 Methods

Catch-effort, daily processed, and landed data were extracted from the MPI catch-effort database "warehou" as extract 10261 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 2014–15. This included all fishing recorded on Trawl Catch, Effort and Processing Returns (TCEPRs); Trawl Catch Effort returns (TCERs); Catch, Effort and Landing Returns (CELRs); Lining Catch Effort Returns (LCERs); Lining Trip Catch Effort Returns (LTCERs); Netting Catch Effort Landing Returns (NCELRs); 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 (2016). Data were also groomed for errors using simple checking and imputation algorithms developed in the statistical software package 'R' (R Development Core Team 2016). 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 2014–15 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 2014–15 most hake catch (97%) is still reported on TCEPRs, with TCERs (199.7 t, 2.4%) accounting for the second highest proportion. Significant catches were taken in all three stocks, but with most catches taken in the WCSI and Sub-Antarctic since 2011–12. The largest fishery in 2014–15 was WCSI occurring primarily in Statistical Areas 034 and 035 (Table 3, Figures 3a 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 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 proportion of hake caught in hoki target tows has been slowly decreasing since the late 1990s (Table 3, Figure 3b), although most of the Chatham Rise catch from 2011–12 was caught by target hoki fishing. More than 99% of the Chatham Rise catch is reported on the TCEPR form.

Hake are caught on the Chatham Rise all year around, but more commonly between September and January (Figure 3b, Table 4). 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 2014–15 most of the catch was taken in September 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 2015 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). 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 catches since 2003 was from hake target tows, and the hake caught in hoki target tows has decreased steadily since 2005 (Figure 3c, Table 5).

The timing of the catch on the WCSI has varied slightly between years, but most catch has been taken between June and September (Figure 3c, Table 6). 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 5966 t was the highest since 2007. Catches were taken mainly in Statistical Areas 034 and 035, with most from sub-area North shallow since 2010 (Table 6, 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 5. For hake target vessels, there was a steady increase in tow duration, a decrease in fishing speed, a decrease in fishing depth throughout the fishery, and recent slight increases in hoki catch (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). The majority 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 (Figure 3d, Table 8). 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. 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 2015, most of the catch was taken from November to January on the southern Snares shelf and from the Norwegian Hole (Figures 3d and 4). 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 (Figure 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 2014–15 hake catch from the EEZ at 8196 t was the highest since 2009, but still markedly lower than those taken from 1995 to 2005. The largest current fishery is 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, with targeting for hake concentrating on spawning aggregations. 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 2012.

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 assessment stock area (see Figure 1) from 1989–90 to 2014–15. 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	7 857	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	280	6 195	1 725	304	6 219	3 701	1 800	7 700

Table 1 ctd.

	Estimated catch by 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	3 288	1 771	9 743
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	8 617
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	366	1 635	6 195

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	9 474.1	-	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	7 361.8	-	4.7	-	-	-	7 366.4
1994–95	14 797.0	-	5.2	-	-	-	14 802.2
1995–96	15 984.7	-	4.6	-	-	-	15 989.2
1996–97	13 334.4	-	2.4	-	-	-	13 336.8
1997–98	14 572.6	-	3.9	-	-	-	14 576.5
1998–99	15 223.2	-	8.4	-	-	-	15 231.6
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	10.7	69.3	1.0	5 671.3
2014–15	7 944.2	199.7	0.1	4.8	47.0	0.5	8 196.3

Table 3: Chatham Rise hake TCEPR catch by target species and fishing method, 1989–90 to 2014–15. 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	2 411	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	215	19	0	17	0	–	2	2

Table 4: Chatham Rise estimated hake TCEPR catch (t) by month from 1989–90 to 2014–15. 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	158	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	3 808
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	144	348

Table 5: WCSI hake TCEPR catch (t) by target species and fishing method, 1989–90 to 2014–15. 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	275	4 334	20	297	2 009	1
1998–99	370	1 430	10	1 114	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	4 488	598	11	4	191	0	343	331	0

Table 6: WCSI estimated hake TCEPR catch (t) by month from 1989–90 to 2014–15. 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	3 455	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	1 750	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	196	1 057	1 456	2 859	388	5 966

Table 7: Sub-Antarctic hake TCEPR catch (t) by target species and fishing method, 1989–90 to 2014–15. 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	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	1 352	129	133	–	1	1	–	0	14

Table 8: Sub-Antarctic estimated hake TCEPR catch (t) by month from 1989–90 to 2014–15. 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

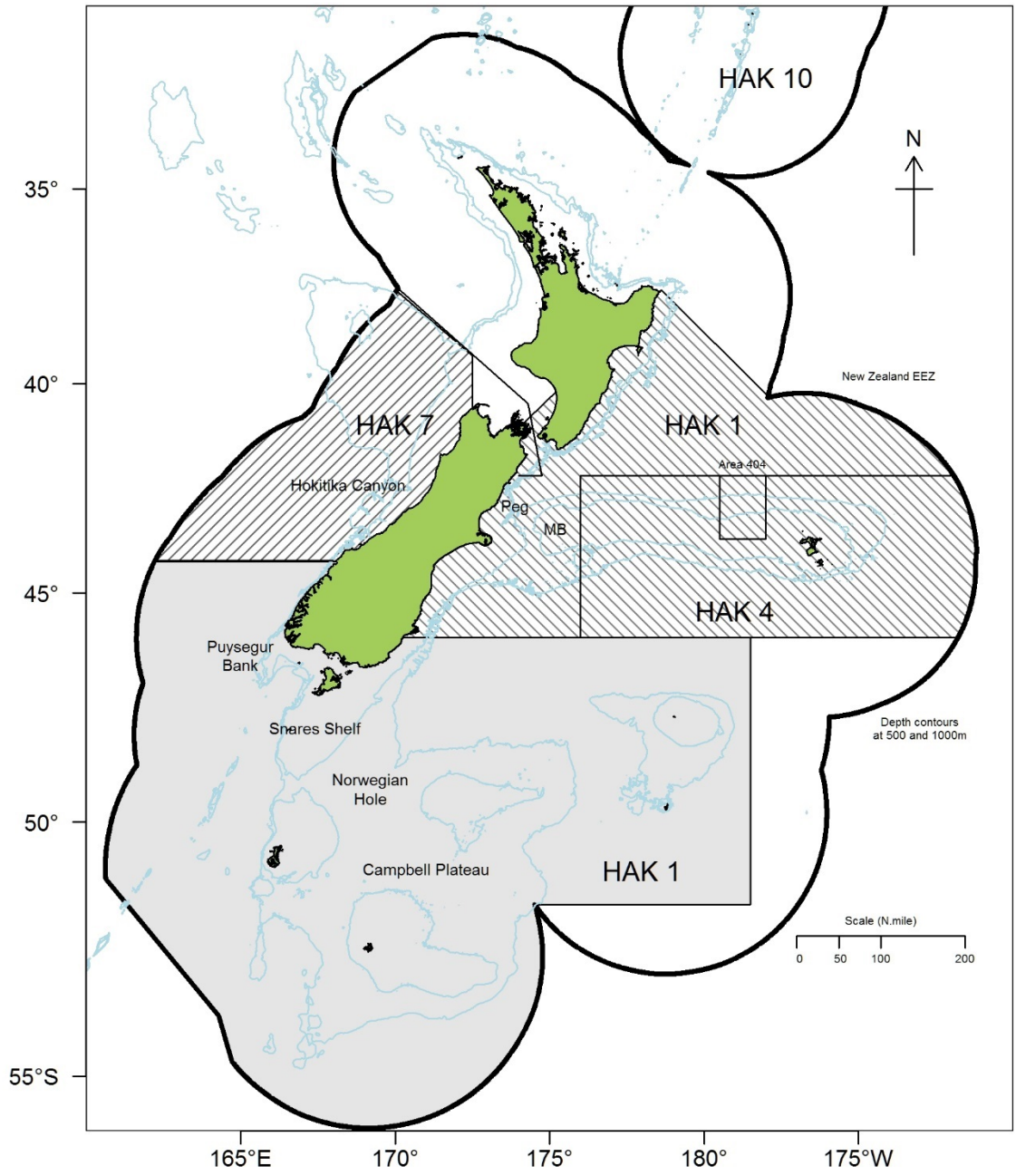

Figure 1: Quota Management Areas (QMAs) HAK 1, 4, 7, and 10, and hake biological stock boundaries, as assumed in this report: West coast South Island (dark stripes over HAK7), Chatham Rise (light stripes over HAK1 and HAK4), and Sub-Antarctic (grey shading over HAK1). Place names referred to in the text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

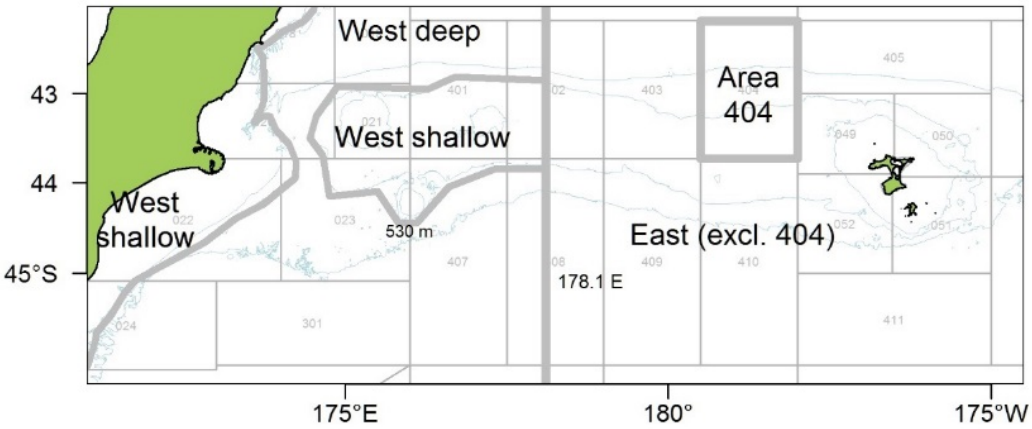

Figure 2a: Location and boundaries of the four Chatham Rise sub-areas used in this analysis: West deep (at least 530 m deep); West shallow (less than 530 m deep); East, excluding Statistical Area 404; and Statistical Area 404.

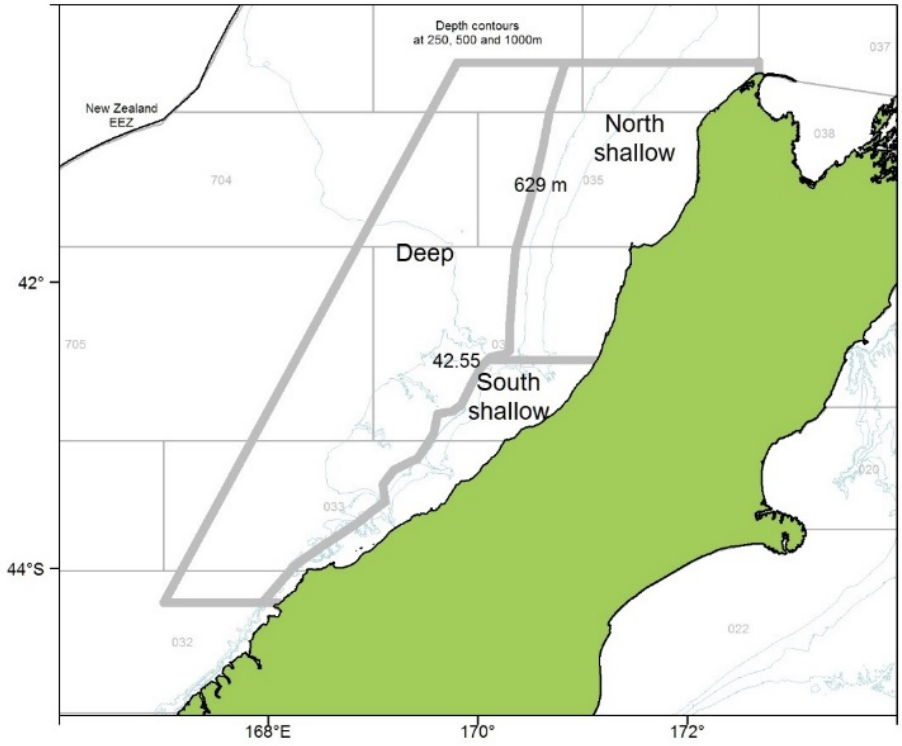

Figure 2b: Location and boundaries of the three WCSI sub-areas used in this analysis: Deep (at least 530 m deep); North shallow (less than 530 m deep, north of 42.55° S); South shallow (less than 530 m deep, south of 42.55° S).

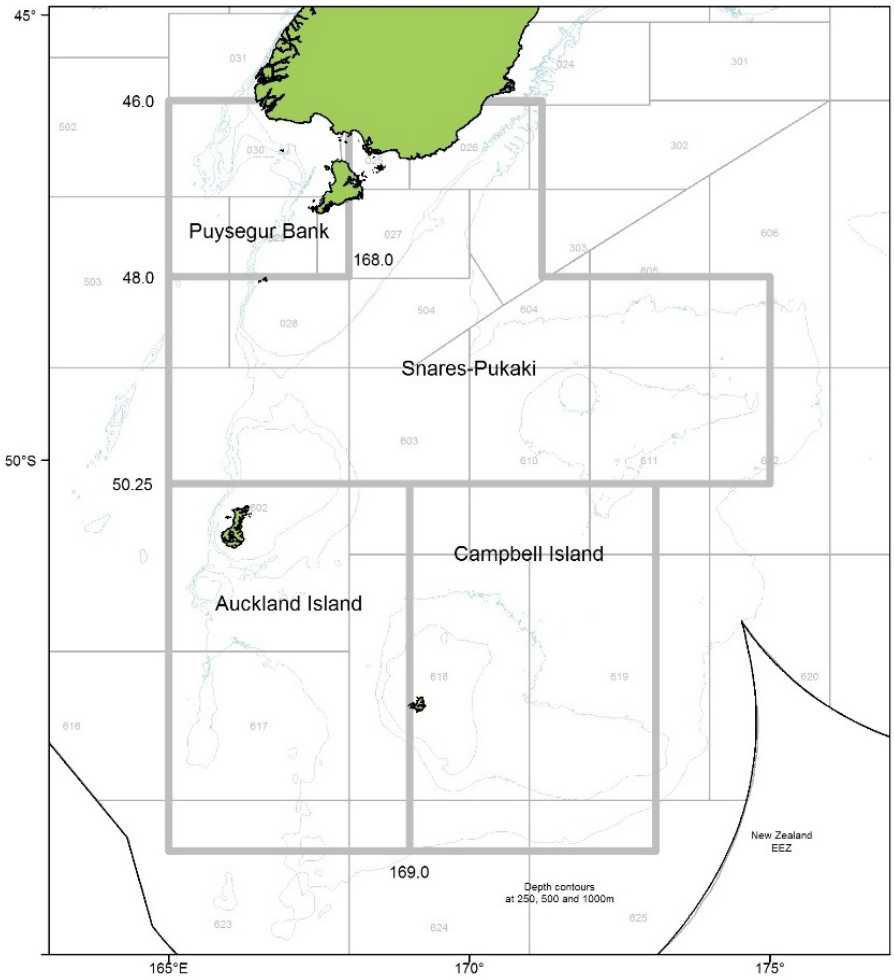

Figure 2c: Location and boundaries of the four Sub-Antarctic sub-areas: Puysegur Bank; Snares-Pukaki; Auckland Island; and Campbell Island.

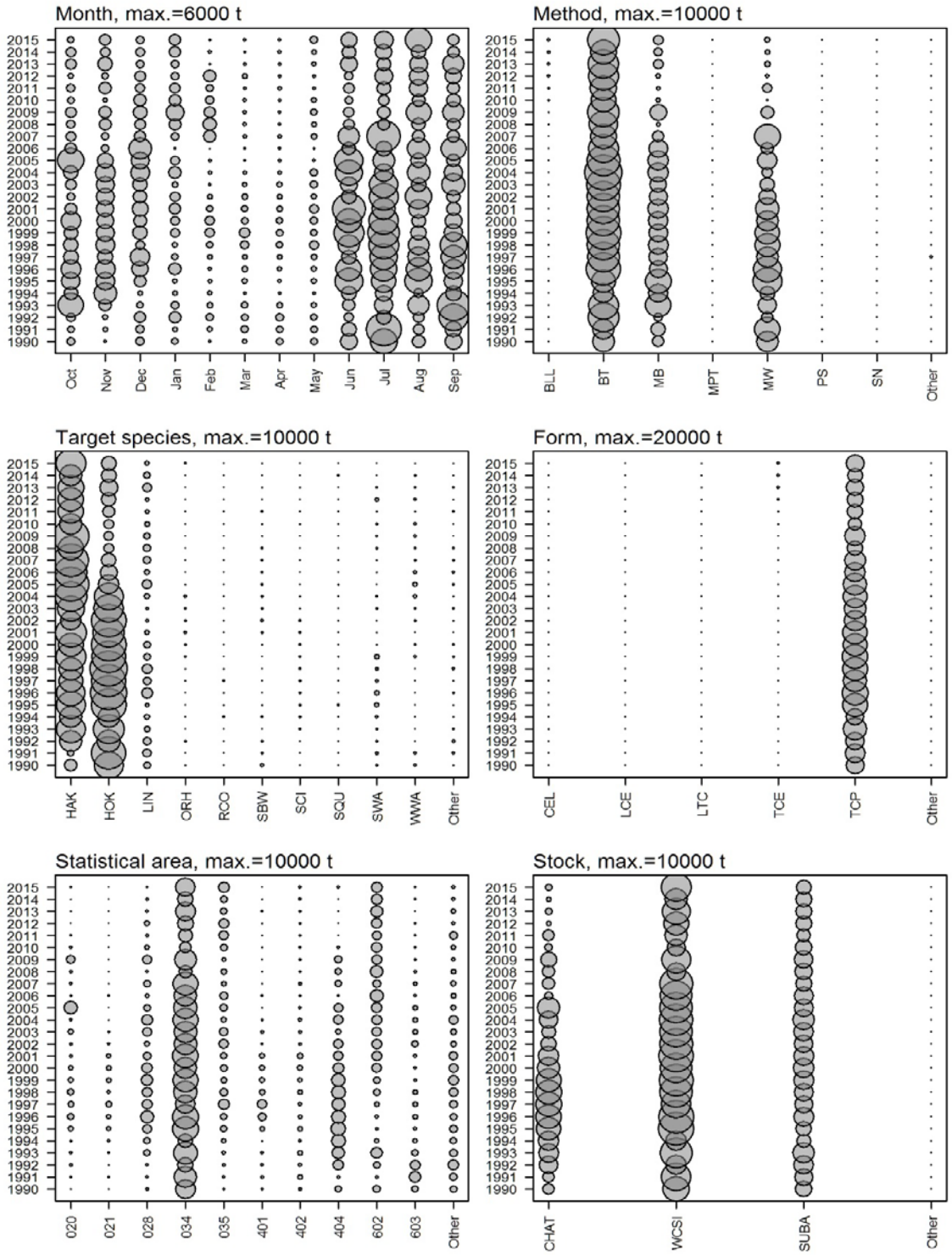

Figure 3a: Distribution of overall hake catch by month, statistical area, method, target species, form type, and area by fishing year since 1989–90 (1990). Circle size is proportional to catch; maximum circle size is indicated on the top of each plot. Statistical areas and sub-areas are defined in Figure 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; PS, purse seine; SN, set net. Species codes: HAK, hake; HOK, hoki; LIN, ling; ORH: orange roughy; RCO, red cod; SBW; SCI, scampi; SQU, arrow squid; SWA, silver warehou; WWA, white warehou.

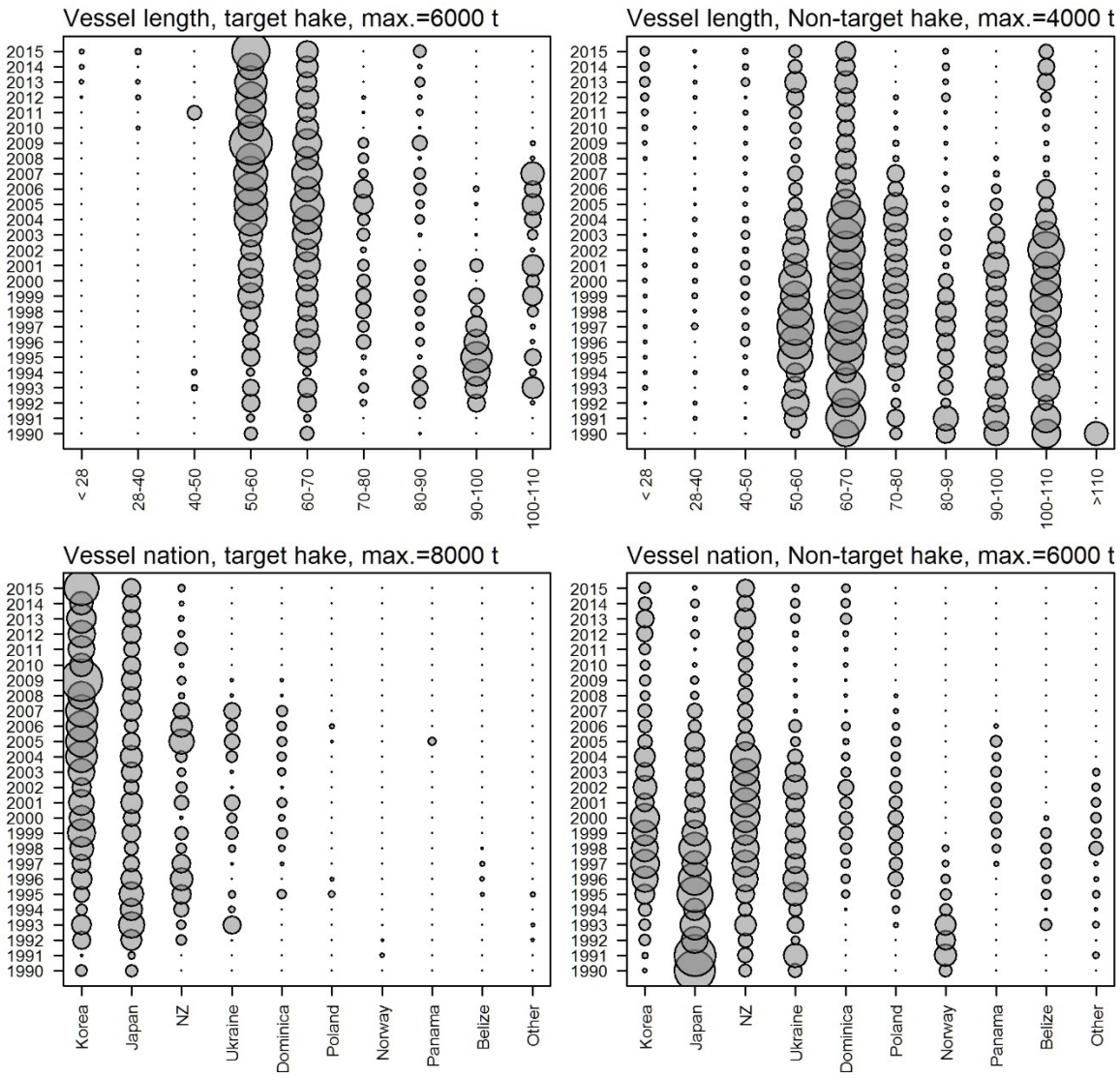

Figure 3a: continued. Distribution of overall target and non-target hake catch by vessel length and nationality by fishing year since 1989–90 (1990). Circle size is proportional to catch; maximum circle size is indicated on the top of each plot.

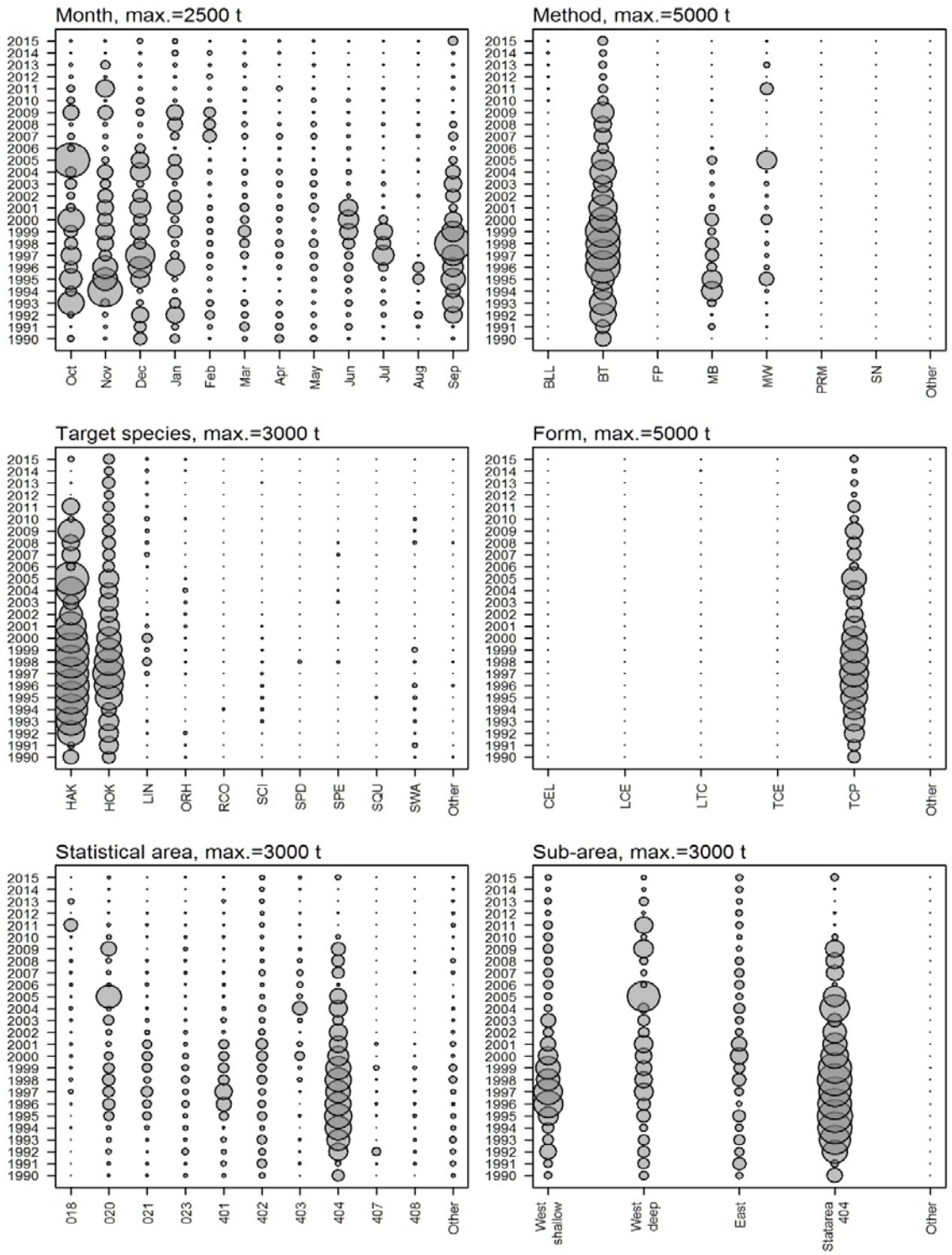

Figure 3b: Distribution of Chatham Rise hake catch by month, statistical area, method, target species, form type, and sub-area by fishing year since 1989–90 (1990). Circle size is proportional to catch; maximum circle size is indicated on the top of each plot. Statistical areas and sub-areas are defined 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; 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.

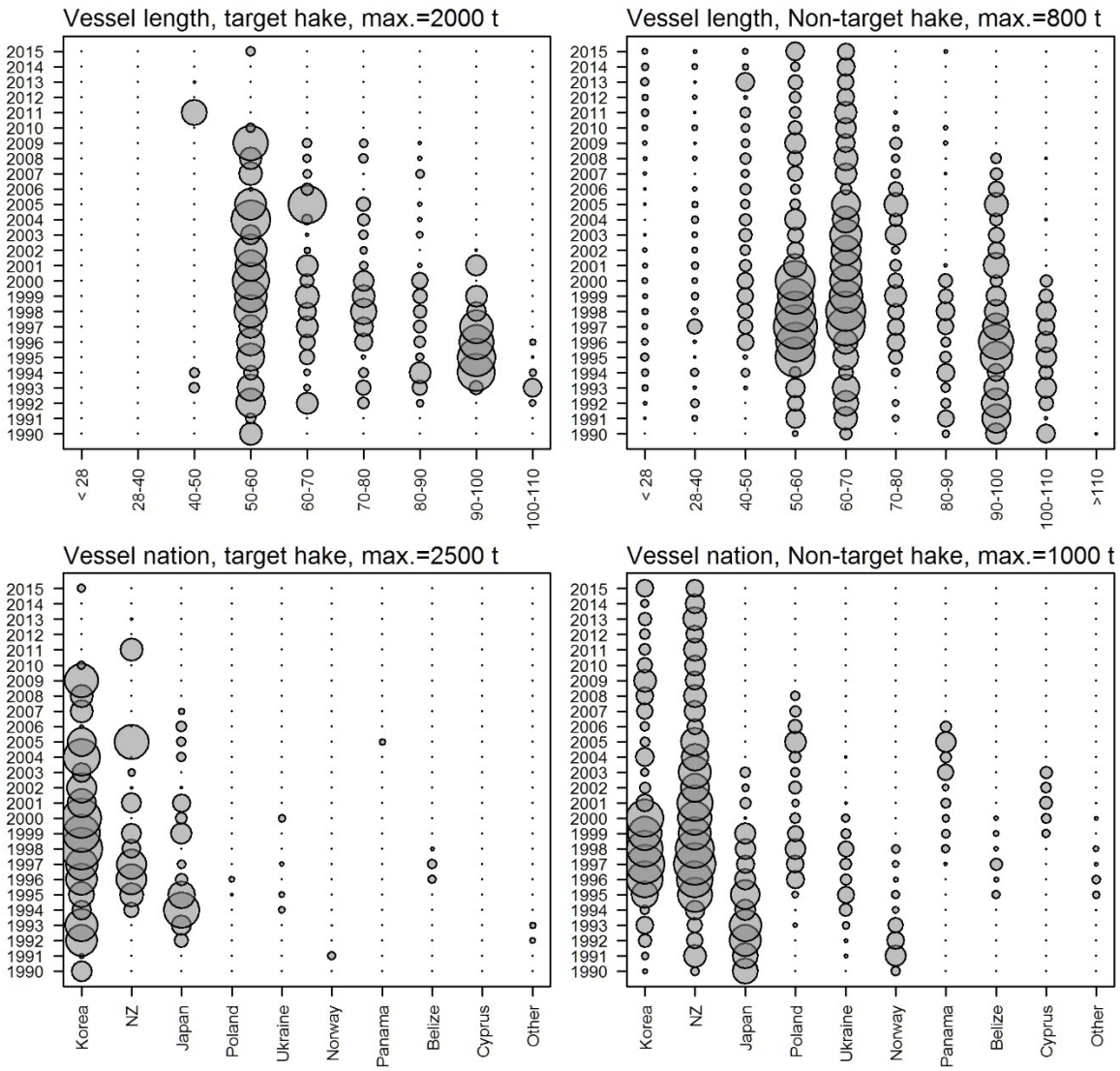

Figure 3b: continued. Distribution of Chatham Rise target and non-target hake catch by vessel length and nationality by fishing year since 1989–90 (1990). Circle size is proportional to catch; maximum circle size is indicated on the top of each plot.

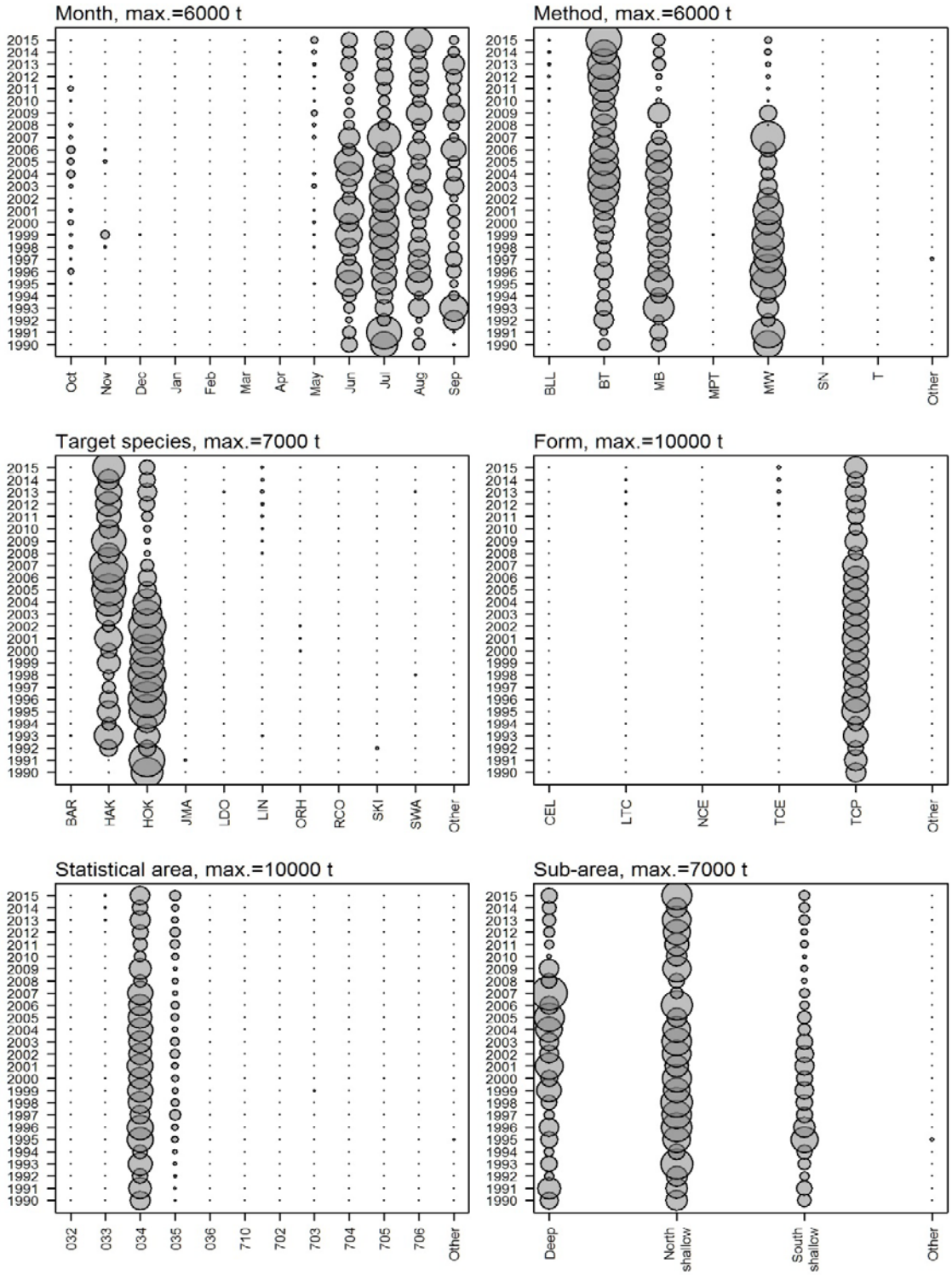

Figure 3c: Distribution of WCSI TCEPR tow-by-tow hake trawl catch by month, statistical area, method, target species, form type, and sub-area by fishing year since 1989–90 (1990). Circle size is proportional to catch; maximum circle size is indicated on the top of each plot. Statistical areas and sub-areas are defined in Figure 2. Form types: CEL is Catch, Effort, Landing Return; LTC is Lining Trip Catch, Effort return; ; NCE is Net Catch Effort Return; TCE is Trawl, Catch, Effort Return; TCP is Trawl, Catch, Effort, and Processing Return. Method definitions: BLL, bottom longlining; BT, bottom trawl; MB, midwater trawl within 5 m of the bottom; MPT: midwater pair trawl; MW, midwater trawl; SN, set net; T, trolling. Species codes: BAR, barracouta; HAK, hake; HOK, hoki; JMA, jack mackerels; LDO: lookdown dory; LIN, ling; ORH, orange roughy; RCO, red cod; SKI, gemfish; SWA, silver warehou.

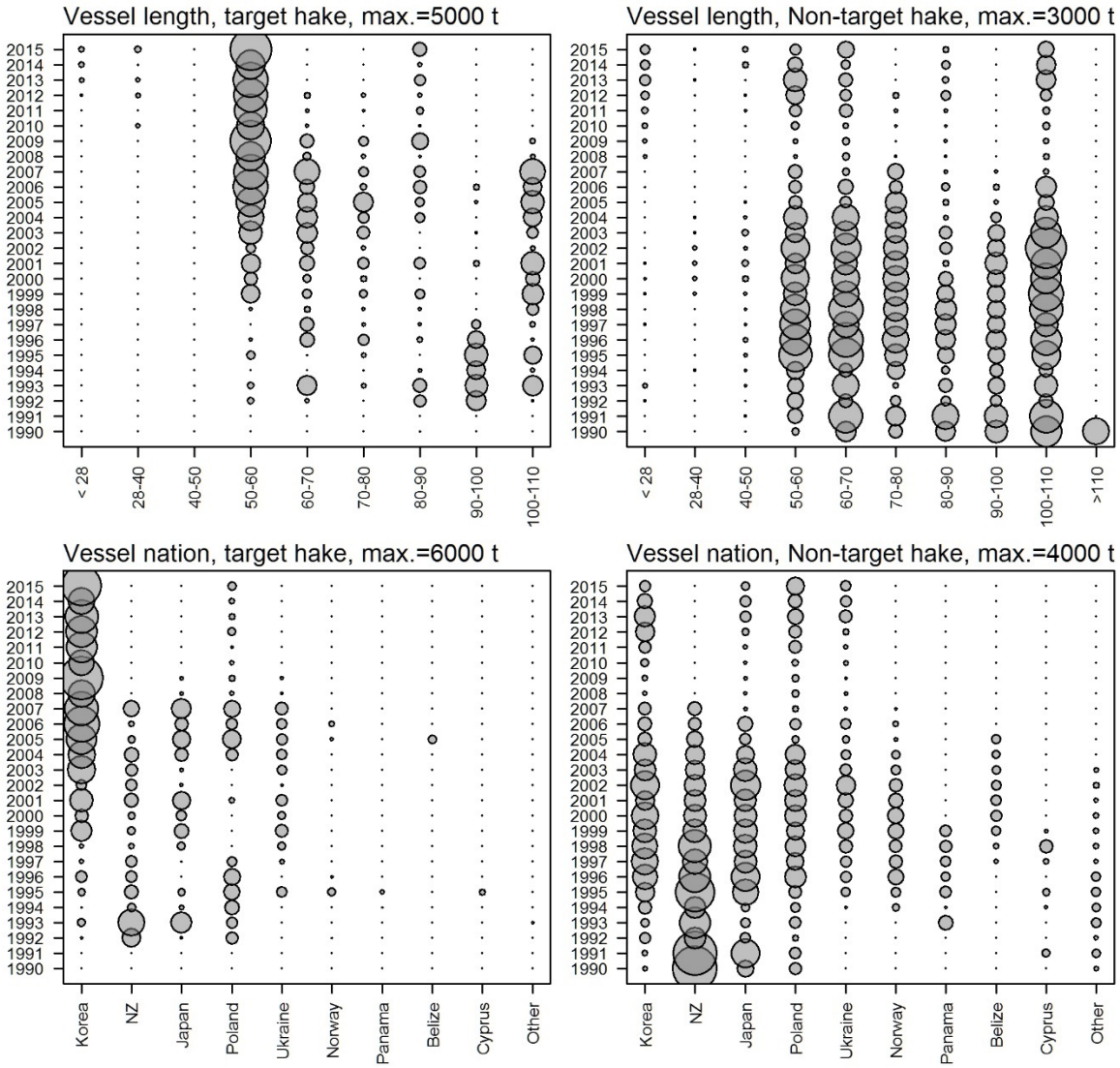

Figure 3c: continued. Distribution of WCSI target and non-target hake catch by vessel length and nationality by fishing year since 1989–90 (1990). Circle size is proportional to catch; maximum circle size is indicated on the top of each plot.

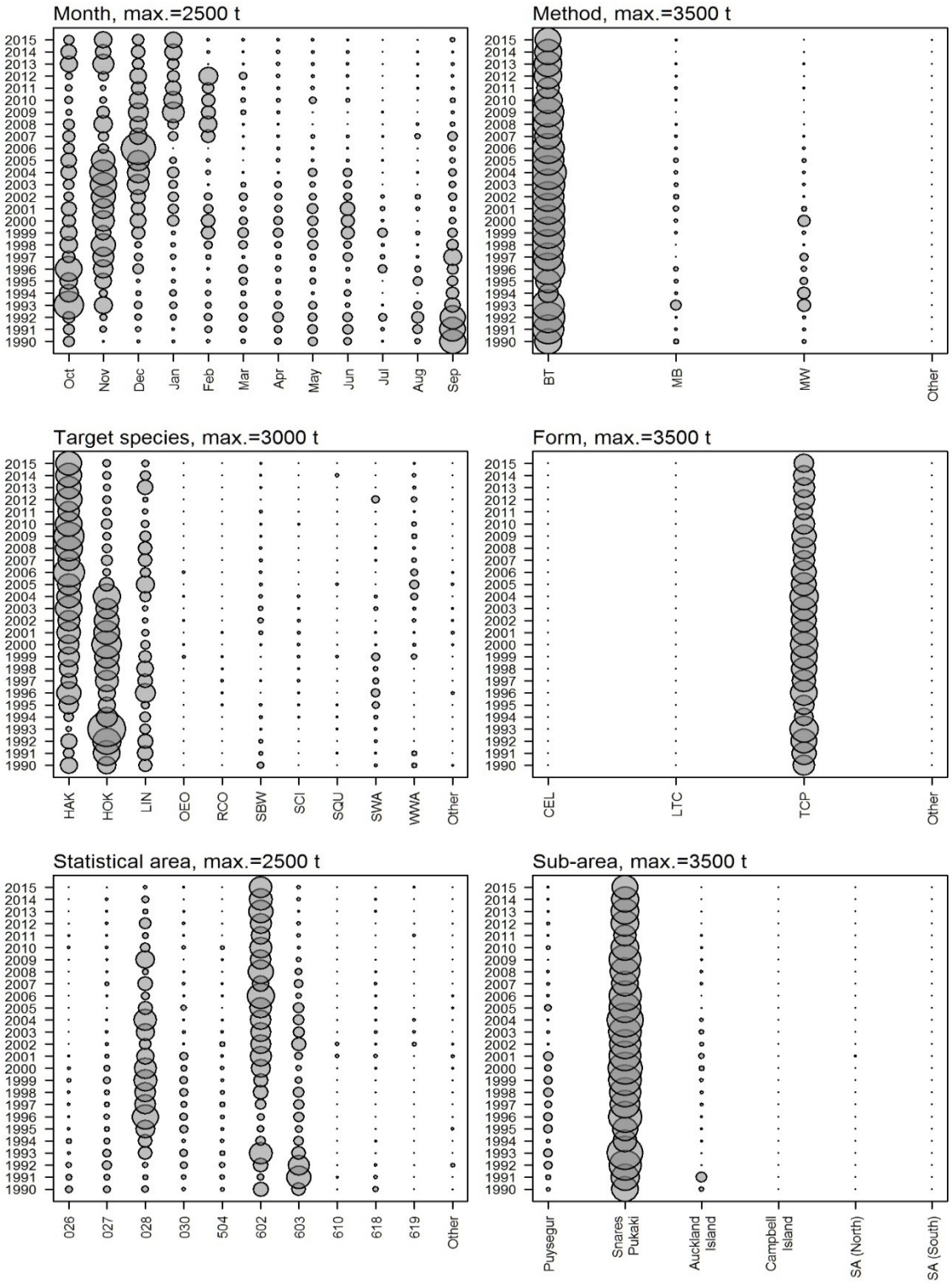

Figure 3d: Distribution of Sub-Antarctic hake catch by month, statistical area, method, target species, form type, and sub-area by fishing year since 1989–90 (1990). Circle size is proportional to catch; maximum circle size is indicated on the top of each plot. Statistical areas and sub-areas are defined in Figure 2. Form types: CEL is Catch, Effort, Landing Return; LTC is Lining Trip Catch, Effort return; TCP is Trawl, Catch, Effort, and Processing Return. Method definitions: BT, bottom trawl; MB, midwater trawl within 5 m of the bottom; MW, midwater trawl. Species codes: HAK, hake; HOK, hoki; LIN, ling; OEO, oreos; RCO, red cod; SBW, southern blue whiting; SCI, scampi; SQU, arrow squid; SWA, silver warehou; WWA, white warehou.

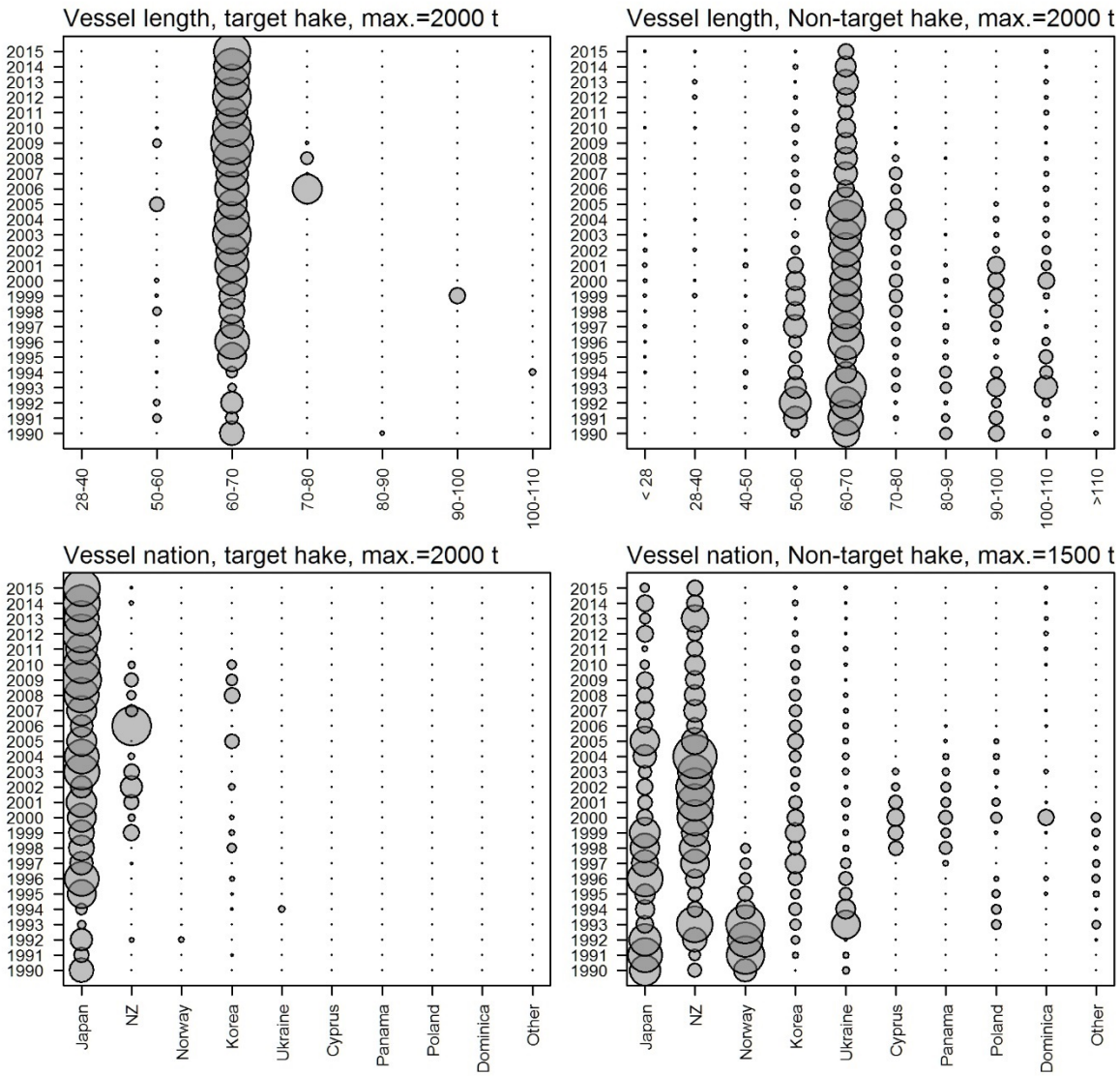

Figure 3d: continued. Distribution of Sub-Antarctic target and non-target hake catch by vessel length and nationality by fishing year since 1989–90 (1990). Circle size is proportional to catch; maximum circle size is indicated on the top of each plot.

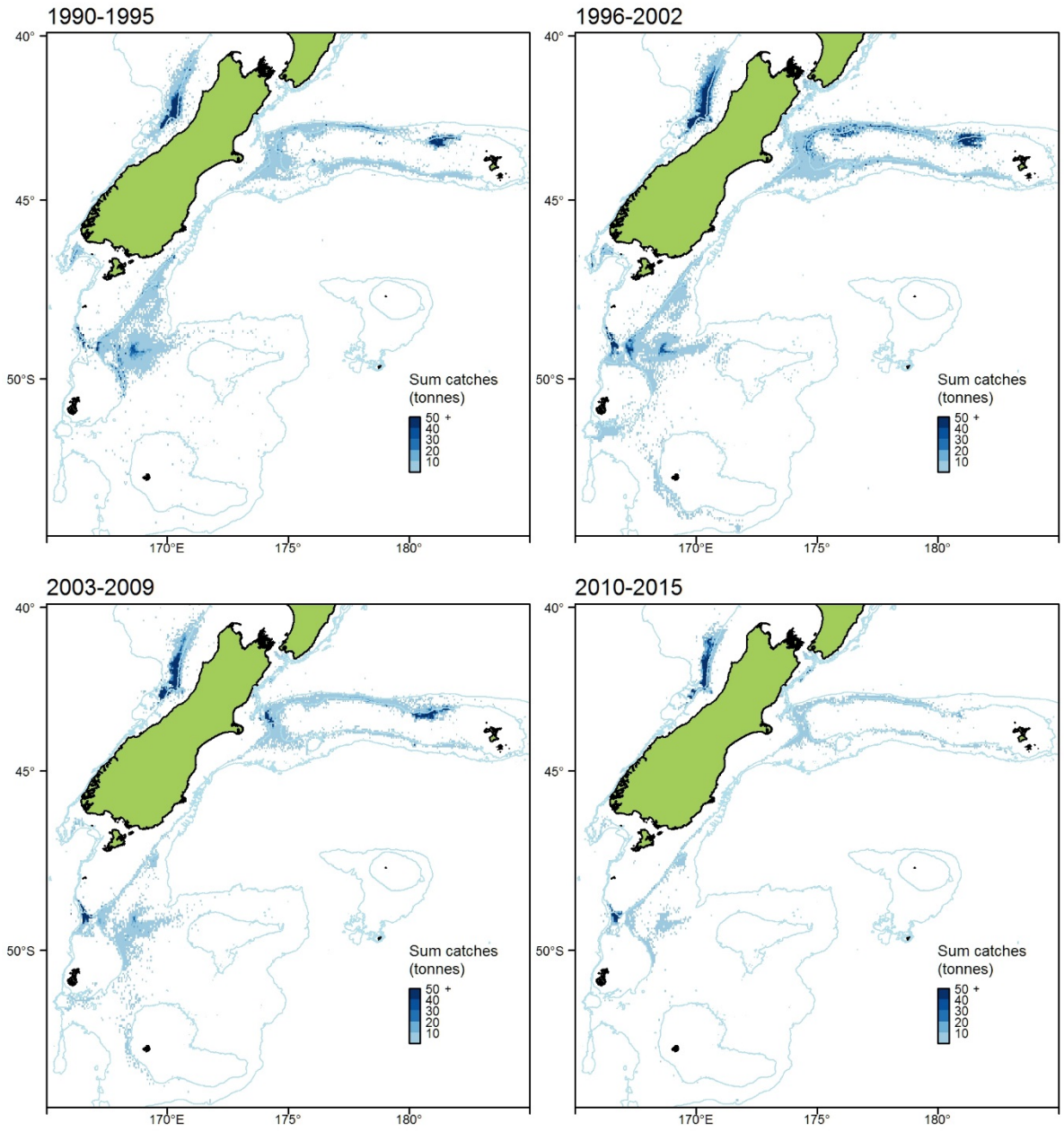

Figure 4: Density plots of commercial hake catches from TCEPR tow-by-tow records for target hake and hoki tows by for fishing year combined blocks.

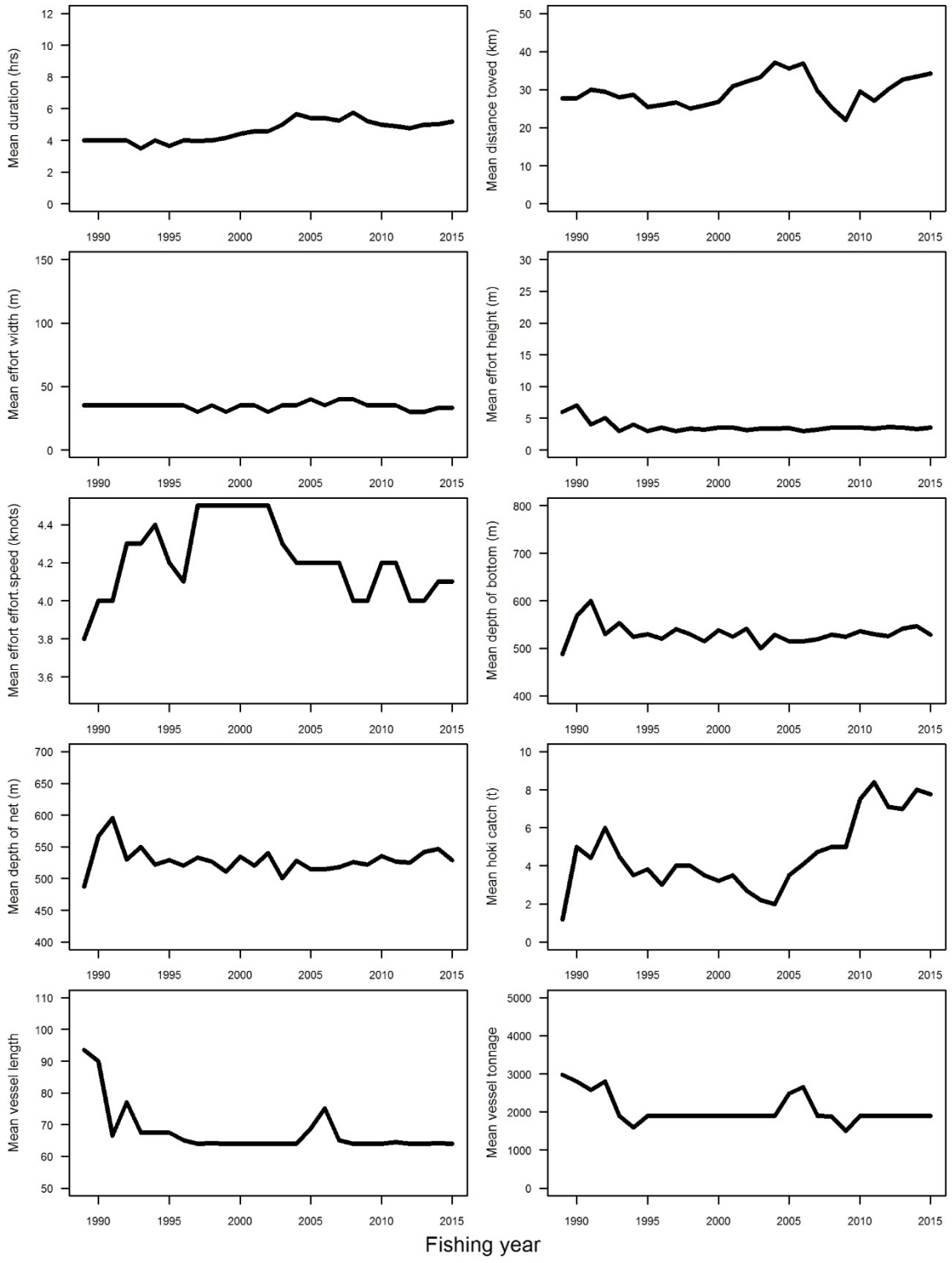

Figure 5a: Means of effort variables by fishing year for Chatham Rise vessels using bottom trawl targeting hake or hoki.

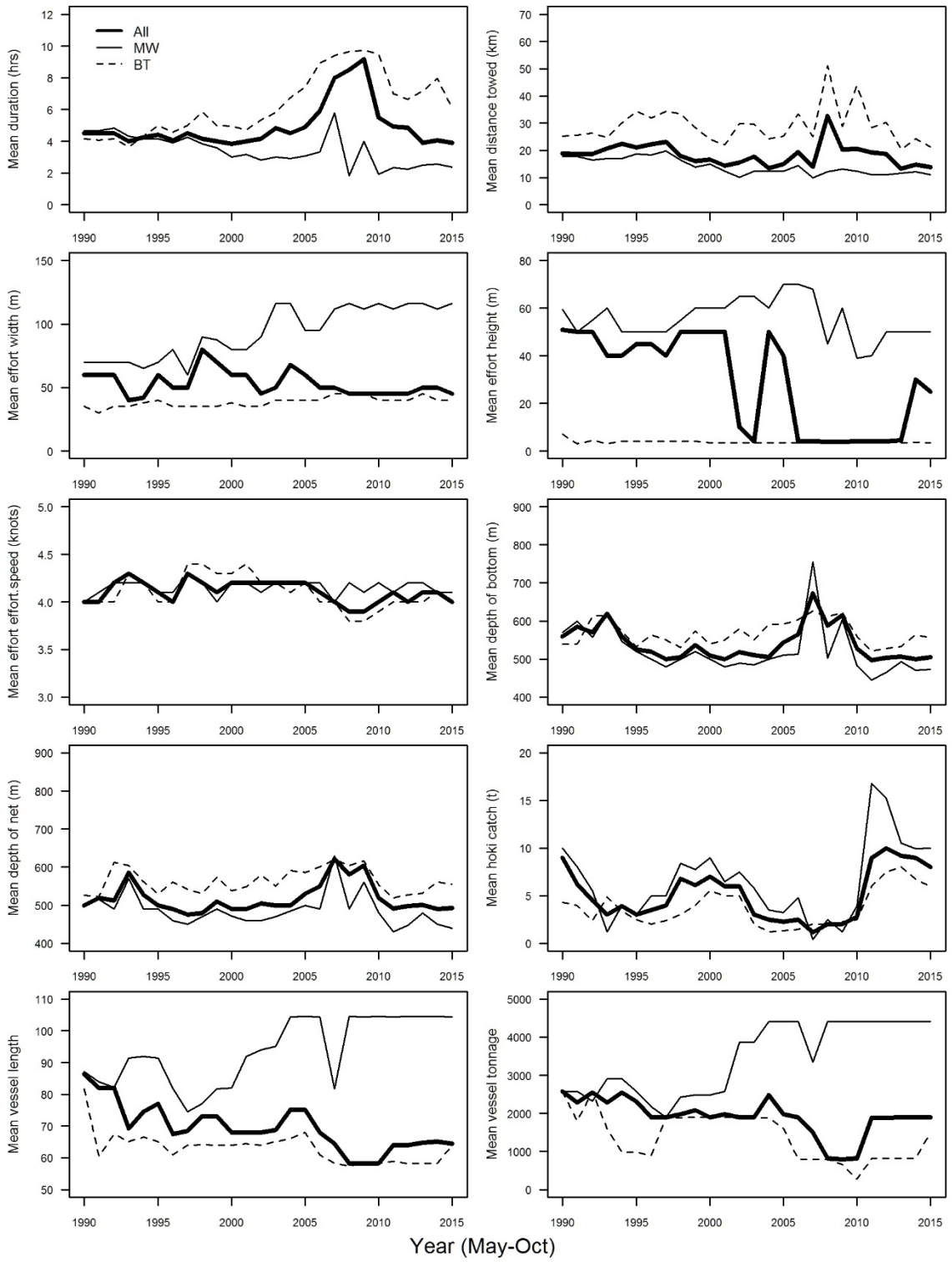

Figure 5b: Means of effort variables by fishing year for WCSI vessels targeting hake or hoki, for all tows (All), bottom tows (BT), and midwater tows (MW).

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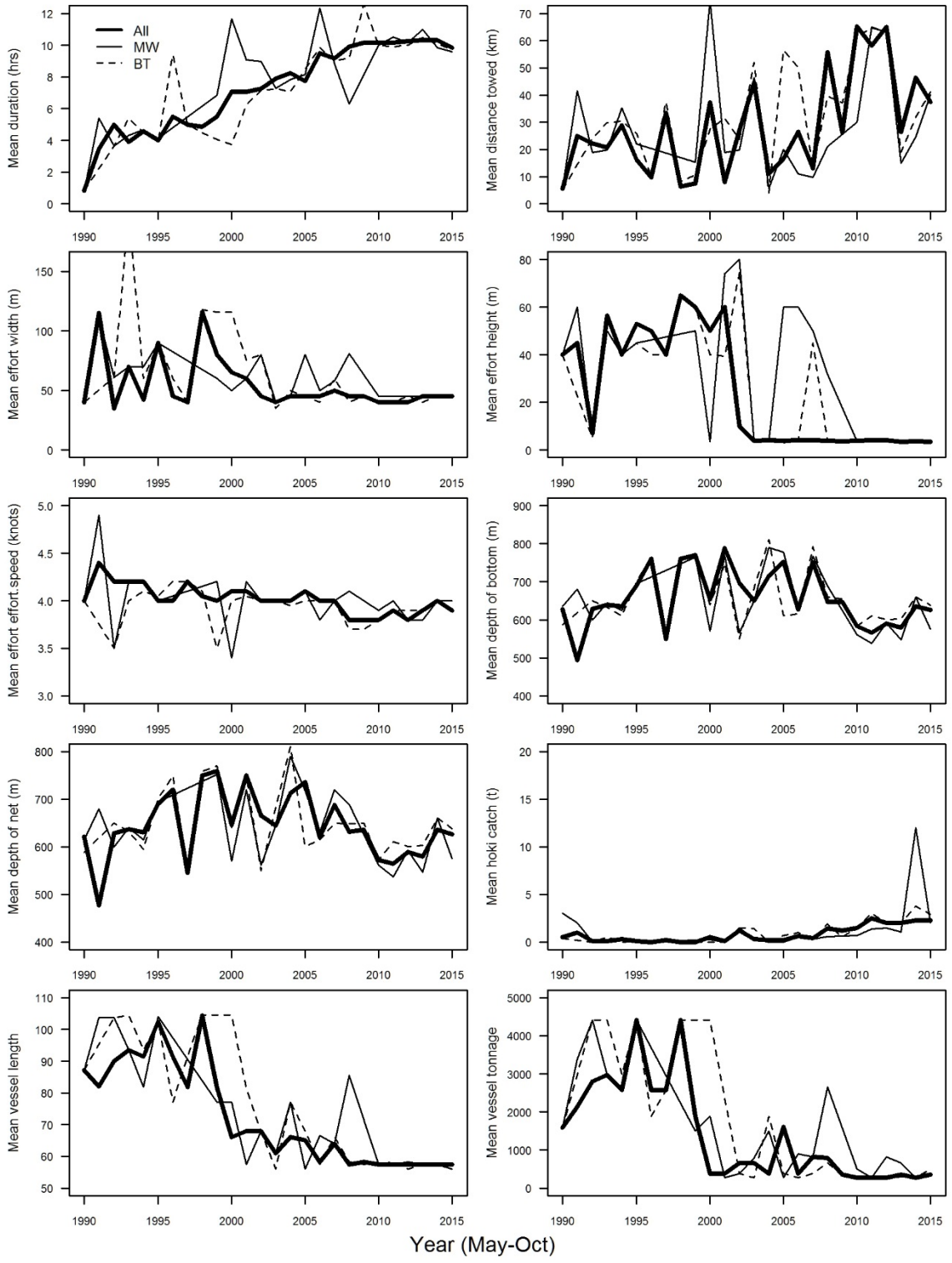


Figure 5c: Means of effort variables by fishing year for WCSI vessels targeting hake, for all tows (All), bottom tows (BT), and midwater tows (MW).

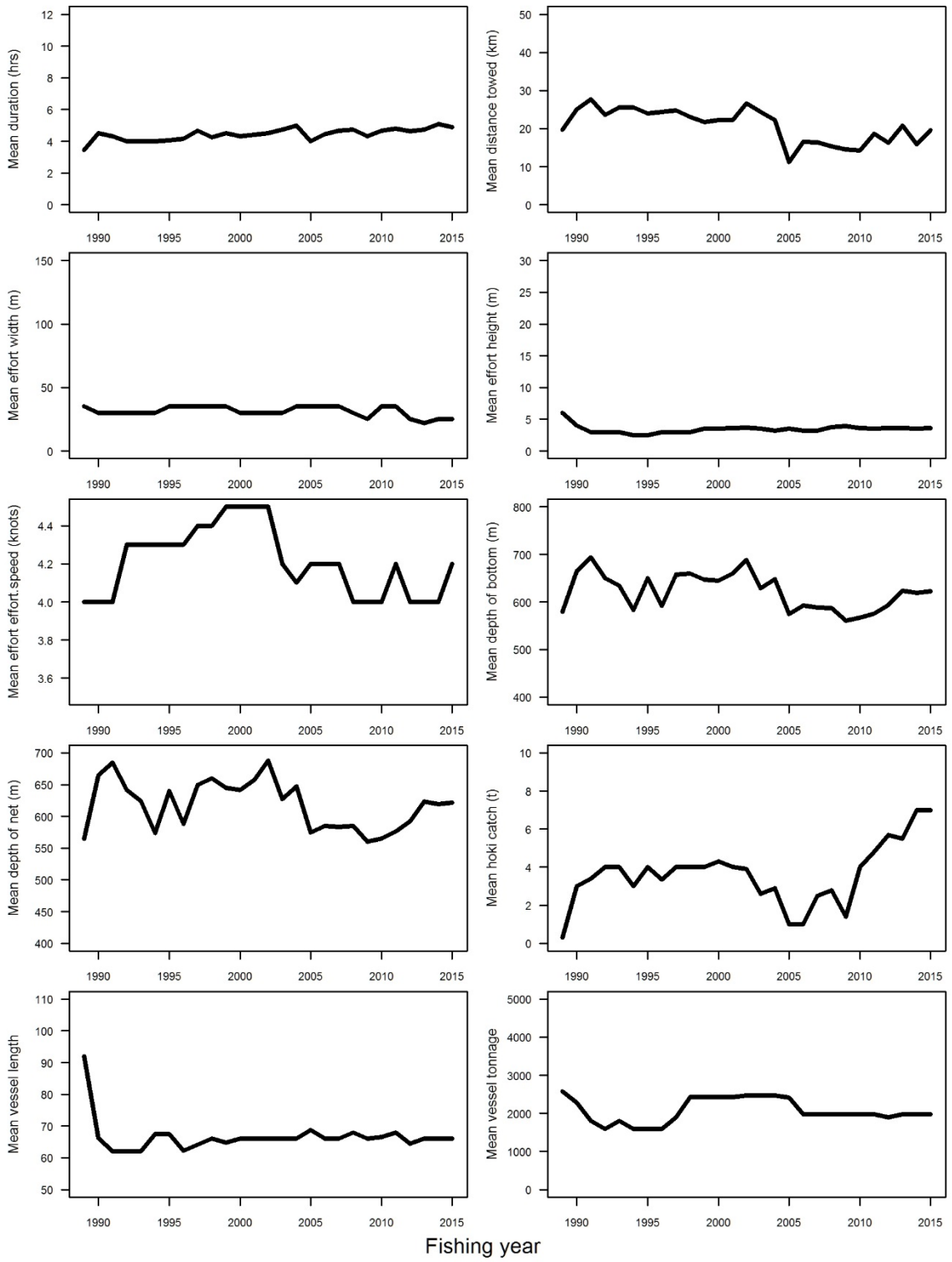


Figure 5d: Means of effort variables by fishing year for Sub-Antarctic vessels using bottom trawl targeting hake or hoki.

3. ESTIMATION OF CPUE

This section presents an analysis to update the series of CPUE indices from the trawl fishery for hake on the East Chatham Rise (HAK 4) and WCSI (HAK 7). CPUE analyses of these fisheries were most recently reported by Ballara (2013). 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 2013). CPUE indices were calculated using catch per tow (in kilograms) for observer tow-by-tow data (WCSI), or catch per vessel-day for daily processed data, with tow *duration* offered as an explanatory variable (Chatham Rise). *Year* was a categorical variable and defined as September–August for the Chatham Rise and June–September for the WCSI. Season variables *month* and *day of year* were offered to the model. Hoki trawling uses both bottom and midwater gear, so method was offered as an explanatory variable, although midwater gear was further defined as midwater trawl, or midwater trawl fished on the bottom, if recorded net depth was within 5 m of recorded bottom depth. 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*.

3.1.3 Data selection

The data used for each CPUE analysis consisted of all records from core vessels that targeted hoki or hake. 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 levels of catch and effort for different years of vessel participation in the fishery. 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 described in Table 10 were met. Catches believed to be misreported were excluded. Core vessel analyses were run for the Chatham Rise for TCEPR daily processed data, and for the WCSI for observer tow-by-tow data.

Hake are caught on the Chatham Rise all year around, but more commonly between September and February (Figure 3b), so the year was defined as September–August. The timing of the catch on the WCSI varied slightly between years, but most hake catch was taken from May to October, often with a peak from June to September, and either as target catch or as bycatch in the hoki target spawning fishery. For the WCSI data, year was defined as June–September as this is when most of the catch was taken.

CPUE indices for the Chatham Rise were derived from daily processed catch from the TCEPR processing summaries as done in the past (Phillips 2005, Dunn & Phillips 2006, Devine & Dunn 2008, Devine 2010, Ballara & Horn 2011, Ballara 2012, 2013, 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 corrected for possible misreporting, using the method of Dunn (2003), and then 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 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. 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 observer tow-by-tow data, or catch (kg) per vessel-day for daily processed data. Estimates of relative year effects were obtained from a stepwise multiple regression method, where the data were fitted using a lognormal model using log transformed non-zero catch-effort data. A forward stepwise multiple-regression fitting algorithm (Chambers & Hastie 1991) implemented in the R statistical programming language (R Development Core Team 2016) 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 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.

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. Model fits to continuous variables were modelled as third-order polynomials, although a fourth-order polynomial was also offered to the models for duration. The CVs represent the ratio of the standard error to the index. The 95% confidence intervals are also calculated for each index. Interaction terms with method were used as there was more than one fishing method in the dataset. *Vessel* was incorporated into the CPUE standardisation to allow for differences in fishing ability between vessels.

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

Model predictions for all variables selected into the final model were plotted against the expected (non-zero) catch. To calculate the *y*-values for a particular variable, all other model predictors must be fixed. These fixed values were chosen to be 'typical' values (see Francis (2001) for further discussion of this method). If different fixed values were chosen, the values on the *y*-axis would change but the appearance of the plots 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 East Chatham Rise and WCSI are presented here. For the analyses of data the estimated catch of hake, number of tows (observer 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 used in the standardised analysis are given in Table 11. The variables retained in each model are listed in Table 12 and the CPUE indices by fishing year are given for each model in Table 13.

3.2.1 CPUE indices for East Chatham Rise

TCEPR daily processed commercial data from vessels targeting hake or hoki on East Chatham Rise were analysed to produce a CPUE series, using the combined model. Forty-six core vessels (range 4–30 per year) that caught an estimated 24 537 t of hake from 13 810 vessel-days were included (Table 11, Figure 6). Although 9 of these vessels had been observed in only five years, 22 had been observed in 10 or more years (with the maximum being 23 years). The proportion of zero catch days (i.e., days fished where either hoki, or hake was targeted, but no hake was processed) for core vessels ranged between 0.00 and 0.19, and was higher in earlier years of the fishery, with overall 942 (6.2%) of vessel-days with no reported hake catch (Table 11). About 92% of the vessel-days were from bottom trawling. Data from the three method categories were included in the model, and *method* was offered as an explanatory variable.

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 69%, with *statistical area* explaining 62% of the residual deviance; for the binomial model, *year* explained about 7% of the variance, with the final model explaining 33% (Table 12). The standardised year effects from the lognormal model (Table 13, Figure 7) 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 *vessel* (Figure 8). The binomial series showed no trend, and the combined indices are similar to the lognormal model (Figure 9). The lognormal and combined indices show a similar trend to the previous analysis despite changes in core vessel definition (Figure

10). Estimated CPUE indices follow a similar trend to the summer eastern Chatham Rise *Tangaroa* trawl survey indices, although between 1992 and 1993 the survey indices show a large decrease not seen in CPUE indices, and indices diverge in the last two years (Figure 11).

Influence plots (Figures 12a) show that fleet dynamics and behaviour have changed. Vessel has a large positive influence on CPUE in the first two years, suggesting a change in fleet dynamics. Vessels with more overall catch tended to have higher expected catches and lower variability. Influence of target species shows that there is a negative influence on CPUE when hake are not targeted, especially in 1992, 1996, 2011–2015, and expected catch rates were higher for target hake catches. Expected catch varied between statistical areas; it was highest for Statistical Areas 049, 402, 403, and especially 404, with the influence on CPUE more positive when there was more effort in these statistical areas. Predicted CPUE by statistical area generally followed the overall lognormal CPUE trend for most statistical areas, although there were some exceptions in individual years (Figure 13). There was little influence from distance as most values were between 0.9 and 1.1. The probability of a zero hake catch was lowest for tows that were deeper, for longer durations, and for bottom tows (Figure 14a).

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

3.2.2 CPUE indices for WCSI

Tow-by-tow data collected by observers from the target hoki and hake trawl fishery off WCSI were analysed to produce a CPUE series, using the combined model. Data from 24 vessels were included in the core dataset (Table 11, Figure 6). Although 4 of these vessels had been observed in only three years, 15 had been observed in 5 or more years (with the maximum being 12 years). There were 13 810 tows in the data set, of which almost 1936 (14.8%) reported no hake catch (Table 11). About 45% of midwater tows were reportedly fished on the bottom. Data from the three method categories were included in the model, and *method* was offered as an explanatory variable.

The lognormal model explained 69% of total variance, with *year* and *target species* explaining about 35%; in the binomial model, *year* explained about 3% of the variance, with the final model explaining 32% (Table 12). The standardised year effects from the lognormal model (Table 13, Figure 7) produced a series that is spiky, but appears to decline from 2002 to 2009, increase to 2013, and then decrease slightly. This index did not match the unstandardised index well, particularly in 2006–2007 and 2011–2012 (Figure 8). The binomial series is flat, and the combined indices are similar to the lognormal model (Figure 9). Observer lognormal and combined indices show a similar trend to the previous observer analysis (Figure 10). Estimated CPUE indices do not match the WCSI *Tangaroa* trawl survey indices (Figure 11).

Influence plots (Figures 12b) show that fleet behaviour has changed. The influence on CPUE of target species, longitude and latitude has swung positively and negatively, so these variables have a large overall influence on observed CPUE from year to year: for target species, a large positive shift in 2007 and 2008; for latitude, a large positive shift in 2004–2007, and a large negative shift in 2003 and 2010; and for longitude, large negative shifts in 2003, 2011, and 2012. Expected catches tended to be higher further south and when hake was targeted (Figure 12b). Vessel has a smaller influence on CPUE.

The probability of a zero hake catch was highest for tows that were shallower, further west and south (Figure 14b). Bottom trawls were marginally less likely to get a zero catch of hake than midwater trawls,

and less likely to get a zero catch at shallower depth of net. *Duration* has a relatively weak effect on the probability of a zero hake catch.

The diagnostics for both lognormal and 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 (Figures 15 and 16).

3.3 CPUE summary

A combined model using QMS data from the eastern Chatham Rise hoki and hake target trawl fishery was updated. Daily processed data was used as this includes most species as a daily summary, and had low proportions of zero hake tows as more species are more likely to be reported in a daily summary. Daily processed data may not capture changes in conversion factors.

It is assumed that there is a proportional relationship between CPUE and abundance. However, there are specific areas and times (e.g., Statistical Area 404 on the Chatham Rise during the spawning season 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 eastern Chatham Rise trawl survey biomass series and the CPUE series, so credence may be given to these indices. The r^2 values for the Chatham Rise CPUE models were relatively high (69%), with statistical area accounting for most of the deviance explained.

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

A combined model using observer data from the WCSI hoki and hake target trawl fishery was updated. There is a large volume of data used in the analysis, and although the resulting series was spiky it appears to decline from 2002 to 2009, increase to 2013, and subsequently decrease slightly. There is no way of establishing whether this analysis is likely to produce a reliable index series. Consequently, we can still not be confident that a reliable index of hake abundance is available from this trawl fishery, although the observer data series should be relatively free of biases. There was poor agreement between the WCSI trawl survey biomass series and the CPUE series.

The binomial indices for both the Chatham Rise and WCSI models showed no trend, and trends in the combined and lognormal indices were similar, implying that little was gained by adding data from zero catches into both these analyses.

Table 9: Description of variables used in the CPUE analysis for the estimated observer tow-by-tow dataset (WCSI) and the daily processed dataset (Chatham Rise). Continuous variables were fitted as third order polynomials except for tow duration which was offered as both third and fourth order polynomials.

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

Table 10: CPUE data constraints for each dataset.

Chatham Rise East	
Data source	TCEPR daily processed
Year range	1990–2015
Year definition	September–August
Fisheries	East Chatham Rise (Stat. Area 404, East Chat)
Statistical areas	049, 051, 052, 402, 403, 404, 408, 409, 410
Method	MW, MB, BT
Target	HOK, HAK
Core vessel selection	80% of catch, ≥ 5 years vessel participation, > 50 vessel-days
Catch	< 80 t
Other	300–1000 m 0.2–24 hours Exclude days with misreported tows Two vessels removed (odd catch values) Latitude < 46°
WCSI	
Data source	Observer data
Year range	2001–2015
Year definition	June–September
Statistical Areas	034, 035, 036
Method	MW, MB, BT
Target	HOK, HAK
Core vessel selection	80% of catch, ≥ 2 years vessel participation; ≥ 20 tows/year
Catch	< 50 t
Other	300–900 m 0.2–15 hours Exclude days with misreported tows Latitude 40–43° Longitude 169.5– 171°

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

Chatham Rise East target hoki and hake

	All vessels					Core vessels				
Fishing year	**No. vessels**	**Catch**	**Effort**	**Prop. Zeros**	**CPUE**	**No. vessels**	**Catch**	**Effort**	**Prop. zeros**	**CPUE**
1990	11	597.9	97	0.13	6.16	4	448.1	58	0.00	7.73
1991	12	523.8	338	0.01	1.55	5	272.3	179	0.01	1.52
1992	22	1 070.8	468	0.14	2.29	12	478.4	207	0.11	2.31
1993	30	1 956.6	553	0.13	3.54	16	1 169.1	304	0.18	3.85
1994	27	2 575.6	356	0.13	7.23	18	2 116.9	298	0.13	7.10
1995	39	2 511.2	761	0.18	3.30	24	2 164.0	636	0.16	3.40
1996	34	2 022.1	385	0.14	5.25	21	1 880.7	333	0.13	5.65
1997	38	1 603.0	578	0.18	2.77	26	1 492.3	462	0.19	3.23
1998	41	884.6	784	0.10	1.13	29	714.7	714	0.10	1.00
1999	36	2 854.1	1 049	0.09	2.72	30	2 686.4	1 031	0.09	2.61
2000	32	1 929.5	655	0.07	2.95	26	1 929.1	654	0.06	2.95
2001	35	2 007.8	797	0.04	2.52	30	1 978.0	768	0.04	2.58
2002	33	1 018.3	839	0.03	1.21	31	1 010.0	827	0.03	1.22
2003	29	683.6	747	0.03	0.92	27	676.9	736	0.03	0.92
2004	30	1 568.5	903	0.04	1.74	28	1 463.8	893	0.04	1.64
2005	23	1 251.6	727	0.05	1.72	21	1 149.6	718	0.05	1.60
2006	19	283.5	387	0.05	0.73	14	177.1	382	0.04	0.46
2007	18	638.4	535	0.03	1.19	17	605.0	529	0.03	1.14
2008	19	680.0	521	0.02	1.31	19	680.0	521	0.02	1.31
2009	16	640.4	381	0.02	1.68	16	640.4	381	0.02	1.68
2010	15	149.9	321	0.01	0.47	15	149.9	321	0.01	0.47
2011	16	138.3	348	0.04	0.40	15	138.0	347	0.04	0.40
2012	17	120.4	450	0.09	0.27	17	120.4	450	0.09	0.27
2013	16	95.9	347	0.04	0.28	16	95.9	347	0.04	0.28
2014	11	127.8	362	0.03	0.35	11	127.8	362	0.03	0.35
2015	16	172.1	411	0.02	0.42	15	171.9	410	0.02	0.42

Table 11 ctd.

WCSI: Observer catch for target hoki and hake

	All vessels					Core vessels				
Fishing year	**No. vessels**	**Catch**	**Effort**	**Prop. Zeros**	**CPUE**	**No. vessels**	**Catch**	**Effort**	**Prop. zeros**	**CPUE**
2001	21	505.9	780	0.21	0.65	9	399.5	565	0.18	0.71
2002	16	1 433.3	1 059	0.15	1.35	12	1 377.1	958	0.14	1.44
2003	13	694.2	629	0.21	1.10	5	97.6	177	0.30	0.55
2004	16	1 245.2	1 113	0.13	1.12	10	923.9	867	0.13	1.07
2005	13	1 089.7	917	0.11	1.19	12	1 079.6	908	0.11	1.19
2006	15	1 690.5	961	0.06	1.76	10	1 449.6	887	0.06	1.63
2007	16	1 136.9	344	0.33	3.30	7	962.0	268	0.20	3.59
2008	14	465.5	427	0.27	1.09	7	438.0	368	0.20	1.19
2009	16	756.0	323	0.32	2.34	6	149.2	232	0.35	0.64
2010	14	409.4	354	0.26	1.16	7	354.9	296	0.28	1.20
2011	11	431.2	453	0.17	0.95	8	310.6	397	0.18	0.78
2012	16	728.6	665	0.22	1.10	10	530.3	538	0.17	0.99
2013	17	3 699.1	1 663	0.11	2.22	16	3 698.9	1 660	0.10	2.23
2014	17	2 391.7	1 531	0.15	1.56	13	2 381.6	1 442	0.14	1.65
2015	20	3 590.5	1 677	0.14	2.14	16	3 579.4	1 598	0.14	2.24

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

Chatham Rise East: TCEPR daily processed core vessels

Lognormal		Binomial	
Variable	r^2	**Variable**	r^2
Fishing year	10.40	Fishing year	7.28
Statistical area	61.98	Vessel	20.53
Vessel	66.69	Statistical area	27.64
Target species	68.24	Depth of bottom	30.69
Distance2	69.42	Duration	32.04
		Method : Headline height	33.11

WCSI: Observer tow-by-tow

Lognormal		Binomial	
Variable	r^2	**Variable**	r^2
Year	4.71	Year	3.06
Target species	35.24	Depth of bottom	21.61
Longitude	42.99	Longitude	25.24
Latitude	45.08	Vessel	27.26
Vessel	49.53	Latitude	28.11
Method : Depth of net	55.40	Method : Depth of net	30.36
Method : Duration	58.72	Method : Duration	31.87

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

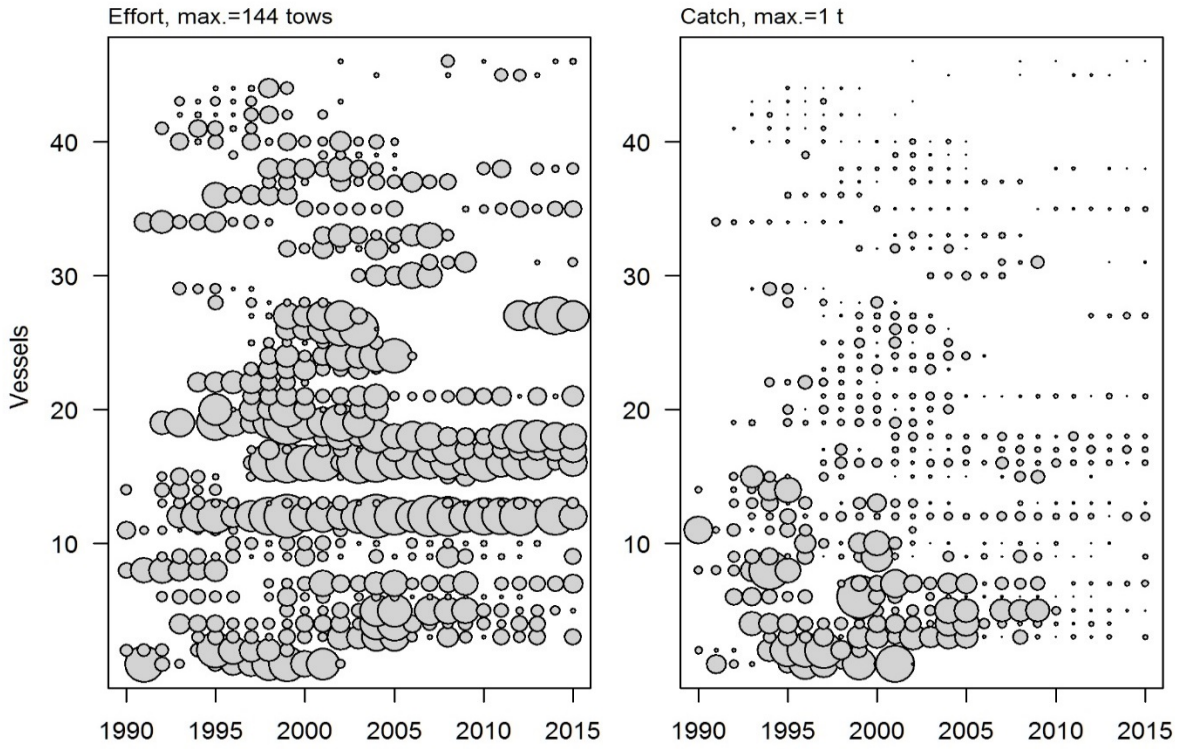
Chatham Rise East: TCEPR daily processed core vessels

	Lognormal		Binomial		Delta lognormal	
Year	**Index**	**CV**	**Index**	**CV**	**Index**	**CV**
1990	2.24	0.15	1	0.00	2.21	0.15
1991	1.84	0.09	0.98	0.00	1.77	0.09
1992	1.32	0.07	0.85	0.00	1.10	0.07
1993	1.36	0.06	0.95	0.00	1.27	0.06
1994	1.54	0.06	0.93	0.00	1.41	0.06
1995	1.11	0.04	0.91	0.00	1.00	0.04
1996	1.46	0.06	0.93	0.00	1.34	0.06
1997	1.38	0.05	0.91	0.00	1.24	0.05
1998	1.07	0.04	0.94	0.00	0.99	0.04
1999	0.96	0.03	0.95	0.00	0.90	0.03
2000	1.30	0.04	0.96	0.00	1.23	0.04
2001	1.13	0.04	0.97	0.00	1.08	0.04
2002	0.99	0.04	0.97	0.00	0.95	0.04
2003	0.77	0.04	0.96	0.00	0.73	0.04
2004	0.88	0.04	0.95	0.00	0.83	0.04
2005	0.56	0.04	0.92	0.00	0.51	0.04
2006	0.57	0.05	0.95	0.00	0.53	0.05
2007	0.88	0.05	0.95	0.00	0.83	0.05
2008	0.91	0.05	0.97	0.00	0.87	0.05
2009	0.99	0.05	0.98	0.00	0.95	0.05
2010	0.79	0.06	0.99	0.00	0.77	0.06
2011	0.66	0.05	0.95	0.00	0.62	0.05
2012	0.56	0.05	0.95	0.00	0.52	0.05
2013	0.69	0.06	0.97	0.00	0.66	0.06
2014	0.82	0.05	0.98	0.00	0.79	0.05
2015	0.92	0.05	0.99	0.00	0.89	0.05

WCSI: Observer tow-by-tow

	Lognormal		Binomial		Delta lognormal	
Year	**Index**	**CV**	**Index**	**CV**	**Index**	**CV**
2001	1.03	0.04	0.98	0.00	0.95	0.04
2002	2.28	0.04	0.99	0.00	2.13	0.04
2003	1.02	0.07	0.98	0.00	0.94	0.07
2004	1.07	0.04	0.97	0.00	0.98	0.04
2005	0.88	0.04	0.97	0.00	0.80	0.04
2006	1.06	0.04	1.00	0.00	1.00	0.04
2007	0.80	0.06	0.95	0.00	0.71	0.06
2008	0.48	0.05	0.97	0.00	0.44	0.05
2009	0.41	0.06	0.94	0.00	0.36	0.06
2010	0.79	0.06	0.97	0.00	0.72	0.06
2011	1.25	0.05	1.00	0.00	1.18	0.05
2012	1.33	0.04	0.99	0.00	1.24	0.04
2013	1.45	0.03	0.99	0.00	1.35	0.03
2014	1.12	0.03	0.98	0.00	1.03	0.03
2015	1.24	0.03	0.99	0.00	1.15	0.03

Chatham Rise East vessels



WCSI vessels

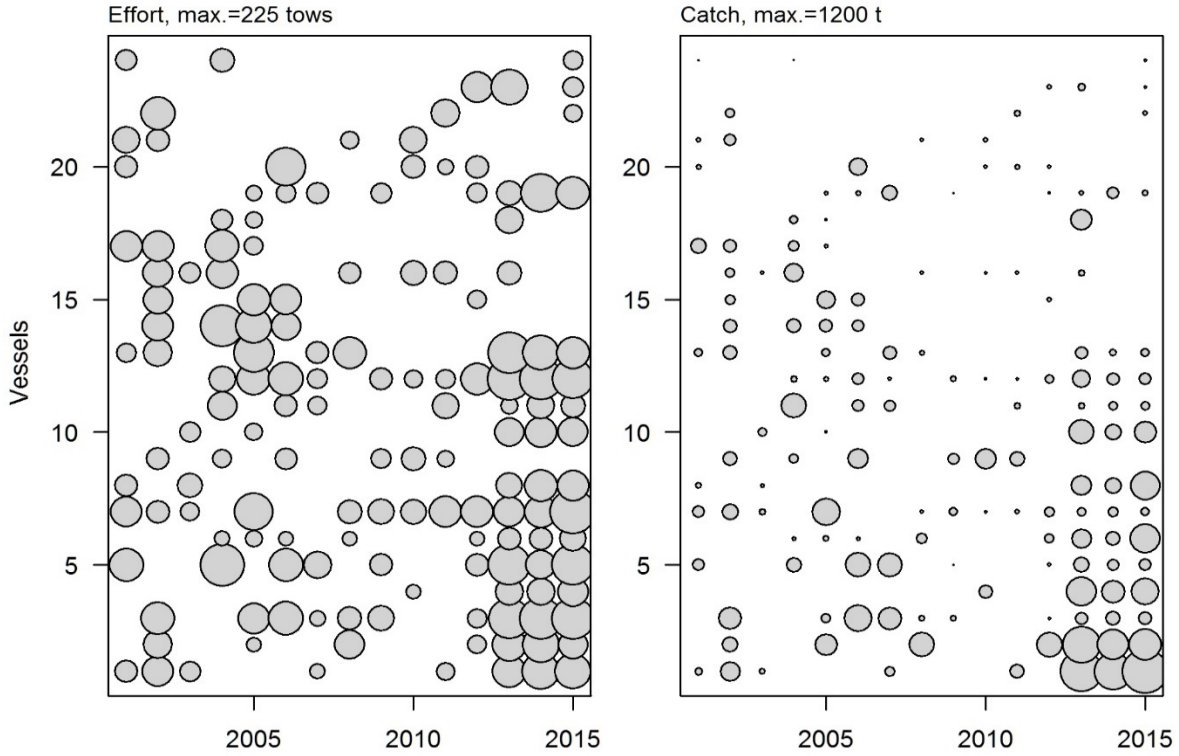


Figure 6: Trawl fishing effort and catches (where circle area is proportional to the effort or catch) by fishing year (September–August) for individual vessels (denoted anonymously by number on the *y*-axis) in the Chatham Rise East and WCSI 'core' CPUE analyses. Year defined as September–August for Chatham Rise data, and June–September for WCSI data.

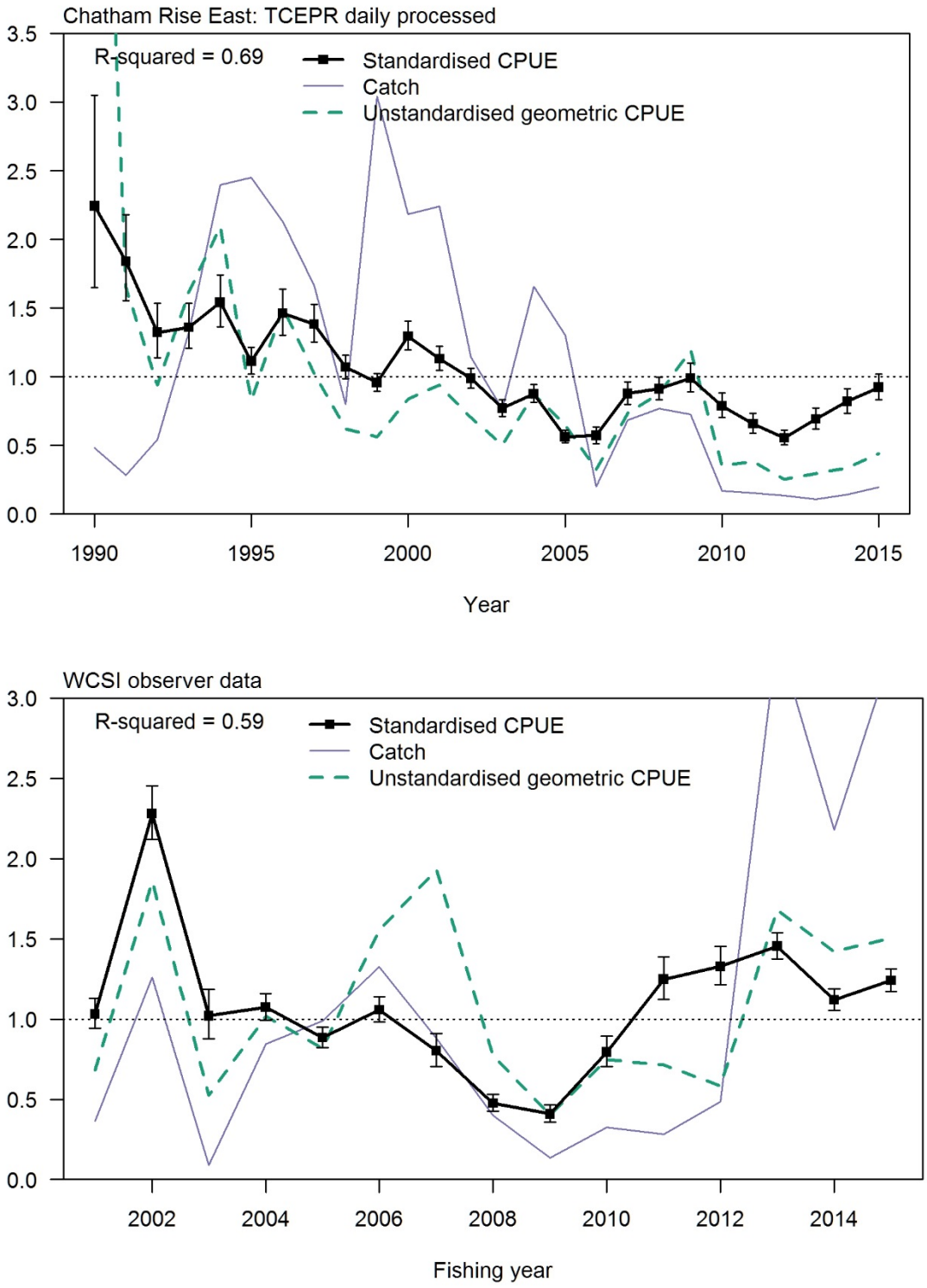


Figure 7: Standardised CPUE indices from the Chatham Rise East and WCSI lognormal models. Bars indicate 95% confidence intervals. Year defined as September–August for Chatham Rise data, and June–September for WCSI data.

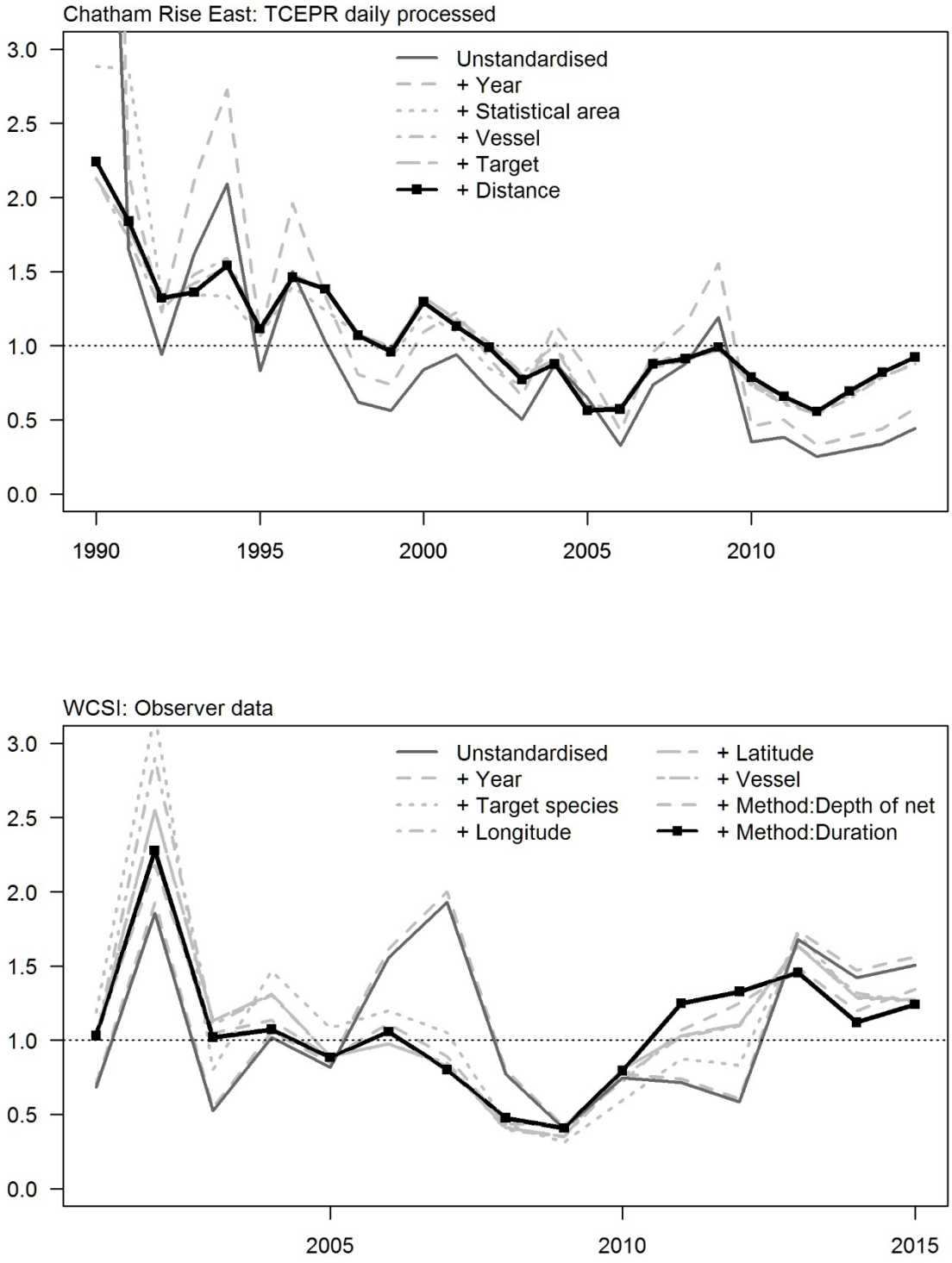


Figure 8: Standardised CPUE indices from the Chatham Rise East and WCSI lognormal model showing the effect of addition of variables. Year defined as September–August for Chatham Rise data, and June–September for WCSI data.

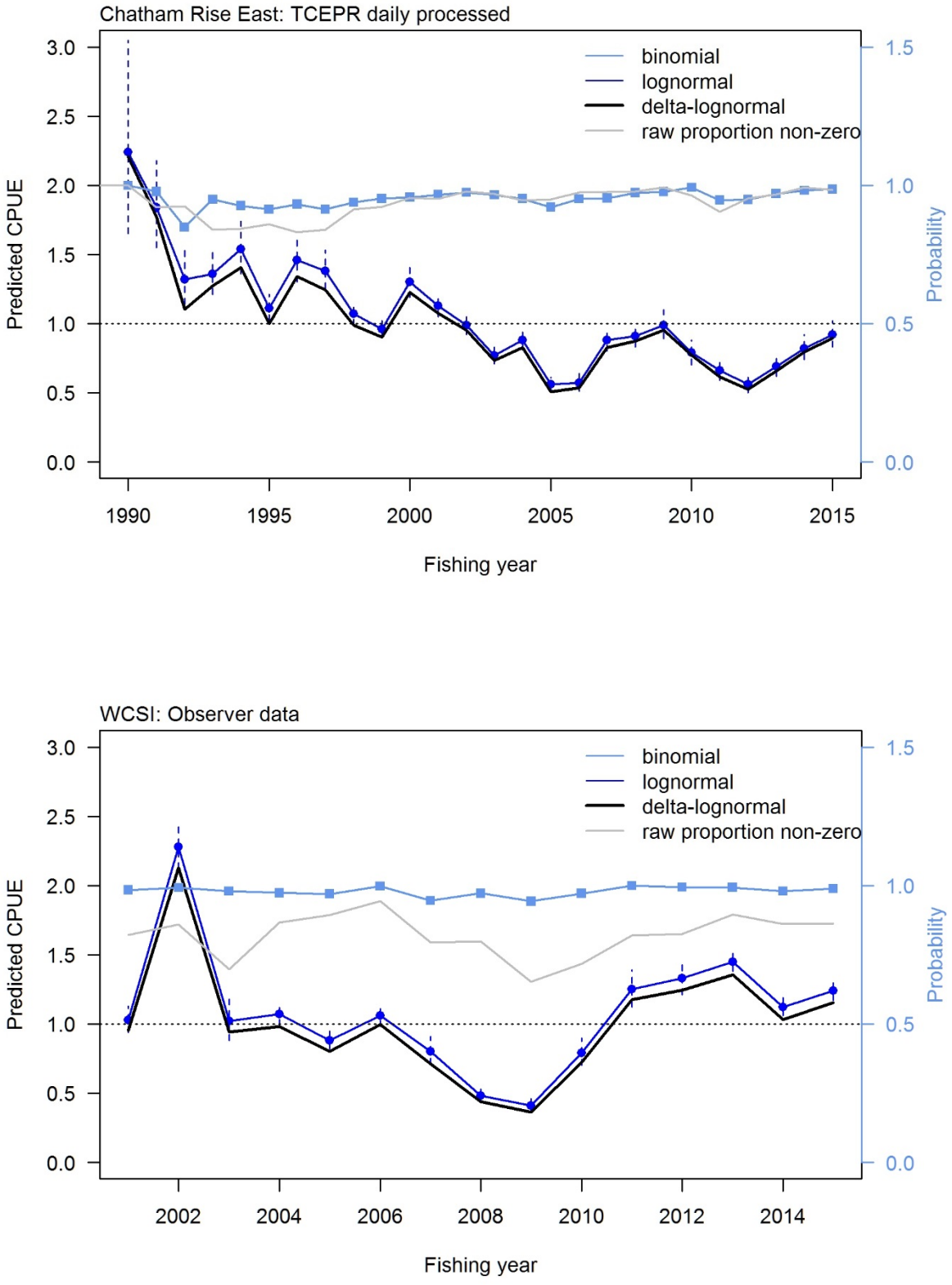


Figure 9: Standardised CPUE indices from the lognormal, binomial and combined model for each fishery. Bars indicate 95% confidence intervals. Year defined as September–August for Chatham Rise data, and June–September for WCSI data.

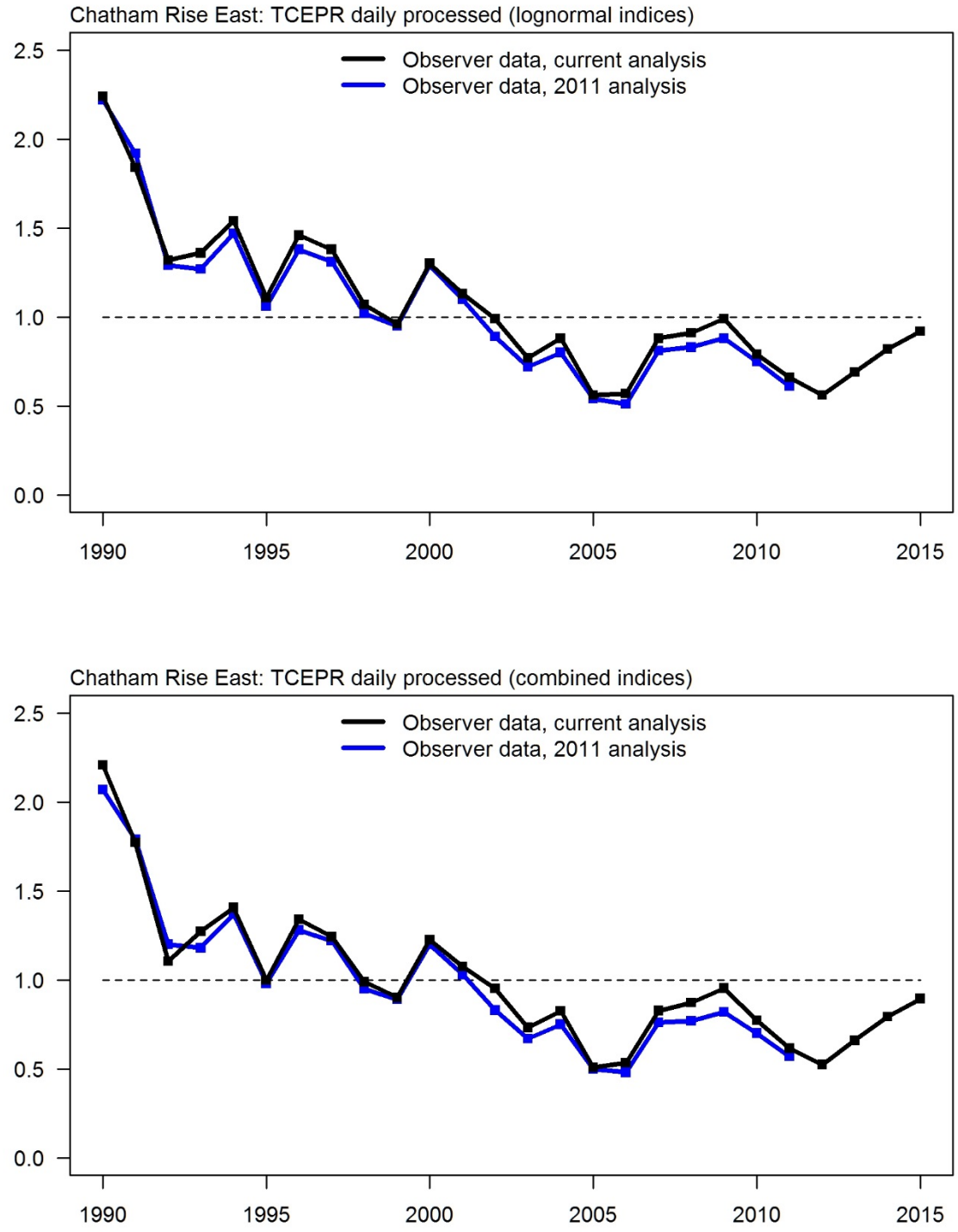
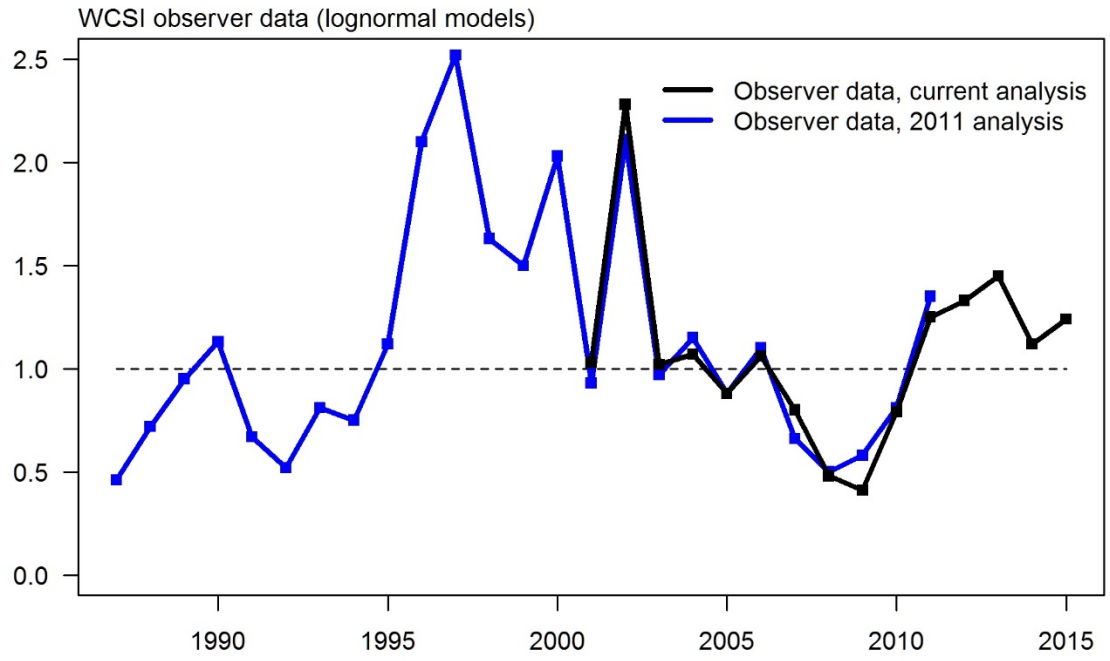


Figure 10: Comparison of CPUE indices for the Chatham Rise East and WCSI lognormal models with the previous results, and TCEPR and Observer models with each other.



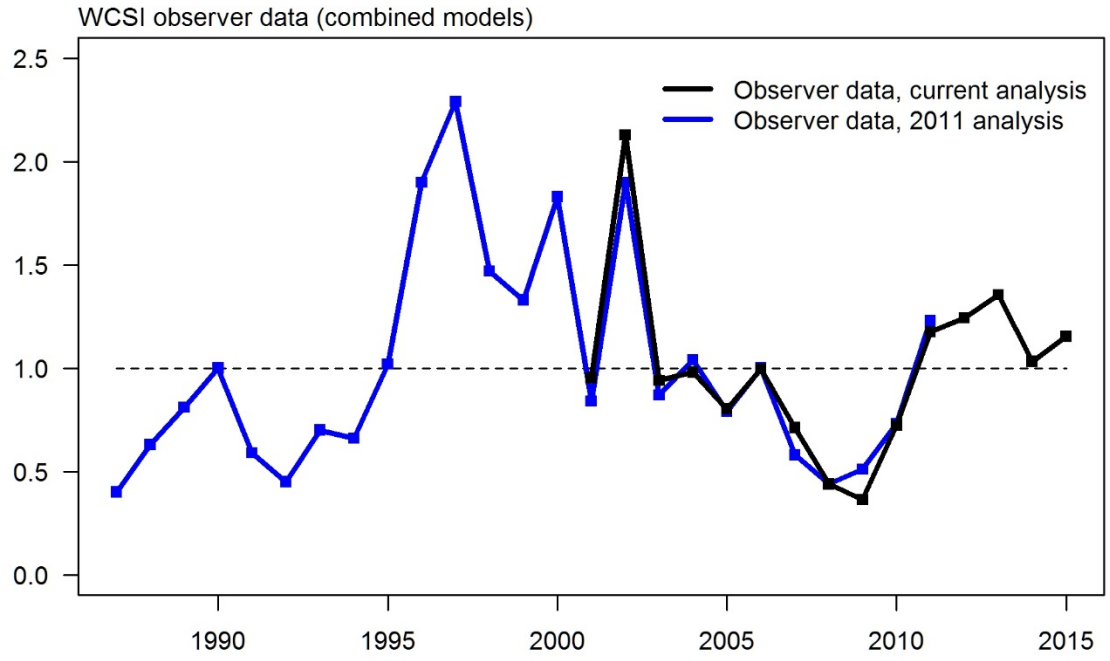


Figure 10 ctd.

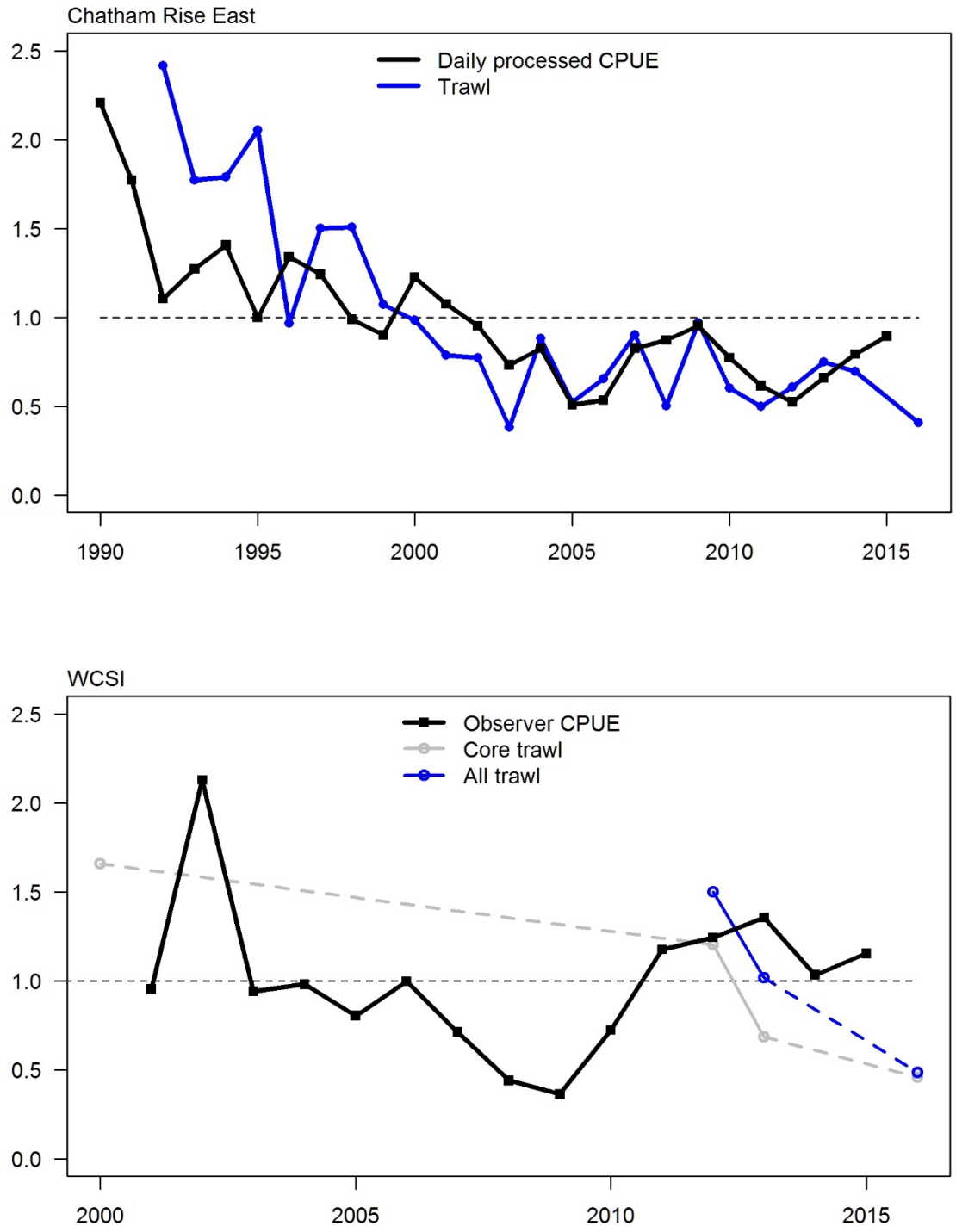


Figure 11: Comparison of trawl survey hake biomass indices with combined indices. All index series have been standardised to a mean of one. Chatham Rise east trawl survey indices plotted are for core strata (200–800 m) east of 178.1° E. WCSI indices are core strata (300–650 m), and all strata (200–800 m). The 2000 WCSI survey abundance estimates were re-calculated using 2012–13 stratum areas.

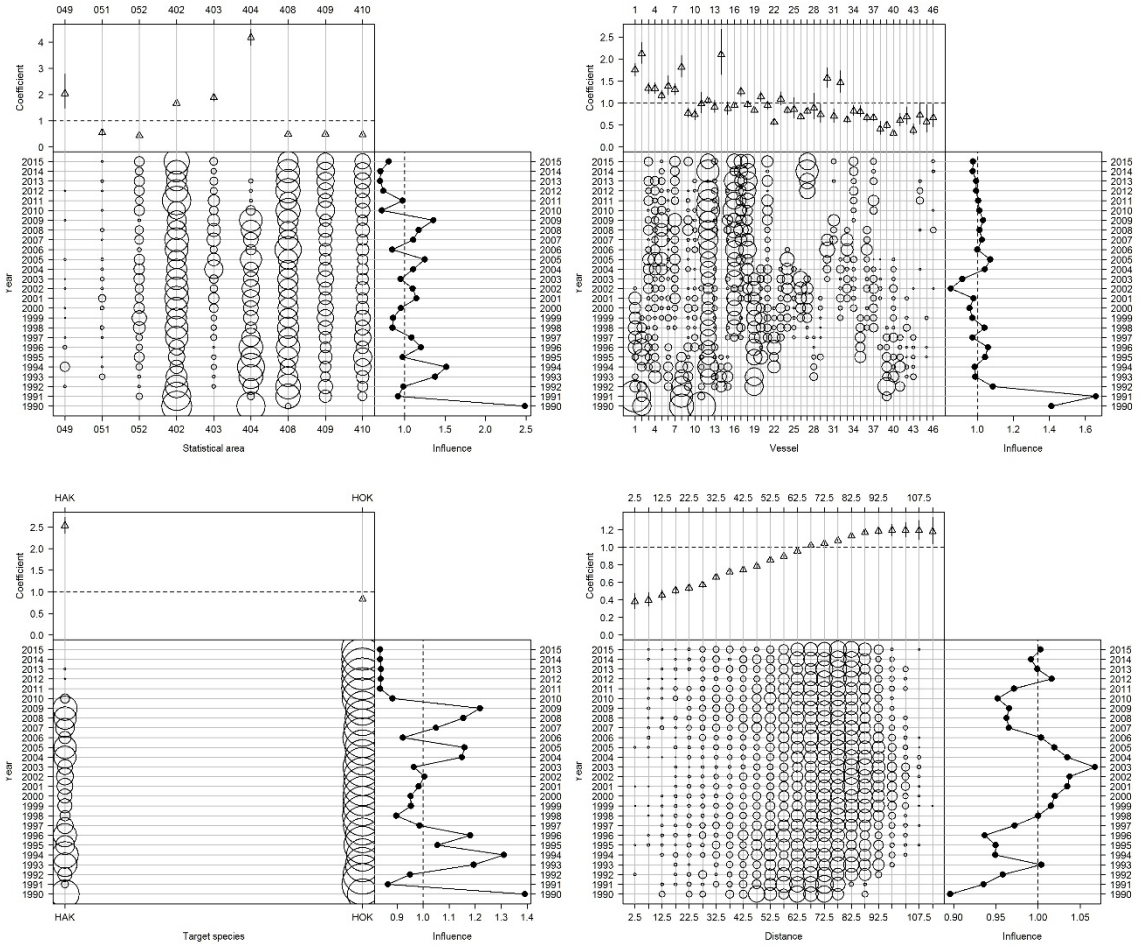


Figure 12a: Effect and influence of non-interaction term variables in the Chatham Rise East daily processed core vessel lognormal model. Top: relative effect by level of each variable. Bottom left: relative distribution of each variable by fishing year. Bottom right: influence of variable on unstandardised CPUE by fishing year.

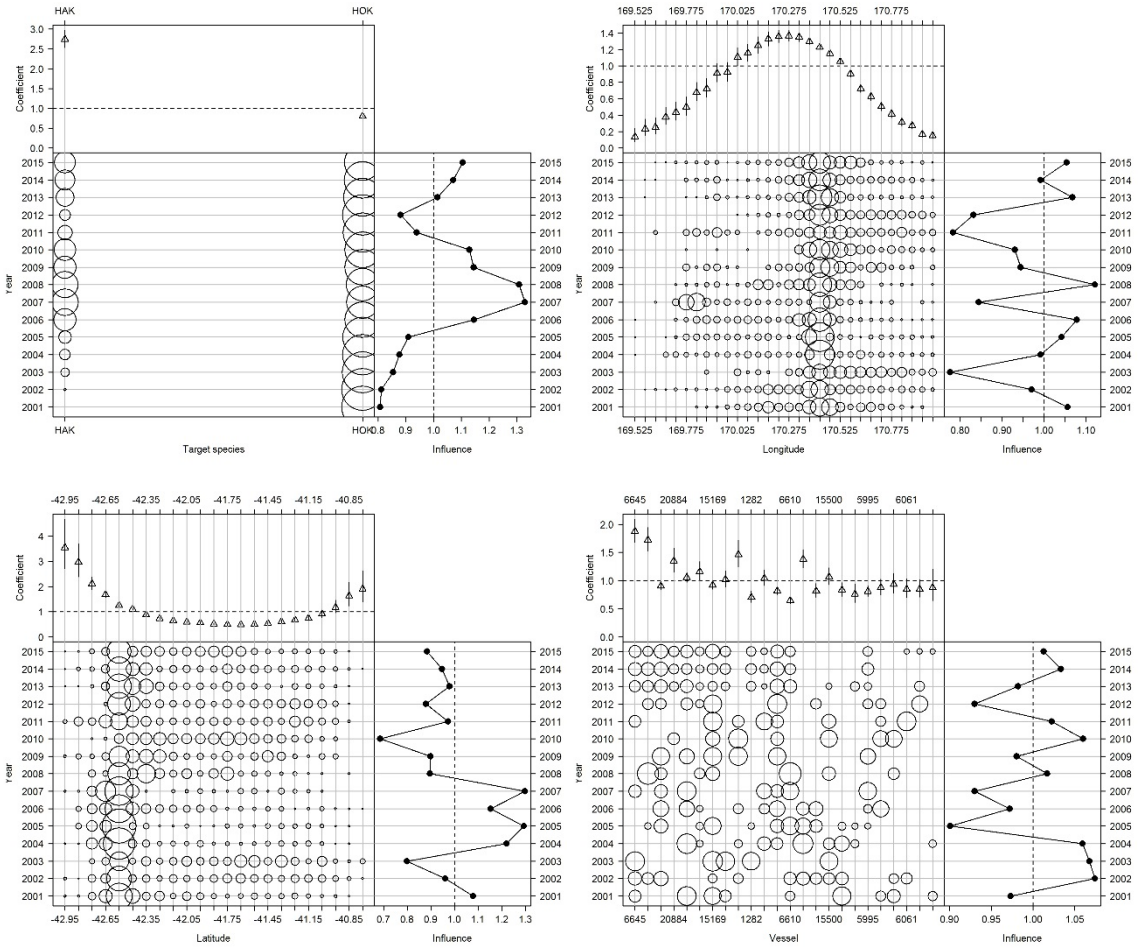


Figure 12b: Effect and influence of non-interaction term variables in the WCSI observer tow-by-tow vessel lognormal model. Top: relative effect by level of each variable. Bottom left: relative distribution of each variable by fishing year. Bottom right: influence of variable on unstandardised CPUE by fishing year.

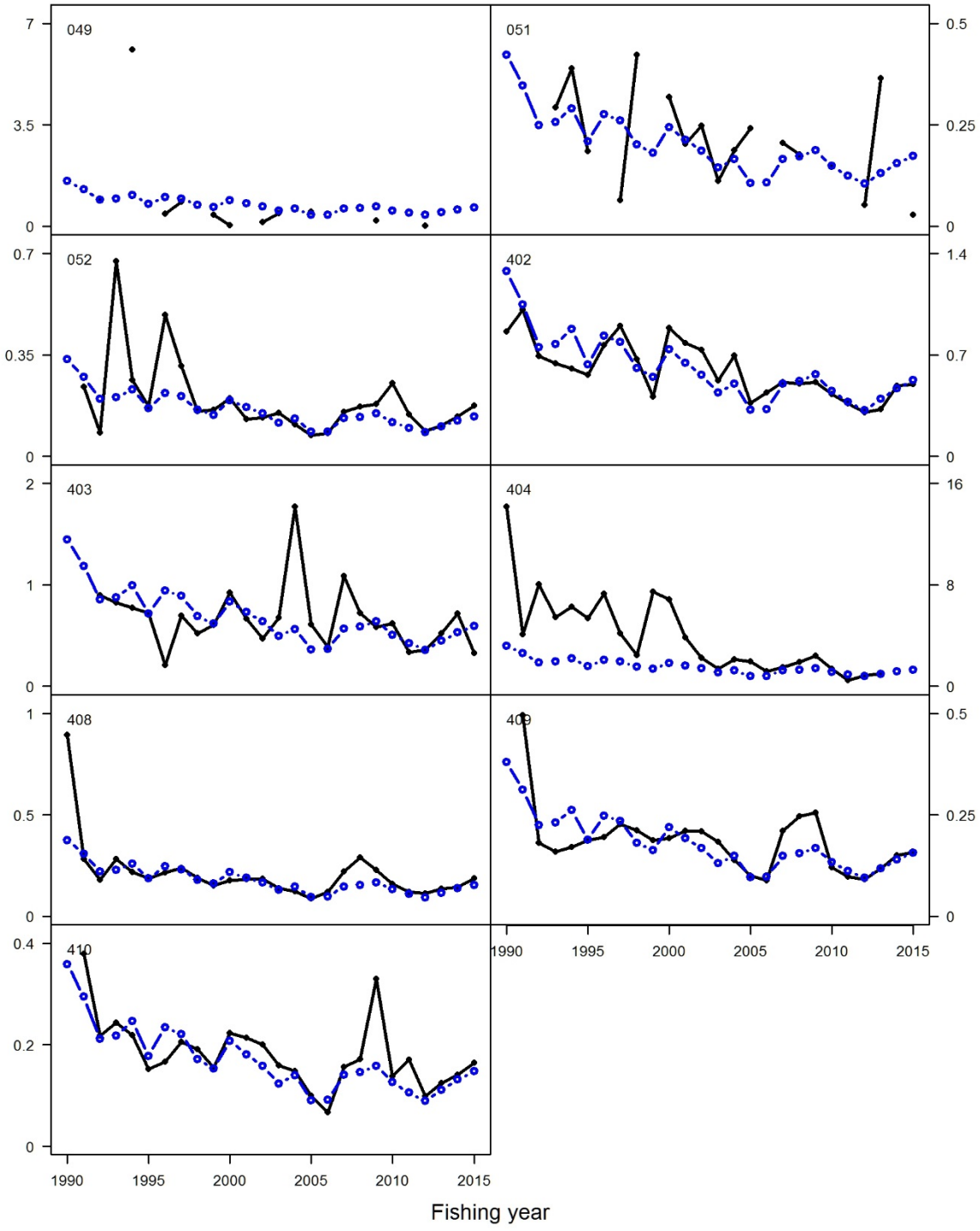


Figure 13: Predicted CPUE by statistical areas for the Chatham Rise East TCEPR processed core lognormal model with year-statistical area interaction (black) and without year-statistical area interaction (blue).

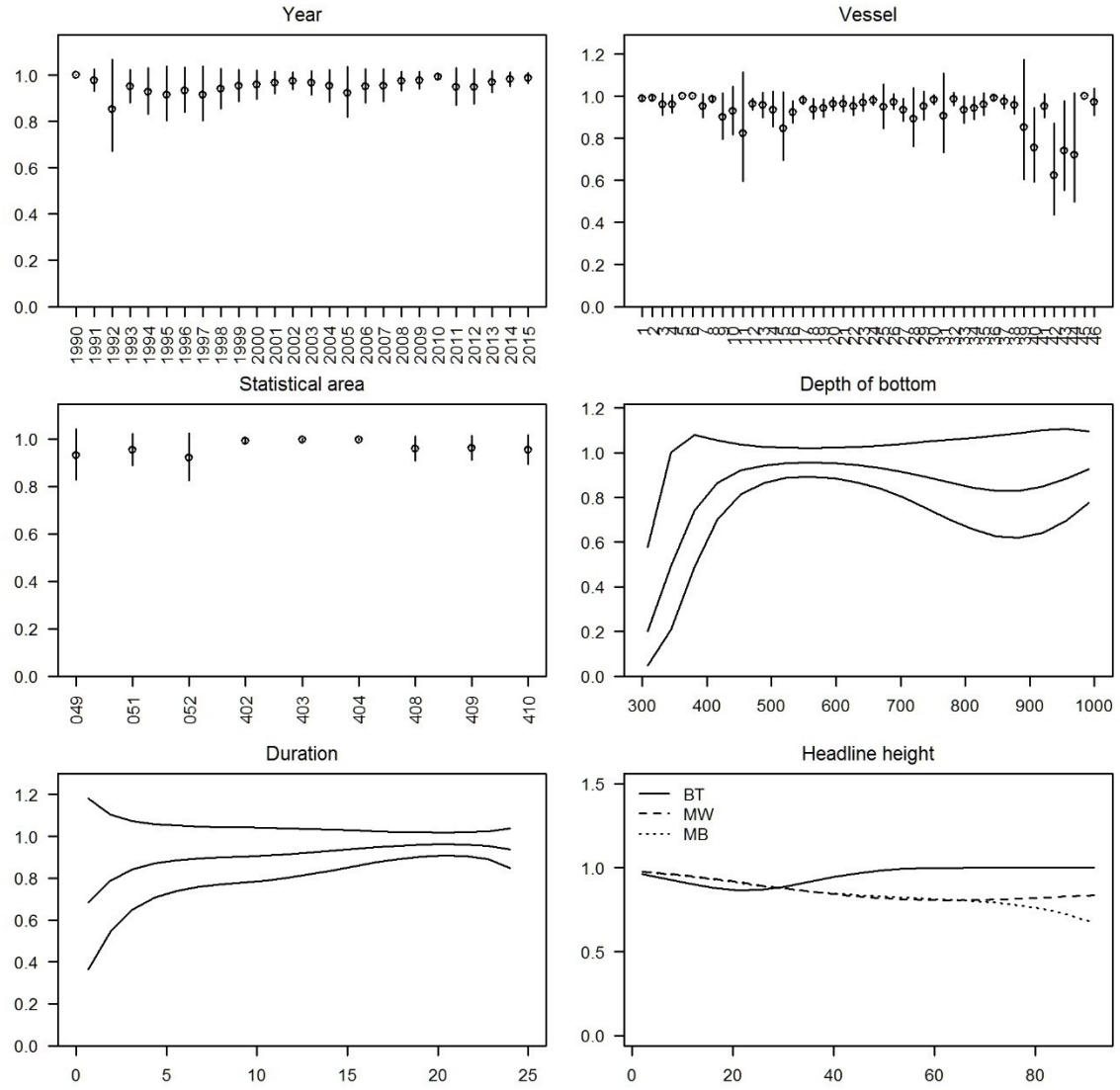


Figure 14a: Expected variable effects for variables selected into the CPUE binomial model for the Chatham Rise East TCEPR daily processed core vessel fishery, 1990–2015. The 95% confidence intervals are shown as bars for categorical variables and as upper and lower lines for continuous variables.

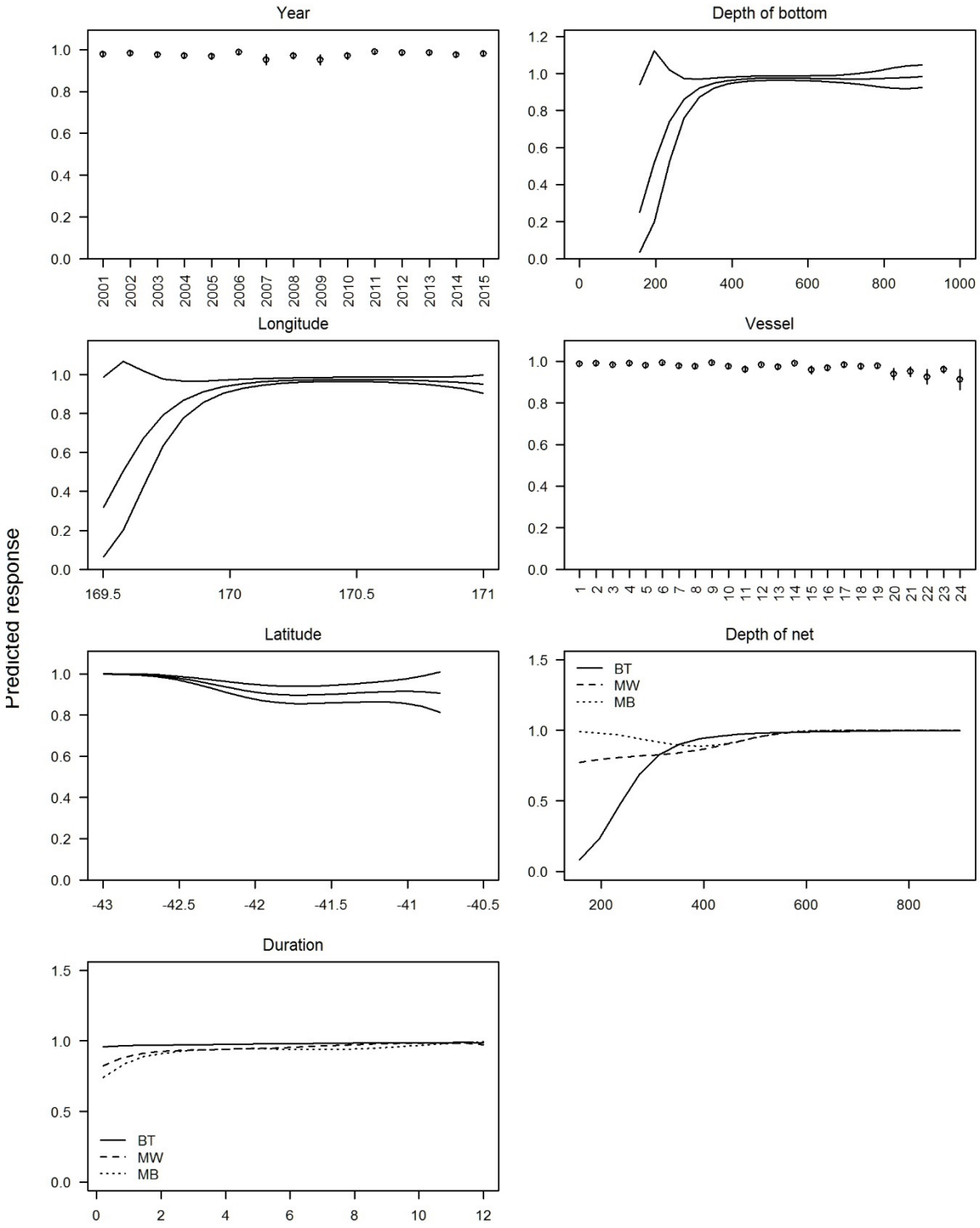
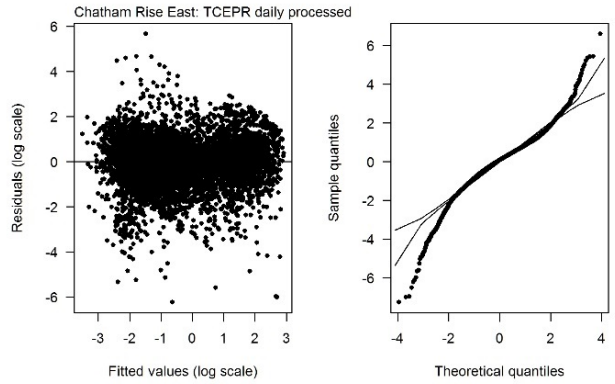


Figure 14b: Expected variable effects for variables selected into the CPUE binomial model for the WCSI observer tow-by-tow vessel fishery, 2001–2015. The 95% confidence intervals are shown as bars for categorical variables and as upper and lower lines for continuous variables.

Chatham Rise East: TCEPR daily processed core vessels



WCSI: Observer tow-by-tow core vessels

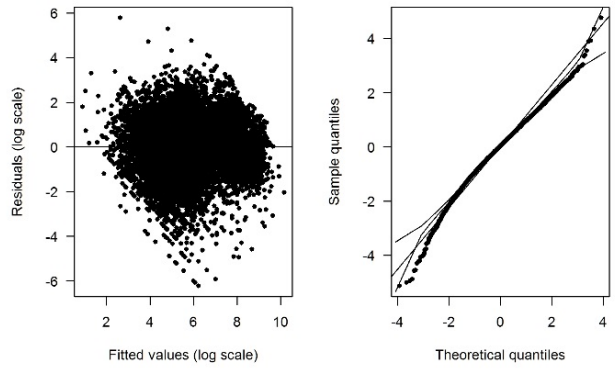
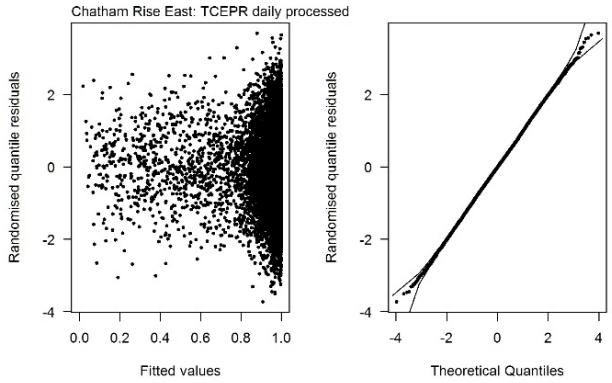


Figure 15: Diagnostic plots for the lognormal CPUE models.

Chatham Rise East: TCEPR daily processed core vessels



WCSI: Observer tow-by-tow core vessels

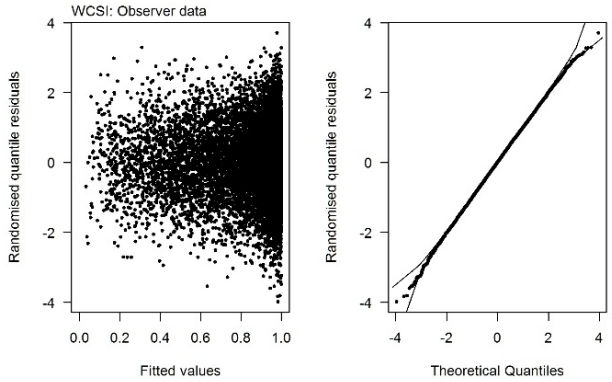


Figure 16: Diagnostic plots for the binomial CPUE models.

4. ACKNOWLEDGEMENTS

I thank the Deepwater Species Fisheries Assessment Working Group for providing useful comments on this work and Peter Horn for reviewing the manuscript. This work was funded by the Ministry for Primary Industries under project DEE201609.

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