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Descriptive analysis and a catch-per-unit-effort (CPUE) analysis of the West Coast South Island (HAK 7) fishery for hake (*Merluccius australis*)

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B. Finucci

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This report provides a descriptive analysis of the catch and effort data for hake from the West Coast South Island (WCSI, HAK 7) fishery and updated catch-per-unit-effort (CPUE) indices for tow-by-tow commercial and observer data. Two time series were developed, from 1989–90 to 2017–18 and from 2000–01 to 2017–18, the latter to remove any influence misreporting in the 1990s may have had on abundance indices.

The WCSI is the largest hake fishery in New Zealand, with a reported catch of 3086 t in the 2017–18 fishing year. Hake is predominately caught by bottom trawl fishing, and most catch is reported between June and September. Since 2003–04, most hake catch has been reported from hake target tows, although in the 2017–18 fishing season, most hake catch (approximately 85%) was reported from hoki target tows. The fishery has undergone a number of changes in the last two decades, and vessel was found to have a large influence on CPUE, particularly in more recent years, resulting from a change in fleet composition. Other variables found to have a significant influence on CPUE were target species, time of day, duration, and depth.

The standardised CPUE indices for commercial and observer data show similar trends over time, with a peak in 1996 and 2002, and low points in the time series in 2008 (commercial) and 2009 (observer). Since 2009, the CPUE indices have been increasing. No substantial differences were found between the 1989–90 to 2017–18 and 2000–01 to 2017–18 indices. The proportion of zero catches in the observer data remained consistently lower than those reported in the TCEPR data (an average of 0.20 in observer data compared to an average of 0.40 in TCEPR data), suggesting either that some underreporting by commercial fishers may continue or that observer coverage was not representative of the fishing fleet.

Additional CPUE analyses were developed for the 2000–01 to 2017–18 time series using a grid covering the extent of the spatial fishing effort. When selecting the top five grid cells (based on total hake catch in t), grid cell was selected as a predictor for the commercial data, but not for observer data. A similar temporal trend was shown in these top five grid cells (where the majority of catch was reported), with some variation in the magnitude and timing of these trends. However, none of these additional analyses showed large differences from the initial CPUE indices.

The CPUE indices produced here continued to provide conflicting results with those from research trawl surveys. It is unlikely that any WCSI hake CPUE series to date is a reliable index of fish abundance. All CPUE indices were presented to the Deepwater Fisheries Assessment Working Group, where it was decided not to use any of the indices in the WCSI stock assessment given uncertainties in reliability.

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 (age 0+) are often found in shallower inshore regions (less than 250 m depth) (Hurst et al. 2000). Hake within the New Zealand Exclusive Economic Zone (EEZ) are managed as three separate administrative Fishstocks: the Challenger Plateau and west coast of the South Island (HAK 7; Figure 1), 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. A comprehensive descriptive analysis of New Zealand hake fisheries was produced by Devine (2009). The last published descriptive analysis of commercial catch and effort data for hake (Ballara 2018) included data up to 2014–15. These reports showed how the hake fisheries in the New Zealand EEZ have evolved and operated, and defined seasonal and areal patterns of fish distribution.

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). Differences in growth parameters, size frequency distributions, and morphometrics were shown to exist between hake from those 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, north-west of the Chatham Islands, and on the Campbell Plateau south of the Snares shelf (Colman 1998).

The largest fishery for hake is on the WCSI, where hake is predominately caught as target catch, but is also caught as bycatch in the hoki fishery (Ballara 2018). The duration of the fishing season is short, taking place mainly during the months of June to September. The fishery has undergone a number of changes in the last two decades (Devine 2010, Ballara 2015, Horn & Ballara 2018), which have included changes in Total Allowable Commercial Catch (TACCs) for both hake and hoki, and changes in fishing practices such as the gear used, tow duration, and strategies to limit hake bycatch. Since 2003, hake has been taken predominately from hake-target tows, and hake reported from hoki-target tows has remained relatively low since 2005.

Evidence of misreporting of catch by a small number of vessels was detected in 2001, and some hake caught in HAK 7 were misreported as catch on the Chatham Rise and Sub-Antarctic in HAK 4 and HAK 1 (Dunn 2003). The misreported catch-effort data has since been corrected (Dunn 2003), and CPUE indices from observer tow-by-tow data estimated from 2001–2015 were considered most likely to be accurate and were used in a recent stock assessment (Horn 2017). However, these indices produced results that conflicted with those produced from trawl surveys and following this, a series of CPUE indices were developed and compared with trawl survey indices (Horn & Ballara, 2018). After refining the catch and effort data set (e.g., removing midwater trawl, separating fleets), estimated CPUE trajectories were found to be similar to those estimated for the entire fishery. No CPUE series was found to match the research trawl survey index and it was deemed unlikely that any WCSI hake CPUE series to date is a reliable index of fish abundance. CPUE indices from the Chatham Rise fishery, estimated from observer tow-by-tow estimated catch for 2000–01 to 2014–15 were considered most likely to be an accurate representation of relative abundance and used in recent hake assessment modelling (Ballara 2018).

This report was prepared as an output from the Fisheries NZ project HAK201801 "Stock assessment of hake in HAK 7" which has the following overall objectives.

Overall objective:

To carry out a stock assessment of hake (*Merluccius australis*) on the west coast of the South Island (HAK 7) including estimating stock biomass and stock status.

Specific objectives

1. To carry out a descriptive analysis of the commercial catch and effort data for hake on the west coast of the South Island and the standardised catch and effort analyses.
2. To carry out a stock assessment of the west coast South Island hake stock including estimates of current biomass, the status of the stock in relation to management reference points, and future projections of stock status as required to support management.

This report addresses Objective 1 of the project, updating on the previous analysis (Ballara 2018), focusing on whether any marked changes have occurred in the fisheries in recent years.

2. METHODS

2.1 WCSI characterisation

Catch-effort, daily processed, and landed data were extracted from the Fisheries New Zealand catch-effort database “warehou”. 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 2017–18 were extracted. 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 the Electronic Reporting System (ERS, newly introduced in 2017–18). High seas versions of these forms were included. Catch and effort data for hake from the Fisheries New Zealand observer sampling programme (administered by NIWA in the *cod* database) were also extracted.

Data were checked for errors based on methods used in previous characterisations (e.g., Ballara 2018). 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). To account for possible misreporting, tow-by-tow commercial and observed catches of hake were corrected using methods outlined by Dunn (2003).

The biological stock of WCSI was divided into three sub-areas: 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 1). These division were based on tree regression analyses of mean fish length (by sex) in the catches sampled by Ministry observers (Horn & Dunn 2007, Horn 2008, Horn & Sutton 2010).

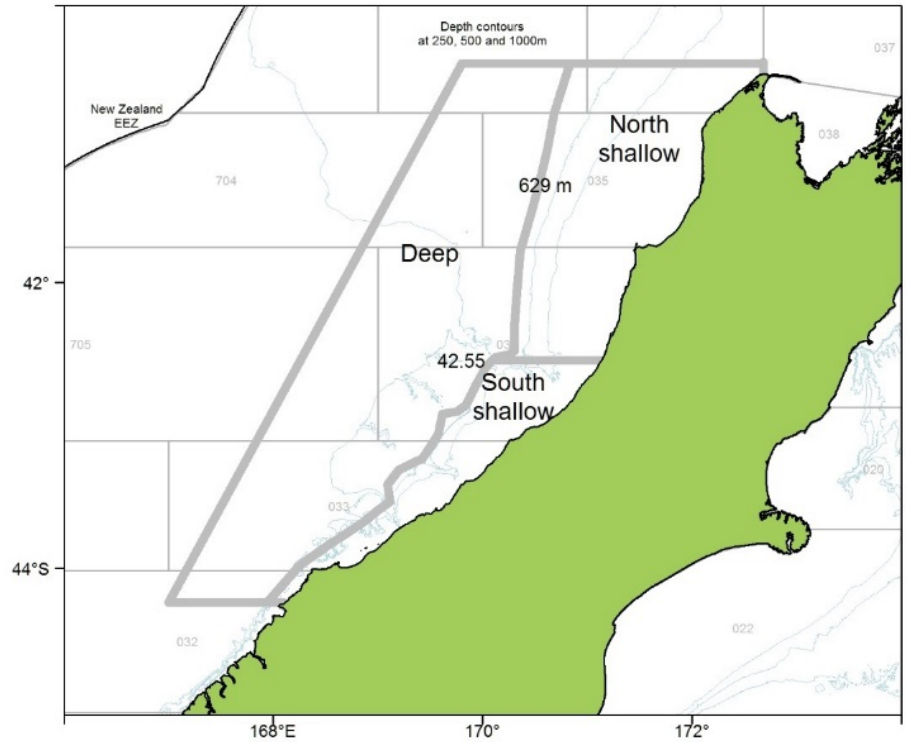

Figure 1: Location and boundaries of the three WCSI sub-areas: North shallow (< 530 m, north of 42.55° S); South shallow (<530 m, south of 42.55° S); and Deep (> 530 m).

2.2 WCSI CPUE indices

Data grooming was carried out as described in Section 2.1.

Predictor variables (categorical or continuous) offered to the model were generally similar to those used in previous analyses (e.g., Ballara 2018) and are described in **Error! Reference source not found.** Categorical data were offered as factors, and continuous variables (e.g., duration, distance, depth of bottom) were modelled as third-order polynomials. Year was defined as 1 October – 30 September to reflect the seasonality of the fishery (Ballara 2018). Gear width was not used as an explanatory variable as reporting of wingspread and doorspread measurements has been found to be inconsistent.

Annual unstandardised (raw) CPUE and standardised CPUE indices were calculated using catch per tow (in kilograms) for TCEPR/ERS and observer tow-by-tow data. The data used for each CPUE analysis followed the same procedures reported previously (e.g., Ballara 2018). Only TCEPR and ERS data were used in the analyses as previous work concluded that there was little difference between CPUE indices including or excluding TCER data (Ballara & Horn 2011). Core vessels included those vessels in the fishery that had fished at least 20 tows each active year, cumulatively reported approximately 80% of hake catches, and had been in the fishery for at least 1) six years for the TCEPR 1990–91 to 2017–18 series; 2) eight years for the TCEPR 2000–01 to 2017–18 series; 3) two years for the observer 1990–91 to 2017–18 series; and 4) five years for the observer 2000–01 to 2017–18 series.

Each dataset was fitted with a delta-lognormal generalised linear model (GLM). Predictors were selected with stepwise regression, using Akaike Information Criterion (AIC), with the year predictor forced in. Predictors were only included in the final model if they were significant and explained at least 1% of the additional deviance.

Table 1: Description of variables used in the West Coast South Island CPUE analysis for the estimated TCEPR/ERS and observer tow-by-tow dataset. Continuous variables were fitted as third order polynomials.

Variable	Type	Description
Year	Categorical	Year (Sep-June)
Vessel	Categorical	Unique (encrypted) vessel identification number
Statistical area	Categorical	Statistical area
Tow duration	Continuous	Duration of tow (hrs)
Target species	Categorical	Target species for a tow
Month	Categorical	Month of the year
Time start	Continuous	Start time of tow, 24 hour clock
Tow distance	Continuous	Distance of tow (in km)
Headline height	Continuous	Headline height (m) of the net for a tow
Bottom depth	Continuous	Median seabed depth (m) for a tow
Net depth	Continuous	Net depth (m) for a tow (depth of ground rope)
Vessel experience	Continuous	Number of years the vessel has been involved in the fishery
Longitude	Continuous	Longitude of the vessel for a tow (start position)
Latitude	Continuous	Latitude of the vessel for a tow (start position)

3. RESULTS

3.1 Fishery characterisation - WCSI

Estimated catches and reported landings (in tonnes), as well as Total Allowable Commercial Catches (TACC) from 1989–90 to 2017–18 are shown in Table 2. Catches were highest in the mid-1990s and again in the early 2000s, with a peak estimated catch of 9673 t in 1994–95. Hake catch (estimated and reported) has not exceed the TACC since quota was increased to 7700 t in 2005–06. Across the time series, use of the TCEPR forms has been the dominant means to report hake catch (Table 3). Fisheries catch reporting on TCEPR forms was replaced with the introduction of ERS in 2017–18, and ERS is now the primary means of reporting catch. Small amounts of hake catch were still reported with TCER (87.2 t), LTCER (22.7 t), TCEPR (1.8 t), and CELR (0.3 t) forms.

The WCSI hake fishery is mainly bycatch of the much larger hoki trawl fishery, and is caught predominately by bottom trawl (Table 4). There have been a number of changes in the fisheries over time, including TACCs for both hake and hoki, and changes in fishing practices (e.g., gear, tow duration, and strategies to limit hake bycatch), as previously reported by Devine (2010), Ballara (2015), and Horn & Ballara (2018). Since 2003–04, most hake catch has been reported from hake target tows, although in the 2017–18 fishing season, most hake catch (approximately 85%) was reported from hoki target tows. Hake are caught year-round, with most catch reported between June and September (Table 5). Some additional catches are also reported in May and in the mid-1990s and 2000s, catch was reported in October as well.

Since 2010, bottom trawl has been the predominant method for hake catch, with most catch reported from depths between 500 and 650 m (Appendix A, Figure 3, Figure 4). 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. Targeted hake catches peaked in the late 2000s, which coincided with the smallest amount of hake catch reported from hoki-targeted fisheries. In recent years, hake catches peaked in 2015 at 6175 t, and declined by over half (2864 t) in the following fishing year. This is attributable to the reduction in fishing by Korean flagged vessels. Catches were taken mainly in Statistical Areas 034, with most from sub-area North shallow since 2010 (Appendix A, Figure 5).

For vessels targeting hoki or hake, apart from a peak in the late 2000s, mean duration (in hours) of tows, along with speed, distance, and depth of net/bottom have remained fairly consistent throughout the time series (Appendix A, Figure 6). Mean hoki catch (t) was variable until 2010, where a steep increase was observed, followed by some decline and consistent trend since 2012. Mean vessel length in the fleet has progressively decreased overall and in particular in the group of vessels using bottom trawl. Mean vessel length has been larger and more variable in the midwater fleet. For hake-targeting vessels, a steady increase in mean duration of tow was observed across the time series (Appendix A, Figure 7). Mean distance towed has been variable, but exhibits a rising trend over time. Mean vessel length declined rapidly in the early 2000s and has remained at a consistent smaller size since. All other variables show no clear trends.

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 and by biological stock area (see Figure 1) from fishing years 1989–90 to 2017–18. Estimated data also includes LCER (from 2003–04), and NCELR estimated data (from 2006–07), TCER and LTCER data (from 2007–08), ERS data (from 2017–18) and TLCER data. All catches have been rounded to the nearest tonne.

	Estimated catch	Reported catch	TACC
Year	HAK 7	HAK 7	HAK 7
1989–90	4 903	4 903	3 310
1990–91	6 175	6 148	3 310
1991–92	3 027	3 027	6 770
1992–93	7 198	7 154	6 835
1993–94	2 990	2 974	6 835
1994–95	9 673	8 841	6 835
1995–96	9 089	8 678	6 835
1996–97	6 849	6 118	6 835
1997–98	7 885	7 416	6 835
1998–99	8 478	8 165	6 835
1999–00	7 041	6 898	6 835
2000–01	8 349	8 360	6 835
2001–02	7 499	7 519	6 835
2002–03	7 406	7 433	6 835
2003–04	7 943	7 945	6 835
2004–05	7 302	7 317	6 835
2005–06	6 897	6 906	7 700
2006–07	7 660	7 668	7 700
2007–08	2 615	2 620	7 700
2008–09	5 945	5 954	7 700
2009–10	2 340	2 352	7 700
2010–11	3 570	3 754	7 700
2011–12	4 428	4 459	7 700
2012–13	5 422	5 434	7 700
2013–14	3 620	3 642	7 700
2014–15	6 175	6 219	7 700
2015–16	2 864	2 864	7 700
2016–17	4 701	4 701	7 700
2017–18	3 086	3 086	7 700

Table 3: Estimated West Coast South Island hake catches (t) by form type and fishing year.

								Catches
Year	**ERS**	**TCEPR**	**TCER**	**CELR**	**LCER**	**LTCER**	**NCELR**	**Total**
1989–90	-	4 902.7	-	0.7	-	-	-	4 903.3
1990–91	-	6 172.7	-	2.3	-	-	-	6 175.0
1991–92	-	3 019.2	-	7.5	-	-	-	3 026.7
1992–93	-	7 163.1	-	33.4	-	-	-	7 196.5
1993–94	-	2 970.8	-	2.0	-	-	-	2 972.8
1994–95	-	9 669.2	-	2.9	-	-	-	9 672.1
1995–96	-	9 082.1	-	2.2	-	-	-	9 084.3
1996–97	-	6 843.1	-	0.7	-	-	-	6 843.9
1997–98	-	7 876.1	-	2.3	-	-	-	7 878.4
1998–99	-	8 438.7	-	6.7	-	-	-	8 445.4
1999–00	-	7 030.5	-	7.9	-	-	-	7 038.4
2000–01	-	8 345.9	-	1.9	-	-	-	8 347.8
2001–02	-	7 497.8	-	0.9	-	-	-	7 498.7
2002–03	-	7 404.0	-	0.7	-	-	-	7 404.6
2003–04	-	7 938.6	-	0.7	-	-	-	7 939.2
2004–05	-	7 297.9	-	0.2	-	-	-	7 298.1
2005–06	-	6 892.0	-	3.8	-	-	-	6 895.8
2006–07	-	7 659.6	-	-	-	-	0.2	7 659.9
2007–08	-	2 582.6	18.3	-	-	10.5	-	2 611.4
2008–09	-	5 912.3	19.1	-	-	12.1	0.3	5 943.8
2009–10	-	2 282.3	34.1	-	-	16.1	1.0	2 333.5
2010–11	-	3 480.3	51.6	-	-	21.0	0.1	3 553.0
2011–12	-	4 298.9	90.5	-	-	37.4	0.2	4 427.0
2012–13	-	5 170.6	201.7	-	-	49.5	-	5 421.9
2013–14	-	3 386.7	183.8	-	0.3	48.8	-	3 619.7
2014–15	-	5 950.4	194.1	-	-	29.9	-	6 174.4
2015–16	-	2 733.0	108.3	-	-	21.2	0.1	2 862.7
2016–17	-	4 592.0	89.5	1.5	-	17.7	-	4 700.7
2017–18	2 973.1	1.8	87.2	0.3	-	22.7	-	3 085.1

Table 4: West Coast South Island hake TCEPR and ERS catch by target species and fishing method, 1989–90 to 2017–18. Values have been rounded to the nearest tonne, so '0' denotes catches from 1 to 499 kg and '–' denotes zero catch.

	Bottom trawl			Midwater traw			Midwater, on bottom		
	Target			Target			Target		
Year	**Hake**	**Hoki**	**Other**	**Hake**	**Hoki**	**Other**	**Hake**	**Hoki**	**Other**
1989–90	4	614	4	2	3 391	0	1	885	0
1990–91	–	247	3	0	4 626	2	5	1 246	44
1991–92	1 224	355	74	45	837	1	249	232	2
1992–93	536	607	21	962	1 065	0	2 548	1 409	15
1993–94	53	638	20	173	934	2	761	386	3
1994–95	0	631	98	851	4 417	20	1 870	1 767	14
1995–96	221	1 204	79	1 198	4 348	25	217	1 740	50
1996–97	56	1 073	45	511	3 118	48	280	1 572	70
1997–98	58	850	18	277	4 334	22	297	2 010	1
1998–99	368	1 362	10	1 119	3 143	7	1 205	1 209	2
1999–00	286	1 890	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	674	15	701	410	0	1 940	576	0
2006–07	1 591	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	51	0	12	93	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	4 510	582	9	4	187	0	335	324	0
2015–16	1 409	733	4	–	136	0	0	450	0
2016–17	2 729	1 347	8	1	142	0	7	352	0
2017–18	454	1 571	11	–	290	0	1	601	1

Table 5: West Coast South Island estimated hake TCEPR catch (t) by month from 1989–90 to 2017–18. 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	1 425	1 832	3 343	7 163
1993–94	0	0	0	0	0	1	0	0	885	1 234	381	470	2 971
1994–95	14	0	2	0	0	3	1	24	3 237	2 365	3 682	342	9 669
1995–96	85	0	0	0	0	1	0	1	2 530	2 625	2 747	1 093	9 082
1996–97	57	0	0	0	0	0	0	0	942	2 451	2 033	1 361	6 843
1997–98	64	31	0	0	0	0	2	22	1 754	3 336	2 159	507	7 876
1998–99	51	332	15	0	0	4	1	14	3 151	3 478	1 031	362	8 439
1999–00	151	0	–	–	0	2	1	44	1 775	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	–	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	275	19	0	0	0	0	0	0	774	1 092	2 185	2 547	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	1 410	610	3 480
2011–12	25	–	–	0	–	–	–	0	283	1 371	1 526	1 092	4 299
2012–13	0	–	–	–	0	–	–	5	1 143	814	1 284	1 924	5 171
2013–14	–	–	0	0	0	0	0	58	774	1 109	879	567	3 387
2014–15	8	0	0	2	0	0	0	204	1 159	1 424	2 795	359	5 950
2015–16	0	–	–	2	–	0	1	20	917	922	409	462	2 733
2016–17	0	–	–	4	2	0	0	18	518	1 760	1 632	658	4 592
2017–18	2	0	5	2	0	3	1	18	464	894	1 296	290	2 975

3.3 Commercial CPUE

In the 1990–91 to 2017–18 time series, a total of 246 unique vessels caught 145 000 t of hake from 158 110 tows. From these, 56 vessels were selected as core vessels (range 7 to 43 per year) which caught an estimated 120 830 t of hake from 106 764 tows (Table 6). There were 35 core vessels in the fishery for 10 or more years (with the maximum being 26 years) (Appendix A, Figure 8). In the 2000–01 to 2017–18 time series, a total of 78 unique vessels caught 90 746 from 83 827 tows. From these, 28 vessels were selected as core vessels (range 15 to 27 per year) which caught an estimated 77 533 t of hake from 61 067 tows (Table 6). There were 23 core vessels in the fishery for 10 or more years (with the maximum being 19 years) (Appendix B, Figure 8, Figure 9). The proportion of zero catch tows (i.e., tows where hake was targeted, but no hake was caught) for core vessels ranged between 0.20 and 0.65 (Appendix B, Figure 10, Figure 11). For both core and all vessels, the proportion of zero catch tows showed no trend from 1995 to 2016, followed by a decline to the lowest levels in the time series in the last 2 years.

Both time series produced very similar indices where overlap occurred (Appendix B, Figure 12). The delta-lognormal model produced an index which peaked in 1996, and steadily declined (with a small increase in 2002) until its lowest level in 2008. The index then rose rapidly until 2013 and remained without trend since. Diagnostics for the lognormal model are reported in Appendix B, Figure 15 and indicated an acceptable fit to the data. Model outputs from both time series are reported in Appendix B, Table 9 and Table 10.

The same six variables, including year, were selected for the lognormal model for each time series: target, vessel, start time, duration and depth of bottom (Table 7). These variables together explained 30.5% (1990–91 onwards series) and 31.9% (2000–01 onwards series) of the residual deviance, with most of the explained deviance attributable to target. Coefficient distribution influence (CDI) plots were similar for both time series, and thus, those produced for the long time series are presented in Appendix B, Figure 16. Target was also the most influential predictor (Appendix B, Figure 14, Figure 16), with most hake-targeted fishing occurring mid- to late 2000s. Increased duration and fishing at depths of around 600 m produced the highest catch rates, but in recent years, there was a shift to fishing with shorter tows and at shallower depths (500–550 m). Vessel was also an important predictor, and recently the fishery has seen the reappearance of a group of vessels that were active in the late 1990s. These vessels negatively influenced hake catch rate.

Table 6: For the following two pages. Summary of data for all and core vessels included in the CPUE datasets, by year. Data include: number of unique vessels fishing (No. vessels), number of tow records (Effort), proportion of tows that caught zero catch (Prop. zeros), estimated catch, and unstandardised CPUE (CPUE).

TCEPR	All vessels					Core vessels, 1990–91 to 2017–18					Core vessels, 2000–01 to 2017–18				
Fishing year	No. vessels	Catch	Effort	Prop. zeros	CPUE	No. vessels	Catch	Effort	Prop. zeros	CPUE	No. vessels	Catch	Effort	Prop. zeros	CPUE
1990	75	4 605.9	4 479	0.43	1.03	7	747.5	692	0.31	1.08	-	-	-	-	-
1991	72	5 475.8	3 154	0.60	1.74	12	1 453.1	649	0.48	2.24	-	-	-	-	-
1992	66	2 639.3	1 677	0.73	1.57	10	983.8	477	0.60	2.06	-	-	-	-	-
1993	60	5 886.2	2 102	0.70	2.80	17	3 136.6	938	0.61	3.34	-	-	-	-	-
1994	65	2 769.4	2 047	0.76	1.35	20	2 027.1	1 122	0.65	1.81	-	-	-	-	-
1995	60	6 297.2	3 049	0.61	2.07	25	4 424.3	1 855	0.53	2.39	-	-	-	-	-
1996	58	7 955.3	3 832	0.43	2.08	29	6 180.1	2 525	0.44	2.45	-	-	-	-	-
1997	74	5 234.2	3 905	0.50	1.34	37	4 061.8	2 629	0.46	1.54	-	-	-	-	-
1998	67	6 332.7	4 154	0.44	1.52	42	4 889.1	3 167	0.40	1.54	-	-	-	-	-
1999	57	7 058.9	3 500	0.48	2.02	36	6 451.5	2 877	0.44	2.24	-	-	-	-	-
2000	50	6 151.3	3 710	0.48	1.66	39	5 862.1	3 569	0.48	1.64	23	4 405.3	2 231	0.47	1.97
2001	62	7 285.3	4 501	0.45	1.62	43	6 989.4	4 188	0.44	1.67	27	5 681.6	2 803	0.42	2.03
2002	55	6 959.8	4 197	0.43	1.66	40	6 835.2	3 946	0.40	1.73	25	5 385.5	2 560	0.41	2.10
2003	50	6 609.0	4 090	0.44	1.62	37	5 982.8	3 789	0.42	1.58	25	4 855.8	2 733	0.43	1.78
2004	50	6 891.8	3 667	0.42	1.88	33	6 701.6	3 419	0.33	1.96	25	5 800.7	2 729	0.34	2.13
2005	36	6 632.4	2 259	0.45	2.94	27	5 963.0	2 075	0.42	2.87	22	5 399.2	1 638	0.45	3.30
2006	35	6 115.6	2 556	0.37	2.39	28	5 866.1	2 380	0.35	2.46	23	5 482.4	2 129	0.34	2.58
2007	31	4 818.6	1 340	0.48	3.60	23	4 667.1	1 270	0.44	3.67	22	4 549.9	1 235	0.45	3.68
2008	25	2 389.8	1 458	0.36	1.64	19	2 317.8	1 339	0.35	1.73	19	2 317.8	1 339	0.35	1.73
2009	24	4 234.8	1 187	0.34	3.57	16	3 895.9	1 085	0.25	3.59	16	3 895.9	1 085	0.25	3.59
2010	28	2 101.9	1 124	0.51	1.87	16	1 911.2	988	0.43	1.93	15	1 906.2	959	0.44	1.99
2011	27	3 094.7	1 921	0.35	1.61	26	3 085.4	1 904	0.35	1.62	24	2 964.8	1 817	0.35	1.63
2012	30	4 112.6	1 773	0.45	2.32	25	4 023.8	1 694	0.38	2.38	22	3 916.7	1 593	0.34	2.46
2013	26	4 994.6	1 958	0.39	2.55	20	4 915.9	1 871	0.33	2.63	20	4 915.9	1 871	0.33	2.63
2014	26	3 249.2	2 064	0.46	1.57	23	3 180.4	1 959	0.45	1.62	22	3 171.9	1 922	0.43	1.65
2015	28	5 117.2	2 631	0.41	1.94	24	4 964.4	2 497	0.40	1.99	22	4 938.0	2 435	0.38	2.03
2016	26	2 602.3	2 304	0.46	1.13	21	2 498.0	2 108	0.46	1.19	19	2 485.7	2 025	0.43	1.23
2017	27	4 501.0	3 089	0.32	1.46	21	4 283.2	2 576	0.30	1.66	19	3 383.7	2 332	0.29	1.45
2018	26	2 883.8	3 260	0.21	0.88	19	2 531.2	2 539	0.20	1.00	16	2 075.5	2 325	0.21	0.89

OBSERVER	All vessels					Core vessels, 1990–91 to 2017–18					Core vessels, 2000–01 to 2017–18				
Fishing year	No. vessels	Catch	Effort	Prop. zeros	CPUE	No. vessels	Catch	Effort	Prop. zeros	CPUE	No. vessels	Catch	Effort	Prop. zeros	CPUE
1990	14	2 201.4	1 293	0.12	1.70	5	617.5	483	0.06	1.28	-	-	-	-	-
1991	14	1 293.1	852	0.22	1.52	5	704.5	395	0.18	1.78	-	-	-	-	-
1992	12	604.4	447	0.36	1.35	3	64.0	120	0.27	0.53	-	-	-	-	-
1993	15	1 452.5	629	0.43	2.31	8	372.0	401	0.32	0.93	-	-	-	-	-
1994	15	248.9	646	0.56	0.39	6	109.7	339	0.50	0.32	-	-	-	-	-
1995	9	1 055.6	645	0.17	1.64	6	300.1	350	0.18	0.86	-	-	-	-	-
1996	15	1 311.9	890	0.15	1.47	10	1 042.1	702	0.13	1.48	-	-	-	-	-
1997	12	529.3	549	0.18	0.96	9	476.6	477	0.17	1.00	-	-	-	-	-
1998	16	961.9	704	0.19	1.37	11	916.2	628	0.19	1.46	-	-	-	-	-
1999	14	1 172.9	858	0.22	1.37	12	1 156.2	834	0.22	1.39	-	-	-	-	-
2000	17	1 029.4	925	0.19	1.11	12	951.0	883	0.20	1.08	6	556.6	479	0.24	1.16
2001	21	505.9	780	0.21	0.65	12	481.1	679	0.18	0.71	9	399.5	565	0.18	0.71
2002	16	1 439.9	1 078	0.15	1.34	14	1 438.0	1 069	0.14	1.35	11	1 332.3	892	0.10	1.49
2003	13	694.3	630	0.21	1.10	12	689.1	611	0.21	1.13	5	97.6	177	0.30	0.55
2004	16	1 245.4	1 114	0.13	1.12	13	1 165.9	1 013	0.13	1.15	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	12	1 079.6	908	0.11	1.19
2006	15	1 692.8	964	0.05	1.76	10	1 452.0	890	0.06	1.63	10	1 452.0	890	0.06	1.63
2007	16	1 136.9	344	0.33	3.30	7	962.0	268	0.20	3.59	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	7	438.0	368	0.20	1.19
2009	16	757.4	324	0.32	2.34	6	149.2	232	0.35	0.64	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	7	354.9	296	0.28	1.20
2011	11	431.2	453	0.17	0.95	9	340.8	422	0.17	0.81	7	288.3	317	0.20	0.91
2012	16	731.1	667	0.22	1.10	12	604.2	622	0.20	0.97	9	519.9	458	0.16	1.14
2013	17	3 699.3	1 664	0.11	2.22	16	3 699.1	1 661	0.10	2.23	15	3 668.3	1 560	0.09	2.35
2014	17	2 406.5	1 534	0.15	1.57	15	2 405.3	1 519	0.15	1.58	13	2 396.4	1 445	0.14	1.66
2015	20	3 597.2	1 684	0.14	2.14	18	3 595.9	1 665	0.14	2.16	14	3 565.6	1 545	0.13	2.31
2016	17	1 377.8	1 323	0.20	1.04	13	1 353.3	1 254	0.19	1.08	11	1 298.7	1 130	0.15	1.15
2017	20	2 615.3	1 364	0.15	1.92	17	2 549.4	1 230	0.15	2.07	11	1 634.4	883	0.14	1.85
2018	28	1 740.6	1 883	0.10	0.92	17	1 572.0	1 652	0.08	0.95	12	1 292.5	1 356	0.06	0.95

Table 7: Variables retained in order of decreasing explanatory value by each model (TCEPR and observer) and each time series (1990–91 to 2017–18 and 2000–01 to 2017–18) and the percentage of the deviance explained with the addition of each variable.

1990–91 to 2017–18

	TCEPR		**Observer**
Variable	**% Deviance explained**	**Variable**	**% Deviance explained**
Year	2.1	Year	2.6
Target	23.0	Target	25.7
Vessel	26.4	Vessel	29.1
Start time	27.6	Start time	30.9
Duration	29.3	Duration	32.2
Depth of Bottom	30.5		

2000–01 to 2017–18

	TCEPR		**Observer**
Variable	**% Deviance explained**	**Variable**	**% Deviance explained**
Year	2.5	Year	2.9
Target	25.0	Target	29.7
Vessel	27.1	Start time	32.3
Start time	29.0	Duration	33.8
Duration	30.8	Vessel	35.1
Depth of Bottom	31.9		

3.4 Observer CPUE

In the 1990–91 to 2017–18 time series, a total of 115 unique vessels caught 37 897 t from 32 238 tows. From these, 56 vessels were selected as core vessels (range 3 to 18 per year) which caught an estimated 31 040 t of hake from 26 376 tows (Table 6). There were six core vessels in the fishery for 10 or more years (with the maximum being 15 years) (Appendix B, Figure 9). In the 2000–01 to 2017–18 time series, a total of 62 unique vessels caught 27 065 t from 21 975 tows. From these, 22 vessels were selected as core vessels (range 5 to 15 per year) which caught an estimated 22 410 t from 16 995 tows (Table 6). There were six core vessels in the fishery for 10 or more years (with the maximum being 15 years) (Appendix B, Figure 9). The proportion of zero catch tows for core vessels ranged between 0.06 and 0.50 (Appendix B, Figure 11). For both core and all vessels, the proportion of zero catch tows showed an increasing trend in the early 1990s, peaking in 1994, followed by a marked decline the following year, some stable trend and further decline until 2006, increased in 2007 and has since steadily declined. The proportion of zero catches in the observer data remains consistently lower than those reported by in the TCEPR data (an average of 0.20 in observer data vs an average of 0.40 in TCEPR data).

Both time series had similar trends in indices (Appendix B, Figure 13). The delta-lognormal model produced an index showing a peak in 1998, decline and further sharp peak in 2002, followed by steady decline until 2009 to its lowest point, with some recovery to 2013 and no trend since. The observer indices were similar to those produced by the TCEPR from around 2004 onwards (Figure 2).

Diagnostics for the lognormal model are reported in Figure 15 and indicated a poor fit to the data. Model outputs from both time series are reported in Appendix B, Table 11 and Table 12.

The same five variables, including year, were selected from the lognormal model for each time series: target, vessel, start time, and duration (Table 7). These variables together explained 32.2% (1990–91 onwards series) and 35.1% (2000–01 onwards series) of the residual deviance, with most of the explained deviance attributable to target. CDI plots for observer predictors also showed similar results to those produced by the TCEPR data. These plots were similar for both time series, and thus, only those produced for the long time series are presented in Appendix B, Figure 17. Target was also the most influential predictor (Appendix B, Figure 14, Figure 17), with the most hake-targeted fishing occurring mid- to late 2000s. Vessel was also an important predictor, but influence was not as pronounced here as in the all commercial data analyses. Duration and time of day had little influence on hake catch.

3.5 Additional analyses

Additional CPUE analyses were requested by the Deepwater Fisheries Assessment Working Group. These included developing CPUE indices using 1) a grid covering the extent of the spatial fishing effort, 2) using the top five grid cells (based on total hake catch in t), and 3) using the top five grid cells with a year interaction term. These indices were estimated for the 2000–01 to 2017–18 time series on both the TCEPR and observer data (although grid cell was not selected as a predictor for the observer data beyond the first analysis and was thus not evaluated further). None of these additional analyses showed any significant differences from the initial CPUE indices (i.e. grid selection had no material influence on trends in hake catch rates).

In the first analysis using all available grids, target, vessel, start time, duration and grid number were selected as predictors for both TCEPR and observer datasets (in different orders of deviance explained). When estimating CPUE indices using only the top five cells, grid was not selected as a predictor for either TCEPR or observer data. However, grid cell was selected in the TCEPR data when an interaction with year was introduced, in addition to target, vessel, start time, and duration. A similar temporal trend was shown in these top five grid cells (where the majority of catch was reported), with some variation in the magnitude and timing of these trends. Outputs from these analyses are presented in Appendix C (Figures 18–25, Table 12, Table 13) for information.

3.6 Comparison with trawl surveys

None of the CPUE indices corresponded well with any of the research trawl survey indices reported by O'Driscoll & Ballara (2019) (Table 8, Figure 2). The trawl survey *all strata* index (inclusive of depths 200-800 m) estimated a considerably higher abundance than any of the CPUE indices in 2012, corresponded with the indices in 2013, and in 2016 and 2018 estimated a considerably lower abundance than the CPUE indices. The *core strata* index (depths of 200–650 m) indicated a downward trend in hake abundance since 2012, whereas the standardised CPUE indices of abundance for commercial data showed no trend and the observer indices show some increase since 2014. The *deep strata* index (depths of 200–1000 m) appeared to correspond with the standardised indices for the observer data, however, there are currently only two years of data available and an extension of the time series will be necessary to confirm this.

Table 8: Research survey indices of abundance (biomass in tonnes) and associated CVs (in parentheses) for core (200−650 m), all (200−800 m), and deep (200−1000 m) strata. Indices have been standardised to the geometric mean.

Year	Core	All	Deep strata	Core index	All index	Deep strata index
2000	803 (0.13)	–	–	2.18	–	–
2012	583 (0.13)	1 103 (0.13)	–	1.53	1.73	–
2013	331 (0.17)	747 (0.21)	–	0.87	1.17	–
2016	221 (0.24)	335 (0.16)	502 (0.13)	0.58	0.56	0.75
2018	229 (0.33)	559 (0.18)	899 (0.14)	0.60	0.88	1.34

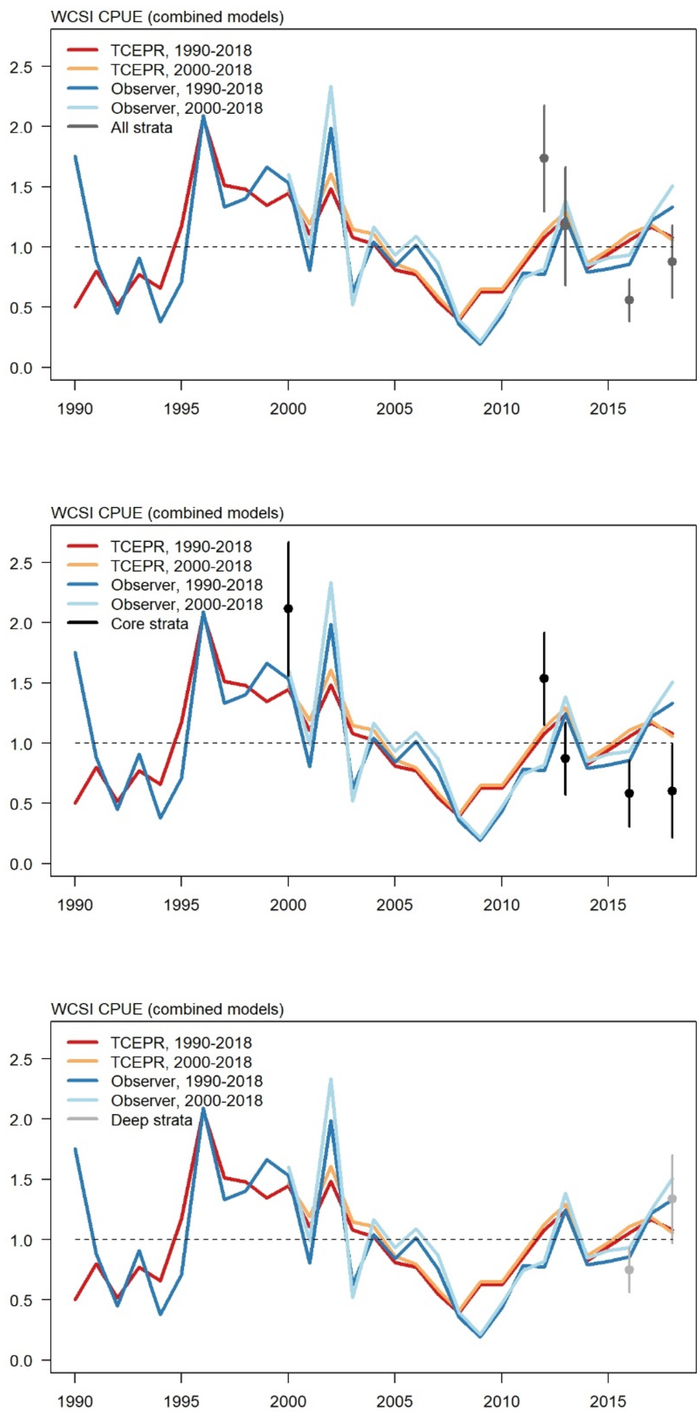

Figure 2: Comparison of combined hake indices for TCEPR and observer time series and abundance estimates (with corresponding coefficients of variation) from WCSI trawl surveys (all strata 200–800 m; core strata, 200–650 m; and deep strata 200–1000 m) as reported by O'Driscoll & Ballara (2019). Trawl survey hake biomass indices have been standardised to a mean of one.

4. SUMMARY

This work has presented an updated characterisation of the West Coast South Island (WCSI) hake fishery and updated catch-per-unit-effort (CPUE) indices for tow-by-tow commercial (TCEPR) and observer data across two time series (1990–91 to 2017–18 and 2000–01 to 2017–18). The fishery has undergone a number of changes in the last two decades, including changes in Total Allowable Commercial Catch (TACCs) for both hake and hoki (where hake is a bycatch) and changes in fishing practices.In addition, evidence of misreporting of catch by a small number of vessels was detected in 2001. The proportion of zero catches in the observer data remained consistently lower than those reported in the TCEPR data (an average of 0.20 in observer data versus an average of 0.40 in TCEPR data), suggesting some underreporting by commercial fishers continues or that observer coverage is not representative of the fishing fleet. Vessel had a large positive influence on CPUE, particularly in the more recent years, suggesting a change in fleet dynamics. Depth was also found to have a positive influence on hake catch rates, with the strongest influence occurring between 500 and 600 m.

In the latest fishing year (2017–18), most hake catch (approximately 85%) was reported from hoki target tows. This may be due to the relatively low abundance of hoki. There are uncertainties over recent trends in WCSI hoki biomass, although the standardised CPUE indices have declined by 43% over the last three years (Fisheries New Zealand, 2019). While the WCSI trawl survey is not thought to be a good index of hoki abundance, the 2018 WCSI trawl estimate of hoki was only a third of the 2016 estimate and less than 10% of the estimate reported in 2012 (O'Driscoll & Ballara, 2019).

The standardised CPUE indices for commercial and observer data show similar trends over time, with peak hake catch rates in 1996 and 2002, and the lowest points in the time series in 2008 (commercial) and 2009 (observer). CPUE indices have since been increasing, and these trends are the same regardless of the separation of data into two time series. The CPUE indices produced here continue to provide results that do not correspond well with those produced from the research trawl survey indices. If it is assumed that the stratified-random research trawl survey provides a reliable biomass index, then the WCSI hake CPUE series is not a reliable index

5. ACKNOWLEDGEMENTS

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APPENDIX A. CHARACTERISATION

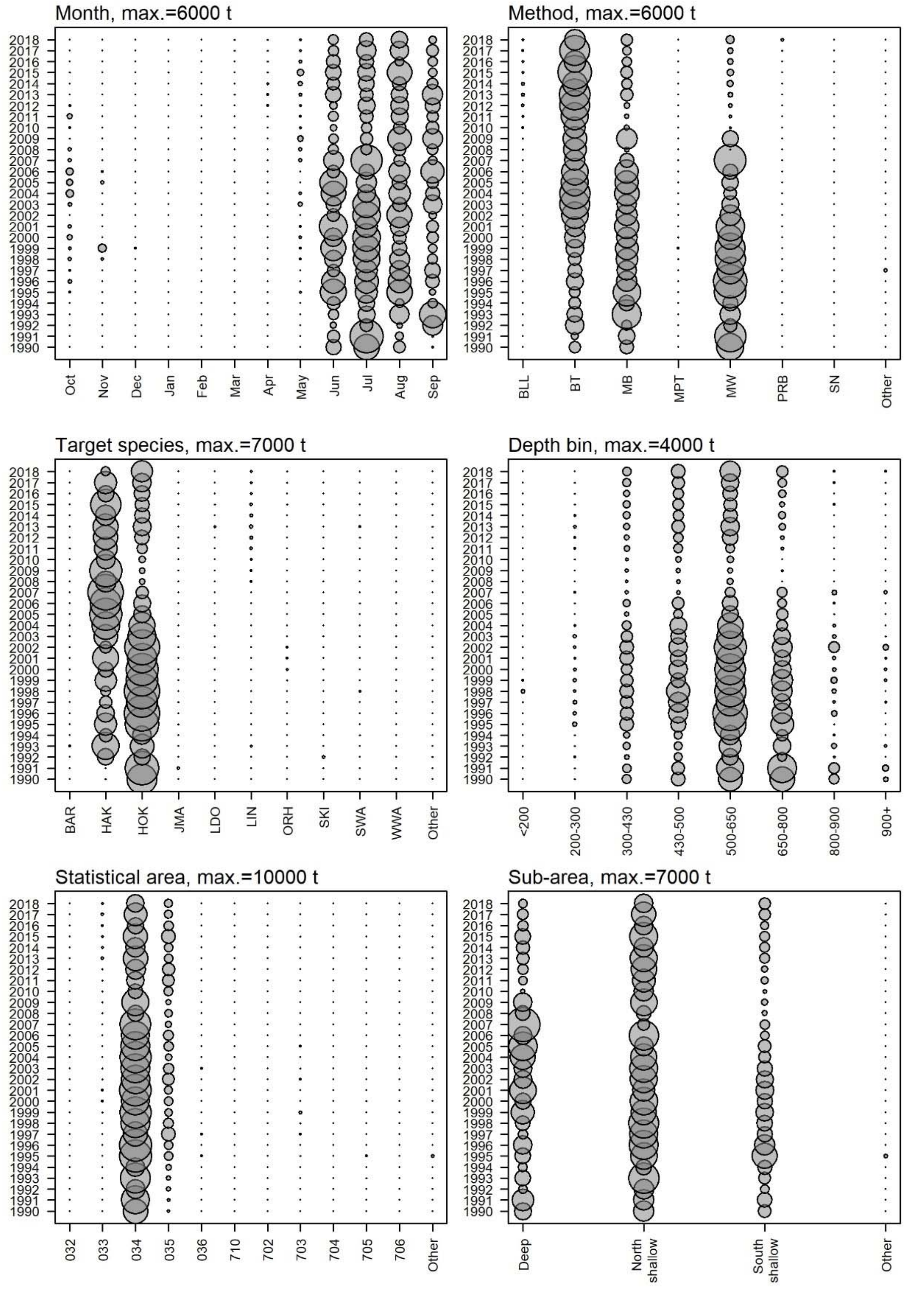


Figure 3: Distribution of WCSI TCEPR tow-by-tow catch by month, method, target species, depth bin, statistical area, and sub-area by fishing year since 1989–90 (1990). Circle size is proportional to catch; maximum circle size is indicated on the top of each plot. Method definitions: BLL, bottom longlining; BT, bottom trawl; MB, midwater trawl within 5 m of the bottom; MPT, midwater pair trawl; MW, midwater trawl; PRB, bottom trawl precision seafood harvesting; SN, set net. Species codes: BAR, barracouta; HAK, hake; HOK, hoki; JMA, jack mackerel; LDO, lookdown dory; LIN, ling; ORH, orange roughy; SKI, gemfish; SWA, silver warehou; WWA, white warehou.

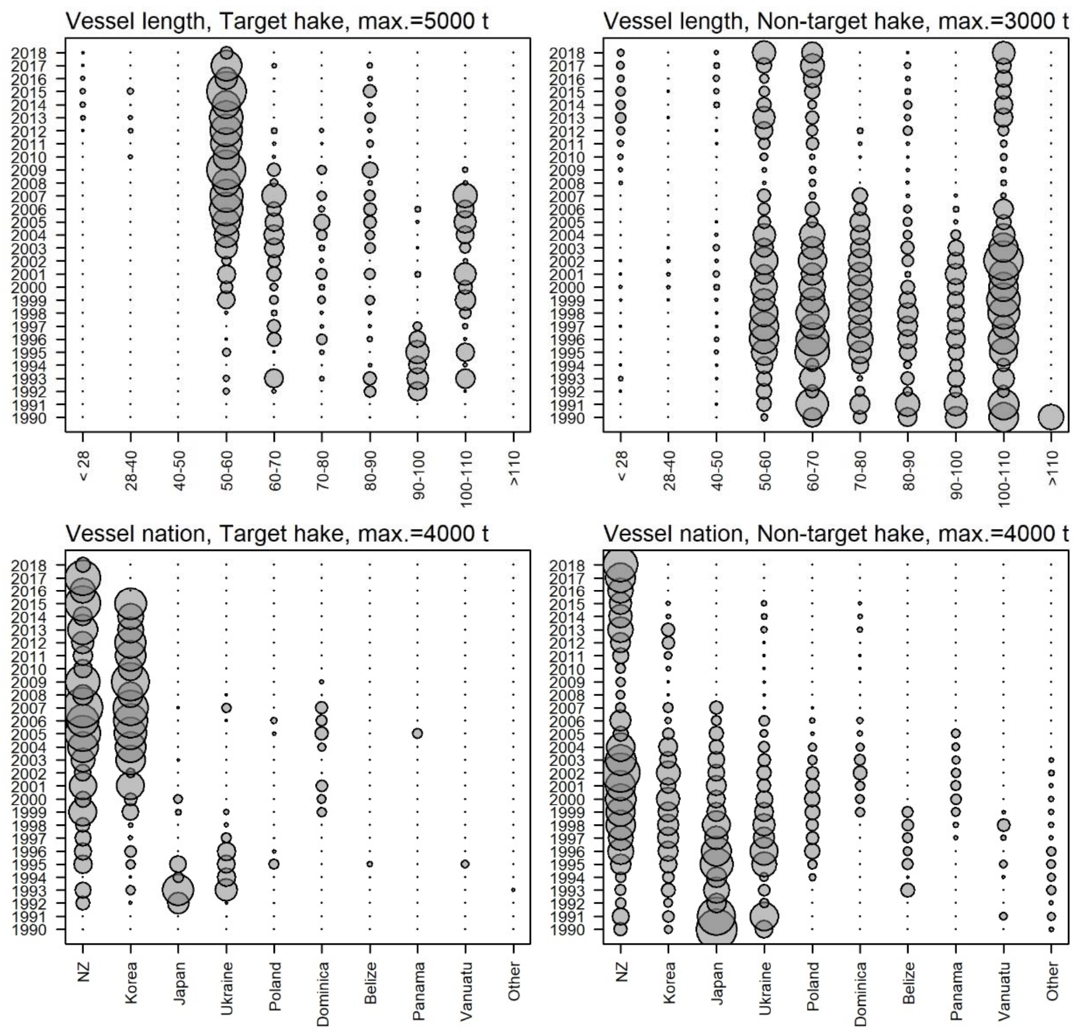


Figure 3 continued: Distribution of overall target and non-target hake catch by vessel length and nationality by fishing year since 1989–90 (1990). Circle size is proportional to catch; maximum circle size is indicated on the top of each plot.

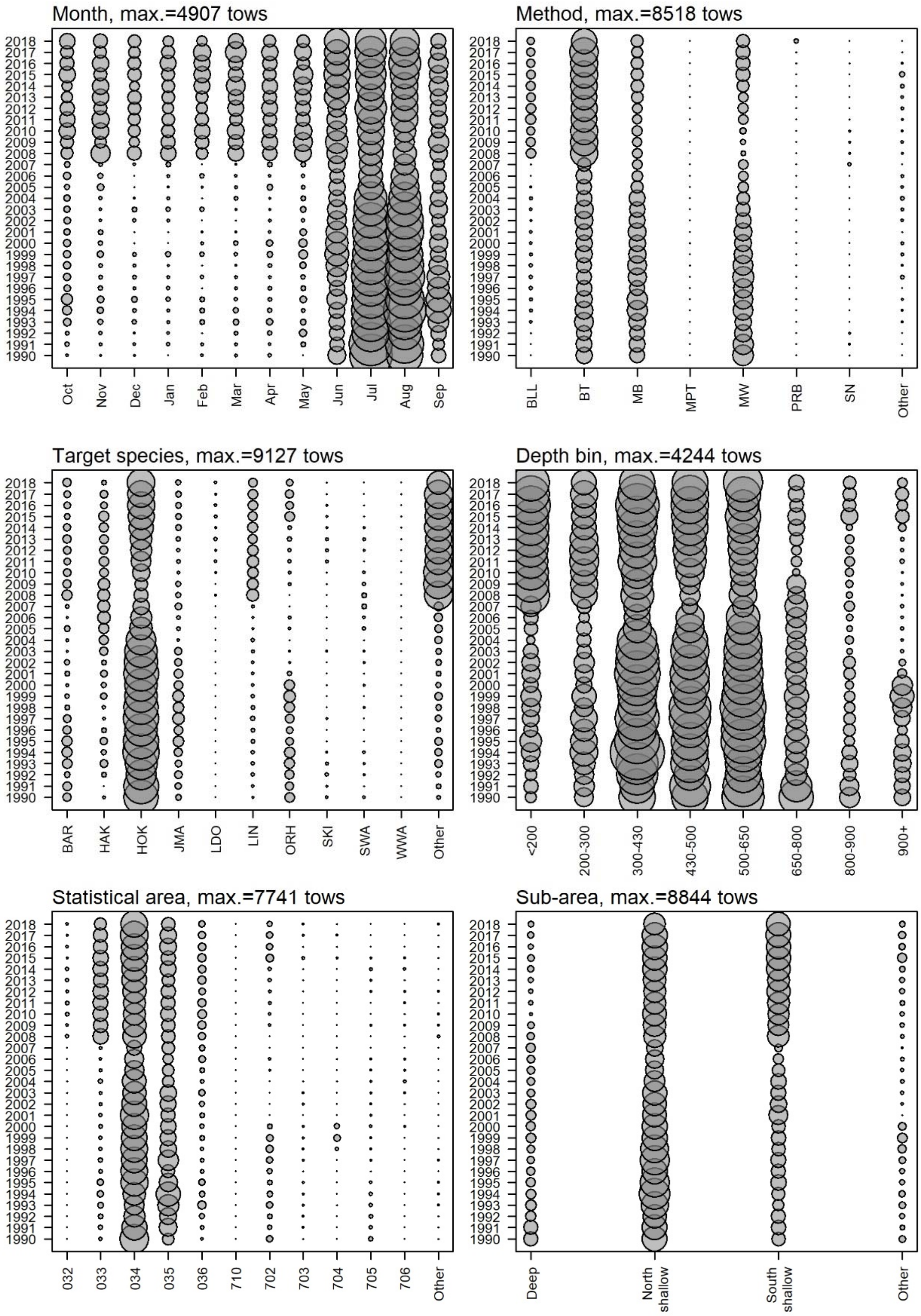


Figure 4: Distribution of WCSI TCEPR tow-by-tow effort by month, method, target species, depth bin, statistical area, and sub-area by fishing year since 1989–90 (1990). Circle size is proportional to effort; maximum circle size is indicated on the top of each plot. Method definitions: BLL, bottom longlining; BT, bottom trawl; MB, midwater trawl within 5 m of the bottom; MPT, midwater pair trawl; MW, midwater trawl; PRB, bottom trawl precision seafood harvesting; SN, set net. Species codes: BAR, barracouta; HAK, hake; HOK, hoki; JMA, jack mackerel; LDO, lookdown dory; LIN, ling; ORH, orange roughy; SKI, gemfish; SWA, silver warehou; WWA, white warehou.

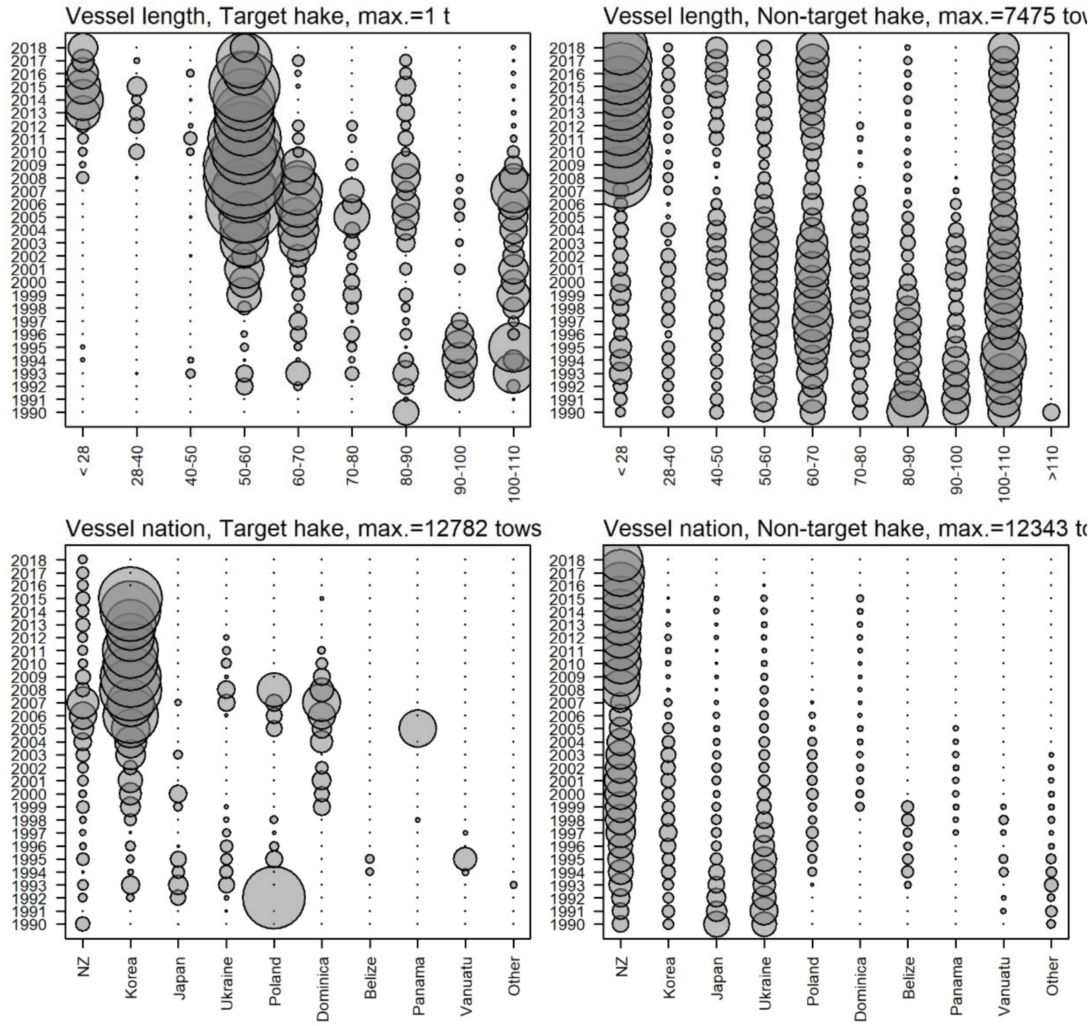


Figure 4 continued: Distribution of overall target and non-target hake effort by vessel length and nationality by fishing year since 1989–90 (1990). Circle size is proportional to effort; maximum circle size is indicated on the top of each plot.

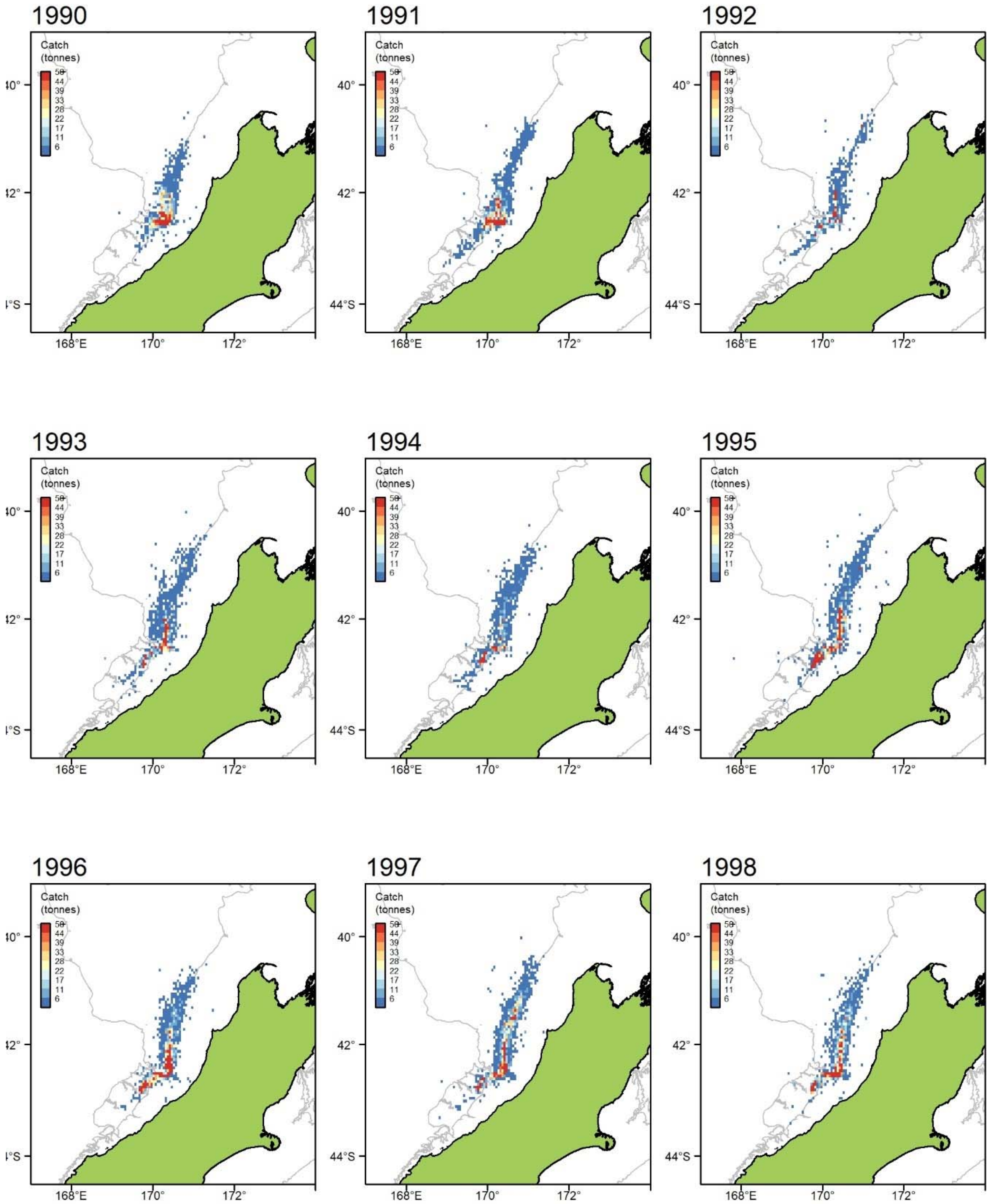


Figure 5: Density plots of commercial hake catches from TCEPR and ERS tow-by-tow records for target hake and hoki tows for fishing year combined blocks.

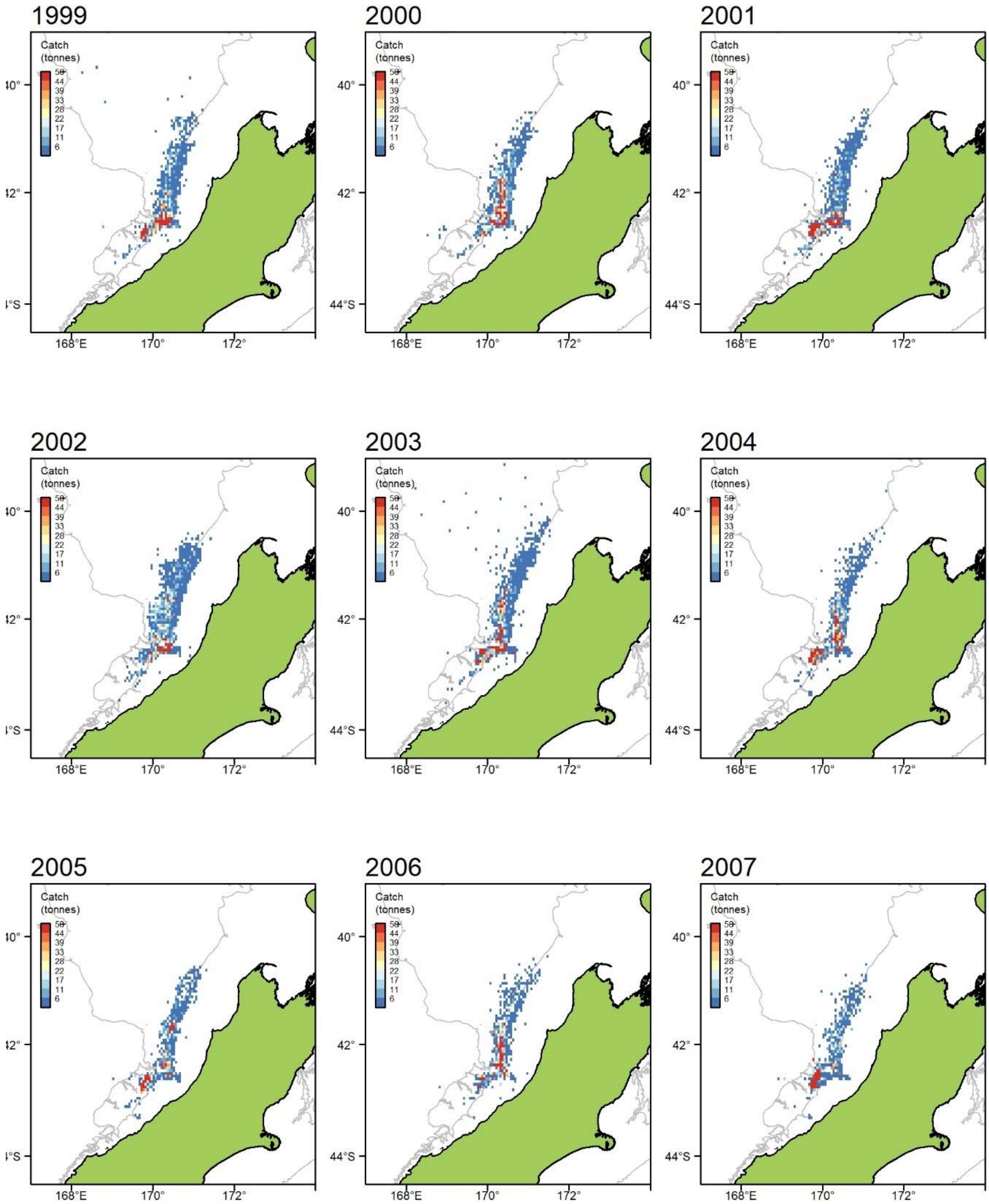


Figure 5 continued: Density plots of commercial hake catches from TCEPR and ERS tow-by-tow records for target hake and hoki tows for fishing year combined blocks.

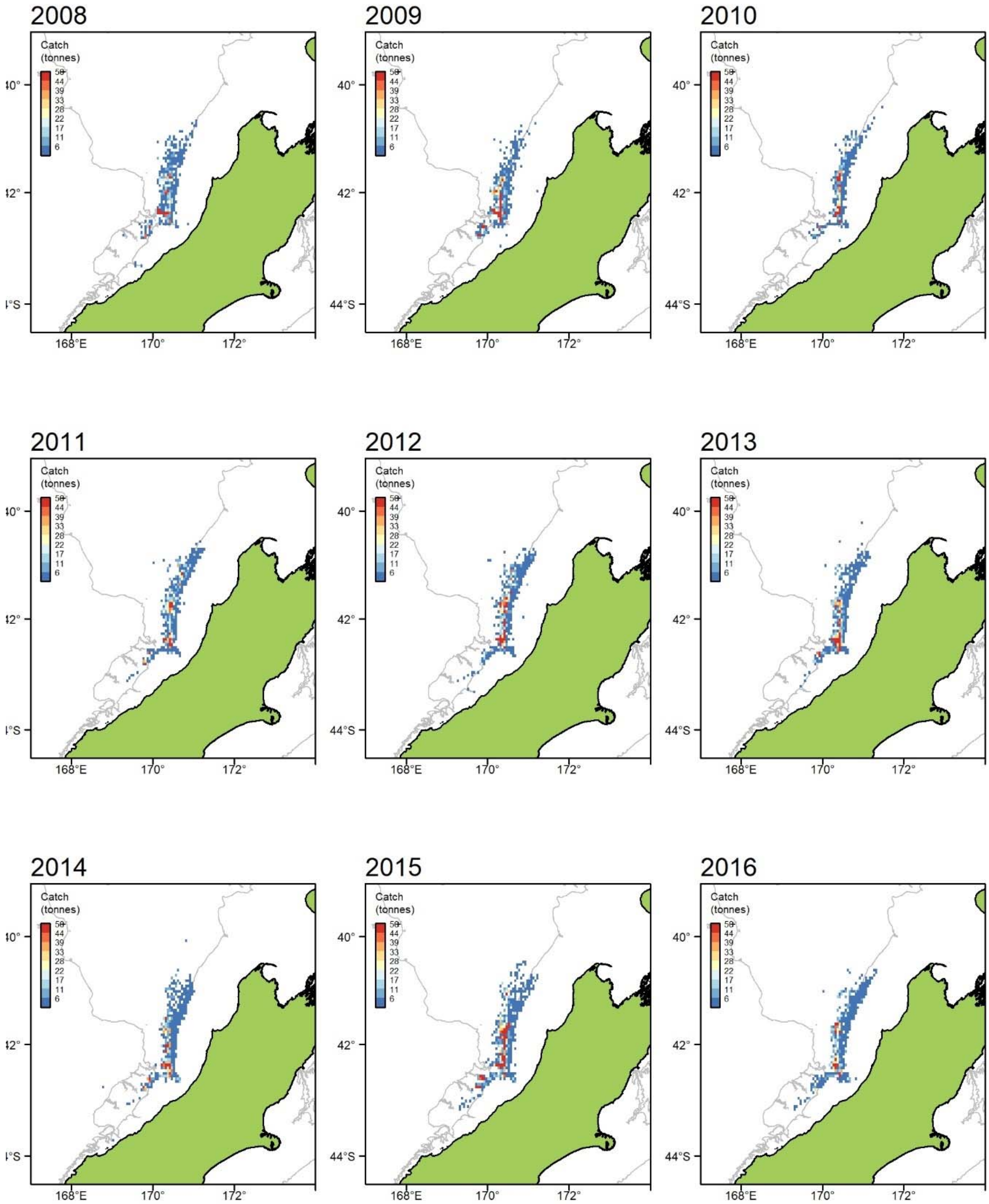


Figure 5 continued: Density plots of commercial hake catches from TCEPR and ERS tow-by-tow records for target hake and hoki tows for fishing year combined blocks.

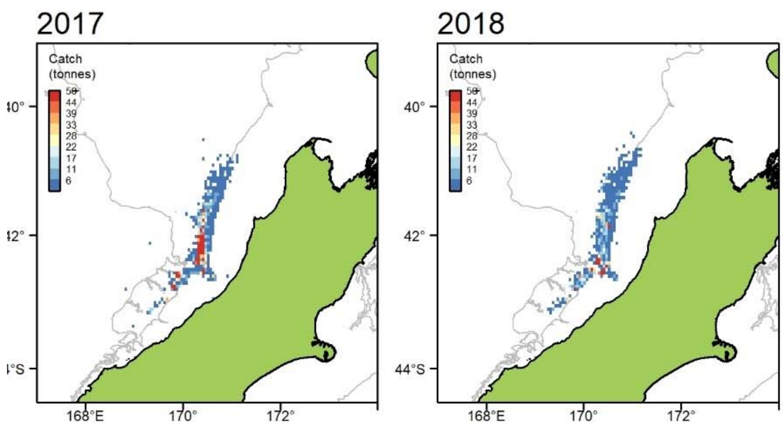


Figure 5 continued: Density plots of commercial hake catches from TCEPR and ERS tow-by-tow records for target hake and hoki tows for fishing year combined blocks.

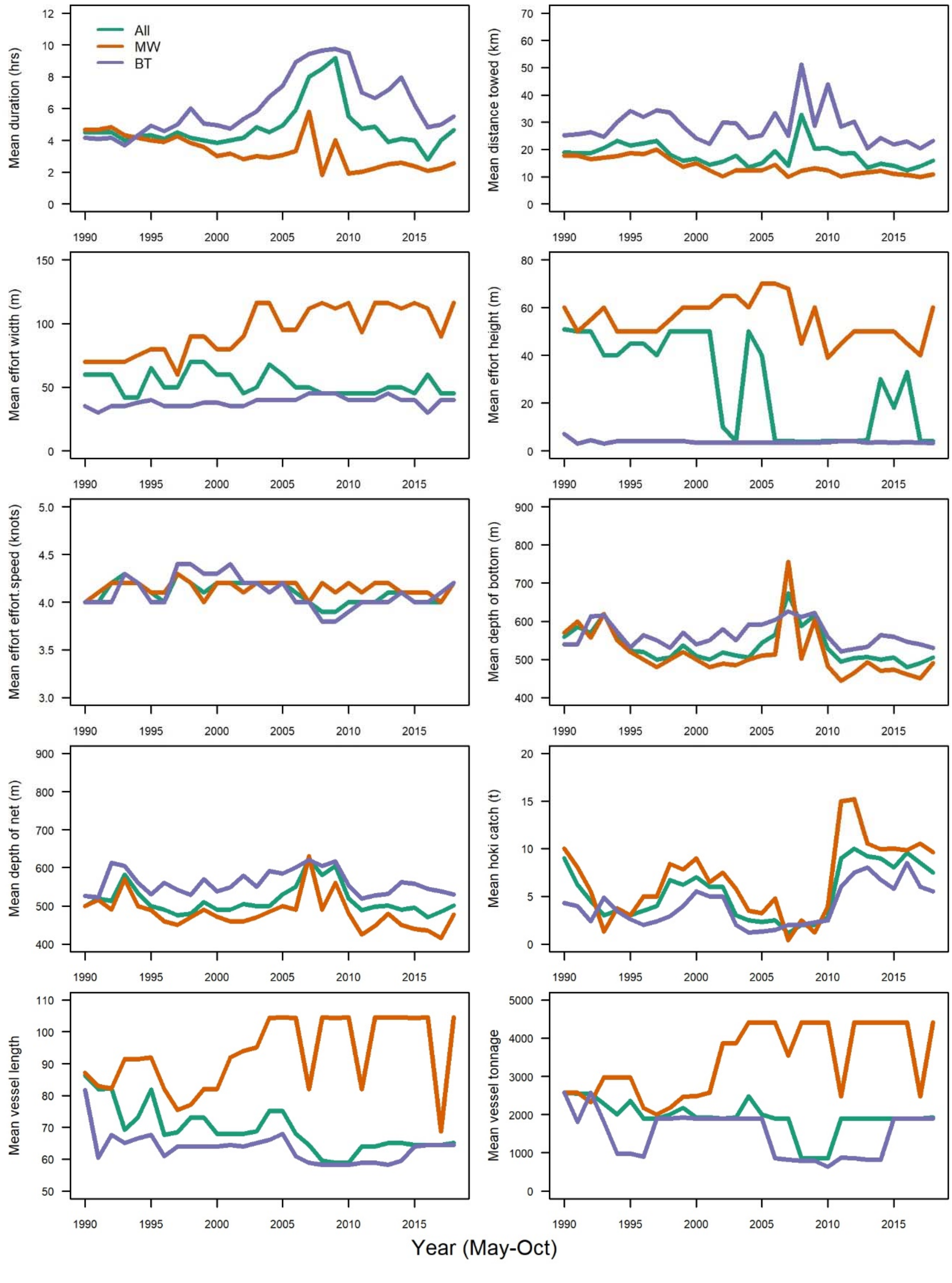


Figure 6: Means of effort variables by fishing year for WCSI vessels targeting hake or hoki, for all tows (All), bottom tows (BT), and midwater tows (MW).

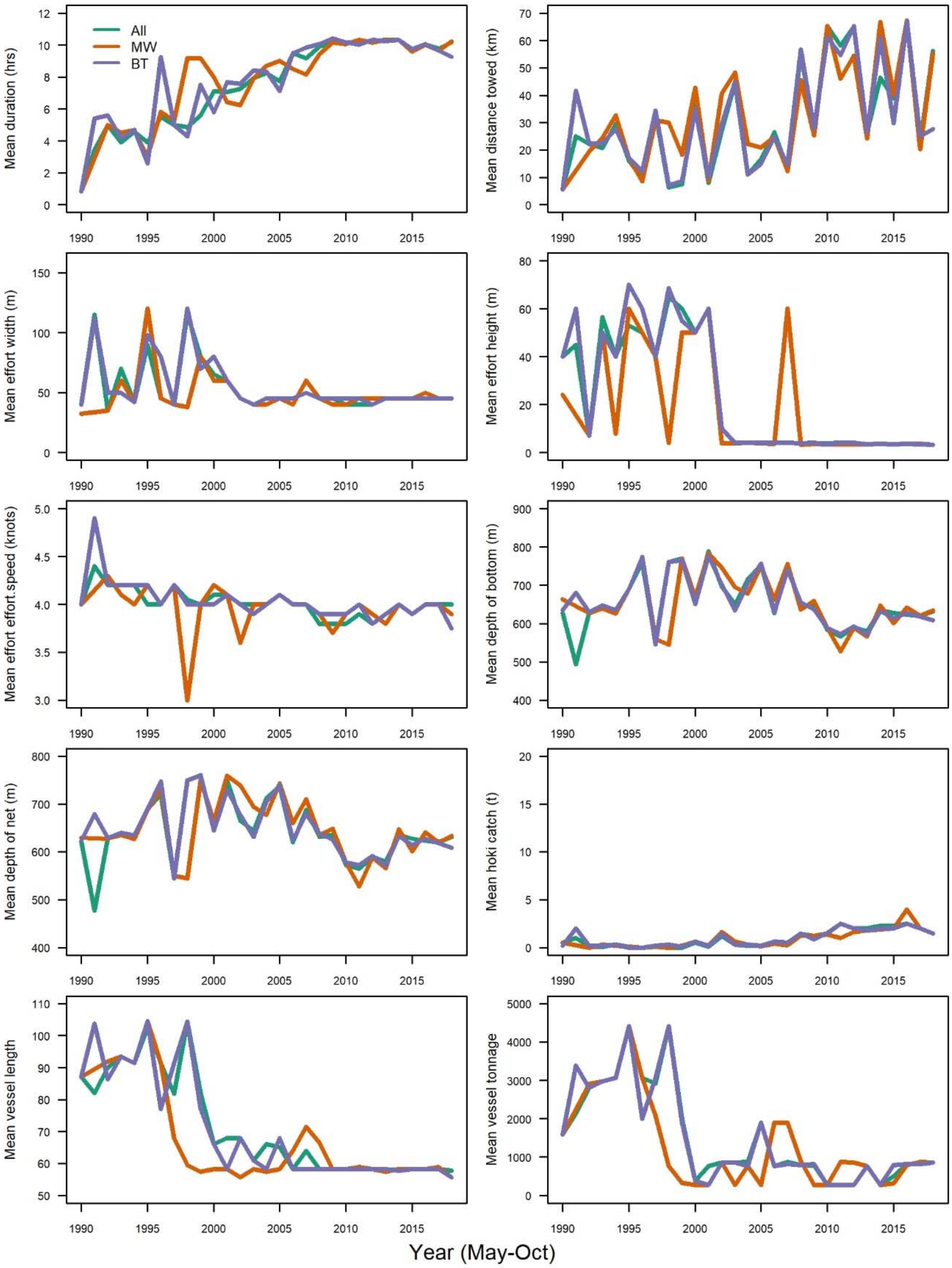
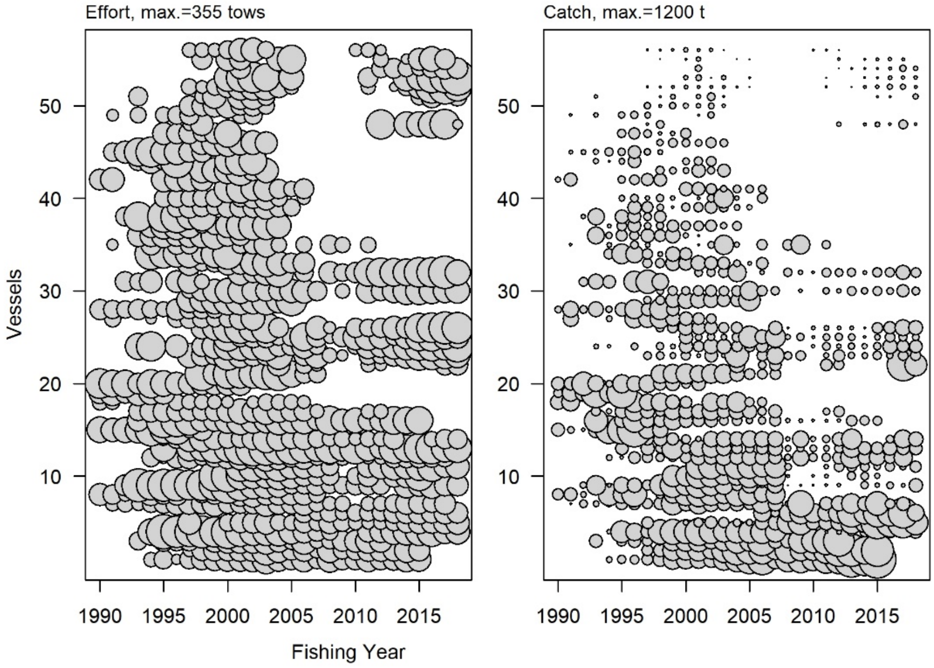


Figure 7: Means of effort variables by fishing year for WCSI vessels targeting hake, for all tows (All), bottom tows (BT), and midwater tows (MW).

APPENDIX B. CPUE OUTPUTS

TCEPR, 1990–91 to 2017–18



TCEPR, 2000–01 to 2017–18

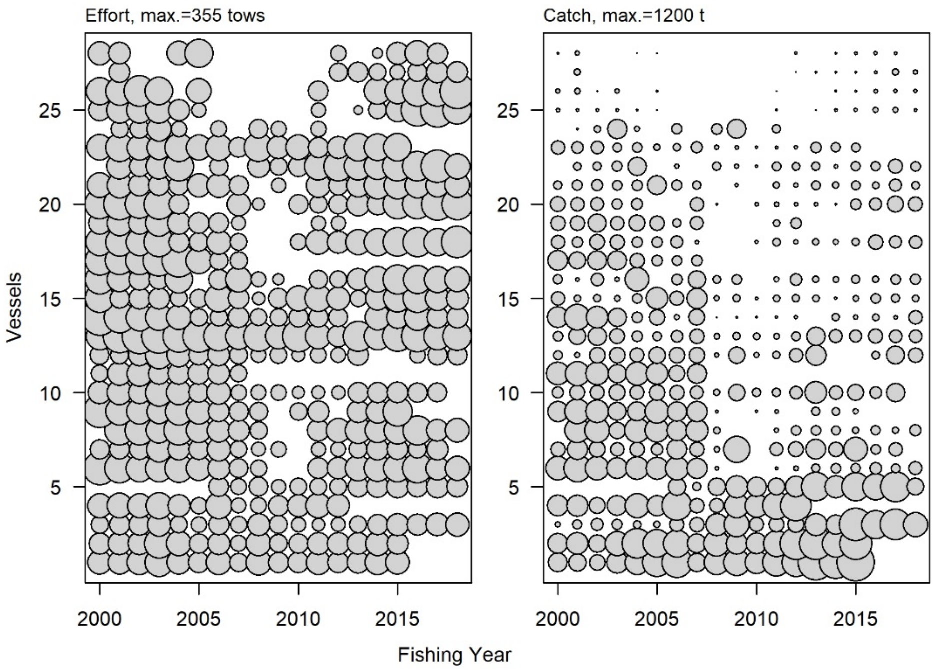
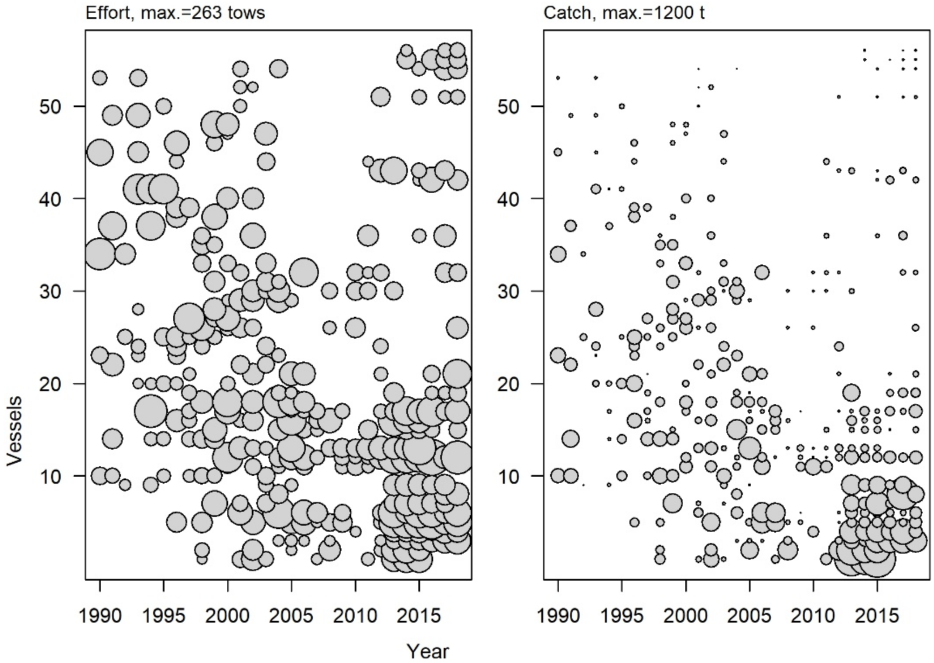


Figure 8: Trawl fishing effort (left) and catches (right) where circle area is proportional to the effort or catch by fishing year (June-September) for individual vessels (denoted anonymously by number on the *y*-axis) in the WCSI 'core' TCEPR CPUE analyses.

Observer, 1990–91 to 2017–18



Observer, 2000–01 to 2017–18

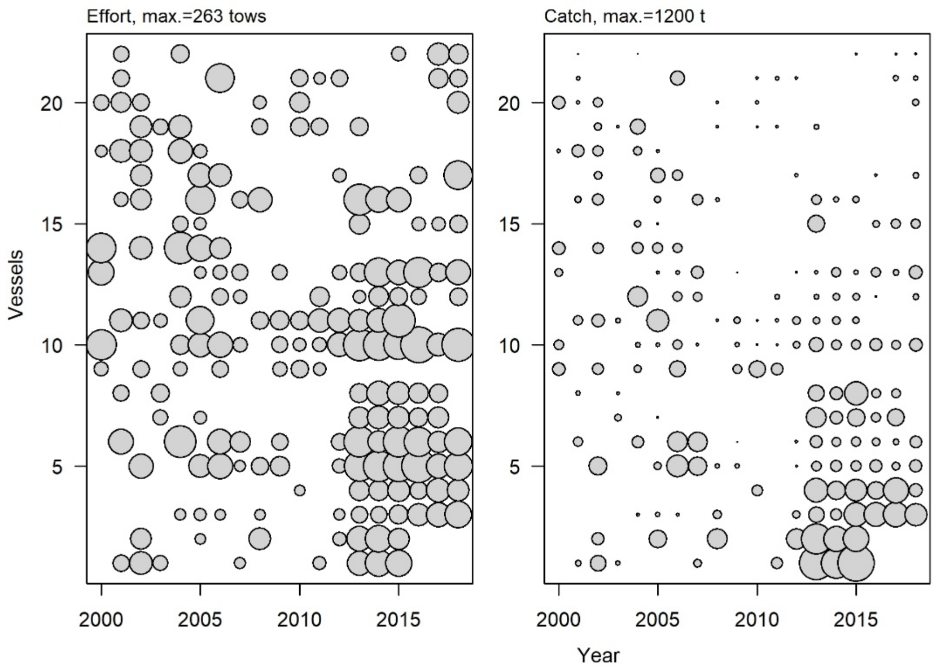
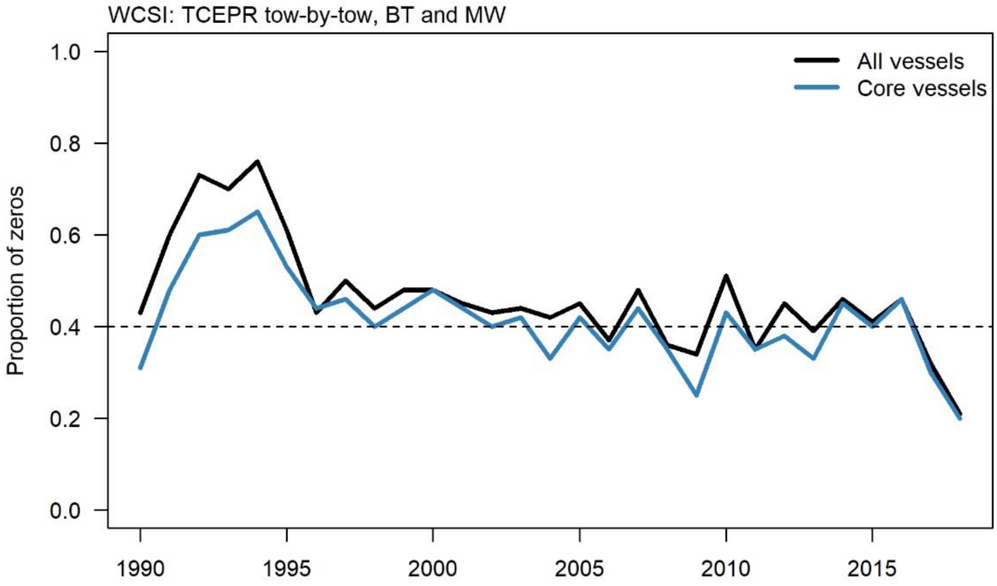


Figure 9: Trawl fishing effort (left) and catches (right) where circle area is proportional to the effort or catch by fishing year (June-September) for individual vessels (denoted anonymously by number on the *y*-axis) in the WCSI 'core' observer CPUE analyses.

TCEPR, 1990–91 to 2017–18



TCEPR, 2000–01 to 2017–18

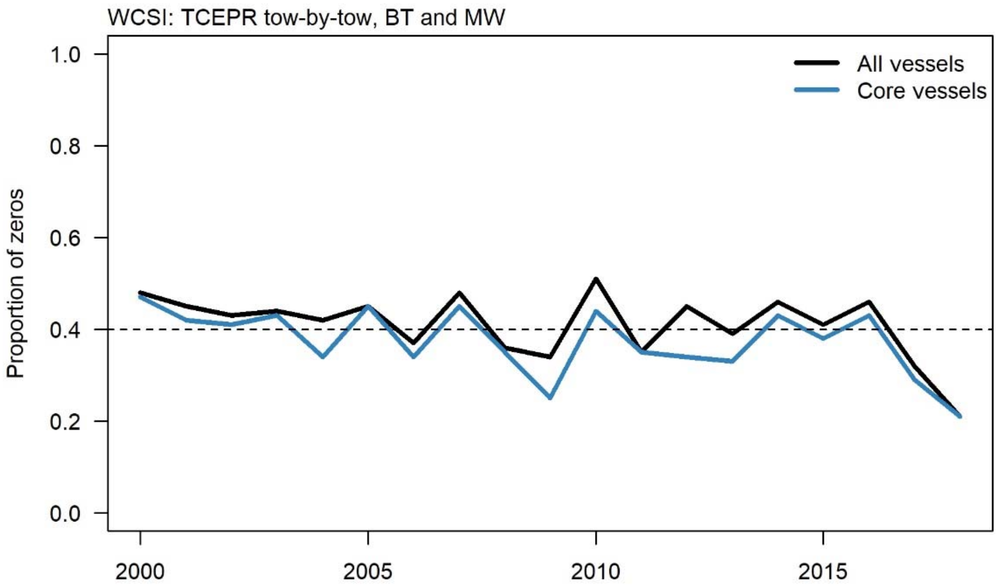
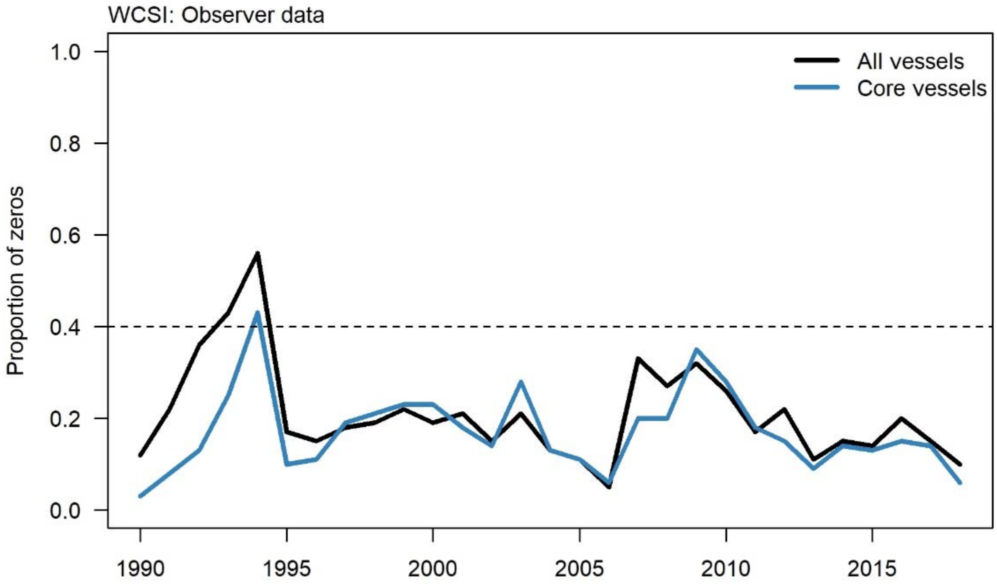


Figure 10: Proportion of zeros for TCEPR 'all vessel' and 'core vessel' datasets by year for each time series.

Observer, 1990–91 to 2017–18



Observer, 2000–01 to 2017–18

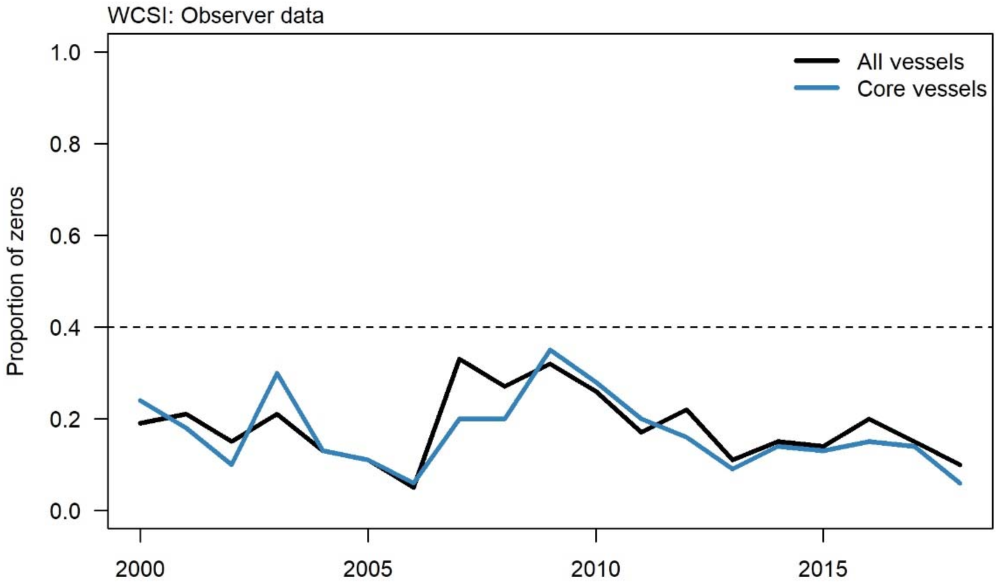
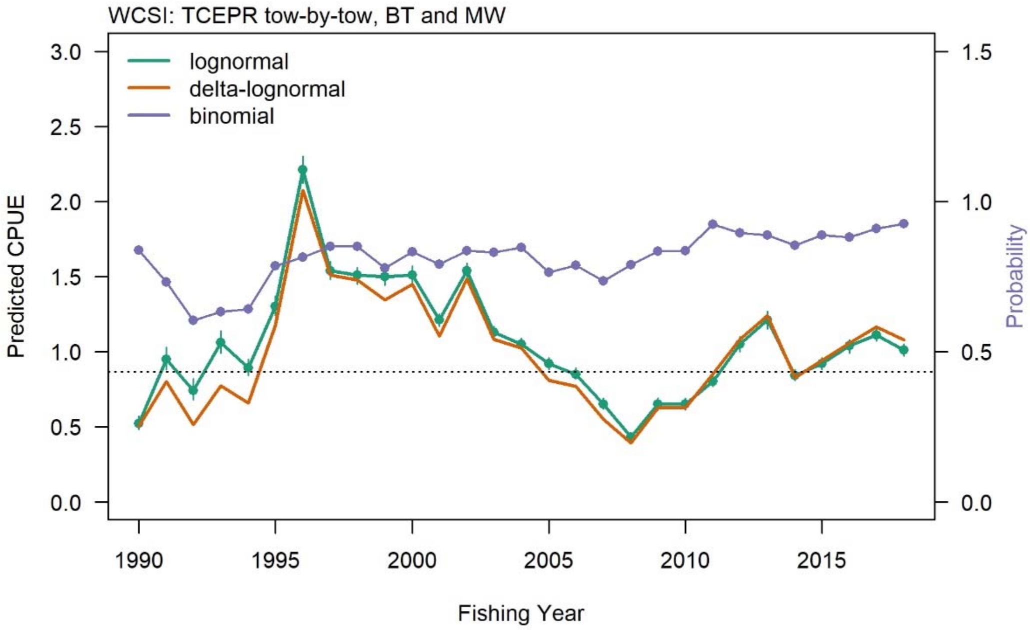


Figure 11: Proportion of zeros for observer 'all vessel' and 'core vessel' datasets by year for each time series.

TCEPR, 1990–91 to 2017–18



TCEPR, 2000–01 to 2017–18

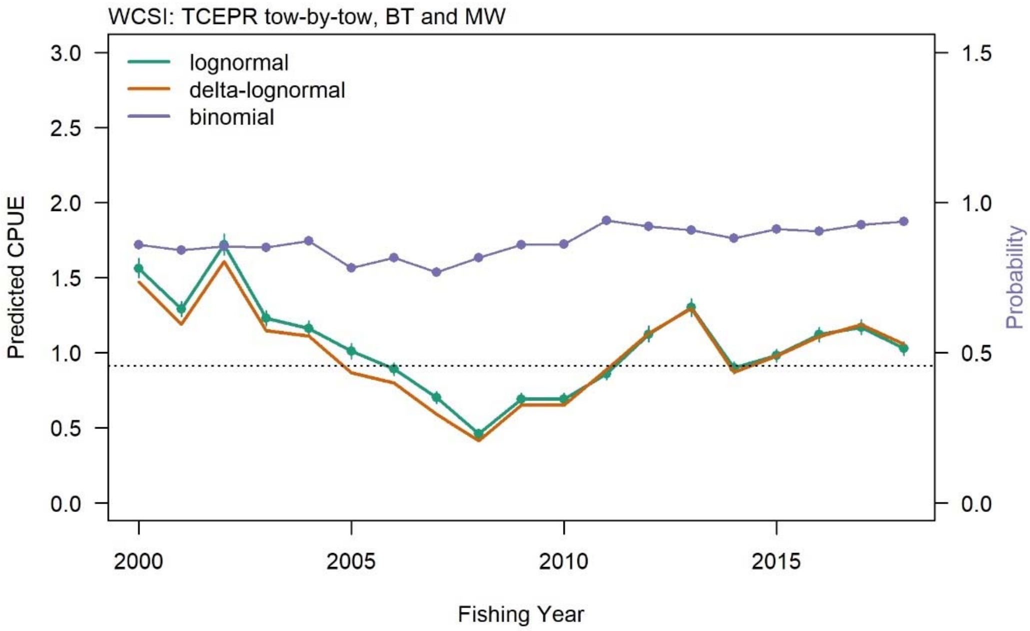
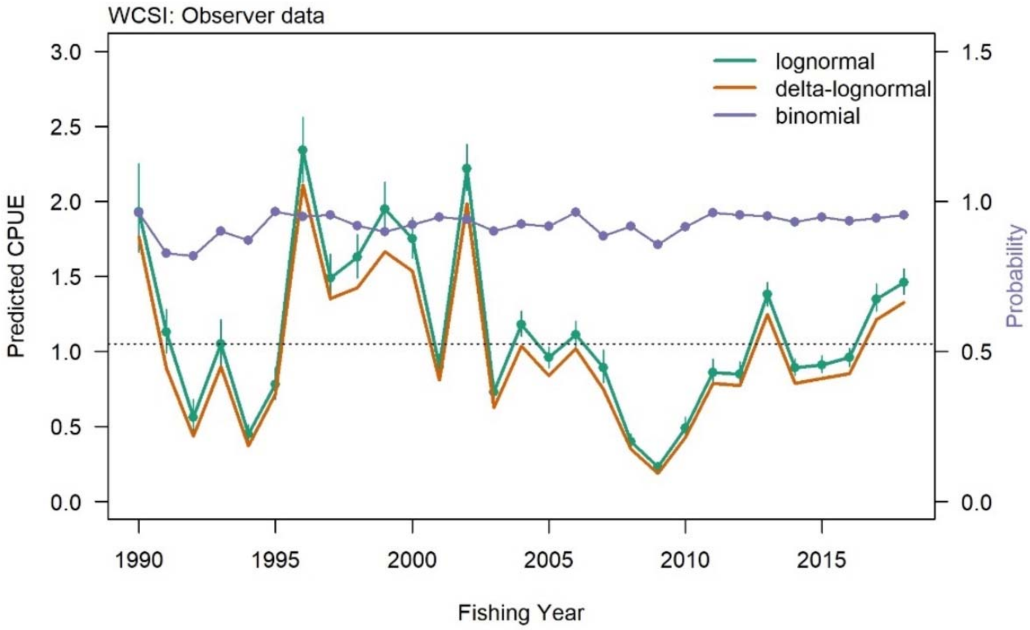


Figure 12: Standardised CPUE indices from the lognormal, binomial, and combined model for each TCEPR time series. Bars indicate 95% confidence intervals. The horizontal dotted line shows the mean of the combined series. The probability scale relates to the binomial and raw proportion non-zero series.

Observer, 1990–91 to 2017–18



Observer, 2000–01 to 2017–18

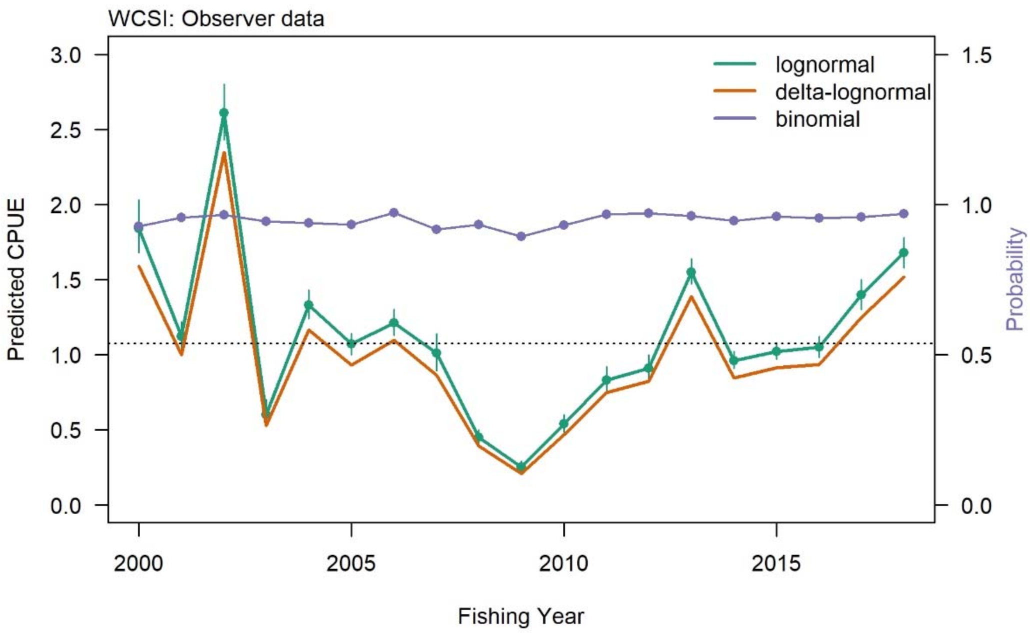
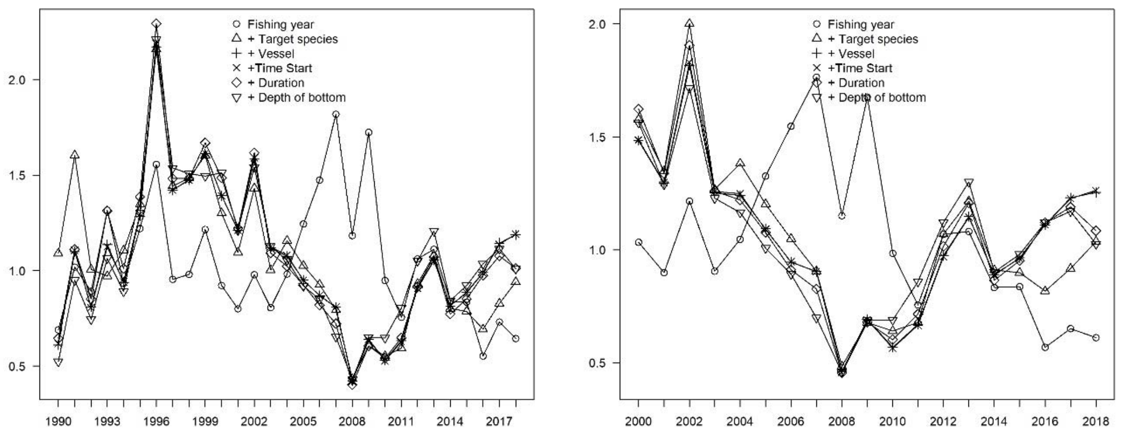


Figure 13: Standardised CPUE indices from the lognormal, binomial, and combined model for each observer time series. Bars indicate 95% confidence intervals. The horizontal dotted line shows the mean of the combined series. The probability scale relates to the binomial and raw proportion non-zero series.

TCEPR data



Observer data

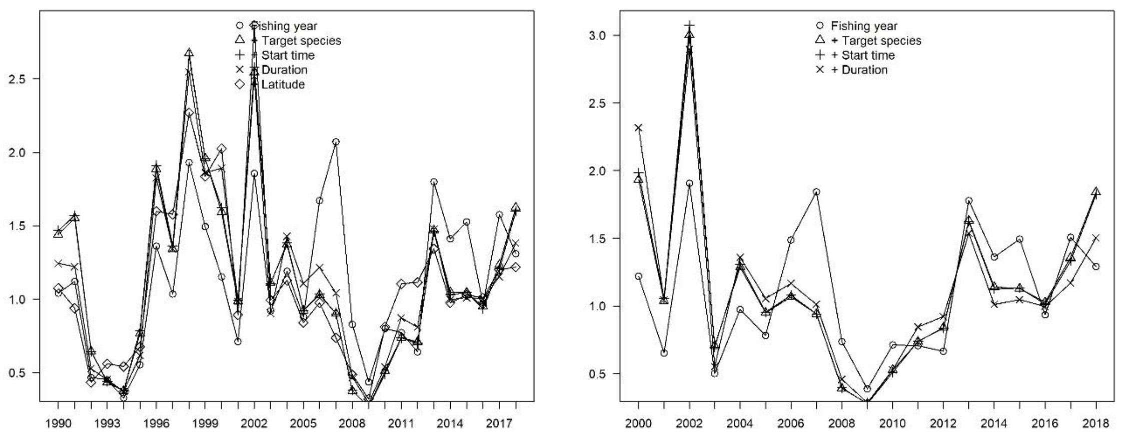
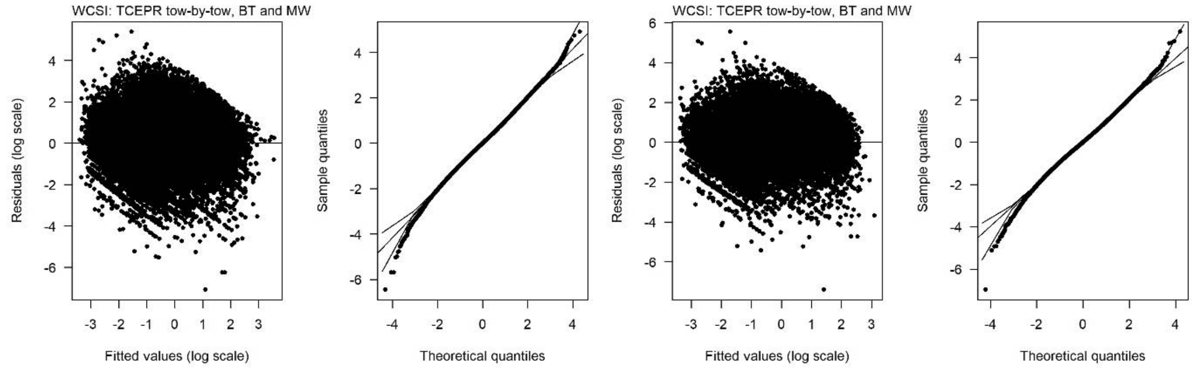


Figure 14: Standardised CPUE indices from the lognormal models showing the effect of addition of variables on the TCEPR (top) time series and observer (bottom) time series.

TCEPR data



Observer data

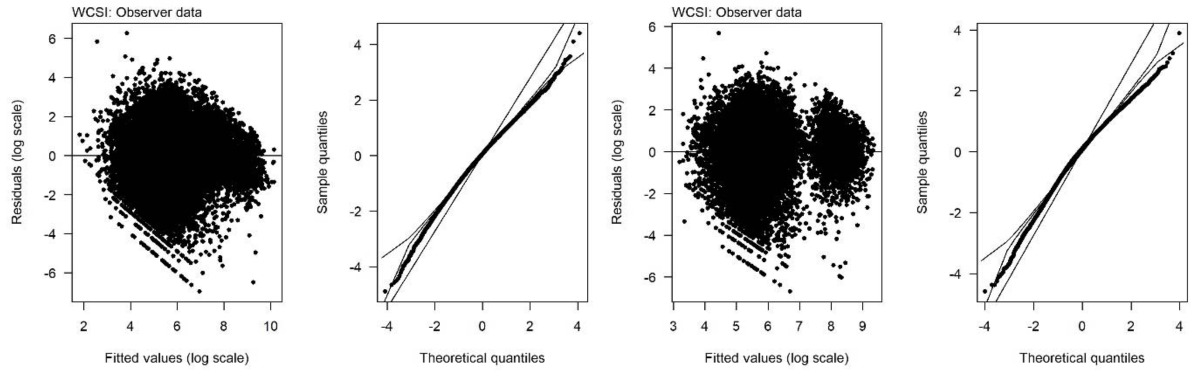


Figure 15: Diagnostic plots for the lognormal CPUE models of the TCEPR 1990–91 to 2017–18 time series (top left), TCEPR 2000–01 to 2017–18 time series (top right), observer 1990–91 to 2017–18 time series (bottom left), and observer 2000–01 to 2017–18 time series (bottom right).

TCEPR data, 1990–91 to 2017–18

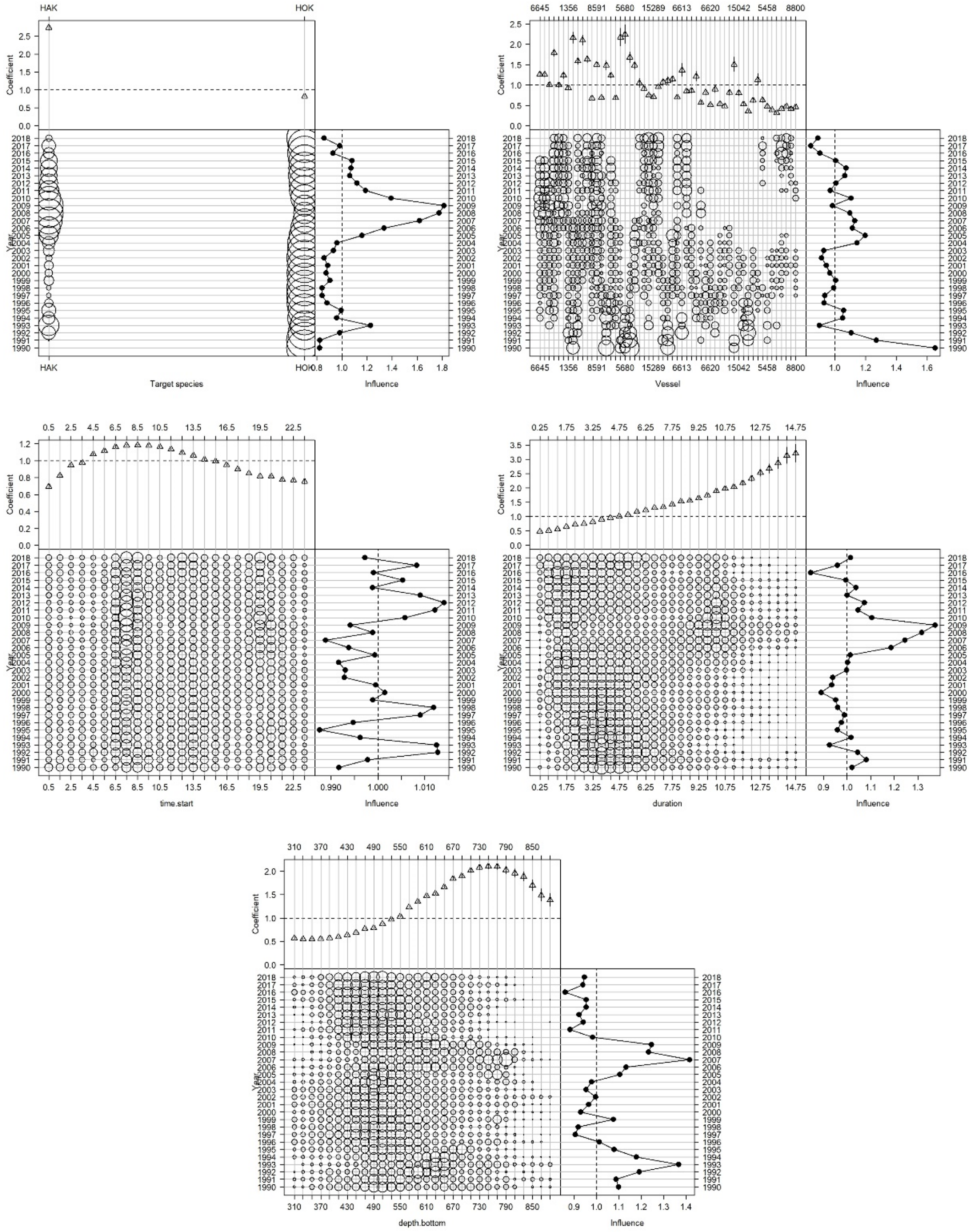


Figure 16: Effect and influence of non-interaction term variables on the TCEPR (1990–91 to 2017–18) core vessel lognormal CPUE model. From top left: target species, vessel, start time, duration, and depth of bottom.

Observer data, 1990–91 to 2017–18

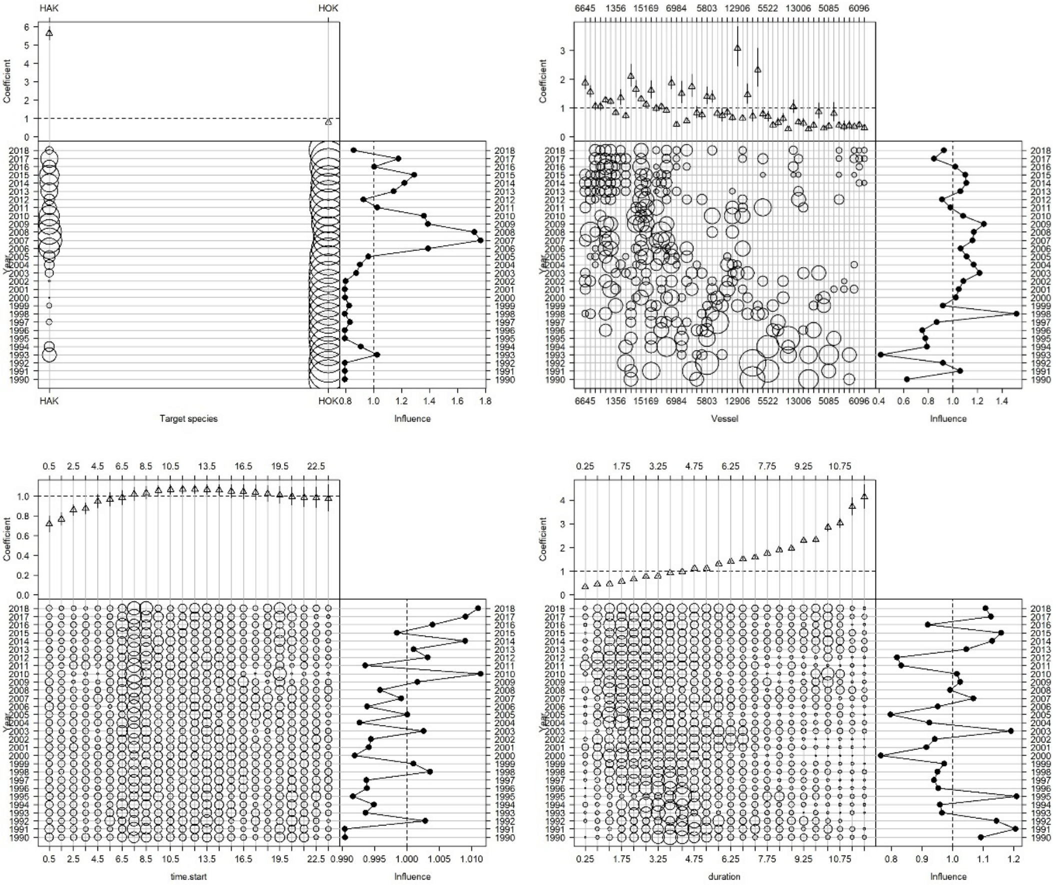


Figure 17: Effect and influence of non-interaction term variables on the observer (1990–91 to 2017–18) core vessel lognormal CPUE model. From top left: target species, vessel, start time, and duration.

Table 9: Lognormal, binomial, and delta lognormal (combined) standardised CPUE indices (with CVs to two decimal places) for the TCEPR data, 1990–91 to 2017–18.

	Lognormal		Binomial		Delta lognormal	
	Index	CV	Index	CV	Index	CV
1990	0.53	0.04	0.97	0.01	0.55	0.04
1991	0.95	0.05	0.81	0.03	0.82	0.06
1992	0.87	0.05	0.65	0.05	0.60	0.07
1993	1.08	0.04	0.63	0.04	0.72	0.06
1994	0.97	0.04	0.70	0.03	0.73	0.05
1995	1.24	0.03	0.86	0.02	1.14	0.04
1996	2.19	0.02	0.89	0.01	2.08	0.02
1997	1.51	0.02	0.93	0.01	1.49	0.02
1998	1.51	0.02	0.93	0.01	1.50	0.02
1999	1.49	0.02	0.85	0.02	1.35	0.03
2000	1.50	0.02	0.91	0.01	1.45	0.02
2001	1.17	0.02	0.87	0.02	1.09	0.03
2002	1.56	0.02	0.91	0.01	1.50	0.02
2003	1.11	0.02	0.90	0.01	1.06	0.02
2004	1.06	0.02	0.92	0.01	1.04	0.02
2005	0.91	0.02	0.84	0.02	0.81	0.03
2006	0.85	0.02	0.87	0.02	0.79	0.03
2007	0.66	0.03	0.81	0.03	0.57	0.04
2008	0.42	0.03	0.86	0.02	0.39	0.04
2009	0.64	0.03	0.91	0.02	0.62	0.03
2010	0.64	0.03	0.91	0.02	0.62	0.03
2011	0.79	0.02	1.00	0.01	0.84	0.02
2012	1.04	0.03	0.97	0.01	1.07	0.03
2013	1.20	0.02	0.96	0.01	1.23	0.02
2014	0.84	0.02	0.93	0.01	0.83	0.02
2015	0.91	0.02	0.96	0.01	0.93	0.02
2016	1.02	0.02	0.96	0.01	1.04	0.02
2017	1.10	0.02	0.98	0.01	1.15	0.02
2018	0.97	0.02	1.00	0.01	1.03	0.02

Table 10: Lognormal, binomial, and delta lognormal (combined) standardised CPUE indices (with CVs to two decimal places) for the TCEPR data, 2000–01 to 2017–18.

	Lognormal		Binomial		Delta lognormal	
	Index	CV	Index	CV	Index	CV
2000	1.56	0.02	0.91	0.01	1.47	0.02
2001	1.29	0.02	0.90	0.01	1.19	0.02
2002	1.72	0.02	0.91	0.01	1.61	0.02
2003	1.23	0.02	0.90	0.01	1.15	0.02
2004	1.16	0.02	0.93	0.01	1.11	0.02
2005	1.01	0.02	0.83	0.02	0.87	0.03
2006	0.89	0.02	0.87	0.02	0.80	0.03
2007	0.7	0.03	0.82	0.02	0.59	0.04
2008	0.46	0.03	0.87	0.02	0.41	0.03
2009	0.69	0.03	0.91	0.01	0.65	0.03
2010	0.69	0.03	0.92	0.01	0.65	0.03
2011	0.86	0.02	1.00	0.01	0.89	0.02
2012	1.12	0.03	0.98	0.01	1.13	0.03
2013	1.3	0.02	0.97	0.01	1.29	0.02
2014	0.9	0.02	0.94	0.01	0.87	0.02
2015	0.98	0.02	0.97	0.01	0.98	0.02
2016	1.12	0.02	0.96	0.01	1.11	0.02
2017	1.17	0.02	0.98	0.01	1.19	0.02
2018	1.03	0.02	1.00	0.01	1.06	0.02

Table 11: Lognormal, binomial, and delta lognormal (combined) standardised CPUE indices (with CVs to two decimal places) for the observer data, 1990–91 to 2017–18.

	Lognormal		Binomial		Delta lognormal	
	Index	CV	Index	CV	Index	CV
1990	0.87	0.09	1.48	0.14	1.21	0.17
1991	0.87	0.05	1.04	0.10	0.85	0.11
1992	0.89	0.04	0.63	0.13	0.52	0.14
1993	0.86	0.06	0.92	0.15	0.74	0.16
1994	0.92	0.02	0.46	0.07	0.39	0.07
1995	0.94	0.02	0.69	0.08	0.60	0.08
1996	0.95	0.01	3.03	0.06	2.70	0.06
1997	0.95	0.01	1.59	0.06	1.41	0.06
1998	0.94	0.01	1.77	0.05	1.55	0.05
1999	0.93	0.02	2.02	0.06	1.75	0.06
2000	0.92	0.02	1.52	0.05	1.31	0.05
2001	0.96	0.01	1.02	0.05	0.91	0.05
2002	0.95	0.01	2.29	0.04	2.04	0.04
2003	0.93	0.02	0.60	0.06	0.52	0.06
2004	0.93	0.01	1.23	0.04	1.07	0.04
2005	0.93	0.02	0.98	0.04	0.85	0.04
2006	0.97	0.01	1.13	0.04	1.02	0.04
2007	0.91	0.02	0.91	0.06	0.77	0.07
2008	0.93	0.02	0.41	0.06	0.36	0.06
2009	0.88	0.03	0.23	0.07	0.19	0.08
2010	0.93	0.02	0.50	0.06	0.43	0.06
2011	0.97	0.01	0.86	0.05	0.78	0.05
2012	0.97	0.01	0.87	0.05	0.79	0.05
2013	0.96	0.01	1.41	0.03	1.26	0.03
2014	0.94	0.01	0.87	0.03	0.76	0.03
2015	0.95	0.01	0.93	0.03	0.83	0.03
2016	0.95	0.01	0.96	0.03	0.85	0.03
2017	0.96	0.01	1.29	0.04	1.15	0.04
2018	0.97	0.01	1.54	0.03	1.39	0.03

Table 12: Lognormal, binomial, and delta lognormal (combined) standardised CPUE indices (with CVs to two decimal places) for the observer data, 2000–01 to 2017–18.

	Lognormal		Binomial		Delta lognormal	
	Index	**CV**	**Index**	**CV**	**Index**	**CV**
2000	1.84	0.05	0.95	0.01	1.59	0.05
2001	1.12	0.04	0.98	0.01	1.00	0.04
2002	2.61	0.04	0.99	0.01	2.35	0.04
2003	0.60	0.07	0.97	0.01	0.53	0.07
2004	1.33	0.04	0.97	0.01	1.16	0.04
2005	1.07	0.03	0.96	0.01	0.93	0.03
2006	1.21	0.04	1.00	0.01	1.10	0.04
2007	1.01	0.06	0.94	0.02	0.86	0.06
2008	0.45	0.05	0.96	0.01	0.39	0.05
2009	0.25	0.06	0.92	0.02	0.21	0.06
2010	0.54	0.06	0.96	0.01	0.47	0.06
2011	0.83	0.06	0.99	0.01	0.75	0.06
2012	0.91	0.05	1.00	0.01	0.82	0.05
2013	1.55	0.03	0.99	0.01	1.39	0.03
2014	0.96	0.03	0.97	0.01	0.85	0.03
2015	1.02	0.03	0.99	0.01	0.91	0.03
2016	1.05	0.03	0.98	0.01	0.93	0.03
2017	1.40	0.04	0.98	0.01	1.25	0.04
2018	1.68	0.03	1.00	0.01	1.52	0.03

APPENDIX C. CPUE ANALYSIS WITH GRID

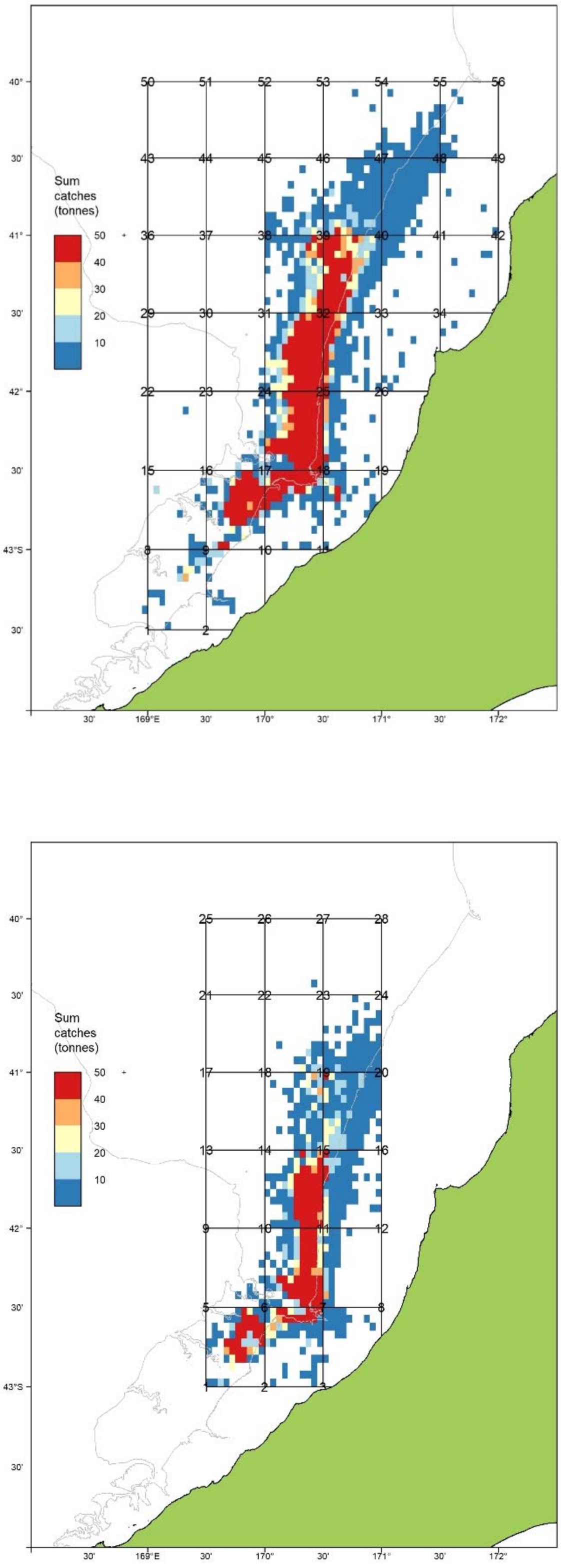
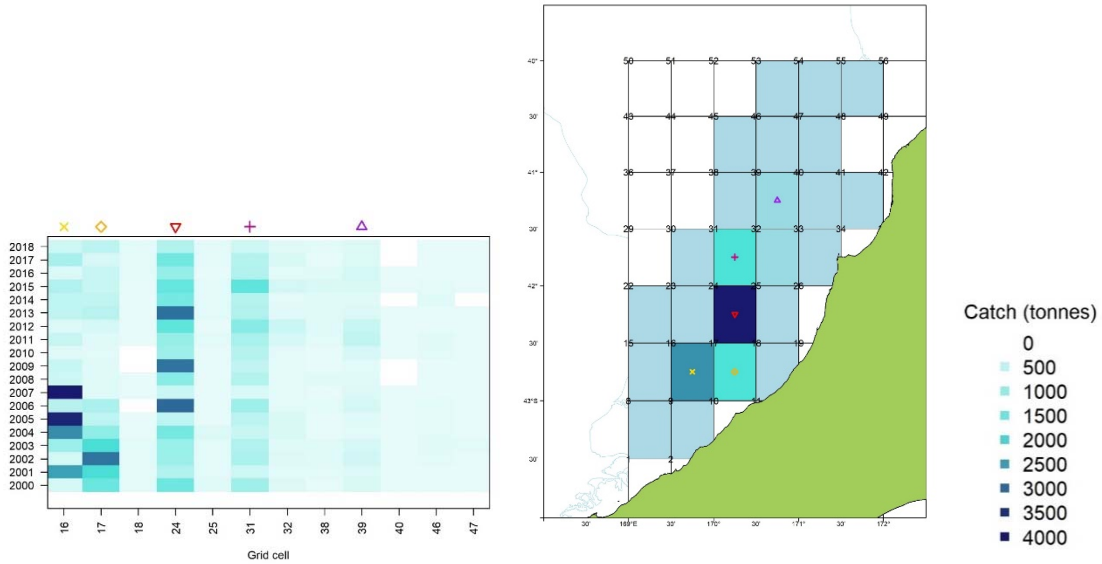


Figure 18: Division of grid and spatial distribution of hake catch for TCEPR (top) and observer (bottom) data for 2000–01 to 2017–18 time series.



Grid No.	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
24	1 460.82	633.72	908.95	928.20	1 330.93	492.41	2 975.34	336.42	1 133.50	2 896.86
16	170.12	2 480.88	206.58	909.67	2 664.11	3 625.82	574.64	3 739.81	305.45	355.79
17	1 494.95	1 893.16	2 893.94	1 909.25	1 084.62	503.08	700.40	86.79	66.59	87.96
31	876.07	307.43	716.94	635.13	376.80	512.47	853.29	164.53	583.41	451.09
39	131.80	125.26	275.06	170.81	46.53	58.35	212.11	123.18	74.90	54.03

Grid No.	2010	2011	2012	2013	2014	2015	2016	2017	2018	Total
24	915.20	977.43	1 648.66	2 927.54	1 330.94	1 577.70	955.51	1 407.92	622.40	25 460.45
16	66.11	372.22	96.84	457.01	496.28	624.40	101.99	736.16	281.30	18 265.18
17	42.63	58.09	183.87	578.69	440.10	373.84	381.94	200.25	513.92	13 494.07
31	612.99	743.87	1 158.65	642.30	591.55	1 630.09	642.14	605.25	307.11	12 411.11
39	198.11	459.40	365.35	95.49	84.91	166.76	219.19	126.39	122.80	3 110.43

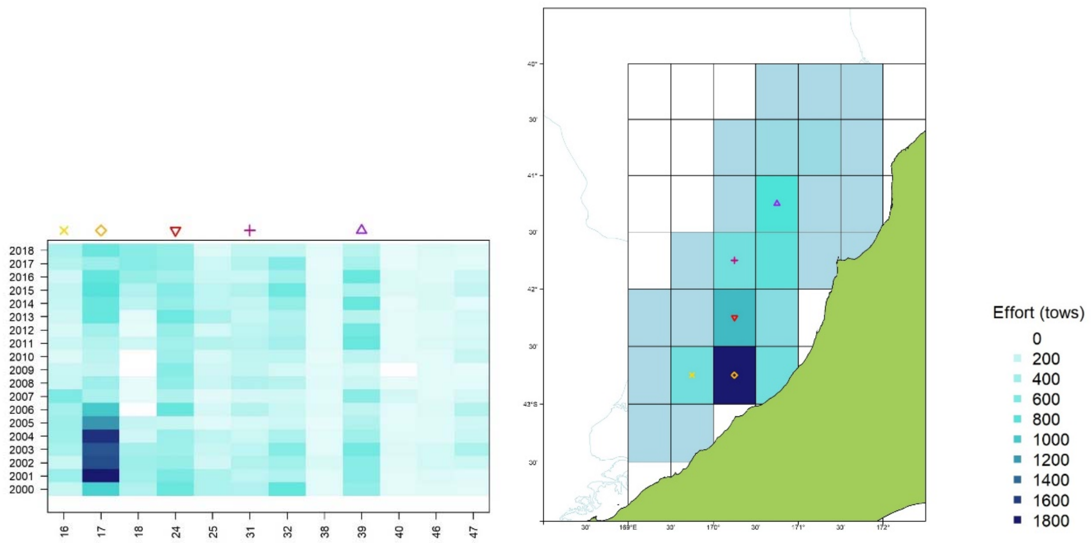
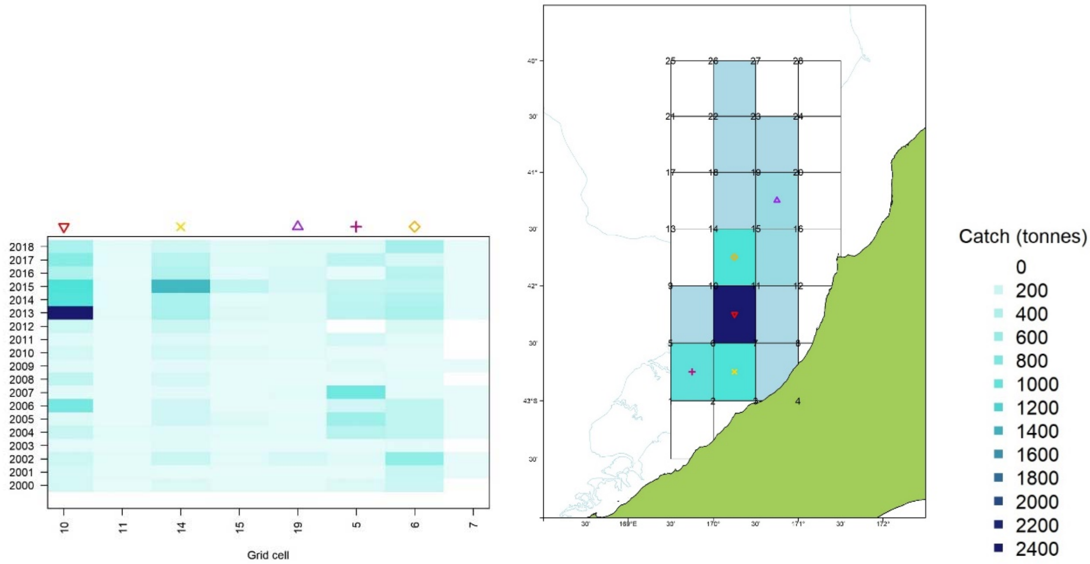


Figure 19: For TCEPR data (2000–01 to 2017–18), distribution of catch for each grid cell (top left), grid cell location (top right), annual catch by grid for the top five cells, distribution of effort for each grid cell (bottom left), and grid cell location (bottom left).



Grid No.	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
10	144.43	121.30	179.85	13.24	227.00	76.94	814.72	14.04	280.57	45.01
14	73.80	9.64	195.50	34.59	45.31	148.23	160.60	20.42	109.97	23.35
6	203.06	220.53	652.85	24.60	273.35	259.68	281.64	22.09	17.65	8.48
5	73.54	5.32	46.00	2.20	337.01	514.63	151.54	879.23	7.15	52.31
19	29.63	7.17	119.26	6.54	12.64	13.97	11.05	21.73	9.62	6.93

Grid No.	2010	2011	2012	2013	2014	2015	2016	2017	2018	Total
10	132.31	37.36	185.36	2254.06	1082.95	1134.68	404.20	706.69	420.99	8 275.70
14	143.47	72.54	202.57	459.71	429.67	1341.62	373.11	338.17	168.89	4 351.16
6	2.76	20.09	78.94	459.50	375.47	279.03	340.54	115.52	478.67	4 114.45
5	2.44	123.81	NA	312.35	286.24	241.93	8.40	298.77	62.10	3 404.97
19	27.74	20.60	22.50	37.38	46.21	122.60	104.15	76.62	62.13	758.47

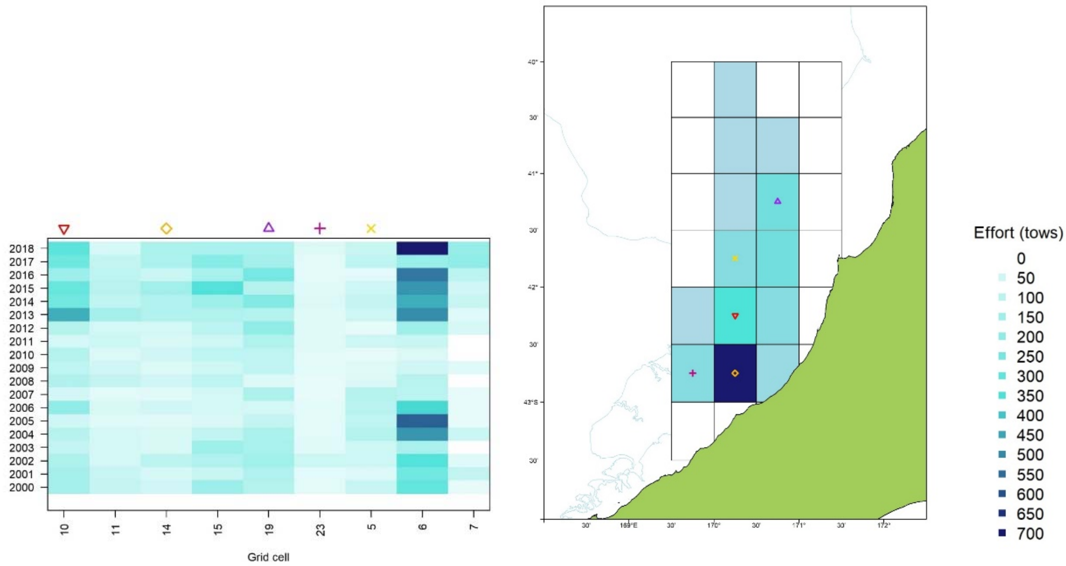


Figure 20: For observer data (2000–01 to 2017–18), distribution of catch for each grid cell (top left), grid cell location (top right), annual catch by grid for the top five cells, distribution of effort for each grid cell (bottom left), and grid cell location (bottom left).

Table 13: Variables retained in order of decreasing explanatory value by each model.

	TCEPR	Observer	
Variable	**% Deviance explained**	**Variable**	**% Deviance explained**
Year	2.5	Year	2.9
Target	25.0	Target	29.7
Vessel	27.1	Time Start	32.3
Start Time	29.0	Duration	33.8
Duration	30.8	Vessel	35.1
Grid Number	32.0	Grid Number	35.9

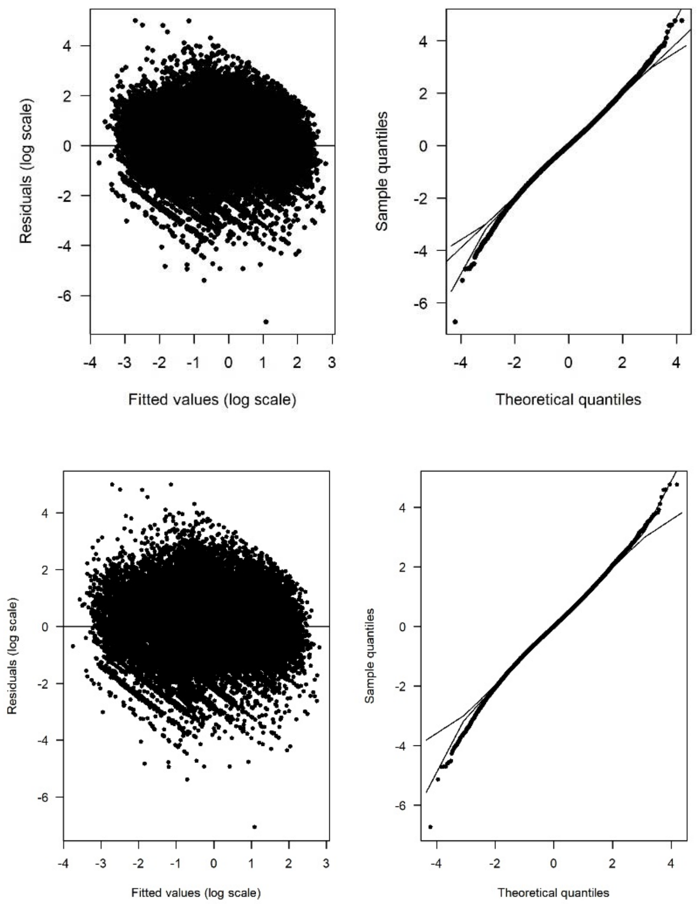


Figure 21: Diagnostic plots for the lognormal CPUE models of the TCEPR (top) time series and observer (bottom) time series.

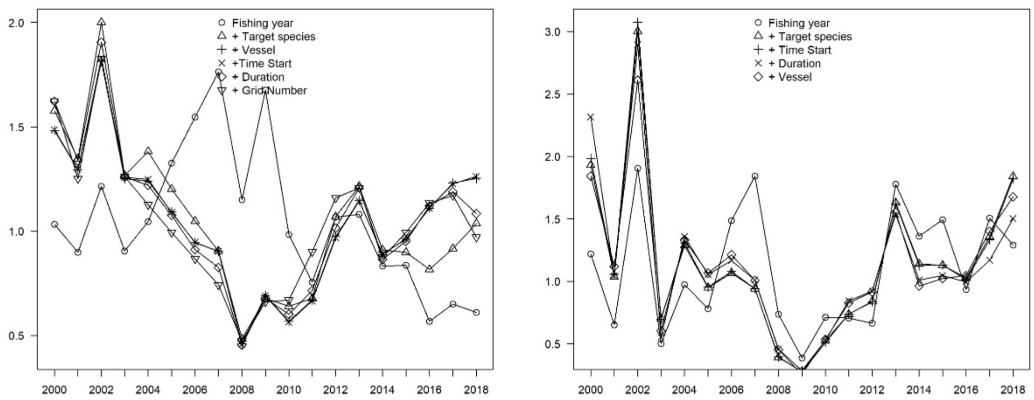


Figure 22: Standardised CPUE indices from the lognormal models showing the effect of addition of variables on the TCEPR (right) time series and observer (left) time series.

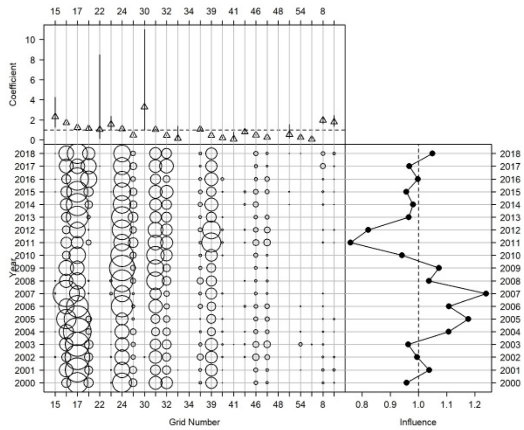


Figure 23: Effect and influence of the variable *grid cell* on the TCEPR core vessel lognormal CPUE model. Note this was not a selected predictor for the observer data.

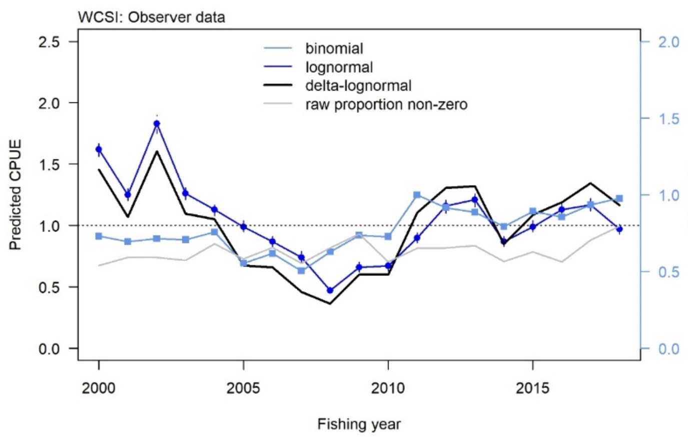
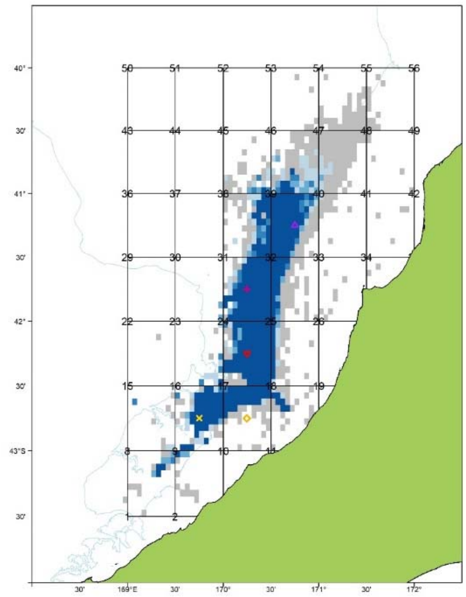
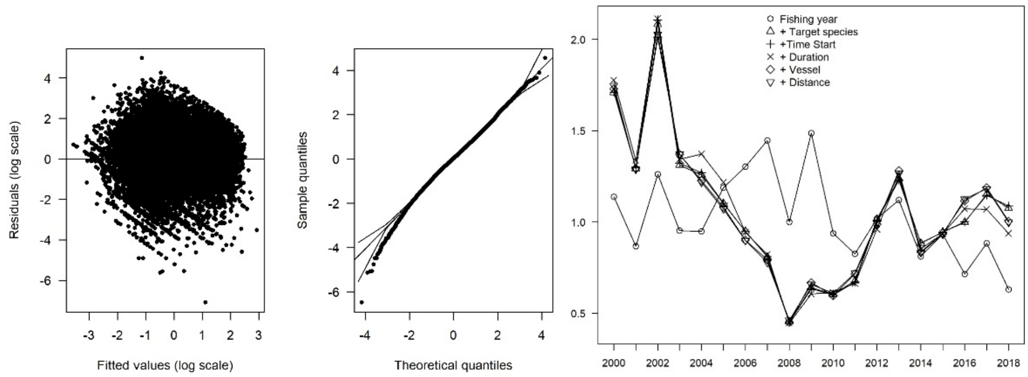


Figure 24: Standardised CPUE indices from the lognormal, binomial, and combined model for the TCEPR time series. Bars indicate 95% confidence intervals. The horizontal dotted line shows the mean of the combined series. The probability scale relates to the binomial and raw proportion non-zero series.



Top five cells		Fyear*grid	
Variable	% Deviance explained	Variable	% Deviance explained
Year	2.2	Year	2.5
Target	23.6	Target	25.0
Start time	26.0	Vessel	27.1
Duration	27.8	Start Time	29.0
Vessel	29.9	Duration	30.8
Distance	31.1	Grid Number	32.0
		Year*Grid Number	36.4



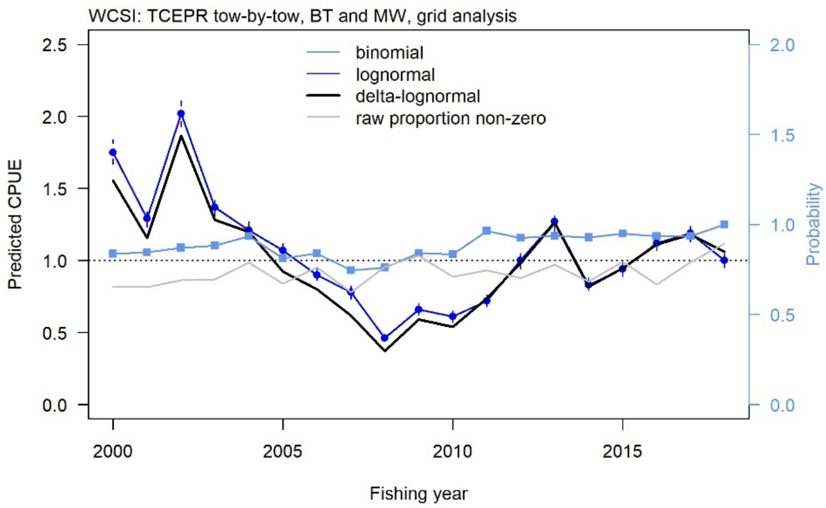


Figure 25: For TCEPR 2000–01 to 2017–18 data only. Location of top five cells (based on total hake catch, t), predictors selected with top five grid cells and when a year interaction was introduced, diagnostic plots for the top five grid cell model, standardised CPUE index from the lognormal models showing the effect of addition of variables, and the final standardised CPUE indices produced by the top five grid cell analysis.