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Fishery characterisation and standardised CPUE analyses for silver warehou (*Seriolella punctata*) in SWA 3 and 4, 1989–90 to 2015–16

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Contents

EXECUTIVE SUMMARY

McGregor, V.L. (2019). Fishery characterisation and standardised CPUE analyses for silver warehou (*Seriolella punctata*) in SWA 3 and 4, 1989–90 to 2015–16.

New Zealand Fisheries Assessment Report 2019/59. 57 p.

This report is an update on the previous characterisation and CPUE of fishing years 1997–98 to 2010–11 (McGregor, 2016), with additional information and analyses where appropriate.

Silver warehou has been exploited since the mid–1960s, with substantial fishery development in the 1970s. After Silver Warehou was introduced into the QMS in 1986, it was originally mainly a bycatch component of bottom trawl fisheries both on the shelf and in middle depths to 500 m. Since 2008 there has been an increased proportion of silver warehou target fishing. Commercial harvest generally exceeded the TACC in SWA 3 and SWA 4, until the 2008 fishing year which coincided with an increased deemed value for silver warehou.

The distribution of silver warehou catch roughly conforms to the 100–400 m slope area, generally with smaller fish in shallower waters and larger fish in deeper waters. Within SWA 3 and 4, the main areas of catch are: Southland, which encompasses the Stewart-Snares shelf, Puysegur region, and the Auckland Island shelf (and is mainly driven by target silver warehou fishing or bycatch in the squid fishery); the east coast of the South Island focusing on the area surrounding Banks Peninsula to Mernoo Bank; and to a lesser extent, the eastern Chatham Rise, centered around the Chatham Islands. Catch in these areas is seasonal depending on the target fishery, and targeting of SWA occurs by some vessels throughout the year, especially in Southland. Most catch is by bottom trawl.

Length frequency distributions are available from research bottom trawl surveys and from observer samples. Although the data are noisy, strong length modes are often visible, and those from observer samples often track from year to year as the fish grow. There is typically an adult length mode of 40–50 cm and often 1–3 modes of smaller lengths. There is some modal progression which seems to correspond to fluctuations in CPUE, especially in Southland.

A standardised catch per unit effort (CPUE) analysis of fisheries in western Chatham Rise and Southland was conducted using tow-level data (unmerged data) from 1990 through to 2016. Generalised linear models used to estimate year indices for each area and dataset fit the data moderately well, explaining 20–35% of the null deviance. The trend in standardised CPUE is generally flat or increasing for western Chatham Rise except for a sudden drop in 2008. The Southland CPUE is generally flat with small increases and decreases. In both areas, the binomial models fitted to the probability of non-zero catches were generally flat, suggesting no trend in the probability of positive catch.

The CPUE abundance indices using observer-only data were very similar to the full commercial CPUE indices, with differences only apparent in the early few years of the series.

Catch-at-age distributions and age-depth analyses show variation in age by depth and year that may be related to population and/or fishery dynamics. More work is required in this area.

1. Introduction

The New Zealand silver warehou (*Seriolella punctata*) fishery dates back to the 1960s, although recorded landings only date back to 1974 and the fishery came under the Quota Management System (QMS) in 1986. There has been no formal stock assessment for the fishery to date. There have been characterisations, fishery independent trawl surveys, observers recording biological data onboard commercial fishing vessels, catch-at-age analyses, and catch per unit effort (CPUE) analyses (key references for these are in Table 1).

This works updates the last characterisation for SWA 3 & 4, with further analyses of catch and effort data in pursuit of CPUE likely to index abundance.

This report summarises the analyses carried out for the Ministry for Primary Industries under project DEE2016-16, Objective 1:

1. To update the descriptive analysis of the commercial fisheries for silver warehou in SWA 3 and SWA 4
    - Carry out a descriptive analysis of the catch and effort data, scientific observer data, and other research data (updating the sections of McGregor (2016) that are relevant to an assessment of SWA 3 & 4).
    - Identify fishery/stock combinations suitable for standardized catch-per-unit-effort (CPUE) analyses and carry out standardized CPUE analyses for these fishery/stock combinations, following the approach of McGregor (2016).

This report also includes re-estimated von Bertalanffy growth curve parameters using catch-at-age from Horn & McGregor (2018).

Table 1: Key documents relating to the New Zealand silver warehou fishery.

Date	Description	Reference
2018	Catch-at-age for silver warehou (*Seriolella punctata*) on the western Chatham Rise in the 2000–01, 2012–13 and 2015–16 fishing years	Horn & McGregor (2018)
2017	SWA Plenary Report	Ministry for Primary Industries (2017)
2016	Characterisation and CPUE for SWA 1, 3 & 4 up to 2011	McGregor (2016)
2011	Characterisation and CPUE for SWA 3 & 4 up to 1999	Parker & Fu (2011)
2001	Stock structure of silver warehou, includes catch-at-age	Horn et al. (2001)

2. FISHERY SUMMARY

2.1. Commercial fisheries

Silver warehou (also recorded as *S. maculata* Forster) are caught in coastal waters mainly around the South Island of New Zealand, as well as on the Chatham Rise and Campbell Plateau at depths to about 500 m (Anderson et al., 1998). Most of the commercial catch is taken from the Chatham Rise, Canterbury Bight, southeast of Stewart Island, and the west coast of the South Island. Historically, most of the silver warehou catch was taken as a bycatch of the hoki (*Macruronus novaezelandiae*), squid (*Nototodarus sloanii*, *N. gouldi*), barracouta (*Thyrsites atun*), and jack mackerel (*Trachurus* spp.) trawl fisheries, although some targeting occurred (Knuckey et al., 1998; Phillips, 2001). The current analyses show that from 1990 the southern fishery (south of -45.5^o latitude) was predominantly squid target then silver warehou target, and the western Chatham Rise (WCHAT) fishery (east of 180^o longitude) predominantly hoki target until 2008 after which the catches from hoki and silver warehou target were similar.

The fishery is currently managed as three separate fish stocks based on the Quota Management Areas: North Island and the west coast of the South Island (SWA 1), southeast coast of the South Island (SWA 3), and sub-Antarctic, Southland, and the eastern Chatham Rise (SWA 4) (Figure 1). Horn et al. (2001) suggested four possible stocks based on four distinct spawning areas (off west coast South Island, southern South Island, eastern North Island, and on the Chatham Rise), with likely mixing between them. An administrative stock exists for the Kermadec area (SWA 10), but no catch of silver warehou has been recorded from that area.

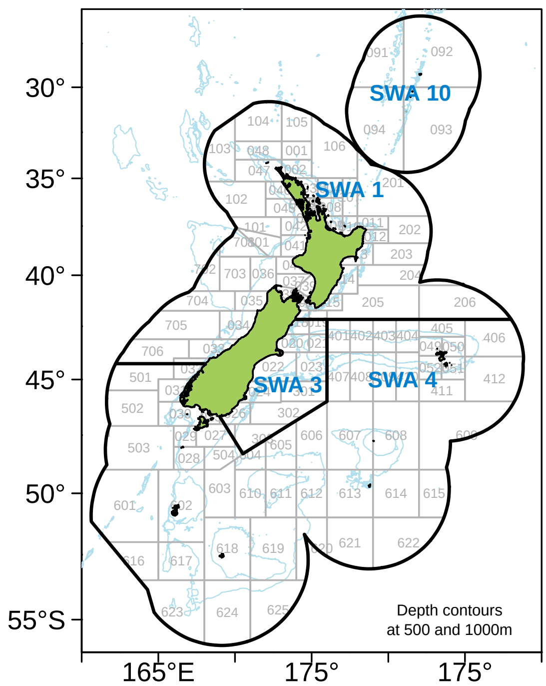


Figure 1: SWA QMA boundaries for SWA 1, SWA 3, SWA 4, and SWA 10, statistical areas (grey), and 500 m and 1000 m depth contours (blue lines).

Commercial fishing for silver warehou developed in the late 1960s and early 1970s. Estimated total annual catches were about 13 000 t in 1976, 1977, and 1978 (Paul (1980), table 1 in Livingston 1988). After the introduction of the EEZ (Economic Exclusion Zone), an initial TAC (Total Allowable Catch) of 18 000 t was set but this was subsequently halved in 1980–81 (Livingston, 1988). Catches dropped after the establishment of the EEZ, and the reported landings fluctuated between 3000 t and 8000 t between 1978–79 and 1985–86 (table 1 and table 3 in Livingston 1988). In 1986 a TAC of 8010 t was set under the new QMS (Quota Management System) and divided between three stocks comprising the areas SWA 1, SWA 3 and SWA 4 that are still current today. There were several increases to the TAC, reaching a maximum of 10 380 t in 2003 where it has since remained (Ministry for Primary Industries, 2017)

The TAC was generally exceeded from 1996–2008 (Figure 2). From 1 October 2007 the deemed values were increased and the effect was seen immediately in 2007–08 as catch fell well below the TACs in both SWA 3 and SWA 4 (Figure 2).

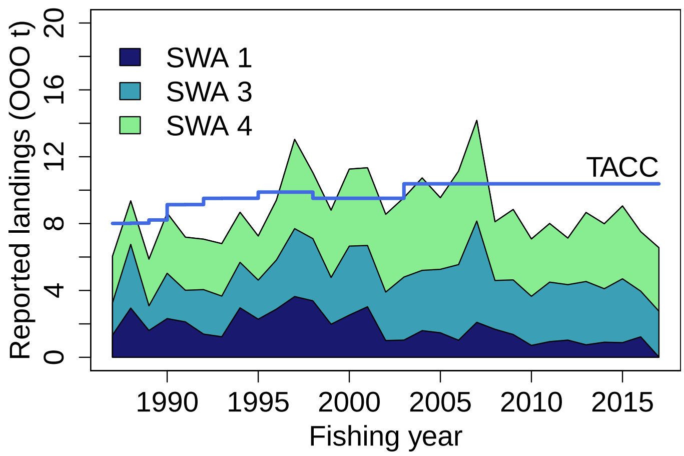


Figure 2: SWA landings by QMA.

2.2. Illegal and misreported catch

Silver warehou have been misreported as white or blue warehou in the past. In addition, juvenile silver warehou are commonly caught in shallower coastal waters which could lead to non-retention of unmarketable fish. The extent of these practices is unknown and could lead to under-reporting of silver warehou catches.

2.3. Recreational and customary fisheries and other sources of mortality

There are no current recreational fisheries for silver warehou, no quantitative information of the current level of customary non-commercial catch, and no other known sources of mortality.

3. Biology

3.1. Distribution

Globally, *Seriolella punctata* can be found throughout the southern hemisphere from latitudes 33–47 ° S in waters less than approximately 600 m deep (Pequeño (1989), Paulin et al. (1989)).

Research trawl tows where silver warehou were measured show juveniles occurring in a high proportion of tows inside the 200 m depth contour all around the New Zealand coast (Horn et al., 2001). Length and age data collected during the course of trawl surveys and by the Scientific Observer Programme from commercial fishing vessels that smaller fish tend to be in shallower water, in particular along the Stewart-Snares Shelf and near Banks Peninsula and Mernoo Bank (Figure 3).

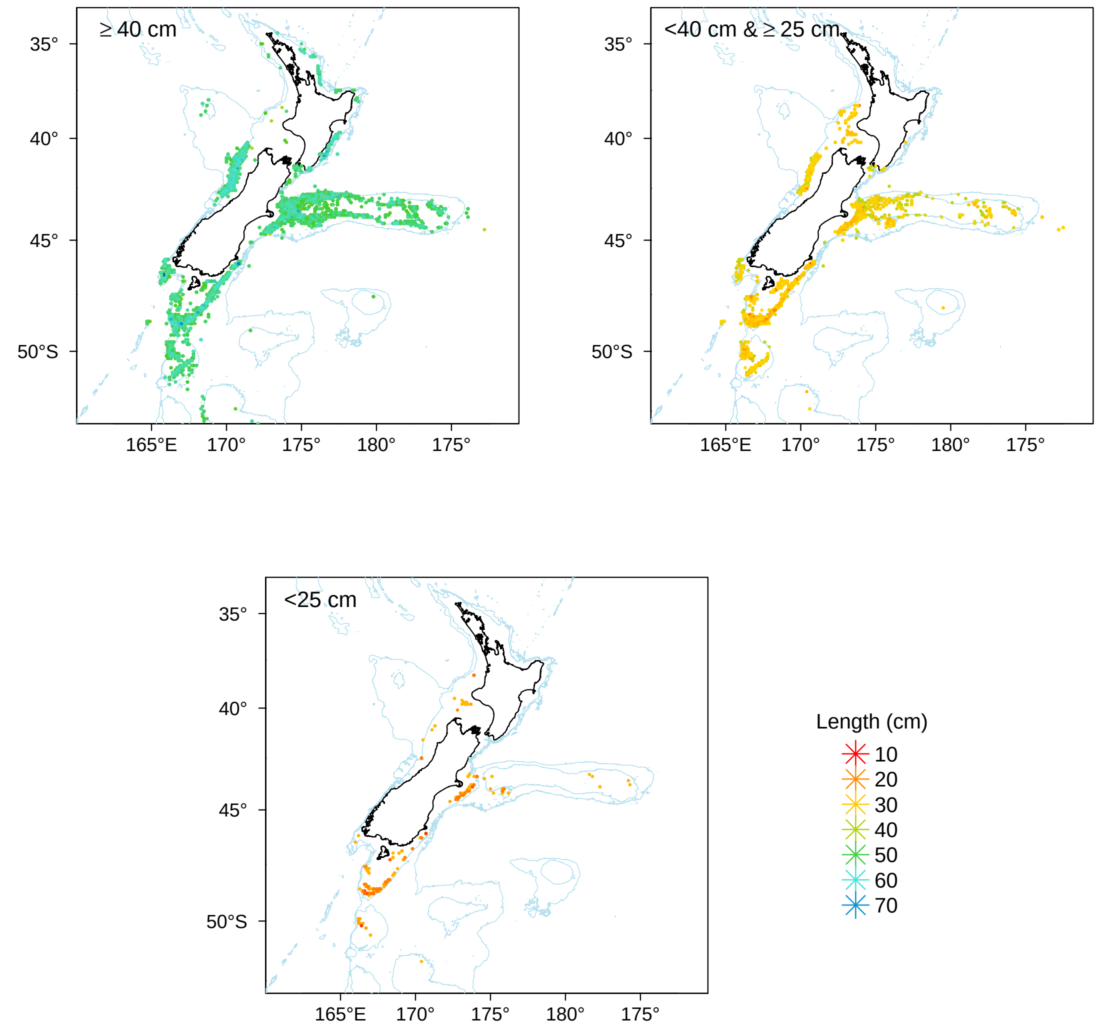


Figure 3: Spatial distribution of observer samples coloured by length from fishing years 1990–2016 with only lengths greater than or equal to 40 cm (top left), less than 40 cm (top right), and less than 25 cm (bottom).

The spatial distribution of silver warehou commercial catches shows that silver warehou are mostly caught off the northern west coast of the South Island, off the east coast of the South Island and the Chatham Rise out to the Chatham Islands (especially between Banks Peninsula and Mernoo Bank), and to the south of the South Island (especially on the Stewart-Snares shelf). The spatial distribution of silver warehou catches for fishing years 1991–2015 combined and fishing year 2016 are in Figure 4 and the full set by fishing year are in Appendix C. The fishery on the western Chatham Rise is continuous with ECSI, but with an apparent gap near 180° longitude separating the eastern and western Chatham Rise fisheries. There is another natural break to the south near Otago Peninsula. Catches further south are mostly from the Stewart-Snares Shelf. We redefined the areas for the purpose of characterisation as: WCHAT (includes western Chatham Rise out to 180° longitude), SOUT (the southern high catch density parts of SWA 3 and SWA 4) and CHATE (the Chatham Rise east of 180° longitude) (Figure 5). The SWA 3 and 4 catches were mostly from the SOUT and WCHAT areas, with a small proportion from CHATE and a small proportion from outside of these three areas (Figure 6).

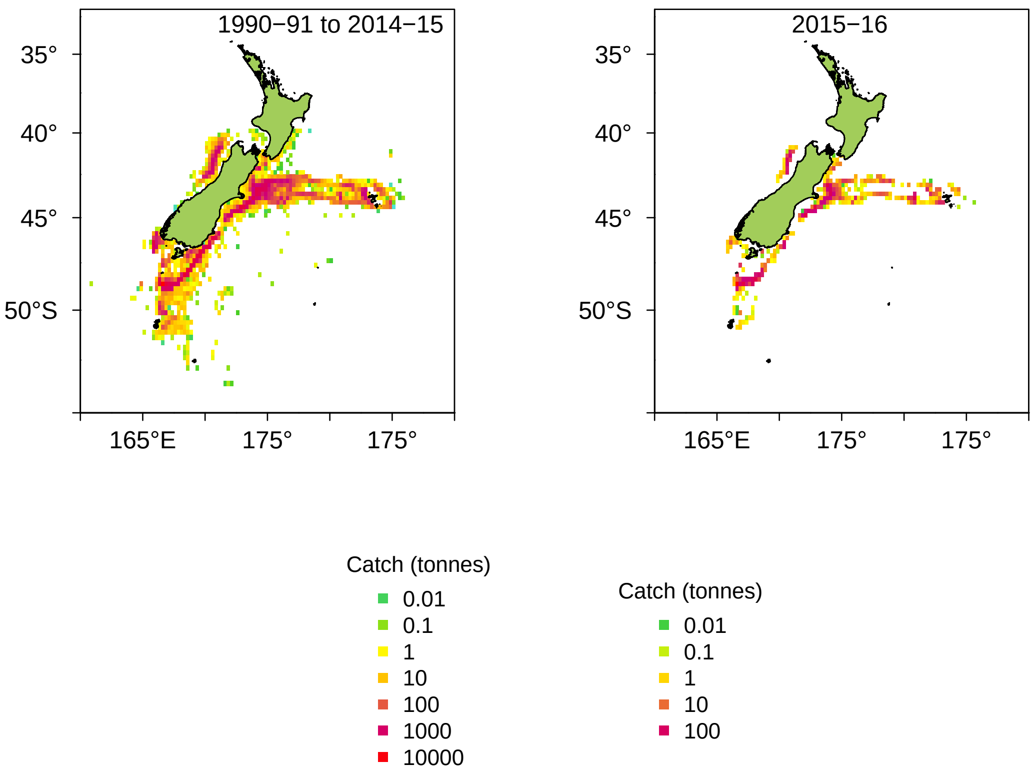


Figure 4: Spatial distribution of landings from fishing years 1991–2015 (left) and fishing year 2016 (right).

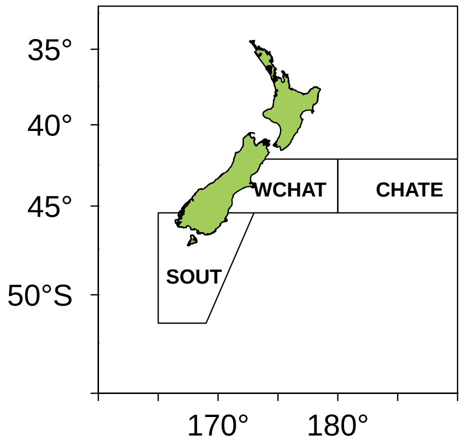


Figure 5: Boundaries of areas used in characterisation, WCHAT (includes western Chatham Rise out to 180° longitude), SOUT (the southern high catch density part of SWA 3 and SWA 4) and CHATE (the Chatham Rise east of 180° longitude).

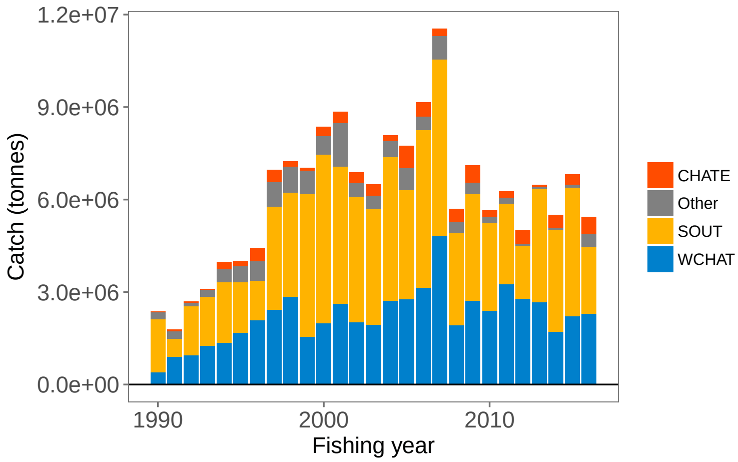


Figure 6: Catch (tonnes) from SWA 3 and 4 by area and fishing year from 1990–2016.

3.2. Spawning

Gavrilov (1979) indicated an age of maturity of 3–4 years (corresponding to a fork length of around 46–48 cm). Observations of developmental stage have been collected on survey and commercial vessels using a five level staging system for females: (1: immature or resting, 2: maturing, 3: ripe, 4: running ripe, 5: spent). It is not possible to estimate maturity ogives with these data as immature and resting fish both score 1 (and are difficult to separate, especially during non-reproductive seasons). Numbers and proportions of maturing fish indicate reproductive development when fish are 30–40 cm. Currently, 47 cm is widely cited as the length at 50% maturity.

Horn et al. (2001) suggested four distinct spawning areas: off west coast South Island, southern South Island, eastern North Island, and on the Chatham Rise, with possible sub-areas of spawning within these. For example, Livingston (1988) inferred from voyage reports that the time of spawning at the Chatham Islands was earlier (spring–summer) than that at the Mernoo Bank (winter–spring).

The peak timing for spawning appears to be earliest on the WCSI (winter), then proceeding in a south-east direction, at the Mernoo Bank (winter-spring), Stewart-Snares Shelf, and around the Chatham Islands (spring–summer). A summary of research survey and observer information (O'Driscoll et al., 2003) gave similar results. Eggs hatch after about 6 days (146 hours at 10–13^{o}C) and emergent yolk-sac larvae are about 3 mm long (Grimes & Robertson, 1981).

3.3. Climate and recruitment

No analyses have examined any link between climate characteristics and recruitment.

3.4. Ageing

Catch-at-age distributions were developed by Horn (2012) for the Chatham Rise fishery in fishing years 2004–05 and 2009–10, by Horn et al. (2001), and by Horn and McGregor (2018) for western Chatham Rise (west of 180^{o} longitude) fishing years 2000–01, 2012–13 and 2015–16. The proportion of old (more than 9 years) fish was largest in the latest year, and the largest proportion of young (more than 5 years) was in the earliest year (Figure 7). The 2005 samples were all from deep tows (more than 400 m) and did not include any juveniles (less than 3 years) (Figure 8).

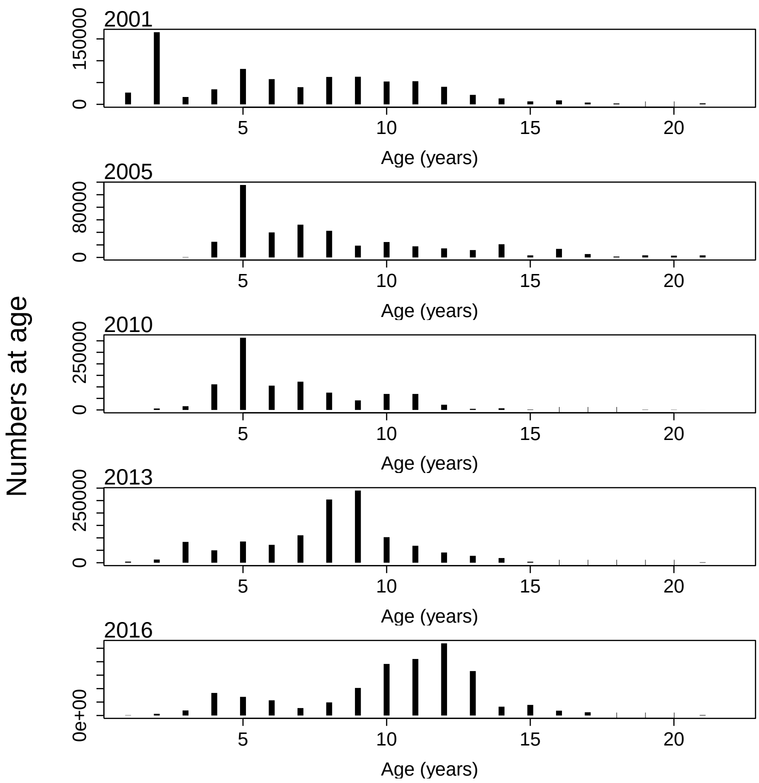


Figure 7: Age-frequency distributions for silver warehou sampled by observers during commercial trawl operations on the western Chatham Rise during all months of 2004–05 and 2009–10, and during September–February of 2000–01, 2012–13, and 2015–16.

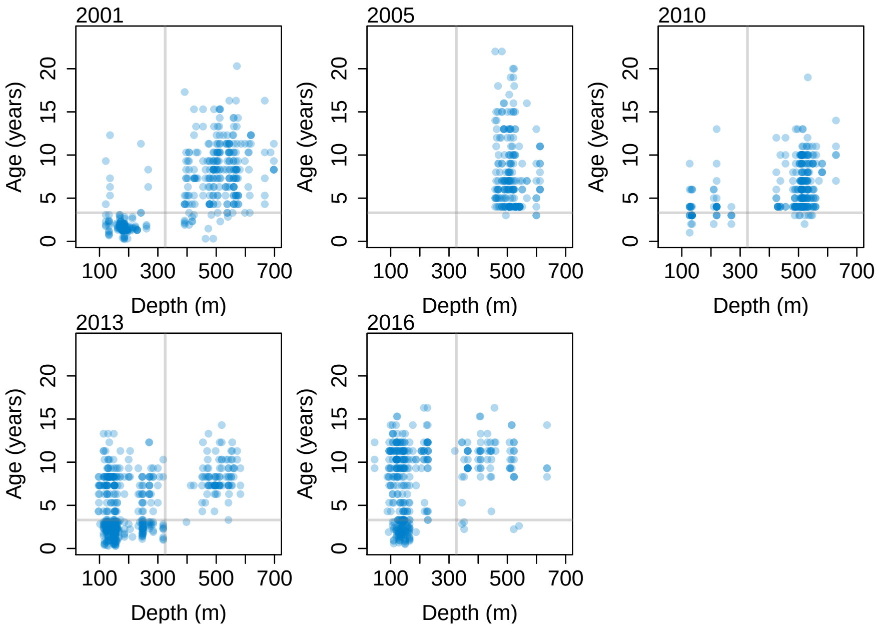


Figure 8: Age-depth distributions for silver warehou sampled by observers during commercial trawl operations on the western Chatham Rise during all months of 2004–05 and 2009–10, and during September–February of 2000–01, 2012–13, and 2015–16.

3.5. Growth curves

Horn et al. (2001) estimated parameters for the 4-parameter von Bertalanffy growth model by sex for the Southern Plateau and Chatham Rise (Table 2). We re-estimated these parameters using the size-at-age data from Horn and McGregor (2018) for male and female combined on the western Chatham Rise (Table 2). These size-at-age data were from fishing years 2001, 2005, 2010, 2013 and 2016. The curve does not lift up for older fish, which is the purpose of using the 4-parameter growth curve rather than the 3 parameter version (Figure 9 (left)). We re-estimated the curve using only 3-parameters and the resulting curve was almost indistinguishable to the eye. The 4-parameter curves estimated using data from 2000–01 and 2004–05 were more similar to the curves estimated by Horn et al. (2012) for Chatham Rise males and females (Figure 9 (right)).

Table 2: Von Bertalanffy estimated parameters for Southern Plateau and Chatham Rise (Horn et al., 2001), and western Chatham Rise.

	L_∞	k	t_0	P
Southern Plateau				
Male	53.0	0.275	-0.06	0.508
Female	56.1	0.217	-0.01	0.462
Chatham Rise				
Male	53.7	0.178	0.02	0.359
Female	58.4	0.115	0.33	0.271
Western Chatham Rise				
All (4 parameters)	49.9	0.365	-0.674	0.826
All (3 parameters)	49.8	0.382	-0.954	

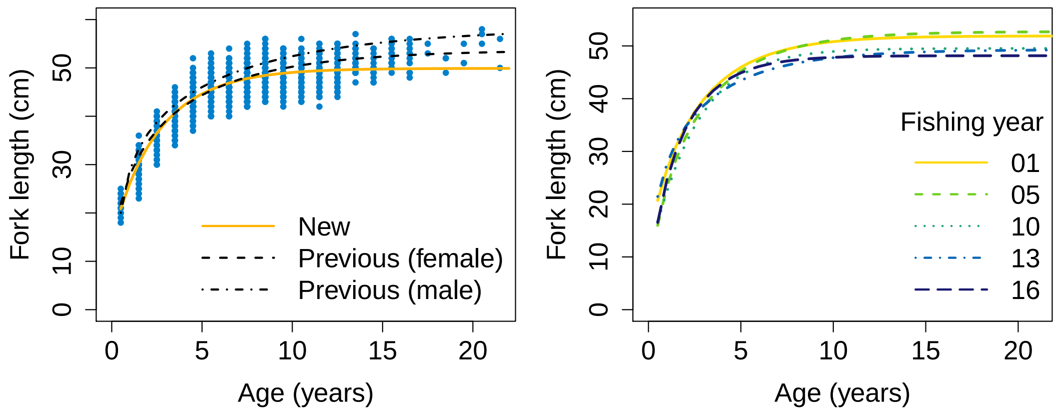


Figure 9: Re-estimated growth curve for western Chatham Rise (both sexes) (left, gold line) using size-at-age data from Horn and McGregor (2018) (blue dots) with Chatham Rise estimated growth curves for Chatham Rise males (black dashed line) and females (black dot-dashed line) from Horn et al. (2012). Re-estimated growth curve fitted to size-at-age data from Horn and McGregor (2018) for 2000–01 (right, gold solid line), 2004–05 (green dashed line), 2009–10 (light blue dotted line), 2012–13 (blue dot-dashed line), and 2015–16 (dark blue dashed line).

3.6. Feeding and trophic status

Gavrilov & Markina (1976) described the progression of juveniles into deeper water with increasing size and in relation to the distribution of their prey. Very young fish of 12–14 cm in length feed on plankton, juveniles 14–15.5 cm feed on Amphipoda and Chaetognatha in coastal waters. At 24–31 cm they move into the deeper part of the shelf, feeding on zooplankton —especially salps. Fish greater than 30 cm long feed on macroplanktonic organisms of the upper slope region. A summary of feeding information from the Chatham Rise research surveys from 2005 to 2007 (Horn et al., 2011) found that 92% of stomachs with food contained salps and that this was consistent across all size classes (22–57 cm); the remaining items were crustacean (euphausiid, amphipod, isopod, natant decapod), teleost (unidentified), polychaetes and squid. Pinkerton et al. (2017) estimated the trophic level of silver warehou to be 3.55 using stable isotope analyses.

4. Fishery independent observations

4.1. Research surveys

Bottom trawl surveys have been conducted since the early 1990s using either the Tangaroa (Chatham Rise and Sub-Antarctic Surveys) or the Kaharoa (ECSI and WCSI surveys). These surveys all encounter silver warehou, however, only the WCSI has been recently optimised for this species. A discontinued survey of Southland (1993–1996) did attempt to optimise for silver warehou (Hurst & Bagley, 1997). The inshore Kaharoa surveys occur in areas and depths where juveniles are present, and so may not represent adult biomass trends.

As the surveys relating to SWA 3 or SWA 4 are either not appropriate for silver warehou or, in the case of the Southland survey, discontinued, they have not been further analysed here beyond what was covered in the previous characterisation (McGregor, 2016).

4.2. Other data

Other research concerning population dynamics and stock structure of *Seriolella punctata* includes genetic work by Robinson et al. (2008) which indicated no genetic differentiation between silver warehou sampled off eastern and western Victoria, Australia. Data from a study of larval distribution in southeastern Australia also suggested that larvae were widely distributed and that little spatial differentiation existed within the region studied (Bruce et al., 2001). Horn et al. (2001) examined age structure and spawning status but other than documenting four putative spawning regions, no evidence for separate stocks was found. Horn et al. (2001) analysed catch-at-age for silver warehou in fishing years 2005 and 2010 in Southland and Chatham Rise and found very different distributions in the two years in terms of modal age and age range.

5. Fishery dependent observations

5.1. Observer data

The Ministry's Scientific Observer Programme has collected silver warehou length, weight, female gonad stage, and otoliths from various fisheries since 1985. We analysed available observer with data from two areas: WCHAT (western Chatham Rise out to 180^o longitude) and SOUT (Figure 5). Sampling coverage is shown spatially in Figure 10. The number of otolith samples by fishing month and fishing year is of interest as only years with sufficient samples can be aged to produce catch-at-age. In WCHAT, a minimum of 300 samples from September–February is required, and the years that meet this criteria are highlighted gold in Table 3. There have consistently been more otolith samples collected from SOUT than WCHAT, with all years since 1998 having more than 300 SOUT otolith samples (Table 4).

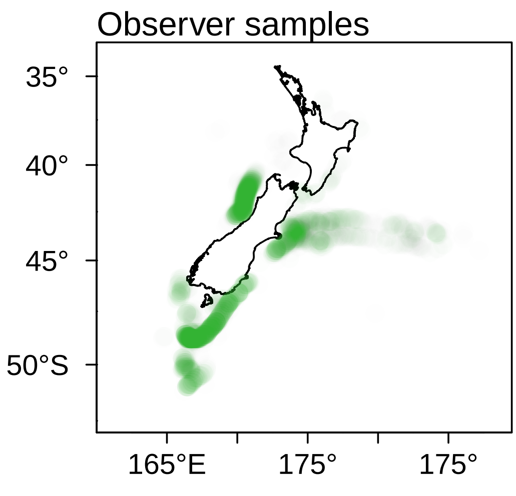


Figure 10: Spatial distribution of observer samples from fishing years 1991–2016.

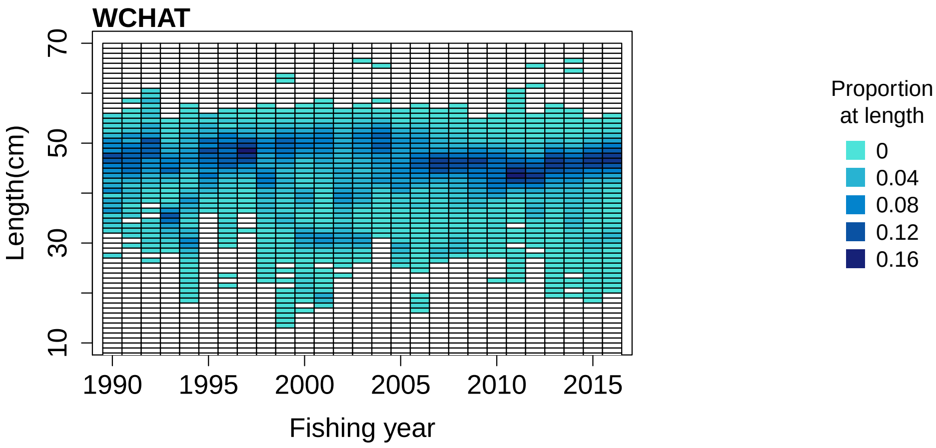
Table 3: Number of otolith samples for WCHAT by fishing year and month, where September–August is a fishing year and September–February is totaled for the six-month totals. Years with at least 300 samples in the six-month totals are highlighted gold as this is the minimum number of samples required for ageing.

	Fishing month												
Fishing year	S	O	N	D	J	F	M	A	M	J	J	A	Total	Total (6 months)
1991	0	58	8	20	18	0	0	0	0	0	0	0	104	104
1992	0	0	0	0	2	0	0	54	0	0	8	0	64	2
1993	0	0	0	5	0	0	0	72	0	0	13	36	126	5
1994	21	46	0	6	0	0	0	11	43	0	0	0	127	73
1995	0	18	0	15	25	0	0	0	0	0	0	5	63	58
1996	8	36	0	15	20	0	0	6	32	14	15	0	146	79
1997	30	29	0	0	0	0	0	2	0	0	5	0	66	59
1998	0	38	29	37	23	0	14	65	31	0	0	5	242	127
1999	18	240	52	42	31	6	4	75	47	8	43	0	566	389
2000	0	48	108	42	5	0	17	45	262	48	0	0	575	203
2001	32	167	75	74	5	119	49	1	5	101	4	1	633	472
2002	8	91	53	20	0	0	0	25	28	0	0	0	225	172
2003	0	279	13	6	0	0	0	15	10	11	2	1	337	298
2004	130	72	0	23	10	0	17	25	24	0	68	99	468	235
2005	106	37	10	17	72	75	17	5	88	95	5	24	551	317
2006	5	95	5	10	0	15	33	5	25	114	50	31	388	130
2007	71	10	105	101	10	5	14	64	127	25	54	0	586	302
2008	0	125	30	0	0	7	0	5	92	0	8	28	295	162
2009	139	41	5	15	0	24	41	33	5	15	0	0	318	224
2010	15	135	25	80	80	10	15	5	10	5	0	0	380	345
2011	25	46	77	242	0	40	80	14	25	5	0	0	554	430
2012	10	34	13	5	15	26	5	15	20	50	0	30	223	103
2013	24	295	138	56	96	20	0	35	137	64	5	0	870	629
2014	208	261	75	61	15	37	15	10	5	10	0	5	702	657
2015	83	174	51	66	27	0	5	5	160	50	0	0	621	401
2016	45	179	114	94	60	5	15	5	22	200	0	0	739	497

Table 4: Number of otolith samples for SOUT by fishing year and month, where September–August is a fishing year and January–April is totaled for the four-month totals. Years with at least 300 samples in the four-month totals are highlighted gold as this is the minimum number of samples required for ageing.

	Fishing month													
Fishing year	**S**	**O**	**N**	**D**	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**Total**	**Total (4 months)**
1991	0	0	0	0	22	13	0	0	7	0	0	0	42	35
1992	0	3	0	0	5	66	59	23	0	5	14	0	175	153
1993	6	33	0	15	0	82	259	139	11	0	0	23	568	480
1994	3	0	5	0	0	101	160	34	0	14	7	0	324	295
1995	14	0	0	0	6	90	103	25	0	0	0	0	238	224
1996	0	21	0	0	0	18	70	120	38	3	0	0	270	208
1997	37	25	0	0	37	1	15	84	0	0	0	0	199	137
1998	0	0	0	94	126	476	102	27	0	0	0	0	825	731
1999	0	5	0	42	35	323	528	109	1	0	0	0	1043	995
2000	12	122	5	0	185	550	419	16	33	38	0	0	1380	1170
2001	28	251	0	0	346	1020	777	73	6	53	0	0	2554	2216
2002	296	9	30	0	15	493	478	134	6	0	0	5	1466	1120
2003	33	16	25	9	264	264	332	184	35	49	0	0	1211	1044
2004	15	0	2	11	471	1005	500	122	0	5	0	0	2131	2098
2005	4	5	5	50	299	573	330	193	28	90	0	5	1582	1395
2006	0	0	59	131	183	490	504	177	90	20	10	0	1664	1354
2007	10	5	56	40	163	619	652	441	55	0	6	0	2047	1875
2008	5	50	40	0	40	442	161	226	25	0	0	0	989	869
2009	0	0	25	19	2	399	75	89	84	41	74	0	808	565
2010	0	5	15	0	104	90	139	82	317	48	30	0	830	415
2011	0	15	10	19	137	90	95	57	8	111	37	0	579	379
2012	0	40	15	0	16	182	112	120	30	10	5	0	530	430
2013	4	10	35	584	455	548	417	400	169	100	20	0	2742	1820
2014	15	53	275	317	245	347	199	78	25	29	0	0	1583	869
2015	15	104	6	268	440	191	240	226	75	0	0	0	1565	1097
2016	1	45	21	15	306	119	301	205	285	56	40	0	1394	931

In both WCHAT and SOUT from 1990–2016, most fish were less than 60 cm, with a dominant adult mode around 45–50 cm (Figure 11 and full length frequency plots scaled to catch in Appendix A). There are some modal progressions evident in SOUT from around 30 cm up to 50 cm, and some in WCHAT, with a period from 1999–2005 with no strong modes. Gavrilov's data (1979) from 1968–1976 showed much larger fish, with a mode in the mid-50s and many fish over 60 cm.



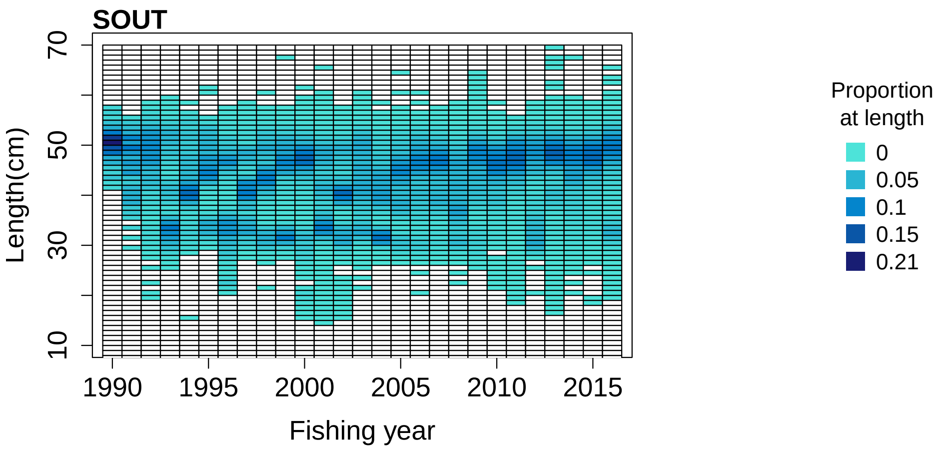


Figure 11: Proportion at length (not scaled to catch) for WCHAT and SOUT silver warehou fisheries from fishing years 1990–2016. Darker colour indicates a higher proportion for a given length for that year.

5.2. Catch and effort data sources

Catch and effort data were requested from the Ministry for Primary Industries catch-effort database '*warehou*' as extract 11156. The data consist of all fishing and landing events associated with a set of fishing trips that reported a positive landing of silver warehou in SWA 3 and 4 between 1 October 1989 and 30 April 2017, although the analyses cut out data later than 30 September 2016. The fishing year extends from October 1 through to September 30 of the next calendar year. In this report, fishing year is labelled as the most recent year (i.e., the 1998–1999 fishing year is referred to as 1999). Fields extracted were the same as those in McGregor (2016). The extracted data were groomed and restratified to derive the datasets required for the characterisation and CPUE following the process described in McGregor (2016). Resulting diagnostic figures and tables relating to this process are in Appendix C.

6. Descriptive analysis of catch

6.1. Summary of catches

Landed catches were often over the TAC in both SWA 3 and 4 from fishing years 1997 to 2008 after which the deemed values were increased, having an immediate effect (Figure 12). In fishing years 1990–1996 a large proportion of the landed catch from SWA 3 and 4 had Destination Code 'T' (transferred to another vessel) or 'R' (retained onboard) (Figure 13) and these were removed for this characterisation and CPUE analyses. The grey bars in Figure 13 correspond to the blue lines in Figure 12 (groomed catch-and-effort landings). The difference between the groomed catch-and-effort landings and QMR/MHR landings in Figure 12 are explained by the orange and blue bars (retained and trasferred landings, respectively) in Figure 13.

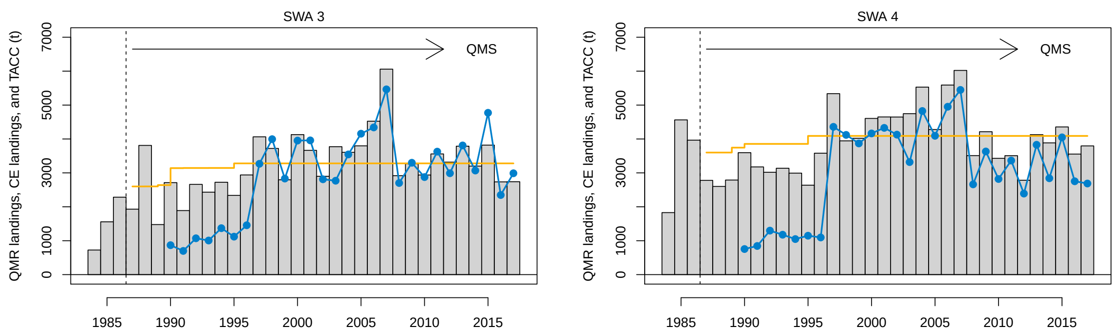


Figure 12: The QMR/MHR landings (grey bars), groomed catch effort landings (dotted blue line), and TACC (gold line) for SWA 3 and 4 from 1984 to 2016.

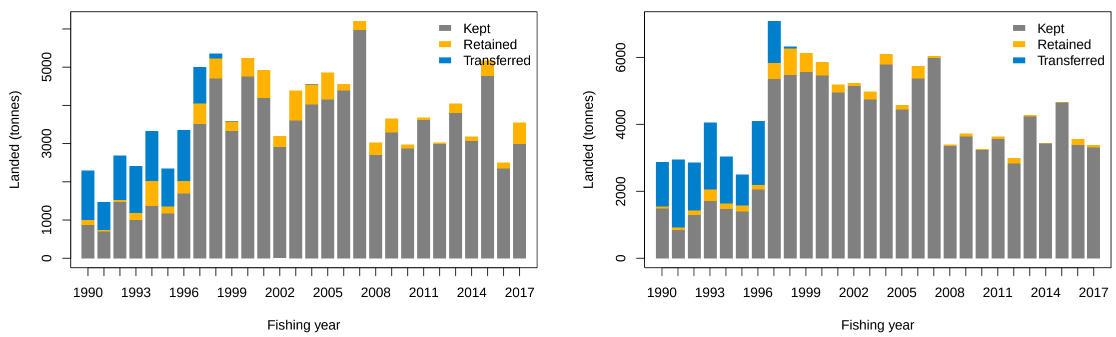


Figure 13: Groomed catch effort landings (grey bars), and dropped landings: transferred to another vessel (blue bars) and retained on board (orange bars) for SWA 3 (left) and 4 (right) from 1990 to 2016.

The estimated catches and retained landings by form type for both fish stocks are shown in Figures 14 and 15. For both stocks the bulk of estimated catches are recorded on TCEPR (with the landings recorded on the corresponding CLR forms), with a small proportion of catch recorded on CELR forms, presumably by smaller vessels fishing in inshore areas. In the 2008 fishing year, all vessels previously reporting SWA catch on CELR forms switched to TCER forms. In SWA 3, this corresponded with an increase in TCER-recorded catches, although most catches were still recorded on TCEPR forms (Figure 14 right). In SWA 4, there has been little to no catch recorded on CELR forms.

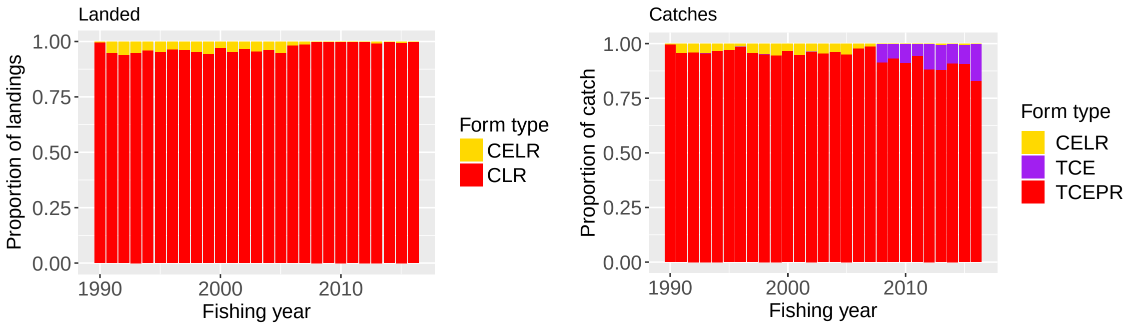


Figure 14: Proportion of SWA 3 landings by form type (left) in the groomed and unmerged dataset, and proportion of estimated catches by form type (right) in the groomed and merged dataset, for SWA 3 from the 1990 to 2016 fishing year. TCE=TCER.

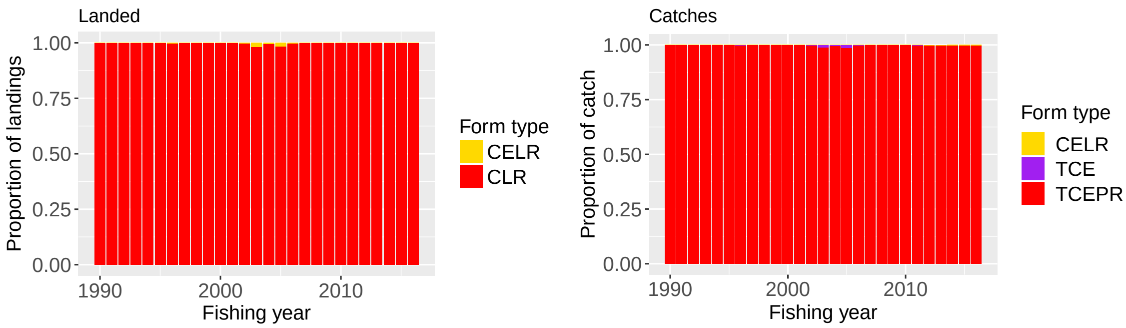


Figure 15: Proportion of SWA 4 landings by form type (left) in the groomed and unmerged dataset, and proportion of estimated catches by form type (right) in the groomed and merged dataset, for SWA 4 from the 1990 to 2016 fishing year. TCE=TCER.

6.2. Fishery summary

The remainder of the analyses focus on SOUT and WCHAT (as defined in Figure 5) separately. Spatial distributions of the catches were mentioned in Section 3.1, and the full set of figures are in Appendix B.

6.2.1. WCHAT

Silver warehou catches from WCHAT have predominantly been from hoki, silver warehou or squid target fishing (Figure 16). The catches from hoki and squid target fishing reduced when deemed values increased from the 2008 fishing year onwards, and the catch from silver warehou target fishing increased.

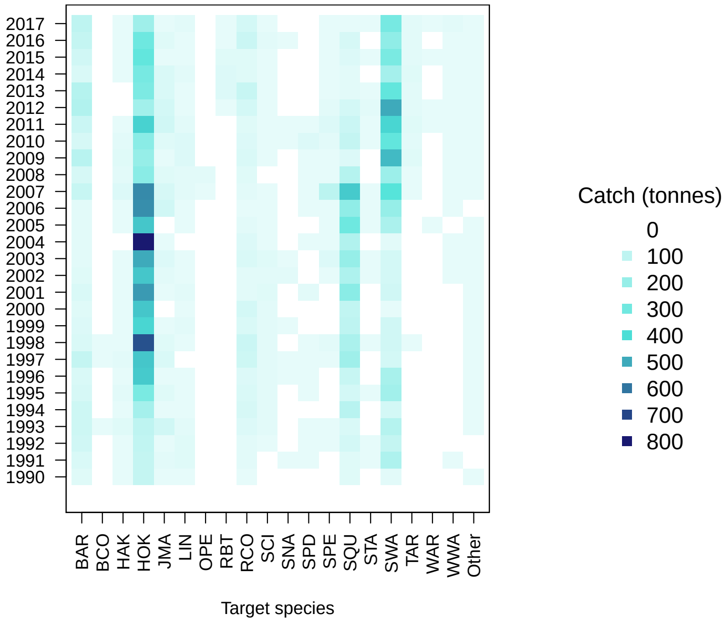


Figure 16: Catch (tonnes) from WCHAT by target species and fishing year from 1990–2016.

Catch by fishing month and year shows that more silver warehou were caught in late Autumn/early Winter in 2005–2007 than these months in the other years. In the other years, September–December were the main months for silver warehou catch in WCHAT (Figure 17). We compared the data from the year-month combinations that appeared to have unusually high catches (May, June and July 2007, June 2006 and May 2005) to the full dataset. Within this high year-month test subset, there was a higher proportion of catch from squid target than within the full dataset, and a higher proportion of the catch was from Korean vessels (Figure 18).

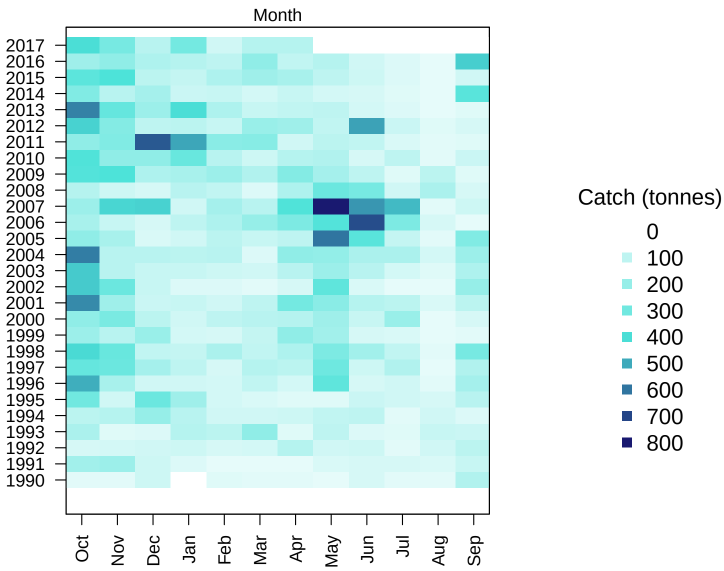


Figure 17: Catch (tonnes) from WCHAT by fishing month and fishing year from 1990–2016.

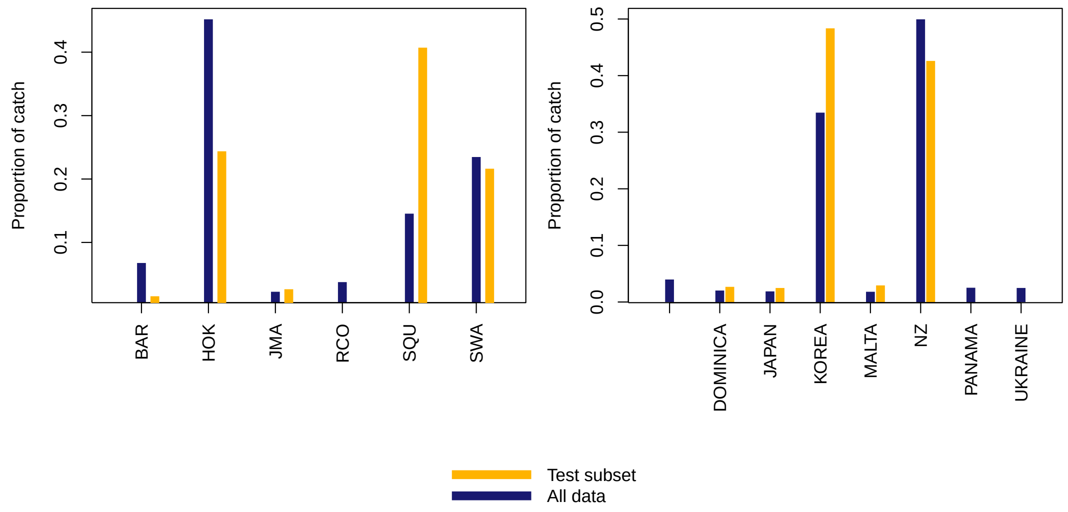


Figure 18: Proportion of catch by target (top left) and vessel nationality (top right) for test subset consisting of data from May, June and July 2007, June 2006 and May 2006 (orange bars) and all months and fishing years 1990–2016 (midnight blue).

There appear to be some spatial dynamics within this fishery that may be influential for CPUE (catch per unit effort). We assigned catches to a 1 degree longitude by 0.5 degree latitude grid (Figure 19). Catches were most concentrated in the grid cells that run along the ridge off ECSI (grid cells 12, 23, 34 and 44, which are marked with symbols that match the grid overlaid on the map (left figure) to the heatmap (right figure)). There seems to have been a shift south from the mid-2000s, with catches less likely from the northernmost of these grid cells (grid cell 44) from 2006 onwards.

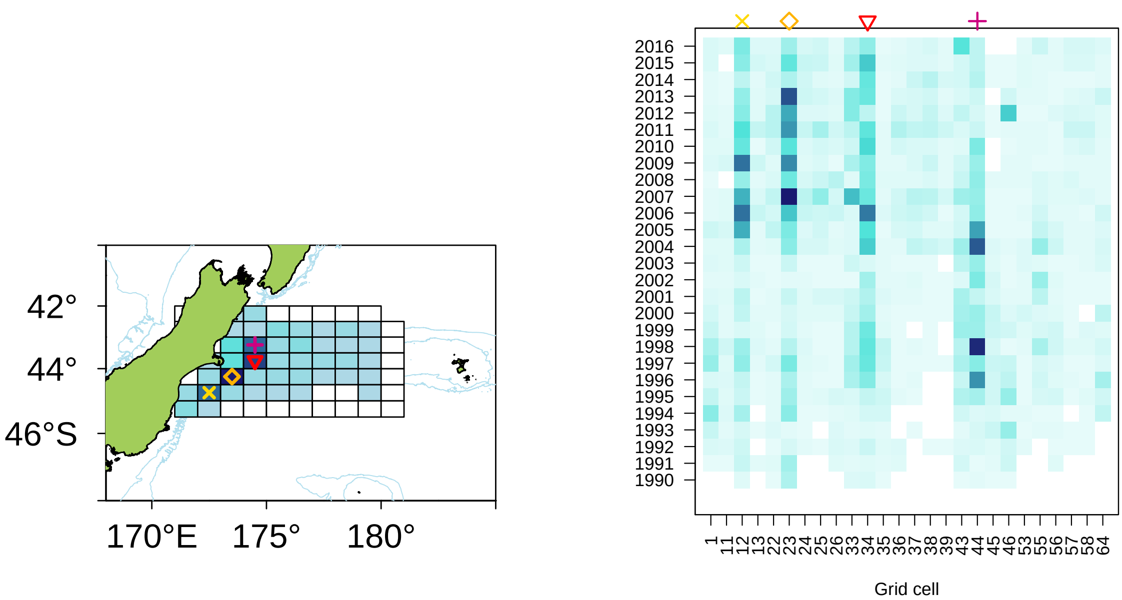


Figure 19: Catches from WCHAT fishing years 1990–2016 by grid cell (left) and by grid cell and fishing year (right). Grid cells with highest catches are marked with symbols that match the grid overlaid on the map (left) to the heatmap (right).

Fishing method was mostly BT (Bottom trawl), from New Zealand or Korean vessels, with increased catch from Korean vessels from 2007, and generally from 60–70 m vessels (Figure 20). The 2007 fishing year stands out as having more catch than the other years —from 70 m vessels that were bottom trawling and of New Zealand or Korean nationality. This was the final year before the increase in deemed values, which came into effect at the start of the 2008 fishing year.

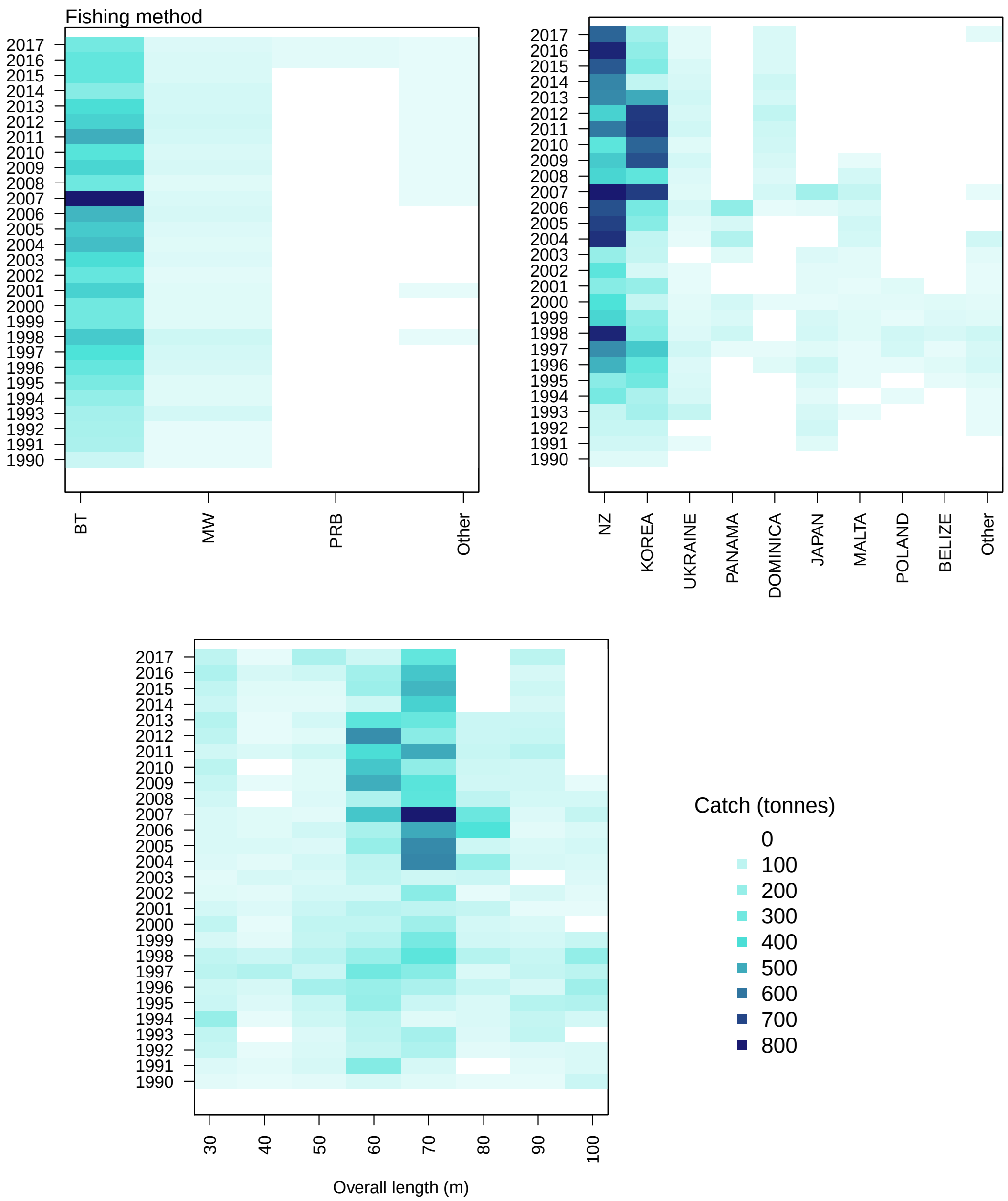


Figure 20: Catch (tonnes) from WCHAT by method (top left), vessel nationality (top right) and vessel length (bottom) from fishing years 1990–2016.

6.2.2. SOUT

Silver warehou catches from SOUT have predominantly been from squid or silver warehou target fishing (Figure 21). The catches from squid target fishing were most variable by fishing year, with high catch years and low catch years. There has been a much smaller amount of catch from hoki target fishing, mostly in the 2000s. Catches by month varied by year, but were generally highest from January–May (Figure 22).

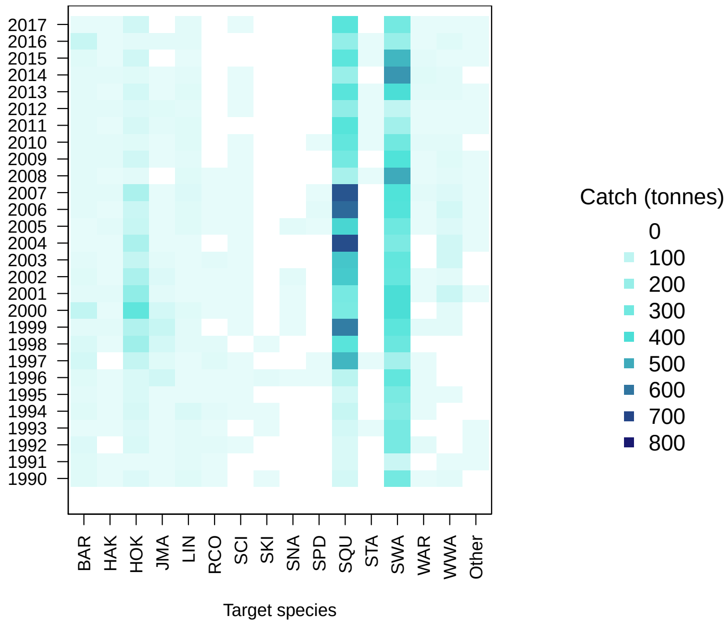


Figure 21: Catch (tonnes) from SOUT by target and fishing year from 1990–2016.

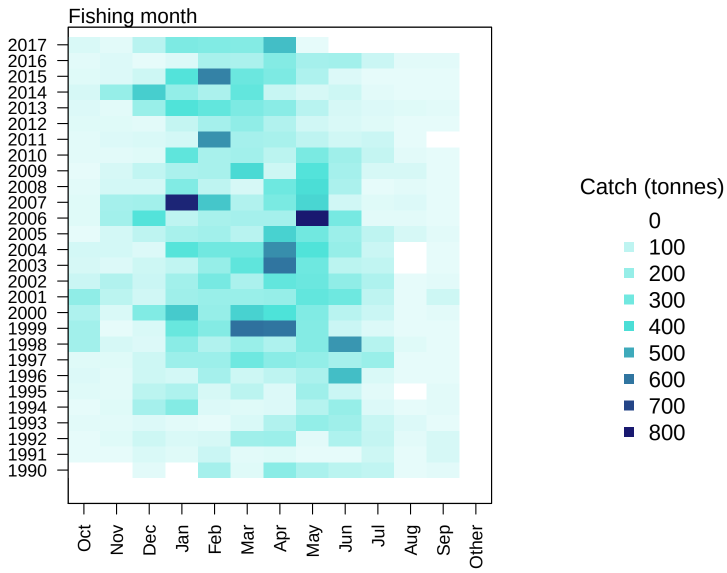


Figure 22: Catch (tonnes) from SOUT by fishing month and fishing year from 1990–2016.

The fishing method was mainly BT (Bottom trawl), from Korean or Japanese vessels of 60–70 m length, with increased catch from 60 m vessels from 2006 onwards, and a decrease from 70 m vessels after 2008 (Figure 23). The 2007 fishing year stands out as having more catch than the other years from Korean vessels. This was the final year before the increase in deemed values, which came into effect at the start of the 2008 fishing year.

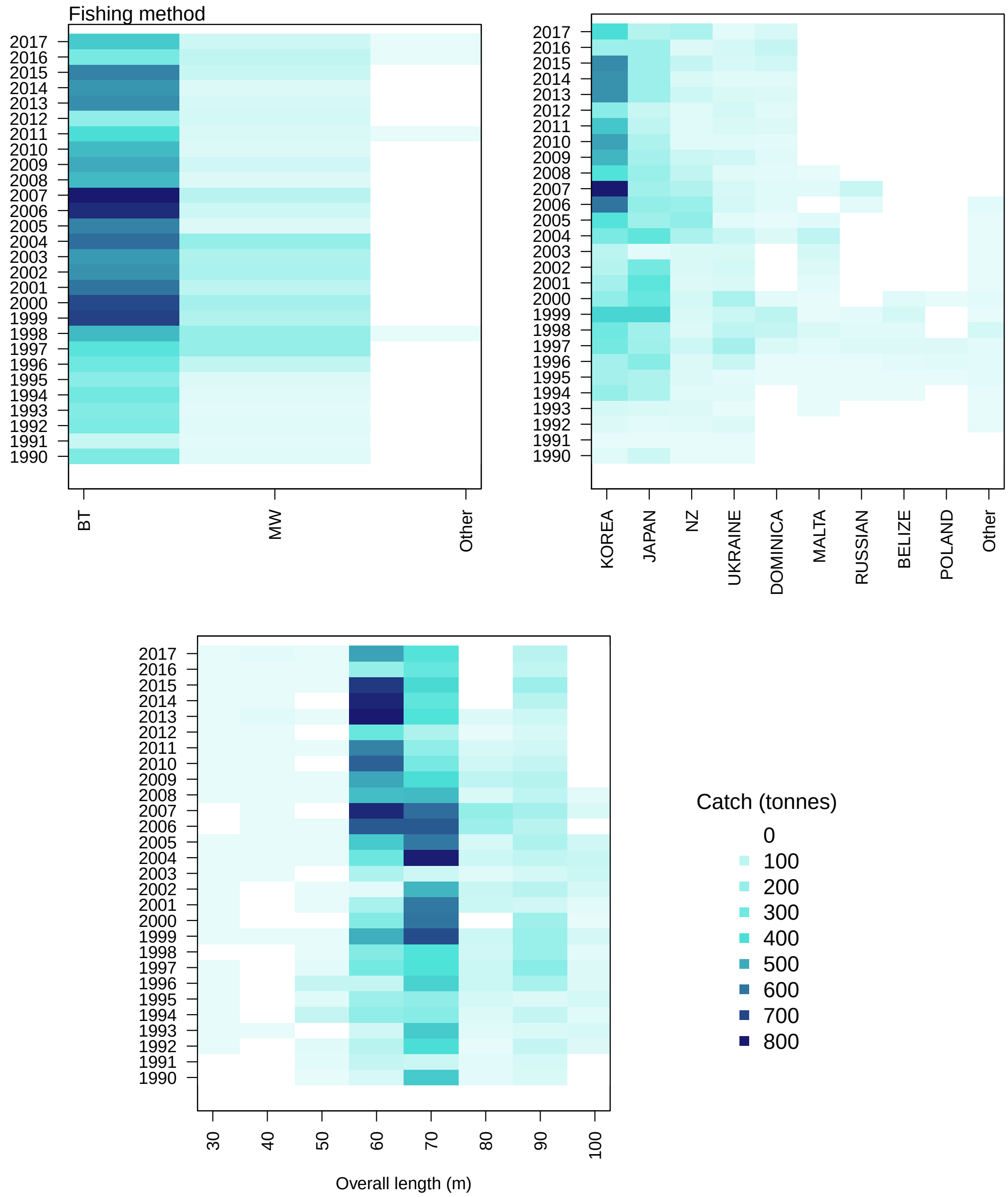


Figure 23: Catch (tonnes) from SOUT by method (top left), vessel nationality (top right) and vessel length (bottom) from fishing years 1990–2016.

We assigned catches to a 1 degree longitude by 0.5 degree latitude grid (Figure 24). The greatest catch overall was from the grid cell south of the Snares Islands, and catch was generally greatest in this cell, and to the northeast along the Snares shelf .

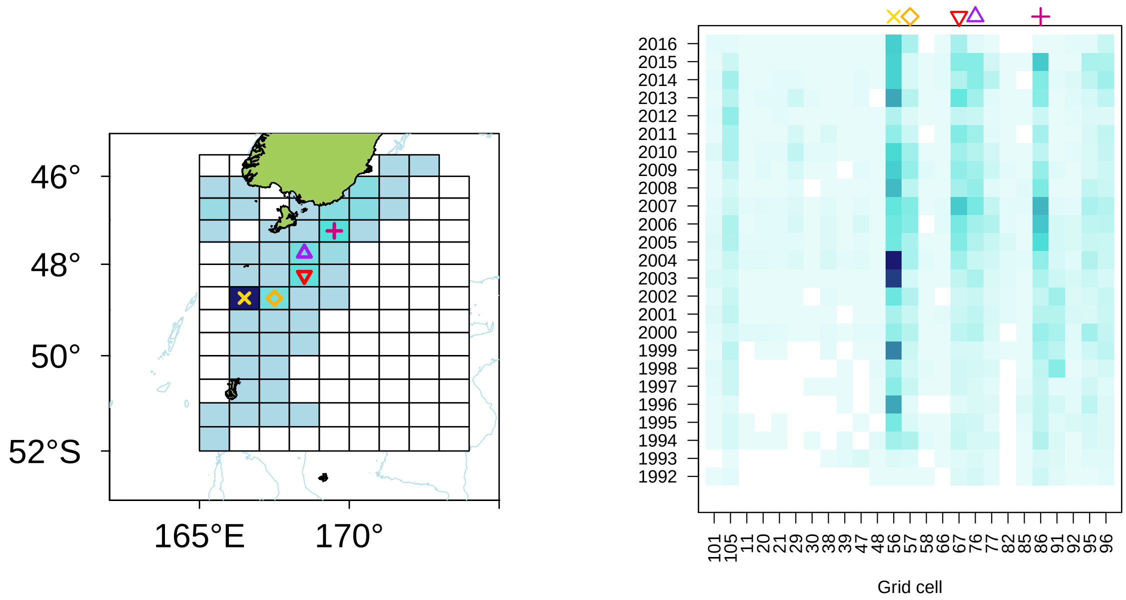


Figure 24: Catches from SOUT fishing years 1990–2016 by grid cell (left) and by grid cell and fishing year (right). Grid cells with highest catches are marked with symbols that match the grid overlaid on the map (left) to the heatmap (right).

7. CPUE

7.1. WCHAT

7.1.1. Core data selection

Of the 223 vessels that caught silver warehou from WCHAT in fishing years 1990 –2016, 65 (29%) only caught silver warehou in one year (Figure 25), thus not having any between-year overlap to contribute to the CPUE. Selecting core vessels as those with at least one tonne of silver warehou catch in at least three fishing years retains most of the catch and effort, although a lower proportion of vessels, as expected (Figure 26).

The core data selected retained 77% of the catch, 69% of the effort (tows) and 42% of vessels (Table 5). The biggest loss in these was in the early part of the series, prior to 1996. Figures 27–29 show the core dataset catches overlaid on the full dataset by fishing month, target species and statistical area, with a good match between them.

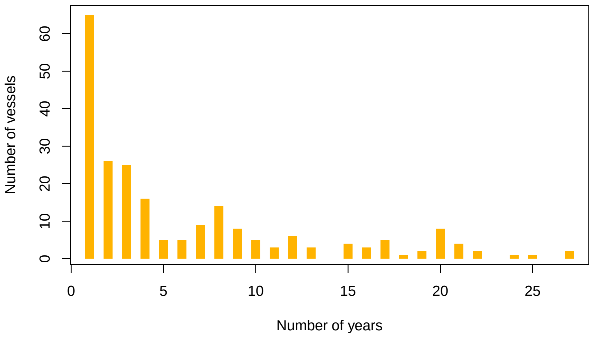


Figure 25: Number of vessels with silver warehou catch from WCHAT in a given number of years within fishing years 1990–2016.

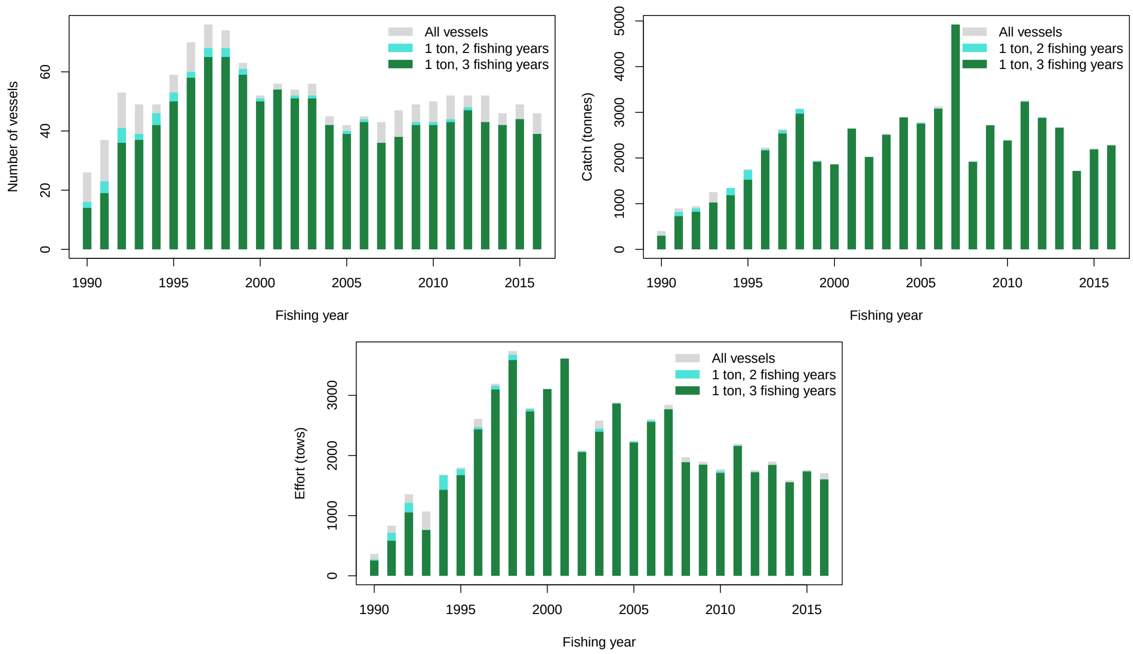


Figure 26: Numbers of vessels (top left), catch (top right), and effort (bottom) for the full WCHAT dataset (grey bars), dataset restricted to vessels with at least one tonne of silver warehou landings in at least 2 fishing years (aqua bars), and at least 1 tonne in at least 3 fishing years (green bars) for fishing years 1990–2016.

Table 5: Catch, effort (number of tows), and number of vessels retained at each step of selection for the core WCHAT dataset.

		% retained		
Variable	**Values retained**	**Catch**	**Effort**	**Vessels**
Vessels	$\geq$1 tonne in $\geq$ 3 years	98	95	49
Method	BT	90	89	46
Fishing month	*all*	90	89	46
Target species	HOK, SQU, SWA, BAR, RCO	86	78	43
Statistical area	020, 021, 022, 023, 024, 401, 402, 407, 408	77	69	42

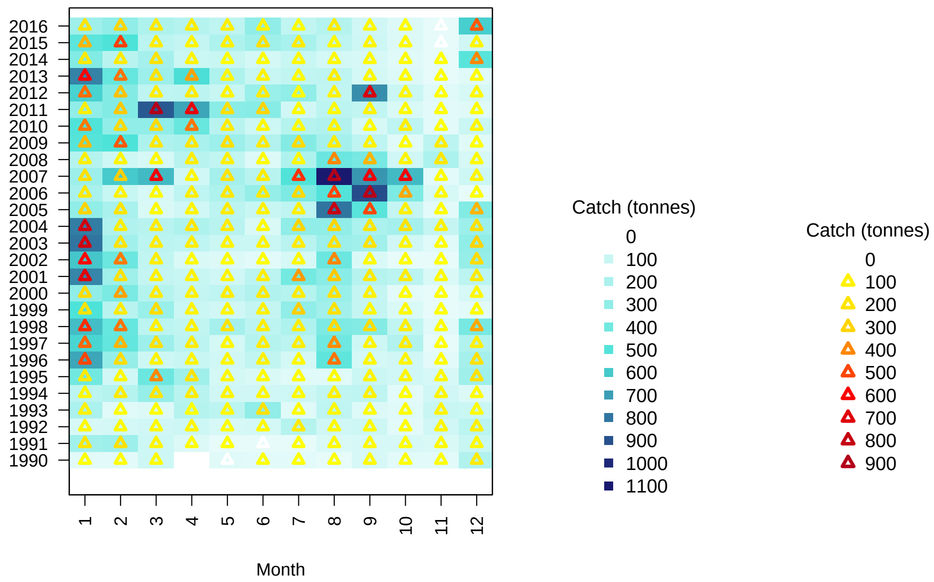


Figure 27: Catch by fishing month and year for WCHAT including all vessels (blue cells) and core vessels (yellow–red symbols).

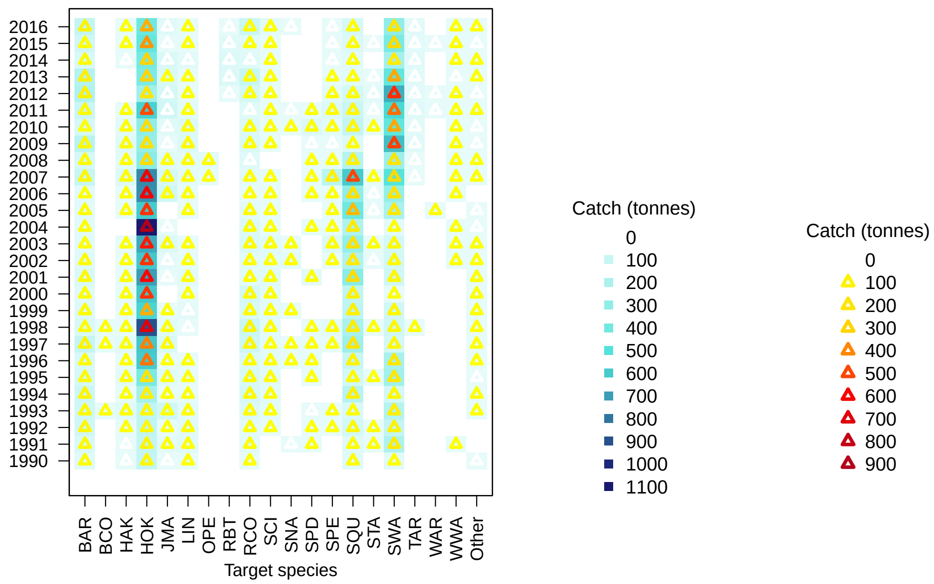


Figure 28: Catch by target and year for WCHAT including all vessels (blue cells) and core vessels (yellow–red symbols).

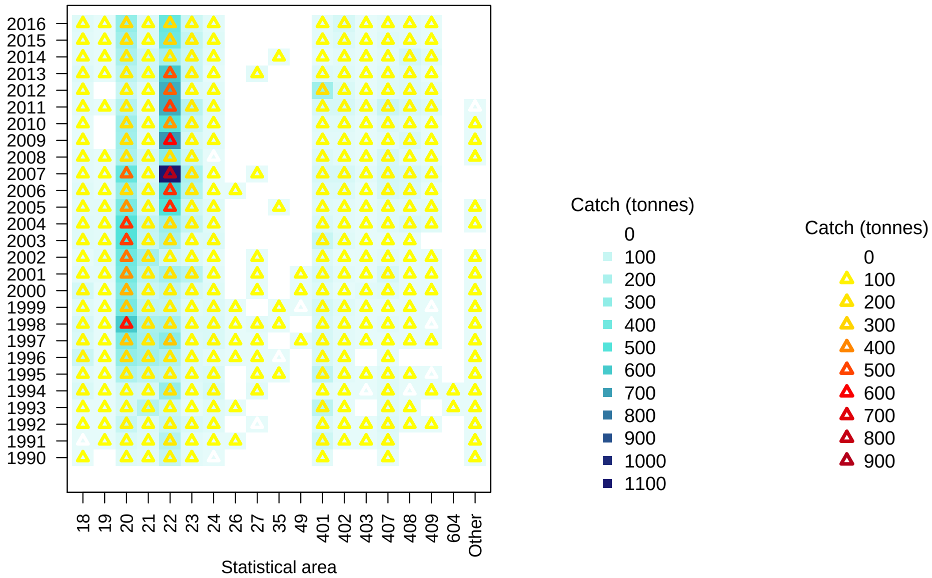


Figure 29: Catch by statistical area and year for WCHAT including all vessels (blue cells) and core vessels (yellow–red symbols).

7.1.2. CPUE model

An initial CPUE model was fitted using a stepwise multiple regression method (explained in McGregor (2016)) with variables fishing year (forced), vessel, grid cell, target species, fishing month, fishing duration, depth, effort width, effort height, fishing distance, start latitude, start longitude, and fishing start time offered, and a stopping rule of 1%. The resulting model used explanatory variables fishing year, vessel, target species, depth, and grid cell (Table 6). Residuals against fitted values and residuals against quantiles of the standard normal distribution show that the assumptions of homoscedasticity and normality of errors in log-space are sufficiently met (Appendix D). The resulting indices as each explanatory variable is added are in Figure 30. The additional variables after ‘Year’ (fishing year) bring the initial part of the series down, and raise the last part a little, but have little effect from 1996–2013. Influence plots show additional vessels coming into the fishery from the late 1990s, and a few dropped out from the early 2000s, with a high influence (which pulls the standardised CPUE down) in the early part of the series and a low influence (taking the standardised CPUE up) in the latter part (Figure 31). Target species influence was high in the latter part of the series, bringing the CPUE down, although as it is added after vessel in the full model, it remains higher than the $lcpue \sim Year$ model (Figures 30 and 31). There is little temporal trend in fishing month and grid cell effects. A delta model was fitted to the probability of non-zero silver warehou catches. The resulting index was generally flat (Figure 32). This model selected explanatory variables vessel, month, depth, longitude, target species, had fishing year forced, and explained 18% of the null deviance.

Table 6: Variables selected for WCHAT initial CPUE model with r^2 values.

Variable	r^2
Fishing year	3.37
Vessel	12.63
Target species	16.64
Fishing month	19.06
Depth	20.23
Grid cell	21.25

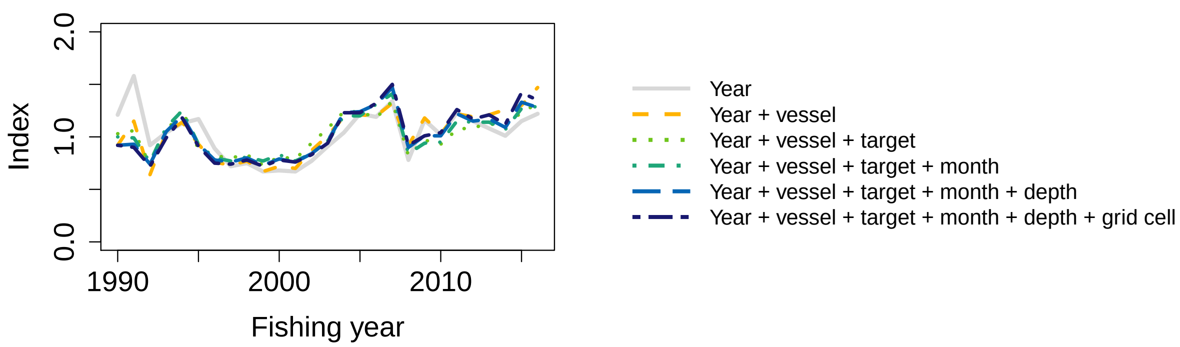


Figure 30: WCHAT initial CPUE showing the index as each explanatory variable is added.

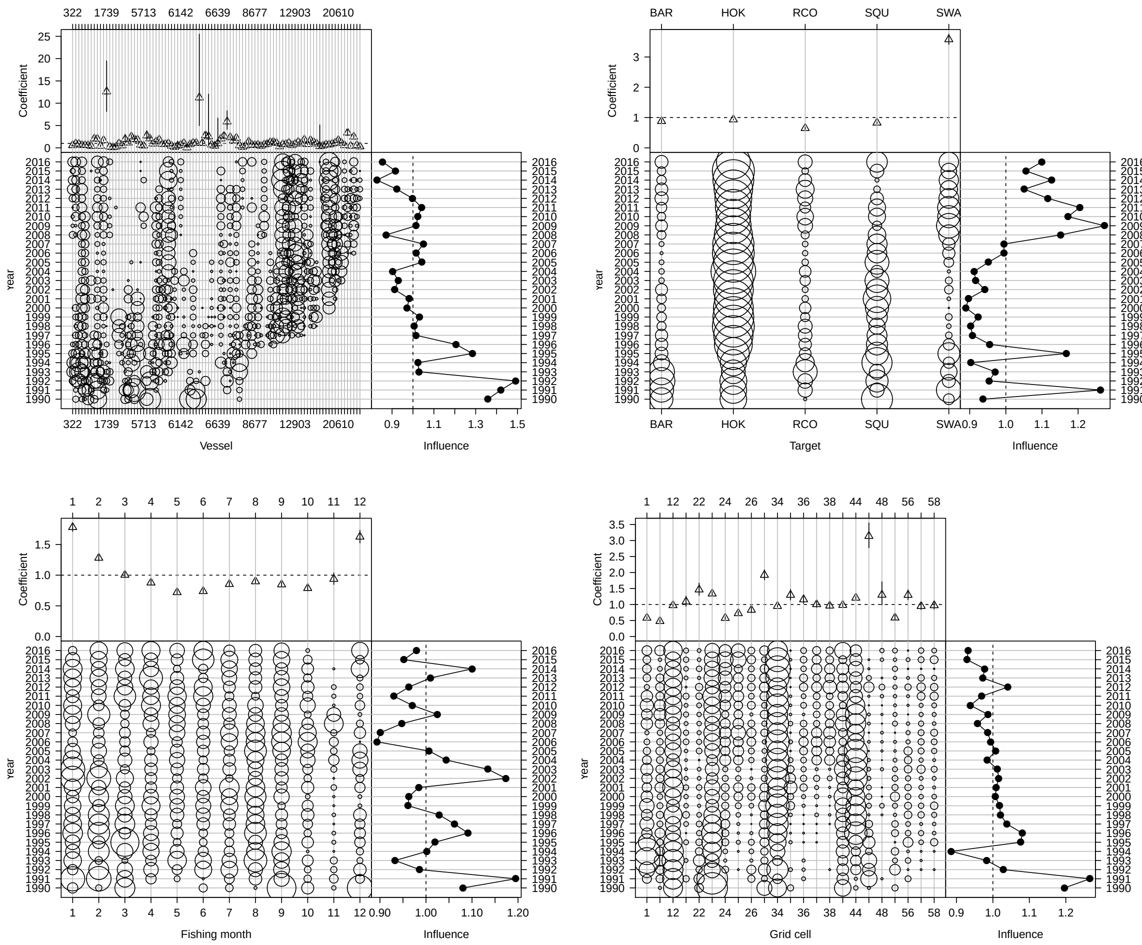


Figure 31: Influence plots for explanatory variables vessel (top left), target species (top right), fishing month (bottom left), and grid cell (bottom right) for the WCHAT initial model.

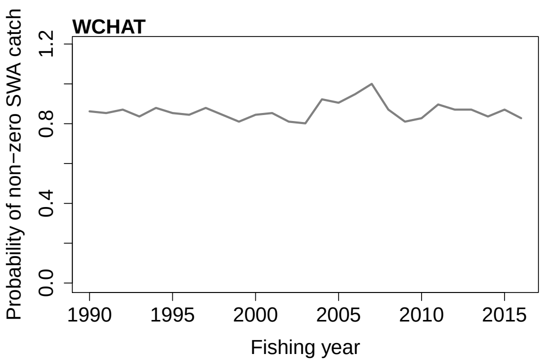


Figure 32: WCHAT delta model for the probability of non-zero silver warehou catches.

7.1.3. Sensitivity analyses and alternative models

We tried several sensitivity analyses and alternative models, largely focused on testing the increase in CPUE up until 2008 which is followed by a sudden drop, as this coincides with the increase in deemed values that came into effect at the start of the 2008 fishing year. The models explored are summarised in Table 7, and Figure 33 shows comparisons of the resulting indices. In all alternative models, including those fitted to observer data, there was a drop in 2008. In most models (exceptions were the 'all grid cells except top 4', and all observer models), there was a general increase from 2000 or just after up until the 2008 drop. The 'all grid cells except top 4' index is generally flat, as are the observer indices, although these have a very slight upward trend.

Table 7: WCHAT CPUE models with variables selected and final r^2.

Description	**Variables**	r^2	$\Uparrow$ **before 2008**	$\Downarrow$ **2008**
Grid cell: fishing month interaction	vessel, target, month, depth, grid cell, month:grid cell	24.54	✓	✓
Depth > 200 m	vessel, target, month, depth, grid cell, month:grid cell	24.41	✓	✓
Exclude spawning months (Sep–Nov)	vessel, target, grid cell	20.57	✓	✓
Only main grid cell (cell 34)	vessel, month, depth, target	24.17	-	✓
Only top 4 grid cells	vessel, target, month, depth	19.23	✓	✓
All cells except top 4	grid cell, vessel, target, fishing duration	19.38	-	✓
Exclude vessels not in ≥2008	vessel, target, month, grid cell, month:grid cell	25.16	✓	✓
Depth:target interaction	vessel, target, month, target:depth	20.64	✓	✓
No vessel effect	target, month, effort width, grid cell, depth, month: grid cell	21.27	✓	✓
Split the series at 2008				
1990–2007	vessel, month, target, grid cell, target:depth, month:grid cell	23.62	✓	NA
2008–2016	vessel, target, grid cell, month, grid cell:month, target:grid cell	34.14	NA	✓
Observer CPUE				
Initial	vessel, grid cell, target, month	51.25	✓	✓
Main grid cell	vessel, month, target, longitude, latitude	59.40	✓	✓
Top 4 grid cells	vessel, target, month	56.10	✓	✓
All cells except top 4	grid cell, vessel, target, fishing duration	19.38	-	✓

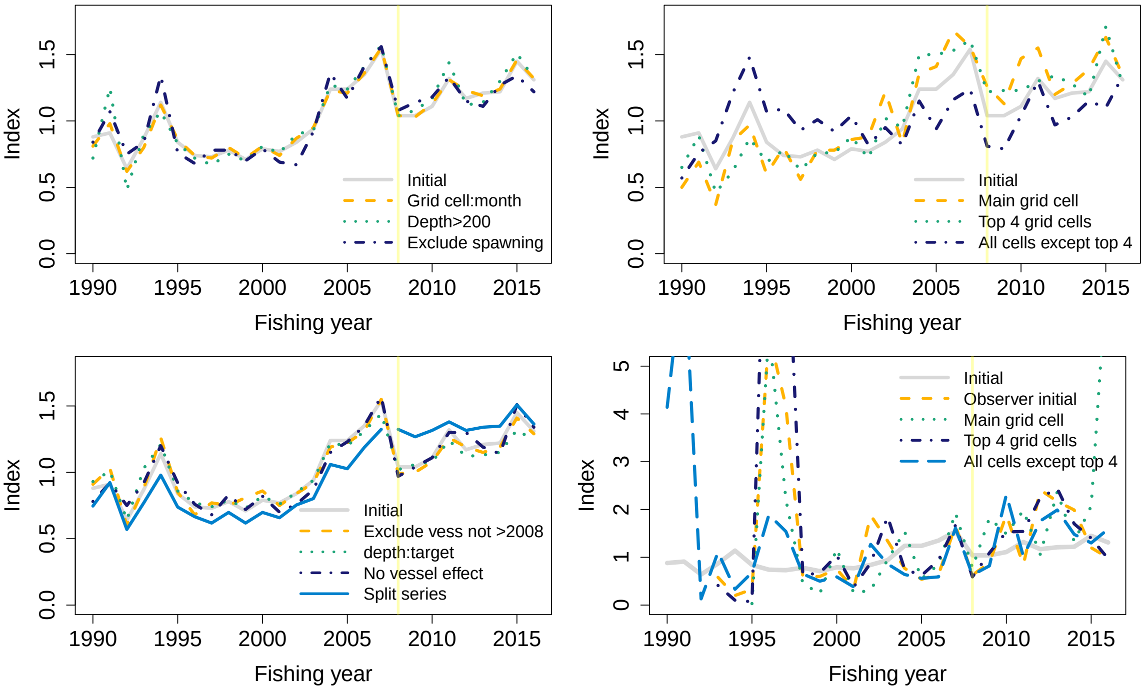


Figure 33: CPUE indices for all models described in Table 7.

7.2. SOUT

7.2.1. Core data selection

Of the 231 vessels that caught silver warehou from SOUT in fishing years 1990–2016, 79 (34%) only caught silver warehou in one year (Figure 34), thus not having any between-year overlap to contribute to the CPUE. Selecting core vessels as those with at least one tonne of silver warehou catch in at least three fishing years retains most of the catch and effort, although a lower proportion of vessels, as expected (Figure 35).

The core data selected retained 90% of the catch and 84% of the effort (tows) (Table 8). Figures 36–38 show the core dataset catches overlaid on the full dataset by fishing month, target species and statistical area, with a good match between them.

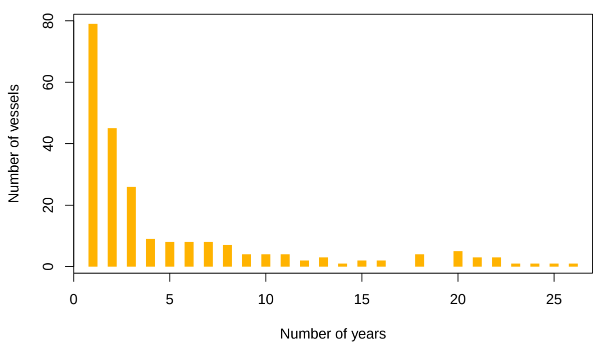


Figure 34: Number of vessels with silver warehou catch from SOUT in given number of years within fishing years 1990–2016.

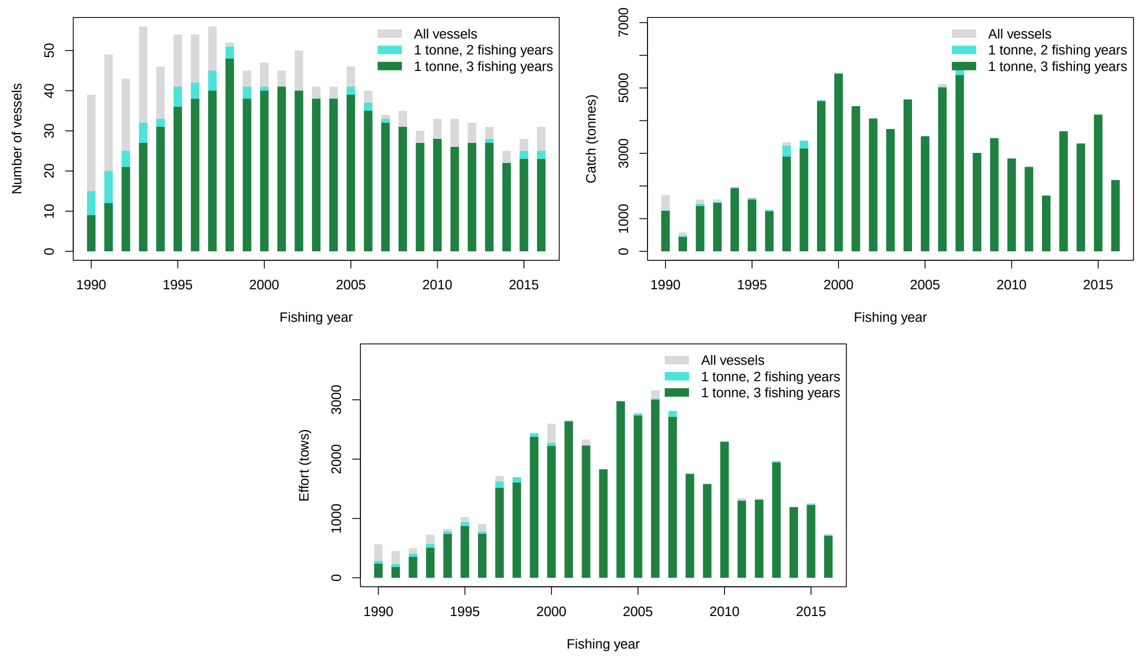


Figure 35: Numbers of vessels (top left), catch (top right), and effort (bottom) for the full SOUT dataset (grey bars), dataset restricted to vessels with at least one tonne of silver warehou landings in at least 2 fishing years (aqua bars), and at least 1 tonne in at least 3 fishing years (green bars) for fishing years 1990–2016.

Table 8: Catch, effort (number of tows), and number of vessels retained at each step of selection for the core SOUT dataset.

Variable	Values retained (or criteria)	% total catch retained	% total effort retained
Vessels	$\geq$1 ton in $\geq$ 3 years	97	96
Method	BT	92	88
Fishing month	*all*	92	88
Target species	SQU, HOK, SWA, LIN, WWA, BAR	90	86
Statistical area	026, 027, 028, 030, 504, 602	090	084

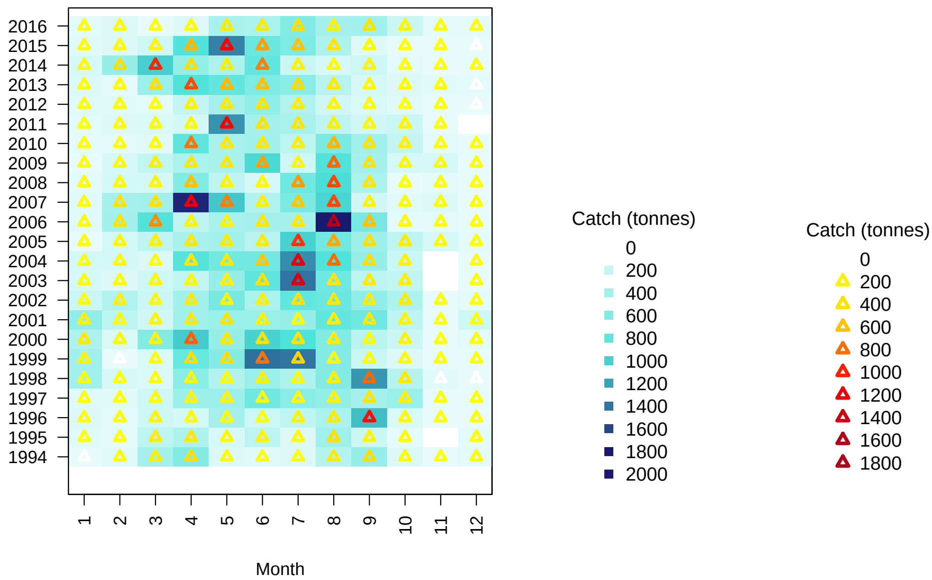


Figure 36: Catch by fishing month and year for SOUT including all vessels (blue cells) and core vessels (yellow–red symbols).

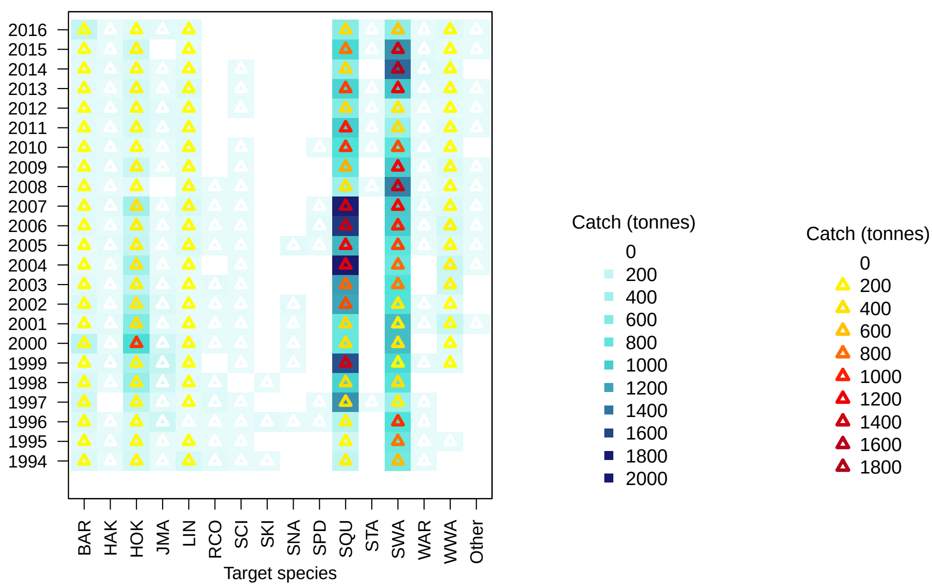


Figure 37: Catch by target and year for SOUT including all vessels (blue cells) and core vessels (yellow–red symbols).

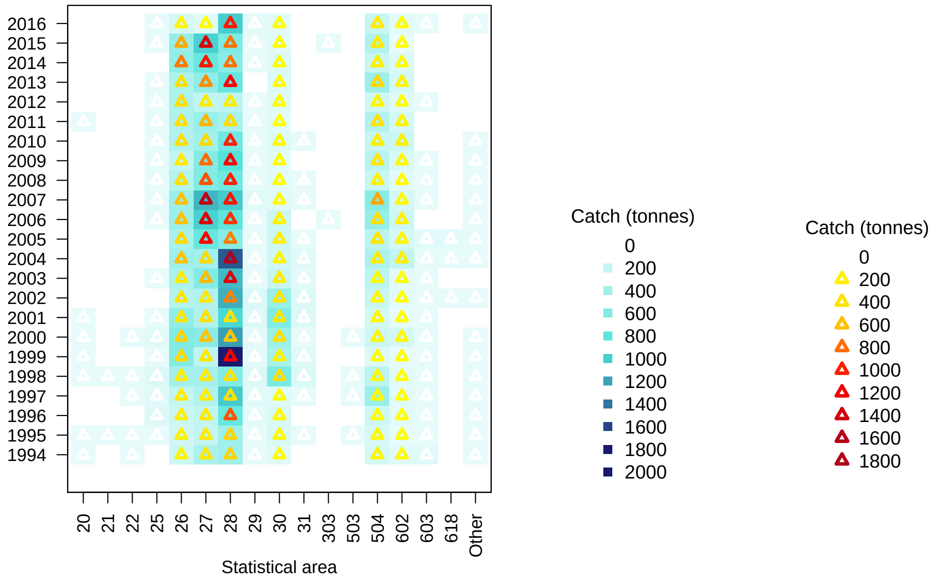


Figure 38: Catch by statistical area and year for SOUT including all vessels (blue cells) and core vessels (yellow–red symbols).

7.2.2. CPUE model

An initial CPUE model was fitted using a stepwise multiple regression method (explained in McGregor (2016)) with variables fishing year (forced), vessel, grid cell, target species, fishing month, fishing duration, depth, effort width, effort height, fishing distance, start latitude, start longitude, and fishing start time offered, and a stopping rule of 1%. The resulting model used explanatory variables fishing year, grid cell, target species, and vessel (Table 9). Residuals against fitted values and residuals against quantiles of the standard normal distribution show that the assumptions of homoscedasticity and normality of errors in log-space are sufficiently met (Appendix D). The resulting indices as each explanatory variable is added are in Figure 39. The grid cell and target species lowered the initial part of the series, and vessel had little effect. Influence plots show additional vessels coming into the fishery from the late 1990s through to the mid-2000s. The first three years (1994–1996) had a large vessel influence, which brought the standardised CPUE down. Target species also had a large influence in these years from a high proportion of effort that was silver warehou target (Figure 40). Grid cell had a large influence in the first five years (1994–1998), which seems to be from an absence of effort in grid cells 11–47. Effort increased in these cells from 2000. A delta model was fitted to the probability of non-zero silver warehou catches. The resulting index was generally flat (Figure 41). This model selected explanatory variables target species, vessel, latitude, depth, had fishing year forced, and explained 26% of the null deviance.

Table 9: Variables selected for SOUT initial CPUE model with r^2 values.

Variable	r^2
Grid cell	19.89
Target species	28.65
Vessel	33.62

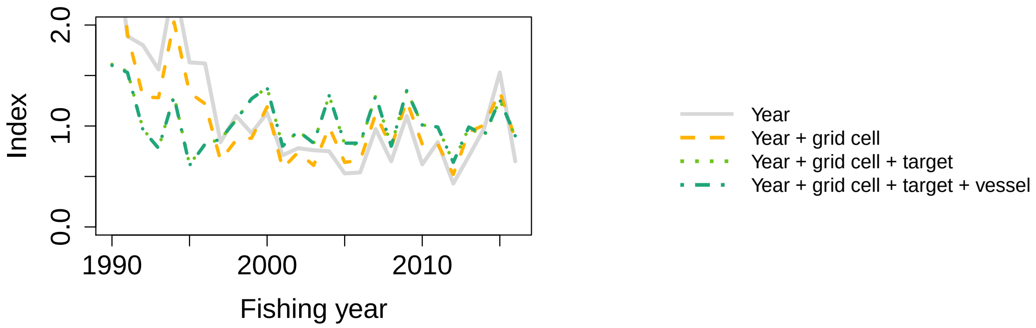


Figure 39: SOUT initial CPUE showing the index as each explanatory variable is added.

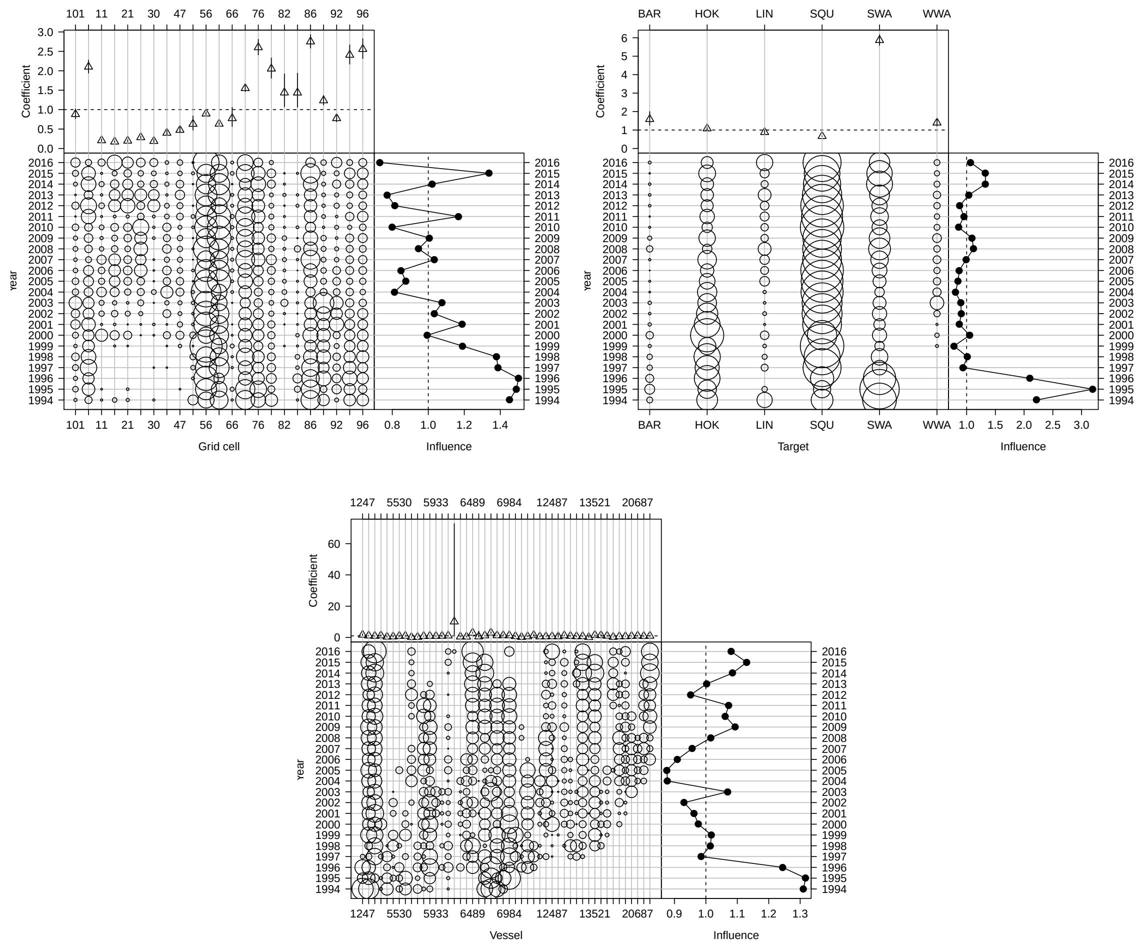


Figure 40: Influence plots for explanatory variables grid cell (top left), target species (top right), vessel (bottom), for SOUT initial model.

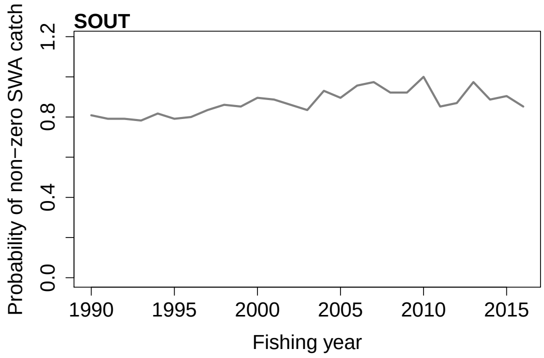


Figure 41: SOUT delta model for the probability of non-zero silver warehou catches.

7.2.3. Sensitivity analyses and alternative models

We tested for spatial and temporal interaction effects with target species by offering interaction terms grid cell:month, target:month, depth:target, and grid cell:target. Only grid cell:target was selected, and this produced very little effect. We evaluated the effect of subsets of the fishery contributing to most of the catch spatially (focus grid cell: 56), temporally (focus months: February–April), and by target species (focus target: squid). The resulting indices were similar to each other and the base CPUE from the late 1990s. The 'grid cell 56' and 'squid target' indices started higher in 1994 followed by an initial decline that is not present for the other indices (Figure 42). The observer CPUE was very similar from late 1990s, but started much lower in 1994, followed by an initial increase (Figure 42).

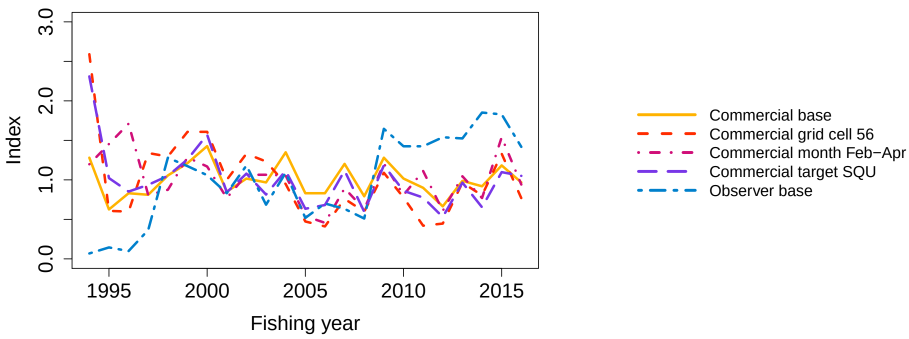


Figure 42: CPUE indices for alternate SOUT data subsets, where 'Commercial' refers to CPUE models fitted to commercial catch and effort data, and 'Observer' used observer data.

8. Summary and recommendations

We remain uncertain about stock structure, with current definitions based on suggested spawning locations and timings and distribution of the fishery. Further, it is uncertain whether the same stock migrates from one area to another, spawning whenever conditions are appropriate, or if there are several separate stocks. The current management boundaries bear little relation to known spawning areas and silver warehou distribution, which is why the current analyses adopted the WCHAT and

SOUT area definitions.

Length frequency distributions are variable among years. The available catch-at-age distributions also appear to vary between years, but as there are so few available and they are several years apart, this is difficult to assess. There is good sampling coverage for both the WCHAT and SOUT fisheries, with sufficient otoliths collected to support catch-at-age analyses for many years.

Silver warehou grow quickly, reaching adult size within the first 4–5 years. They also school by size. The combination of these two attributes can produce variable catch-at-age distributions for the young age classes as they are prone to 'hit-and-miss'. While a school of adult-sized fish may include several year classes, and hence provided a more representative sample for the catch-at-age, a school of juvenile fish is likely to only include one year class. This makes it more crucial to analyse the ages of multiple years, preferably consecutive, if we are to understand patterns and dynamics in between-year recruitment variability. The Australian silver warehou stock assessment makes use of catch-at-age distributions from every year from 1988 to the present day (Day et al., 2015).

The absence of strong modes in the length frequency distributions for WCHAT from 1999–2005 could indicate several strong recruitment years resulting in flattening of the length distributions. This would support an increasing CPUE, suggesting that the 2000–2008 increase that persisted through all alternative CPUE models may be an increase in abundance.

The drop in CPUE in WCHAT that corresponds with the increase in deemed values in 2008, remains unresolved. It is possible there was a coincidental drop in abundance at the time, although it seems more likely that the drop reflects a change in fishing behaviour that has not been accounted for in standardisation. The CPUE can still be used as an index of abundance for a stock assessment, but the CVs (coefficient of variation) should be increased for years 2006, 2007, and 2008.

The size-at-depth distributions of silver warehou seem to have changed by year, and it is difficult to determine from these analyses whether it is a change in fish behaviour or fishing behaviour. The 2001 fishing year showed more young fish in deep water, and the 2013 and 2016 years had more old fish in shallow water. These dynamics are likely to impact on the appropriate structure of a stock assessment model, and may affect CPUE. With the current limited catch-at-age data available, it is unlikely that further analyses will provide much more knowledge beyond speculation. Hence, it is recommended that more otoliths from more years be aged. Following this, detailed analyses of the age distributions with respect to space, depth, time and fishery should be conducted.

The SOUT CPUE is generally flat, but does consist of small increases and decreases. At least some of the increases seem to follow from modes of small fish in the length frequency distributions. Catch-at-age distributions may be able to verify the existence of recruitment pulses.

In both WCHAT and SOUT the CPUE has remained flat or increasing while catches have remained high.

9. Acknowledgements

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Appendix A: Length frequencies

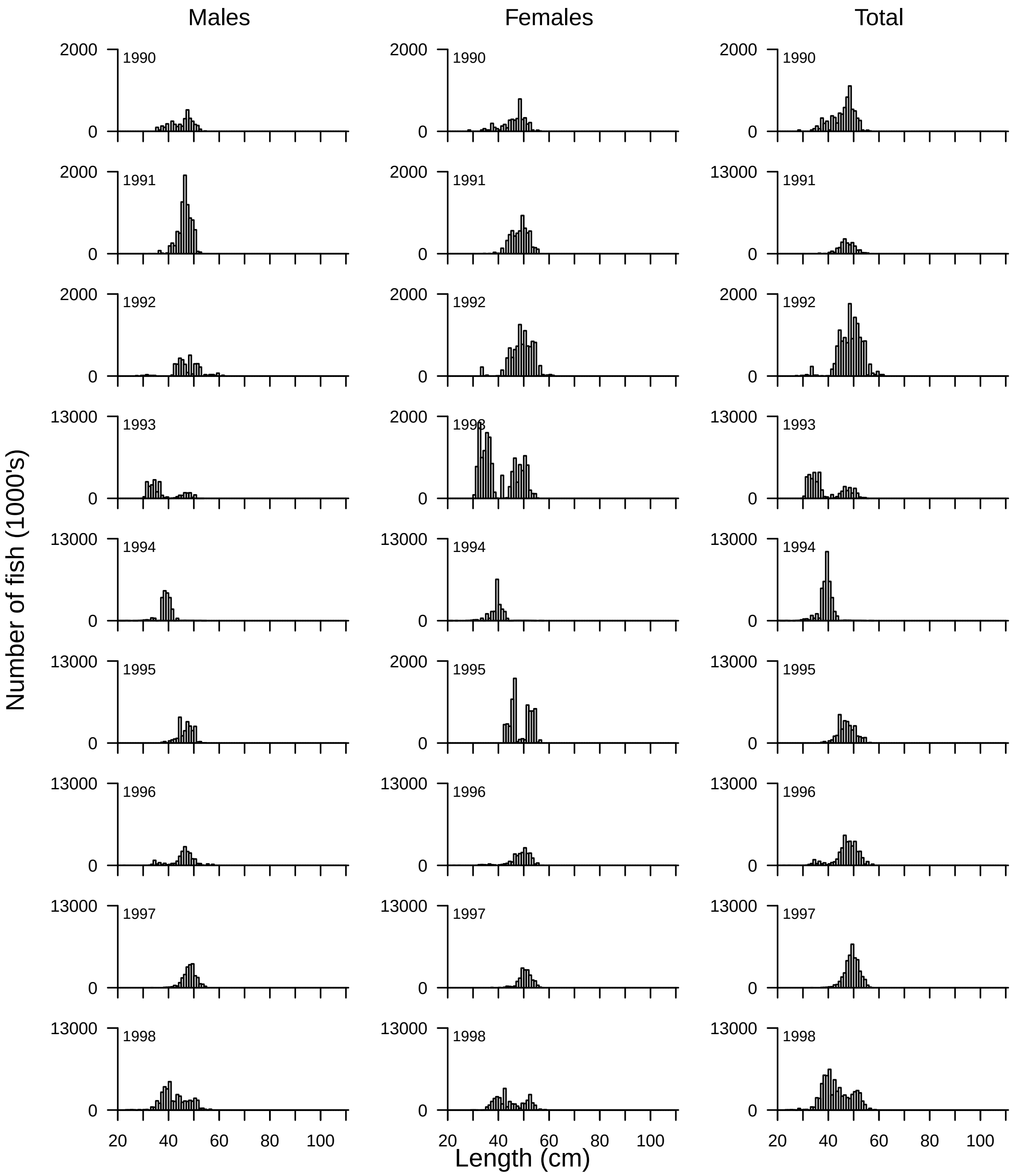


Figure 43: Scaled to catch length frequencies of male, female and unsexed silver warehou from the western Chatham Rise (WCHAT) fishery from 1990 to 1998.

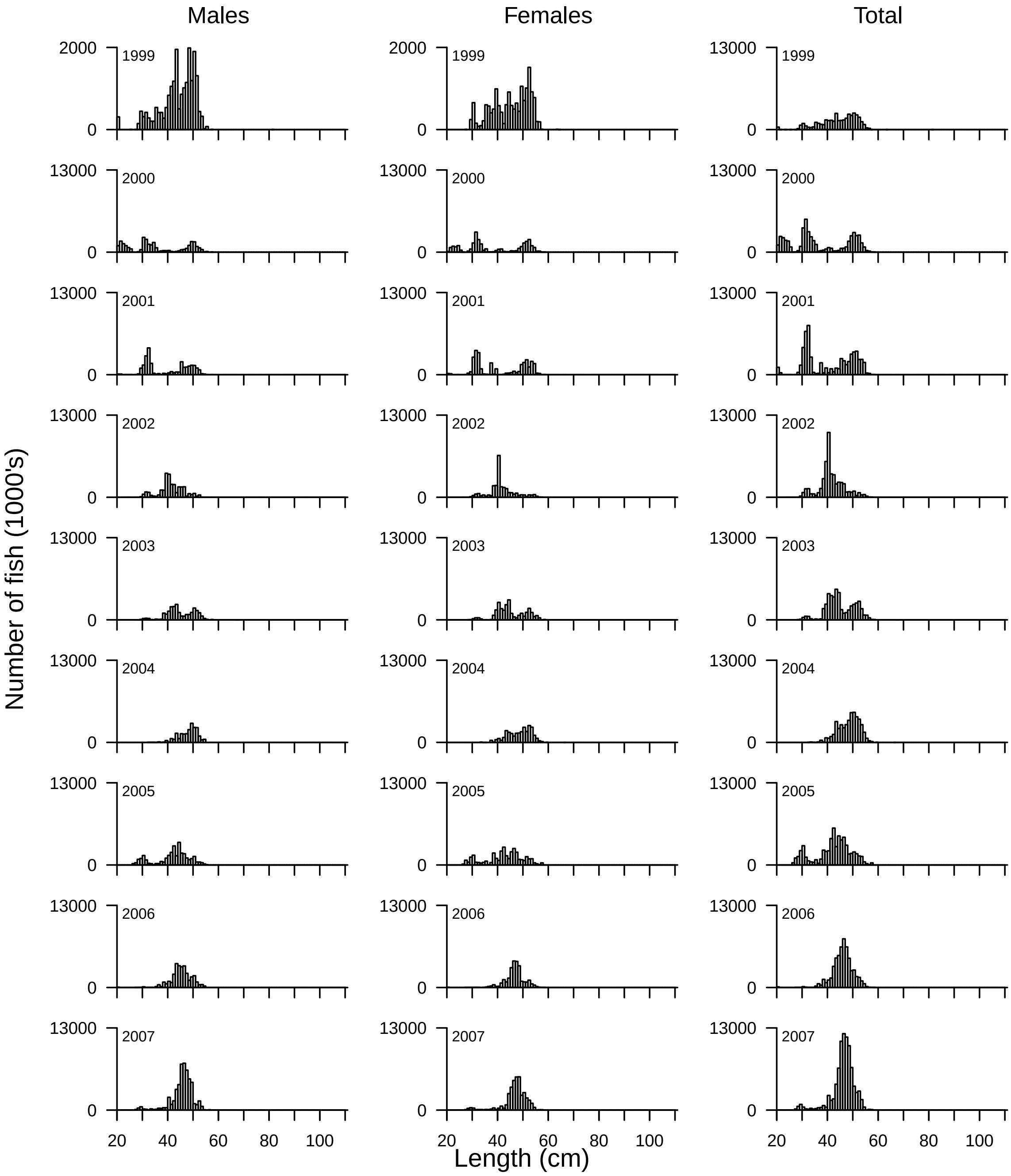


Figure 44: Scaled to catch length frequencies of male, female and unsexed silver warehou from the western Chatham Rise (WCHAT) fishery from 1999 to 2007.

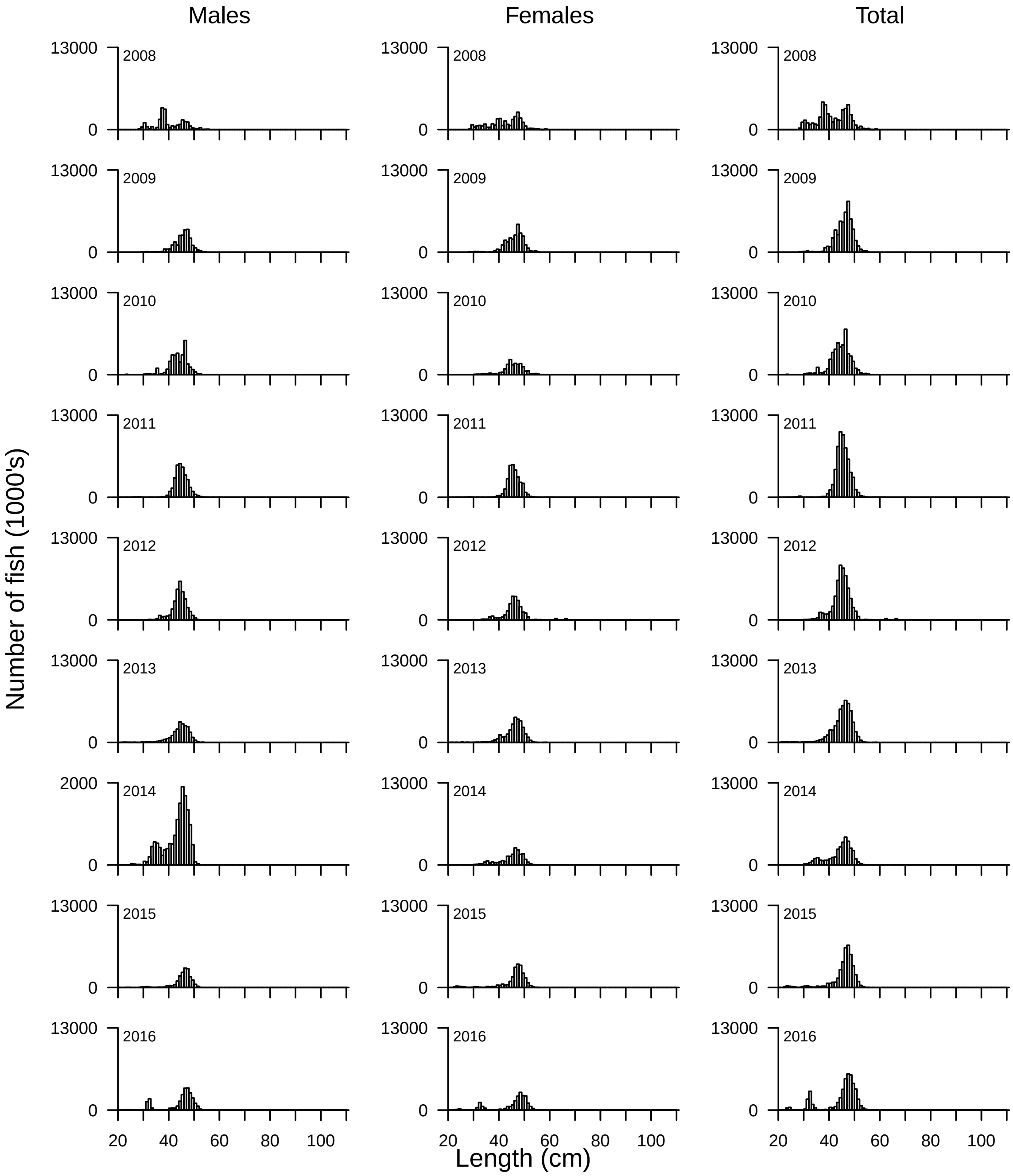


Figure 45: Scaled to catch length frequencies of male, female and unsexed silver warehou from the western Chatham Rise (WCHAT) fishery from 2008 to 2016.

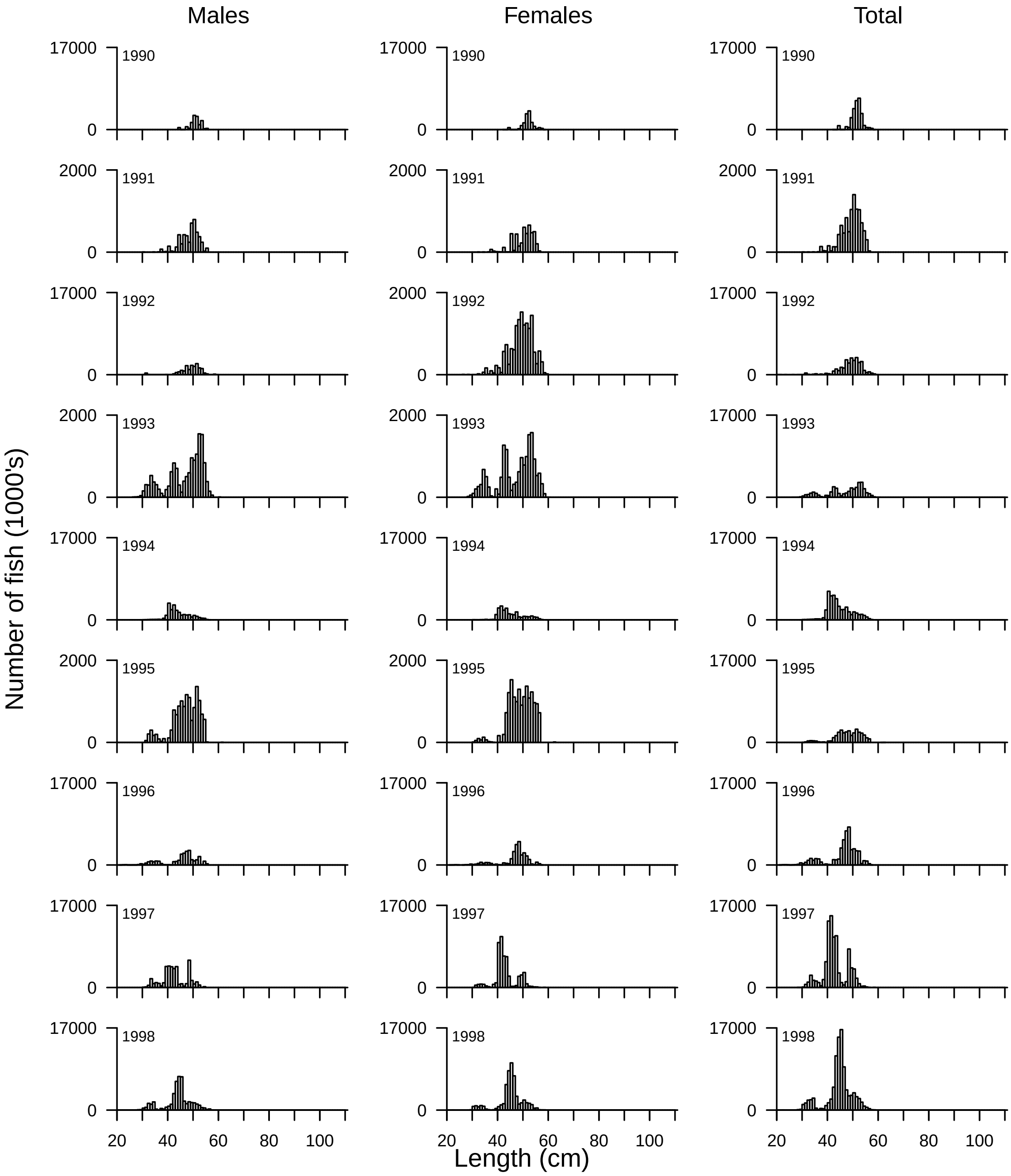


Figure 46: Scaled to catch length frequencies of male, female and unsexed silver warehou from the southern (SOUT) fishery from 1990 to 1998.

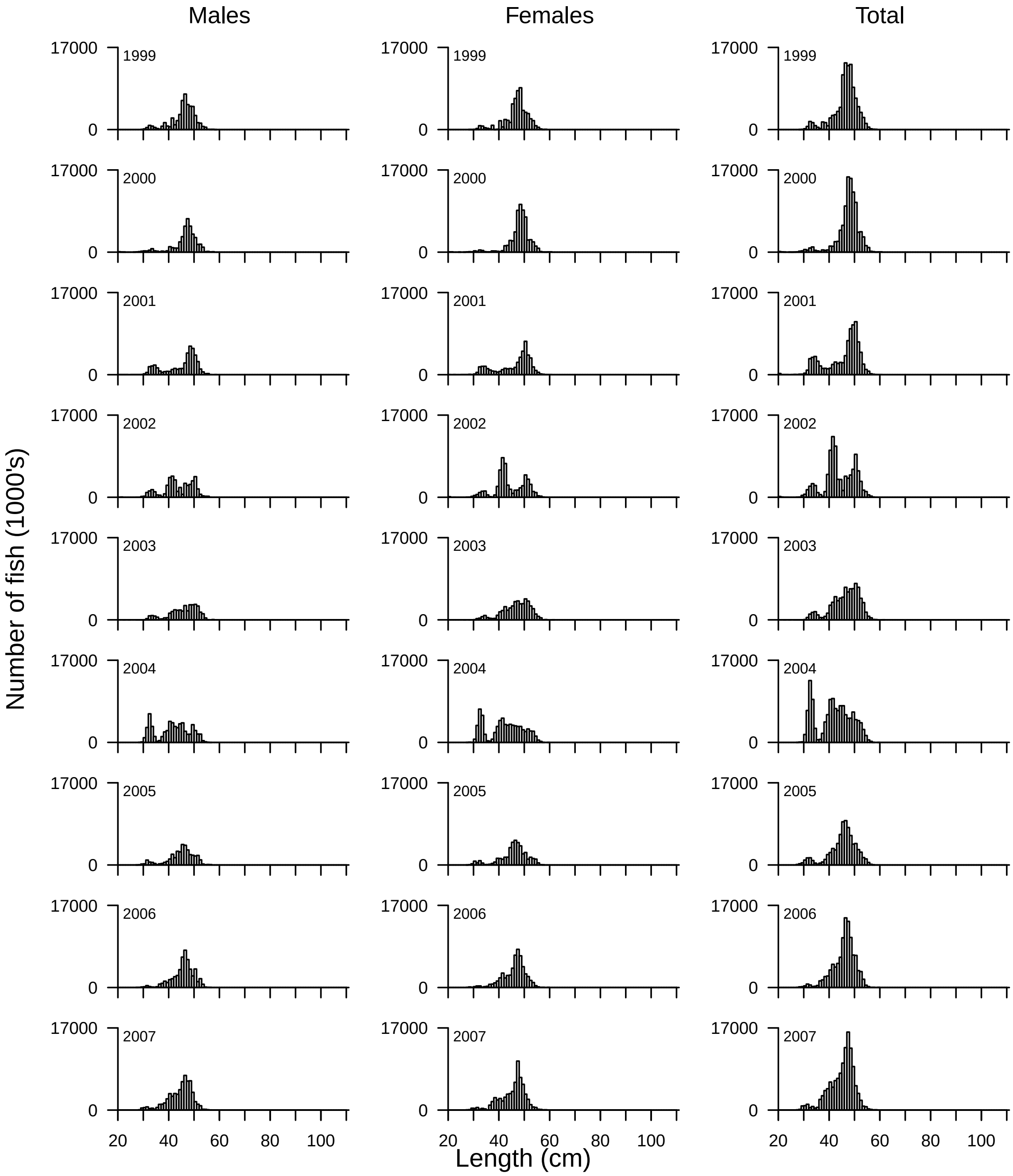


Figure 47: Scaled to catch length frequencies of male, female and unsexed silver warehou from the southern (SOUT) fishery from 1999 to 2007.

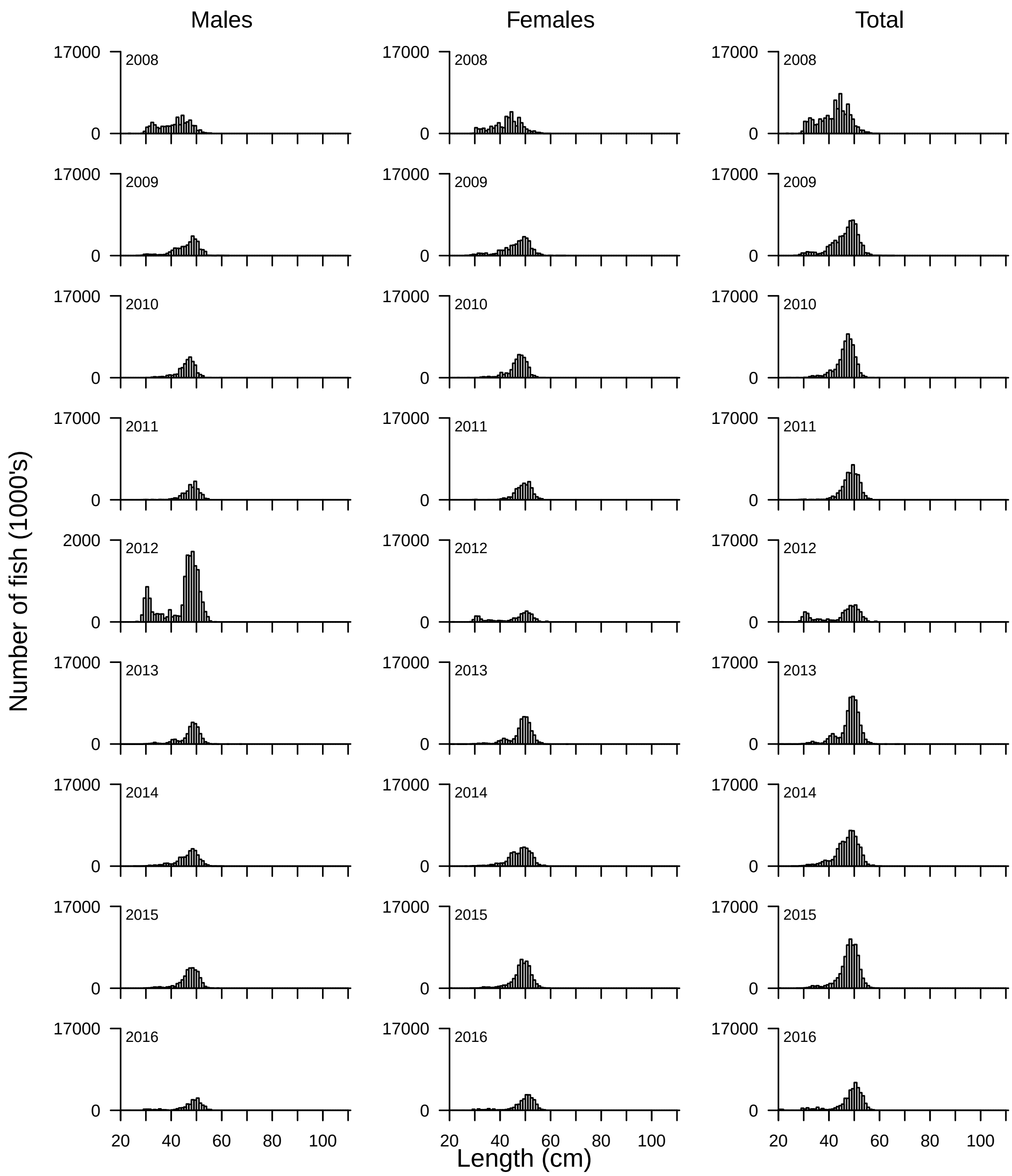


Figure 48: Scaled to catch length frequencies of male, female and unsexed silver warehou from the southern (SOUT) fishery from 2008 to 2016.

Appendix B: Spatial distribution of catch

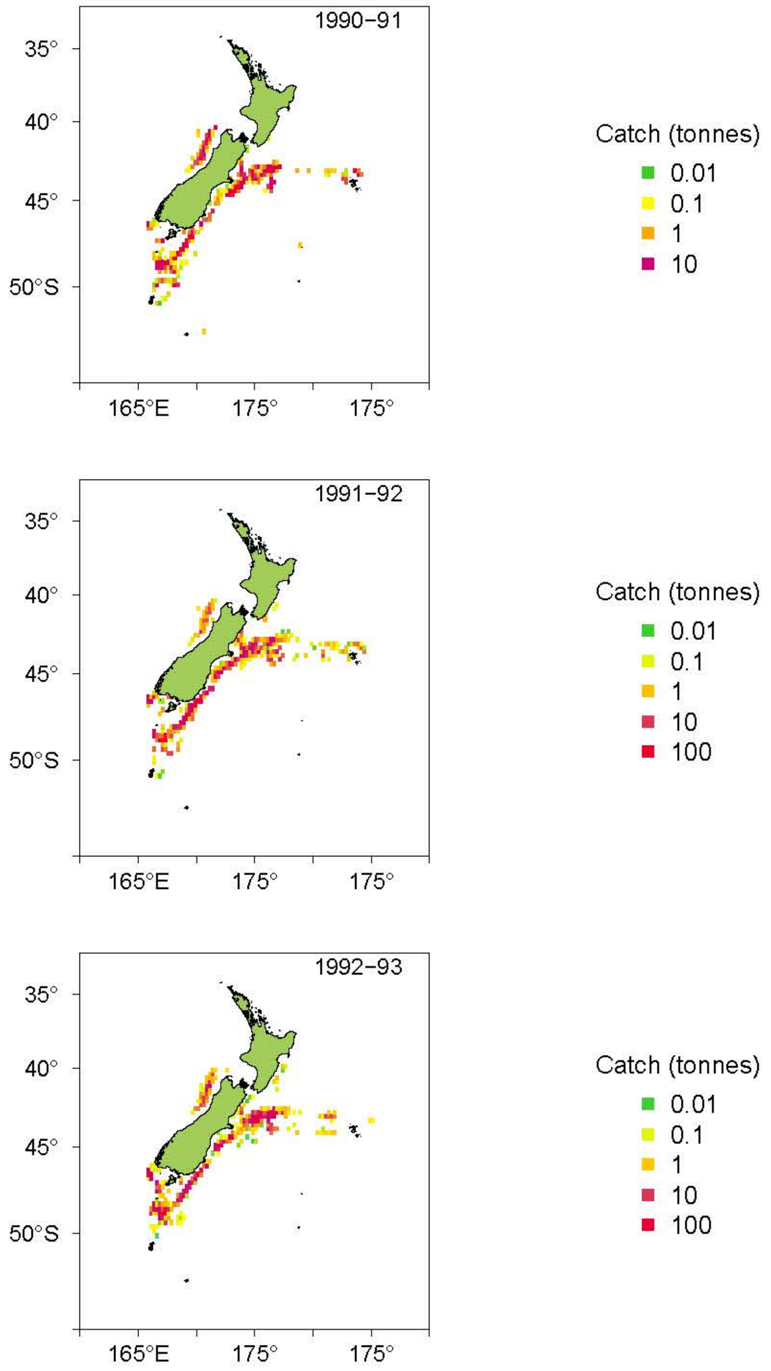


Figure 49: Spatial distribution of catch from fishing years 1991 (top) to 1993 (bottom) on a log scale.

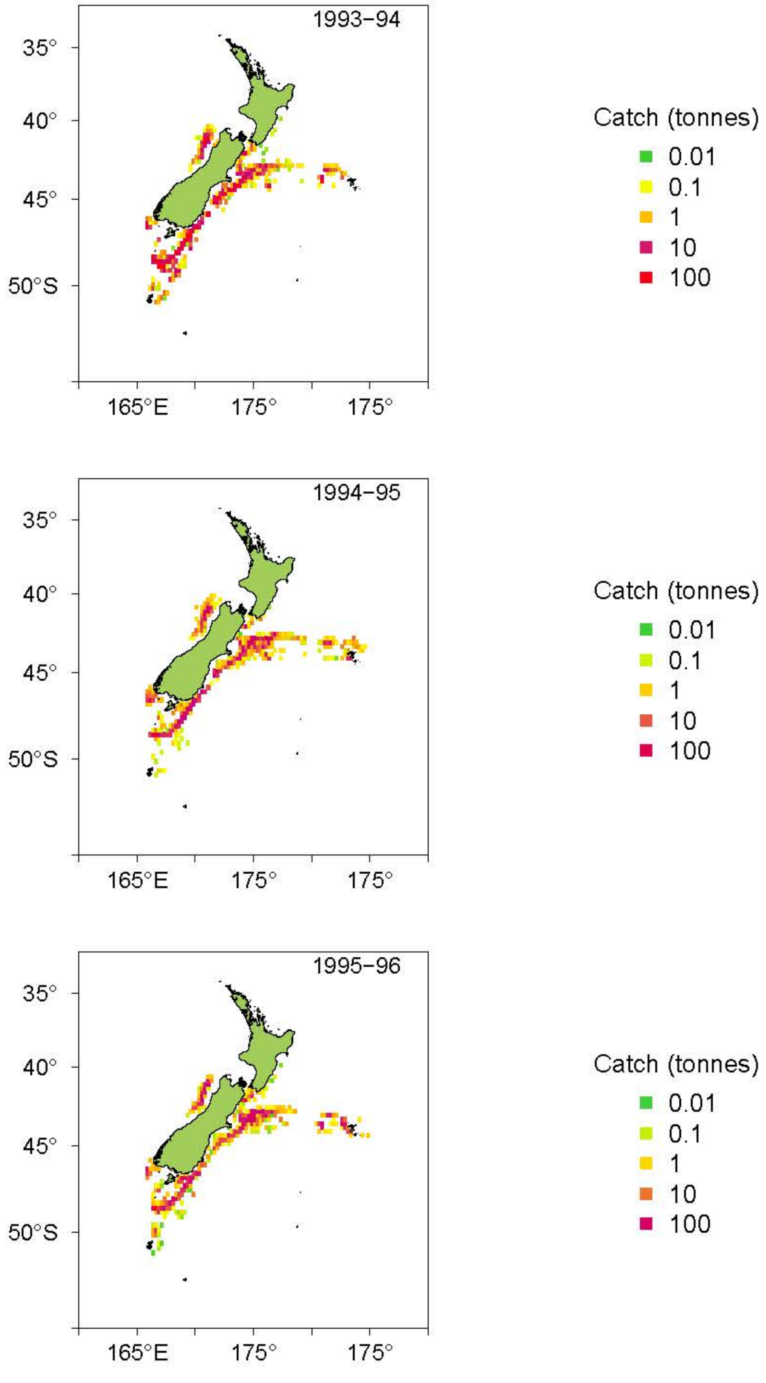


Figure 50: Spatial distribution of catch from fishing years 1994 (top) to 1996 (bottom) on a log scale.

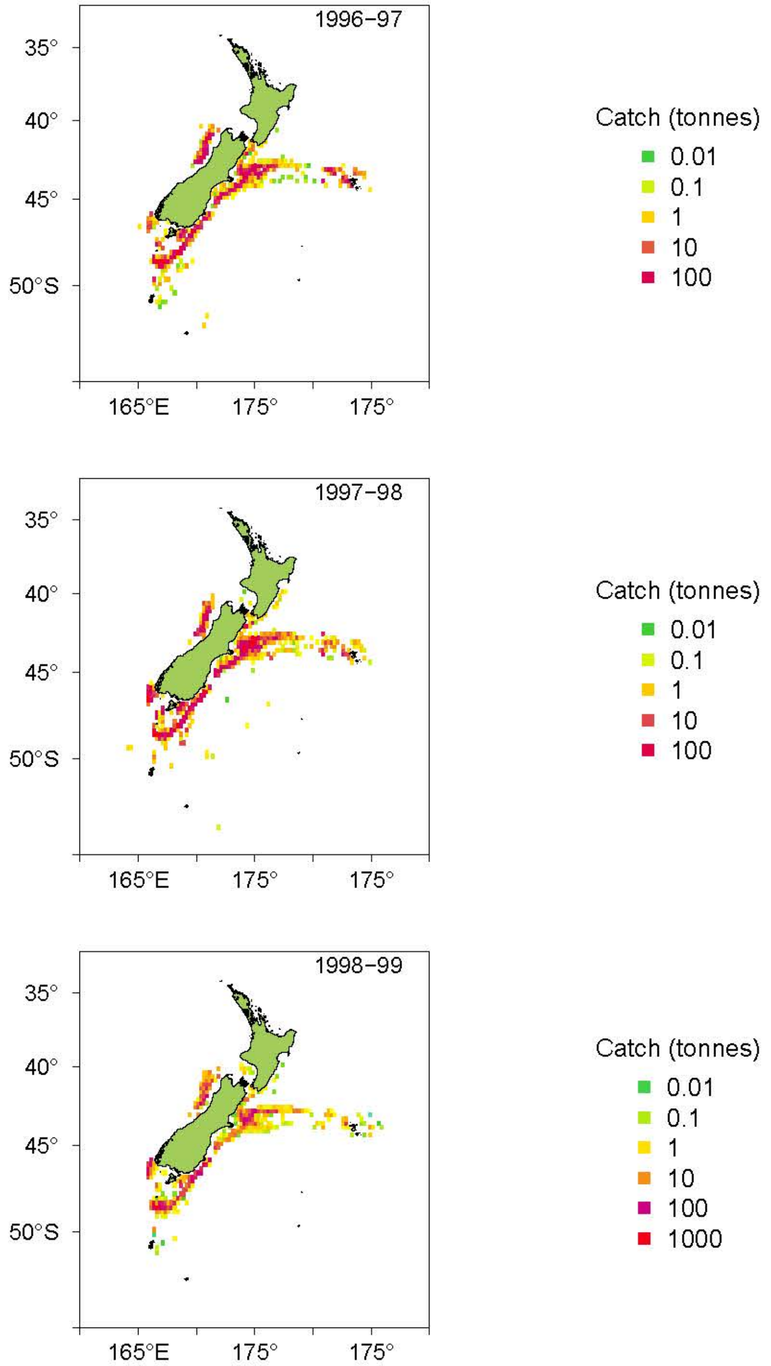


Figure 51: Spatial distribution of catch from fishing years 1997 (top) to 1999 (bottom) on a log scale.

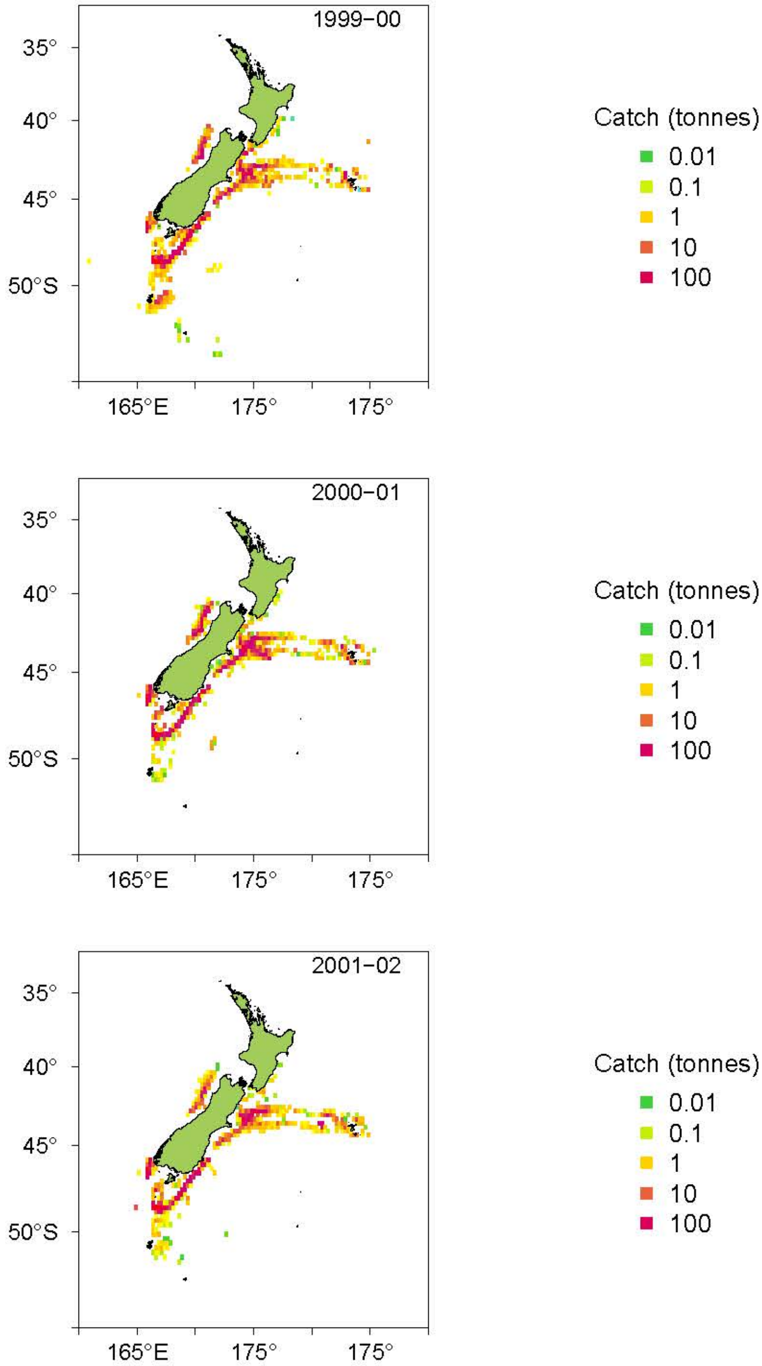


Figure 52: Spatial distribution of catch from fishing years 2000 (top) to 2002 (bottom) on a log scale.

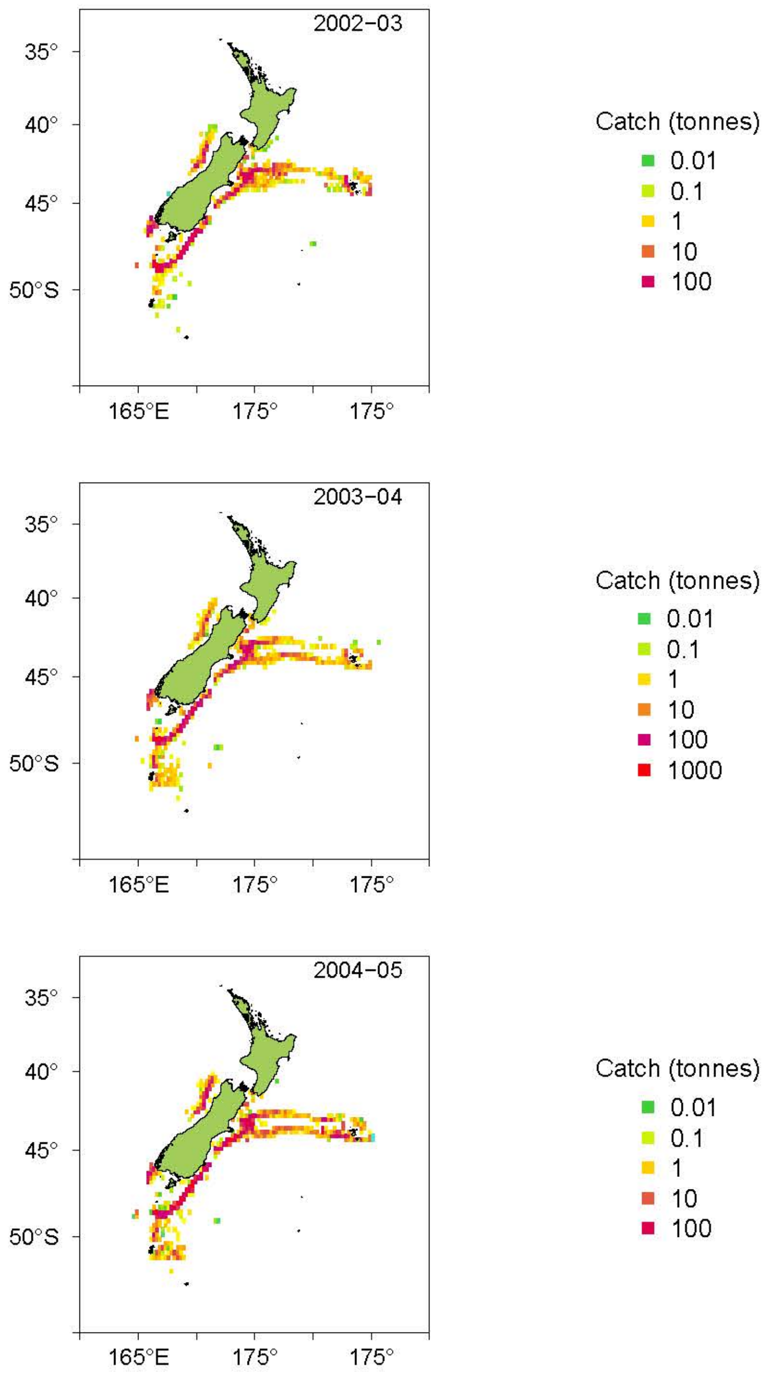


Figure 53: Spatial distribution of catch from fishing years 2003 (top) to 2005 (bottom) on a log scale.

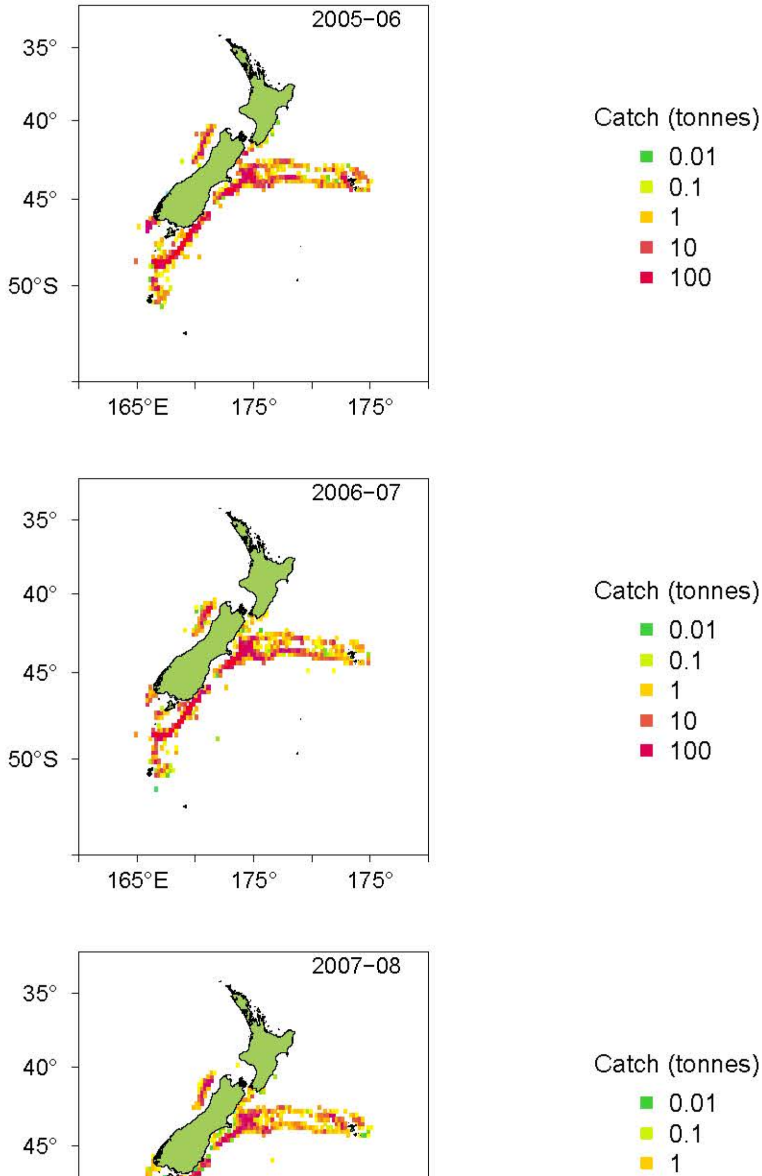


Figure 54: Spatial distribution of catch from fishing years 2006 (top) to 2008 (bottom) on a log scale.

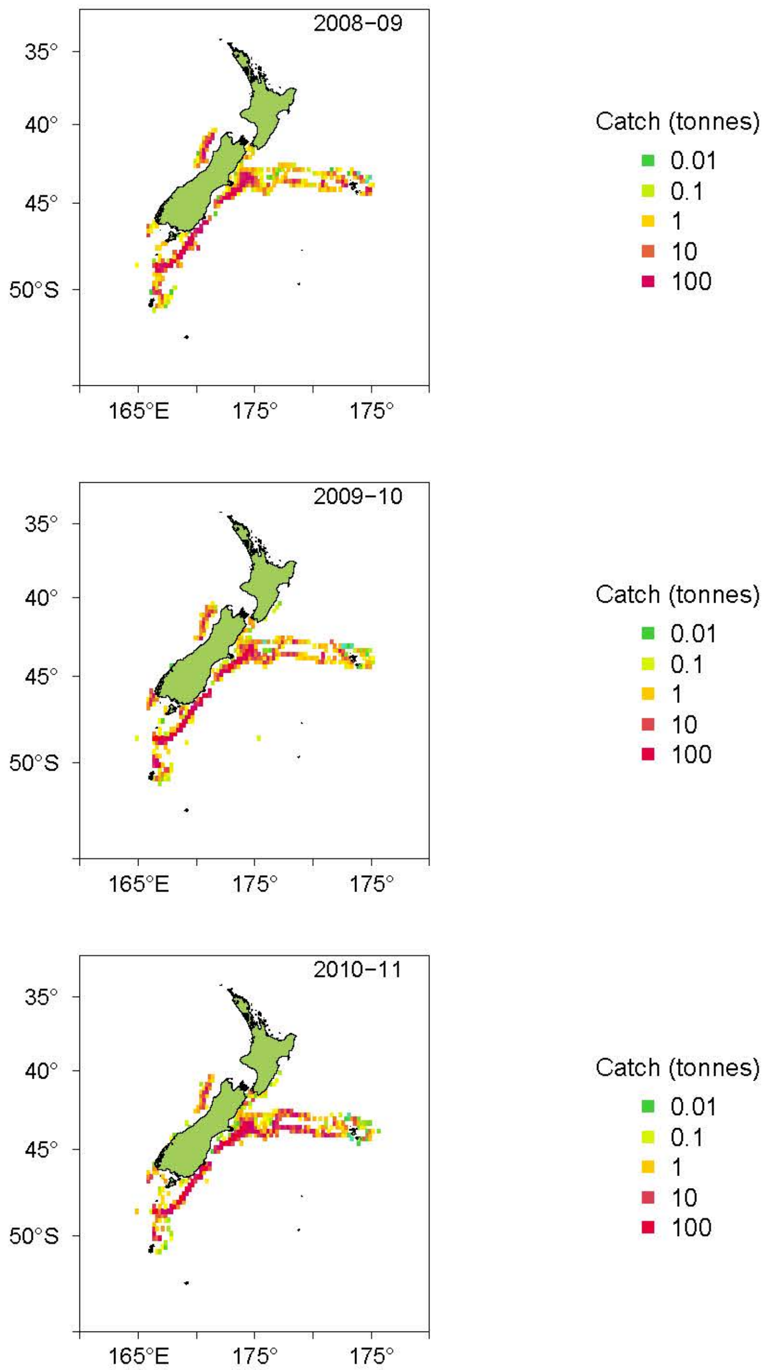


Figure 55: Spatial distribution of catch from fishing years 2009 (top) to 2011 (bottom) on a log scale.

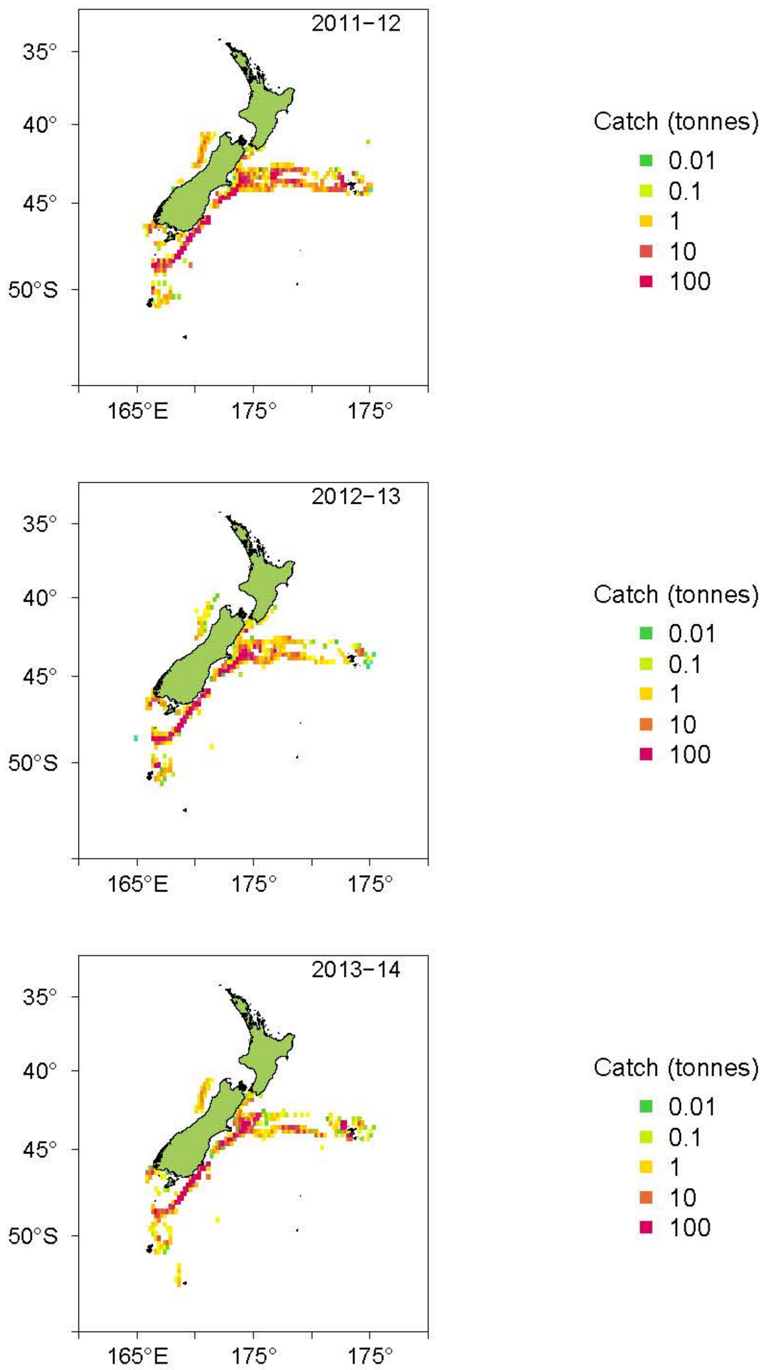
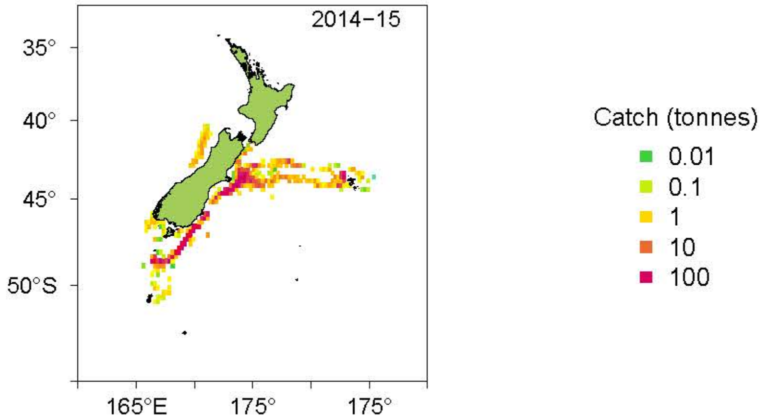


Figure 56: Spatial distribution of catch from fishing years 2012 (top) to 2014 (bottom) on a log scale.



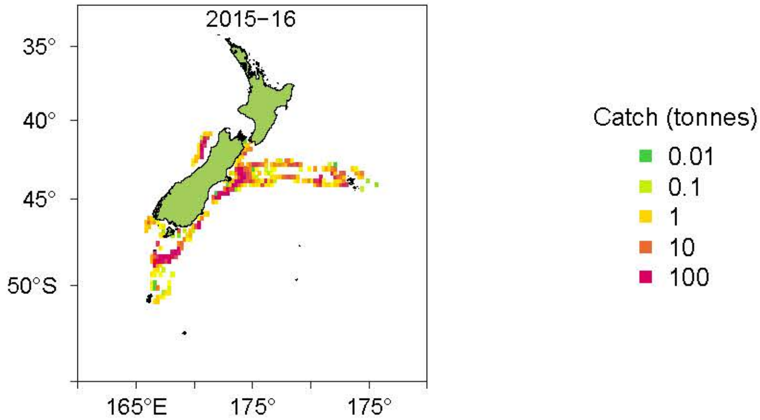


Figure 57: Spatial distribution of catch from fishing years 2015 (top) to 2016 (bottom) on a log scale.

Appendix C: Grooming and merging diagnostics

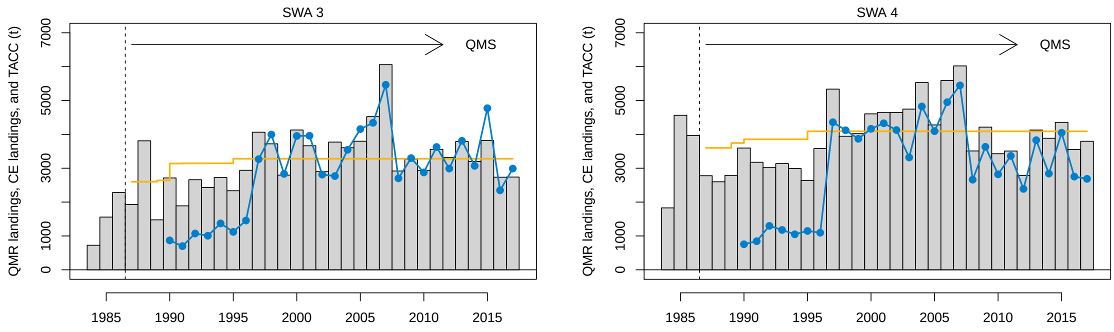


Figure 58: The QMR/MHR landings (grey bars), groomed catch effort landings (dotted blue line), and TACC (gold line) for SWA 3 (left) and SWA 4 (right) from 1984 to 2016.

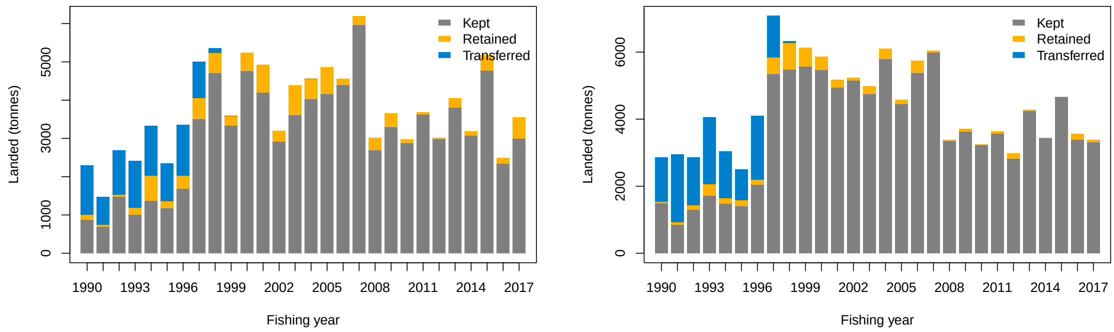


Figure 59: Groomed catch effort landings (grey bars), and dropped landings: transferred to another vessel (blue bars) and retained on board (orange bars) for SWA 3 (left) and 4 (right) from 1990 to 2016.

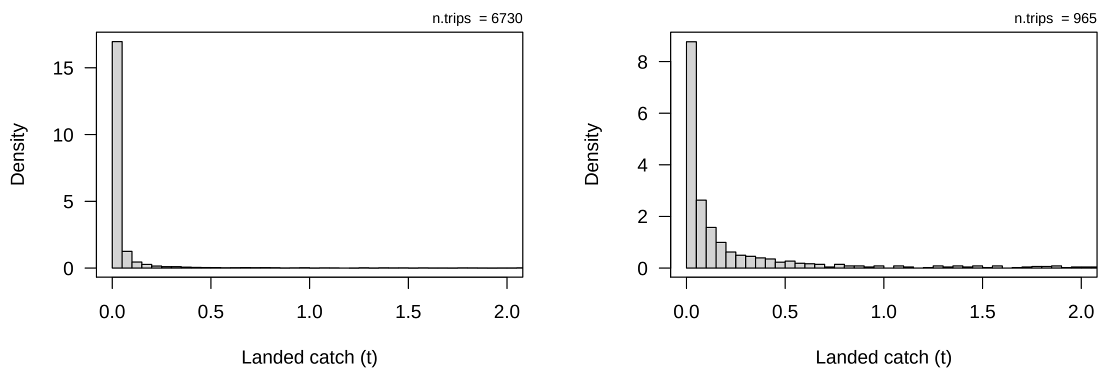


Figure 60: Landed catch for zero estimated catch for SWA 3 (left) and SWA 4 (right).

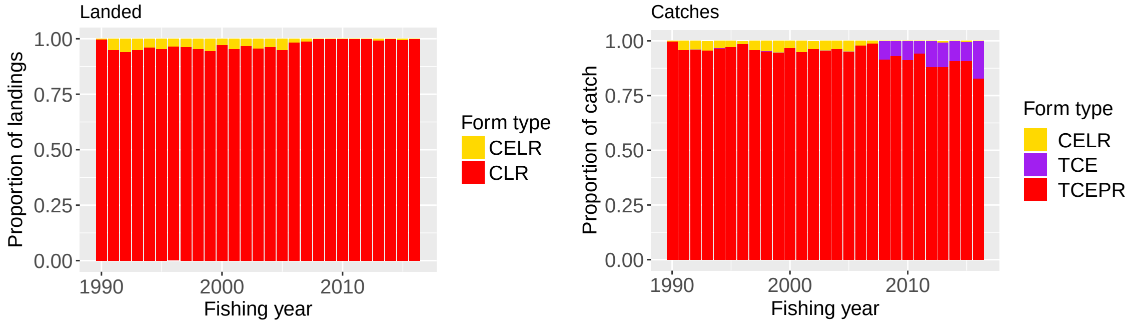


Figure 61: Proportion of SWA 3 landings by form type (left) in the groomed and unmerged dataset, and proportion of processed catches by form type (right) in the groomed and merged dataset, for SWA 3 from the 1990 to 2016 fishing year.

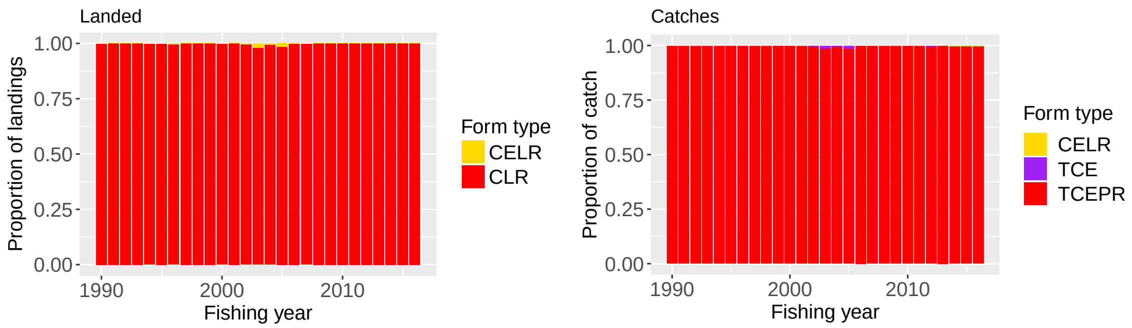
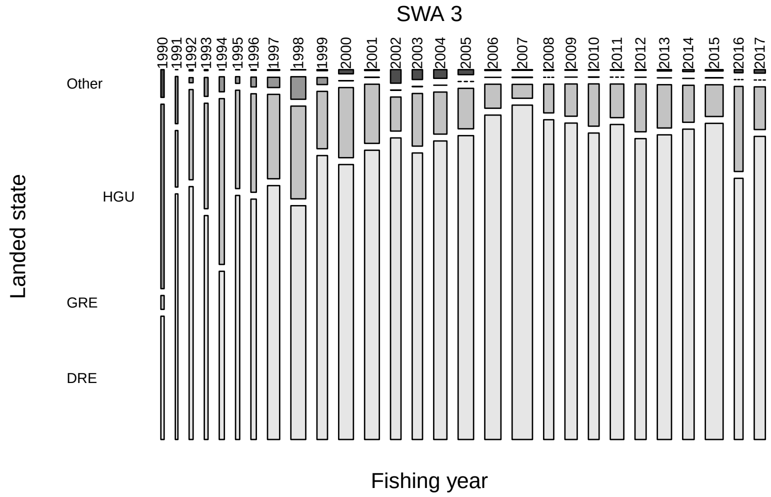


Figure 62: Proportion of SWA 4 landings by form type (left) in the groomed and unmerged dataset, and proportion of processed catches by form type (right) in the groomed and merged dataset, for SWA 4 from the 1990 to 2016 fishing year.



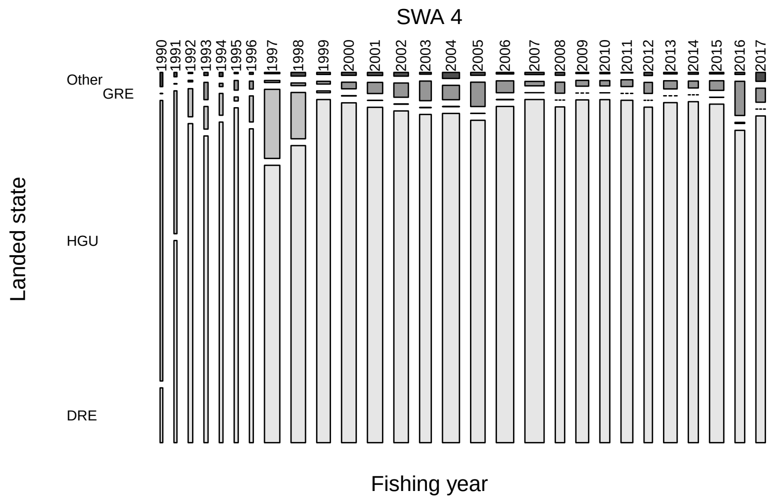


Figure 63: The proportion of retained landings (greenweight) by processed state for SWA 3 (top) and SWA 4 (bottom) from the 1990 to 2017 fishing year in the groomed and unmerged dataset. DRE includes Dressed, Headed, gutted and tailed, Headed and gutted and Trunked; GRE refers to Whole or Green; MEA refers to Mealed and FIL refers to Filleted.

Appendix D: CPUE diagnostics

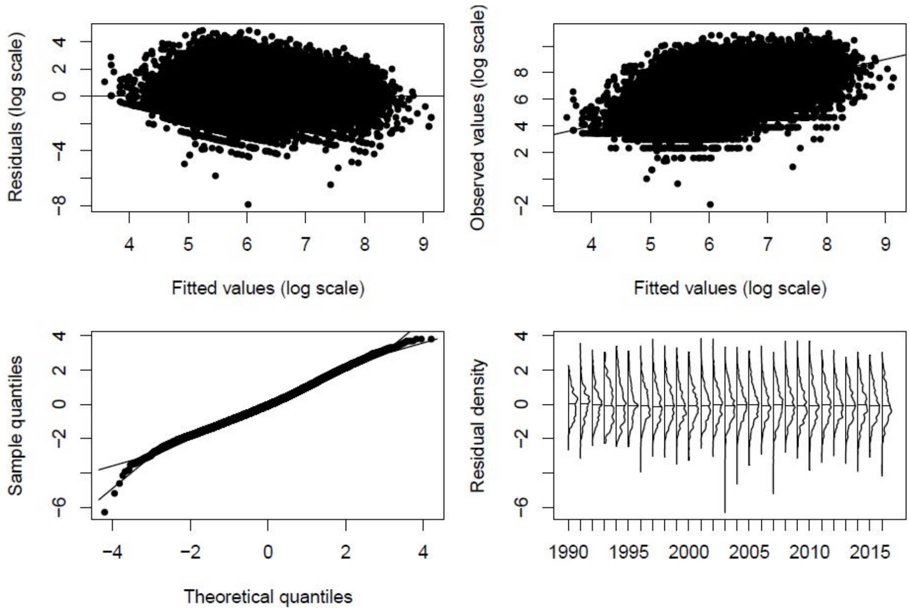


Figure 64: CPUE diagnostics for WCHAT initial model describing the model fit to the data.

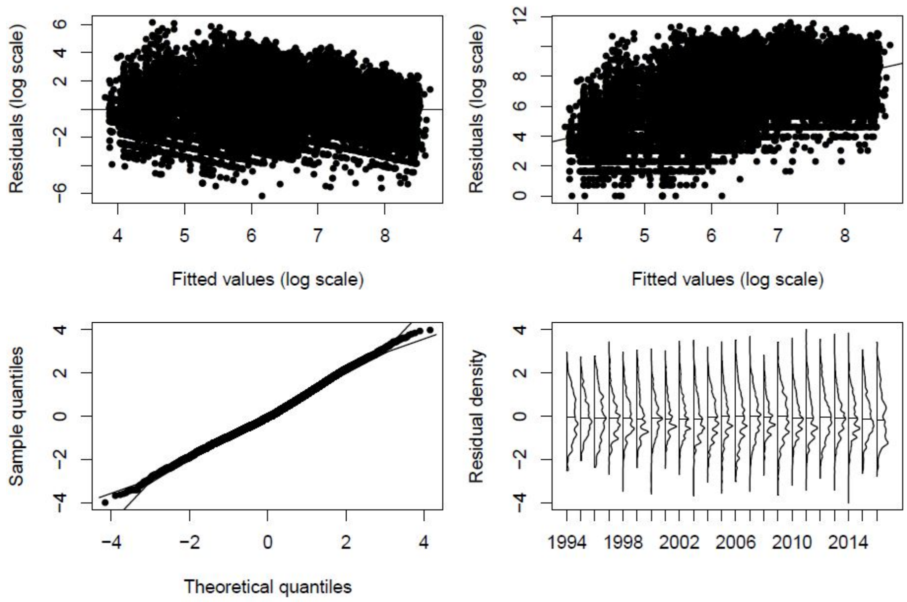


Figure 65: CPUE diagnostics for SOUT initial model describing the model fit to the data.