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Fishery characterisation and catch-per-unit-effort analyses for frostfish (*Lepidopus caudatus*), 1989–90 to 2009–10

New Zealand Fisheries Assessment Report 2014/25

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Frostfish (*Lepidopus caudatus*) is a benthopelagic Trichiurid (cutlassfish) occurring in the Eastern Atlantic, Indian, and Southwest Pacific Oceans in depths of 50–600 m. In New Zealand, frostfish are found between latitudes 34°S and 49°S but are most common off the west coast of the North and South islands between latitudes 37°S and 43°S in depths of 100–300m. Between 1989–90 and 2009–10, the majority of frostfish catch has been taken by trawling off the west coast of the North and South Islands in quota management areas FRO 7, FRO 8, and FRO 9.

Since the mid-2000s, most frostfish landings have come from the trawl fishery targeting jack mackerel (JMA) in the North and South Taranaki Bights and off the west coast of the South Island (statistical areas 035 to 041; FRO 7, 8, 9). In 2009–10, over 80% of the national frostfish landings came from this fishery. Since 1999–2000, the fishery has been dominated by seven vessels which use midwater trawling exclusively. Catches of frostfish have become more concentrated on two distinct periods, October to January and June to July, and in the north and south Taranaki Bight (statistical areas 037, 040, 041) rather than the west coast of the South Island (statistical areas 034, 035, 036).

Catch per unit effort (CPUE) analyses were performed using estimated catches of frostfish from the trawl fishery targeting jack mackerel in statistical areas 034–037 and 039–042. A set of 18 core vessels was defined based on the criteria of at least three trips landing frostfish in each of at least three fishing years. These vessels took 88% of the frostfish catch between 1989–90 and 2009–10. The proportion of tows with frostfish catch recorded varied substantially over the period from a high of 62% in 1989–90, to a low of 22% in 1995–96 with a subsequent increase to 53% in 2009–10. A generalised linear model with a log-logistic error distribution was fitted to the estimated catch of each tow with the explanatory terms chosen by stepwise selection: area × month interaction, vessel, tow duration, tow depth, net height, tow speed and time of day. The standardised CPUE index was flatter than unstandardised CPUE with less of an increase during the 2000s. This is principally due to the influence of the vessel term which takes account of the change in fleet composition. The estimated area × month coefficients support the hypothesis that frostfish migrate annually, possibly for spawning, between the west coast of the South Island (late winter-spring) and the North Taranaki Bight (summer-early autumn). There is low confidence in the overall CPUE index due to uncertainty in reporting behaviour, particularly prior to 1997–98 (the year that frostfish entered the Quota Management System). A sensitivity test which used only data from midwater trawling for the period 1999–2000 to 2009–10 showed little difference in the CPUE index for the period in common.

Prior to the mid 2000s, most of the frostfish catch was taken by midwater trawling targeting hoki during the hoki spawning season (June–September) off the west coast of the South Island (statistical areas 034 and 035; FRO 7). However, in the early 2000s there was a reduction in the total allowable commercial catch (TACC) for hoki and the subsequent reduction in effort in that fishery contributed to a decline in frostfish catches. Frostfish catches from that fishery declined from around 1500 t, about 60% of the national total, during

the early 1990s to less than 200 t, and less than 10% of the national total, during the late 2000s.

Catch per unit effort analyses were done for midwater trawling targeting hoki during June–September in statistical areas 034, 035 and 036. A set of 77 core vessels was defined based on the criteria of at least one trip landing frostfish in each of at least three fishing years. These vessels took 74% of the frostfish catch between 1989–90 and 2009–10 and more restrictive core vessel criteria diminished that percentage significantly. The percentage of tows with recorded frostfish catches was 30% in 1989–90, fell to less than 20% in 1995–96 and increased to around 39% in the mid-2000s. Unstandardised CPUE exhibited a substantial decrease over this period with a particularly sudden drop from 2008–09 to 2009–10. A log-logistic generalised linear model was fitted to the following terms which were selected by stepwise selection: vessel, bottom depth, tow duration, net height and month. The vessel term was highly influential in the standardisation. For example, the substantial drop in unstandardised CPUE in 2009–10 is at least partially explained by the re-entry of several vessels with lower catch rates of frostfish. The standardised CPUE shows a more pronounced overall decline than the unstandardised CPUE. The general downward trend in standardised CPUE was robust to alternative core vessel criteria and data periods. The confidence in the CPUE index is reduced by the low and variable percentage of frostfish catches (17–40%) which shows a contrary trend.

Other fishing activities reporting frostfish catches include trawling targeting barracouta or frostfish off the west coast of the South Island (FRO 7 & 8) and trawling targeting squid off the south and east coast of the South Island (FRO 3 & 5). However, frostfish catches from these activities have been sporadic and account for a small proportion of total landings.

1. INTRODUCTION

Frostfish (*Lepidopus caudatus*) is a benthopelagic Trichiurid (cutlassfish) occurring in the Eastern Atlantic, Indian, and Southwest Pacific Oceans in depths of 50–600 m (Nakamura & Parin 1993, Froese & Pauly 2012). In New Zealand, frostfish are found between latitudes 34°S and 49°S but are most common off the west coast of the North and South islands between latitudes 37°S and 43°S in depths of 100–300m (Anderson et al. 1998).

In New Zealand, the majority of frostfish are caught as bycatch in trawl fisheries targeting jack mackerel and hoki (Ministry for Primary Industries 2012). Frostfish landings are not a valuable component of commercial fishing operations and in the past have not been routinely monitored or assessed. However, under the 10 year Research Programme for Deepwater Fisheries (Ministry of Fisheries 2010) the frostfish fishery is to be characterised every four years in 2011–12, 2015–16 and 2019–20.

This report summarises the analyses carried out for the Ministry for Primary Industries under project DEE2010-07 "Characterisation and fishery monitoring of deepwater and middle depth species", which for frostfish includes the following objectives:

- To characterise the fisheries by analysis of commercial catch and effort data up to 2009–10.
- To carry out standardised CPUE analyses for the major fisheries (Fishstocks) where appropriate.
- To review the indices from CPUE analyses, all relevant research trawl surveys and observer logbooks to determine any trends in biomass estimates, size frequency distributions or catch rates.
- To review stock structure using data accessed above and any other relevant biological or fishery information.
- To assess the availability and utility of developing a series of age frequency distributions from otoliths collected by researchers on trawl surveys or by observers on commercial fishing vessels.
- To make recommendations on future data requirements (including recommendations for annual levels of observer sampling) and methods for monitoring the stocks.

The main body of this report summarises this research and most of the detail, tables and figures are provided in five appendices: A, Summaries of trawl survey data; B, Summaries of observer data; C, Summaries of catch and effort data; D, Catch-per-unit-effort analyses for trawling targeting jack mackerel; E, Catch-per-unit-effort analyses for trawling targeting hoki.

1.1 Commercial fishery

There is no catch data available for frostfish prior to the declaration of the New Zealand Exclusive Economic Zone (EEZ) in 1978 (Ministry for Primary Industries 2012). Between 1978 and 1983 reported landings of frostfish from foreign licensed and joint venture vessels are available (Table 1). Landings fluctuated between 216 and 1615 t per annum and were concentrated in the west coast of the North and South Islands (EEZ areas G and H which roughly correspond to QMAs 7, 8 and 9; Table 1). From 1984–85 to 1997–98, total landings of frostfish varied between 901 t and 4424 t. As for the earlier period, most of the landings came from the west coast of the North and South Islands (Table 2).

Frostfish entered the quota management system on 1 October 1998 with nine quota management areas (QMAs), FRO 1 to 9. In each QMA, the initial TACC was set to a value that was similar to the average of the previous five years landings (Table 2) with a combined TACC of 3858t. An allowance for non-commercial catches of 2t was made in each of FRO 1, 2, 7 and 9. In FRO 2, FRO 3 and FRO 4, landings exceeded the TACC for a number of years and on 1 October 2006 TACCs were increased in each of these QMAs to the average of landings in the previous seven years plus an additional 10% (Ministry for Primary Industries 2012).

1.2 Recreational fisheries

Frostfish are occasionally taken by recreational fishers and small catches have been reported from recreational diary surveys, mainly in FRO 1, and rarely in FRO 2 and 9 (Ministry for Primary Industries 2012).

1.3 Customary non-commercial fisheries

Historically, Maori have collected beach cast frostfish (Graham 1956). However, no quantitative information on current customary non-commercial catches of frostfish is available. Relative to the quantities taken by the commercial fishery it is unlikely to be significant.

1.4 Illegal and misreported catch

No quantitative information on illegal or misreported catches of frostfish is available.

Table 1:Reported landings (t) of frostfish by fishing year and area, by foreign licensed and joint venture vessels, 1978–79 to 1983–83 (Ministry for Primary Industries 2012). The EEZ areas correspond approximately to the QMA as indicated. Fishing years are from 1 April to 31 March. The fishing year indicated as 1983–83 is a 6 month transitional period from 1 April to 30 September. No data are available for the 1980–81 fishing year.

EEZ area	B	C(M)	C(-)	D	E	F	G	H	Total
QMA	1 & 2	3	3	4	6	5	7	8 & 9	
1978–79	5	1	6	0	1	0	1 283	226	1 522
1979–80	13	0	1	23	1	1	26	151	216
1980–81	–	–	–	–	–	–	–	–	–
1981–82	0	5	2	19	1	4	55	464	550
1982–83	0	1	0	9	3	1	56	1 545	1 615
1983–83	0	1	1	1	1	1	22	123	150

Table 2: Reported landings (t) of frostfish by QMA and fishing year, 1983–84 to 2009–10. Sources: 1983–84 to 1988–89, Ministry for Primary Industries (2012); 1989–90 to 1998–99, Groomed landings data from this study (excludes quantities retained onboard vessel and which may be subsequently reported as landed); 1999–00 to 2009–10, QMR/MHR forms.

		FRO 1		FRO 2		FRO 3		FRO 4		FRO 5		FRO 6		FRO 7		FRO 8		FRO 9		Total
	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC
1983–84	2	-	0	-	0	-	10	-	28		7	-	432	-	539	-	457	-	1 475	-
1984–85	0	-	0	-	2	-	1	-	100		0	-	214	-	455	-	129	-	901	-
1985–86	0	-	0	-	9	-	2	-	258		0	-	344	-	574	-	226	-	1 415	-
1986–87	4	-	4	-	5	-	6	-	71		4	-	1 089	-	898	-	190	-	2 272	-
1987–88	2	-	0	-	3	-	1	-	20		0	-	3 466	-	875	-	22	-	4 391	-
1988–89	115	-	0	-	1	-	0	-	15		3	-	1 950	-	413	-	455	-	2 952	-
1989–90	441	-	1	-	48	-	0	-	120		23	-	1 141	-	137	-	0	-	1 911	-
1990–91	89	-	22	-	228	-	0	-	496		67	-	2 830	-	230	-	0	-	3 961	-
1991–92	46	-	9	-	143	-	0	-	230		7	-	2 133	-	546	-	0	-	3 114	-
1992–93	79	-	9	-	49	-	58	-	378		34	-	1 213	-	729	-	0	-	2 548	-
1993–94	102	-	19	-	158	-	0	-	49		15	-	1 438	-	264	-	12	-	2 056	-
1994–95	55	-	14	-	120	-	157	-	87		24	-	2 596	-	315	-	7	-	3 374	-
1995–96	80	-	21	-	64	-	28	-	0		3	-	1217	-	19	-	8	-	1 440	-
1996–97	203	-	6	-	12	-	4	-	3		0	-	2 210	-	110	-	81	-	2 627	-
1997–98	312	-	290	-	35	-	0	-	9		0	-	2 521	-	160	-	177	-	3 504	-
1998–99	146	149	134	20	39	128	0	5	19	135	0	11	2 460	2 623	156	649	33	138	2 987	3 858
1999–00	84	149	161	20	97	128	1	5	57	135	0	11	917	2 623	28	649	48	138	1 393	3 858
2000–01	76	149	194	20	107	128	48	5	33	135	0	11	1 620	2 623	303	649	43	138	2 424	3 858
2001–02	64	149	67	20	177	128	81	5	59	135	0	11	2 303	2 623	138	649	25	138	2 914	3 858
2002–03	127	149	66	20	268	128	15	5	63	135	0	11	1 025	2 623	621	649	67	138	2 252	3 858
2003–04	98	149	52	20	19	128	7	5	14	135	0	11	959	2 623	293	649	367	138	1 809	3 858
2004–05	130	149	38	20	427	128	15	5	20	135	0	11	933	2 623	770	649	328	138	2 660	3 858
2005–06	132	149	40	20	45	128	31	5	17	135	0	11	888	2 623	787	649	182	138	2 121	3 858
2006–07	76	149	31	110	21	176	13	28	16	135	0	11	950	2 623	722	649	142	138	1 970	4 019
2007–08	44	149	30	110	32	176	7	28	5	135	0	11	905	2 623	678	649	136	138	1 837	4 019
2008–09	36	149	24	110	7	176	10	28	2	135	0	11	575	2 623	605	649	110	138	1 369	4 019
2009–10	36	149	24	110	15	176	3	28	4	135	0	11	381	2 623	686	649	238	138	1 386	4 019

2. BIOLOGY

2.1 Distribution

Frostfish are distributed widely in temperate seas but are most commonly reported in the north-eastern Atlantic (including the Mediterranean), in the southern Atlantic off Namibia and South Africa, and in the south-west Pacific around Australia and New Zealand (Nakamura & Parin 1993, Froese & Pauly 2012). Morphometric studies have shown differences in dorsal-fin pigmentation and meristic characteristics between north-eastern Atlantic and southern Atlantic populations (Mikhailin 1977). Genome sequencing of frostfish showed strong genetic differentiation between the northern and southern hemisphere populations and suggests that there are two distinct biological species (Ward et al. 2008).

In New Zealand, frostfish are found between latitudes 34°S and 49°S and, based on commercial fishery and trawl survey catches, appear to be most common off the west coast of the North and South Islands between latitudes 37°S and 43°S (Bagley et al 1988). They are found on the edge of the continental shelf and over the upper slope and are most common in depths of 100–300m (Anderson et al. 1998).

2.2 Feeding and trophic status

Frostfish are a schooling species and migrate from near the bottom into midwater at night to feed on crustaceans, small squid and fish (Nakamura & Parin 1993). Detailed information on the feeding habits of frostfish in New Zealand is not available, but it is likely that their diet is dominated by myctophids and euphausiids as these species groups have been found to be the primary prey of frostfish in a variety of locations including Tasmania, Australia (Blaber & Bulman 1987), the north Atlantic (Klimpel et al. 2006) and the south-east Atlantic (Mikhailin 1978).

2.3 Spawning

Robertson (1980) examined the seasonality and location of frostfish spawning based on the occurrence of planktonic eggs. He concluded that spawning probably occurs around all of New Zealand except for the south-east coast and adults probably congregate in the late spring months, and spawn during the summer and autumn over the mid to outer shelf. Fertilisation was calculated to take place between noon and sunset at depths greater than 50 m where the surface waters have a temperature of 17.5 to 22.0°C. Analysis of data on female gonad stages from the observer programme (see Section 6.1) suggests that for the west coast of both the North and South Islands frostfish have a protracted spawning period starting in mid-winter with a peak from summer to early autumn.

2.4 Stock structure

There is little biological information on which to base stock structure for frostfish. Length frequencies from trawl surveys are only available for the autumn inshore west coast South Island time series, so comparisons of length between areas cannot be made. Other time series (all of which have been discontinued) that have collected information on biomass have not done so by sex so biomass ratios by sex cannot be compared between areas either. There is insufficient length-frequency data from the observer programme outside of the west coast. For this reason comparisons between areas cannot be made for observer data either. The examination of catch-effort data conducted during this study found most of the catch was taken on the west coasts of the North and South Islands. The discontinuity of catches between the west coast and other areas where frostfish are caught may be indicative of a separate stock on the west coast.

2.5 Ageing and growth

A recent study developed ageing methods and estimated growth rates for frostfish from the west coast of New Zealand (Horn 2013). This study confirmed that frostfish are fast growing and relatively short lived. Most fish reach 100 cm FL (fork length) by the end of their third year and the maximum estimated age for both sexes was 10.6 years. The von Bertalanffy parameters estimated for both sexes combined were:L_∞=137 cm, k=0.505 yr^{-1}, t_0=0.07 yr. The estimated growth curves were similar, for the first 4 years, to those estimated for northern hemisphere frostfish (e.g. Demestre et al 1993), although the asymptotic length is lower.

2.6 Natural mortality

Horn (2013) estimated the instantaneous rate of natural mortality to be 0.6 yr^{-1} based on 1% of the population reaching 7–8 years of age.

2.7 Length-weight relationships

A length-weight relationship for New Zealand frostfish is available from the *Kaharoa* trawl surveys (Stevenson 2002). Several estimates of length-weight parameters are available from the Atlantic and Mediterranean with a median value for *b* (the exponent of the length-weight relationship) of about 3.1 (Froese & Pauly 2012).

3. FISHERY INDEPENDENT DATA

3.1 Research surveys

There have been no surveys designed specifically to estimate frostfish abundance. Most frostfish are caught by commercial vessels when using midwater trawl. Therefore, bottom trawl surveys may not provide a good index of abundance for a species that occurs mainly in midwater. Data are sparse for those surveys that have caught frostfish with the most consistent time series being the autumn surveys by *Kaharoa* of the west coast South Island and Tasman and Golden Bays (WCSI). This is also the only ongoing survey that catches and measures frostfish, although only in small quantities. Annual summer trawl surveys of the Chatham Rise and the Sub-Antarctic by *Tangaroa* have caught very few frostfish and in most years have caught none. Other surveys that have caught frostfish are *Kaharoa* surveys in the Bay of Plenty and on the east coast North Island, both of which were discontinued in the 1990s. Length frequencies are only available for some surveys from the WCSI time series. Trends in biomass and length frequencies from *Kaharoa* surveys are presented in Table 3 and Appendix A (Figures A1–A6).

Biomass estimates for the Bay of Plenty time series range from 91 to 328 t (Figure A1). Biomass by sex is not available. Coefficients of variation are high, ranging from 34% to 87%. The series consists of only four surveys over a nine year period and is primarily aimed at surveying snapper, red gurnard, John dory, and other higher value species. This survey is not a good measure of frostfish abundance. Length frequencies are not available for this time series and otoliths have not been collected. Hence it is not possible to construct a catch-at-age history from this time series.

Biomass estimates for the east coast North Island time series range from 493 to 1079 t (Figure A2). Biomass by sex is not available. Coefficients of variation fluctuate, ranging from 16% to 40%. The series consists of only four surveys over a nine year period and was not geared towards surveying frostfish. This survey is not a good measure of frostfish abundance. Length frequencies are not available for this time series and otoliths have not been collected. Hence it is not possible to construct a catch-at-age history from this time series.

Biomass estimates for the west coast South Island autumn series range from 25 to 835 t (Figure A3). For surveys where data by sex is available, females tend to contribute to more of the biomass than males (Figure A4). Coefficients of variation range from 16 to 44%, with a mean of 29% for the series. Abundance appears to increase over the time series with a sharp drop on the last survey in 2011. However, increasing biomass estimates are associated with increasing coefficients of variation. This survey is probably not a good index of frostfish abundance.

For west coast South Island surveys where frostfish were measured for length frequencies, numbers of individuals measured range from 59 to 844. Sex ratios favour females with a mean male:female ratio of 0.6 for the time series (range 0.45–0.79). Fish range in length from 9 to 185 cm FL. Length frequencies for males and females are patchy with no obvious modes and it is difficult to interpret any cohorts through time (Figure A5). Most male fish are between 60 and 120 cm FL. Females appear to grow larger than males and are mainly between 60 and 140 cm FL. Most measured fish, however, are unsexed and are mainly around 50–70 cm (Figure A6). Observer data on female gonad stage (see Section 6.1) suggests that frostfish have a protracted spawning season beginning in mid-winter with a peak in summer. The WCSI trawl survey begins in autumn and so the unsexed juvenile mode of around 18 cm seen in some years (particularly apparent in the 2003 and 2007 surveys) are quite likely to be a 0+ age group from the preceding summer. The 50–70 cm mode visible in a number of years is quite likely to be juvenile as well, probably around 15 months of age. Mean length appears to have increased from 61.5 cm at the beginning of the time series to 88.1 cm in 2011. This could be a result of inconsistent sampling however as frostfish are not a priority species on the survey.

3.2 Other data

No other fisheries independent data was reviewed in this study.

Table 3: Biomass indices (t) and coefficients of variation (c.v.) of frostfish from *Kaharoa* trawl surveys (Assumptions: areal availability, vertical availability, and vulnerability = 1).

	Trip code	Date	Biomass (t)	c.v. (%)
Bay of Plenty (summer)				
	KAH9004	Feb 90	246	87
	KAH9202	Feb 92	91	48
	KAH9601	Feb 96	328	49
	KAH9902	Feb 99	193	34
East Coast North Island (summer)				
	KAH9304	Mar–Apr 93	573	38
	KAH9402	Feb–Mar 94	1079	40
	KAH9502	Feb–Mar 95	493	22
	KAH9602	Feb–Mar 96	662	16
West Coast South Island (autumn)				
	KAH9204	Mar–Apr 92	25	32
	KAH9404	Mar–Apr 94	27	23
	KAH9504	Mar–Apr 95	89	31
	KAH9701	Mar–Apr 97	259	31
	KAH0004	Mar–Apr 00	316	16
	KAH0304	Mar–Apr 03	494	21
	KAH0503	Mar–Apr 05	423	44
	KAH0704	Mar–Apr 07	529	38
	KAH0904	Mar–Apr 09	835	34
	KAH1104	Mar–Apr 11	251	28

4. FISHERY DEPENDENT DATA

4.1 Observer programme data

All tables and figures relating to observer data collected from frostfish fisheries are contained in Appendix B (Tables B1–14, Figures B1–16).

4.1.1 Length and age sampling

The Ministry of Fisheries Observer Programme (now Ministry for Primary Industries Observer Services) has variously collected frostfish length, weight, female gonad stage, and otoliths from various fisheries since 1986, although most data has been taken since the mid-1990s.

Most tows from which frostfish have been measured for length have come from the west coast South Island (797 tows from statistical areas 033–036), South Taranaki Bight (213 tows from statistical areas 037–040), the North Taranaki Bight (111 tows from statistical areas 041 and 042), and 'Other' areas (133 tows from all other statistical areas in the EEZ) (Table B1). Most of the tows sampled for length occur in winter to early spring (Table B2). Given that the majority of frostfish length samples are from the west coast South Island where much of it has been caught as bycatch in the spawning hoki fishery, this timing is not surprising. Table B3 shows that for the west coast South Island nearly all frostfish lengths come from June to October, the same time at which the spawning hoki fishery operates. Aside from one tow in December 2007, there are no observed tows measuring frostfish from this area outside of June to October.

This study found that after 2000 an increasing proportion of frostfish landings have come from the jack mackerel target fishery. Table B4 illustrates increasing numbers of samples coming from the South Taranaki Bight, where much of the jack mackerel catch is taken. Most of the samples taken are from October to January, during which there are peak landings of jack mackerel from JMA 7 (Taylor at al. 2008).

Samples from the North Taranaki Bight are from 2004 onwards (Table B5). Peak sampling periods are at a similar time to those for the South Taranaki Bight (October to January), and also show a peak in June–July, another period in which Taylor et al. (2008) found there to be a peak in jack mackerel landings.

Sampling from the 'Other' areas are spread throughout the year sporadically. They cover a wide geographic range over a number of target fisheries that do not report significant frostfish catches and so will not be discussed further.

The representativeness of observer coverage of frostfish was evaluated by plotting the proportion of the landed catch for each year by area and by month as circles, and overlaying the proportion of the observed catch for the same cells as crosses (Figures B1–5). If the proportions are the same, the crosses align with the circles. If the crosses are smaller than the circles then under-sampling has occurred, and if crosses are larger than the circles, over-sampling has occurred. Figure B1 shows that each area has some over- and under-sampling in some years but in general coverage is representative in most years. Figure B2–4 shows the same information for the west coast South Island, South Taranaki Bight, and North Taranaki Bight areas separately by month. All show that the majority of coverage is occurring at the peak times of operation for the target fisheries in which most frostfish are caught (discussed above). During those peak times over-sampling appears to be occurring. Outside of those times there tends to be under-sampling.

4.1.2 Length and age frequencies

Scaled length frequencies were determined using the ‘Catch at Age’ software (Bull 2002). This process scales the length frequency from each catch up to the tow catch, sums over catches in each stratum, scales up to the total stratum catch, and then sums across the strata to yield overall length frequencies. Numbers of frostfish were estimated from catch weights using the length-weight relationship from the west coast South Island trawl survey on *Kaharoa* in 2000 (KAH0004) (Stevenson 2002).

Few fish from the west coast South Island are less than 80 cm FL (Figures B6–7). For both sexes, most fish are 80–120 cm FL, with slightly more fish being 100–120 cm than 80–100 cm FL in most years. There are relatively few fish greater than 140 cm FL. Length frequencies are often patchy and the tracking of cohorts is difficult.

Scaled length frequencies for the South Taranaki Bight show that catch numbers are lower than for the west coast South Island (note the *y*-axis is in hundreds of thousands for the South Taranaki Bight as opposed to millions for the west coast South Island)(Figures B8–9). There appear to be fewer smaller fish, with none less than 90 cm FL. Most fish are between 110 and 140 cm FL. Again, length frequencies are patchy and tracking of cohorts between years is difficult.

Scaled numbers for the North Taranaki Bight are similar to those for the South Taranaki Bight (Figure B10). Fish are also a similar length with none being less than 90 cm FL and most being between 110 and 140 cm FL. There is no obvious modal progression between years.

There are few data for the rest of the New Zealand EEZ (‘other’ areas), sample sizes are small, scaled population numbers are low, and length frequencies are patchy (Figures B11–12). There is probably no useful information to be gleaned from these figures.

Table 4 below gives the number of frostfish otoliths collected by QMA and fishing year by the observer programme. A validated method to age frostfish has been developed (Horn 2013). A catch-at-age distribution for frostfish caught in FRO 7 in winter 2008 was developed using otoliths and lengths collected by the observer programme (Horn 2013). The catch in that year was strongly dominated by 2-year-old fish. It would be possible to develop a catch-at-age history for fisheries off the west coast of the North and South Islands.

Table 4: Number of frostfish otoliths collected by fishing year and QMA by the observer programme.

Fishing year	FRO 9	FRO 8	FRO 7	FRO 7–9
1998–99	0	0	170	170
1999–2000	0	0	632	632
2000–01	0	119	470	589
2001–02	0	245	499	744
2002–03	0	562	687	1 249
2003–04	115	15	245	375
2004–05	87	57	150	294
2005–06	58	66	126	250
2006–07	18	184	311	513
2007–08	30	130	409	569
2008–09	10	111	352	473
2009–10	88	149	81	318
2010–11	0	40	108	148

4.1.3 Female maturity

Observer-collected data on female maturity stage has used a 5-stage gonad scale (immature/resting, maturing, ripe, running ripe, spent). The numbers of female frostfish staged for the study period, by areas, are given in Tables B11–14.The majority have come from the west coast South Island (6 333 fish), followed by the South Taranaki Bight (1 311 fish), 'other' areas (745 fish), and North Taranaki Bight (731 fish).

The proportions of each gonad stage by month for all years combined are plotted in Figure B13. At any time of year for all areas combined most fish are immature/resting or maturing. Ripe fish appear to be present in all months except for May and June. Running ripe fish are mainly observed in November, December, January, and April. Spent fish are present in most months but with a slight peak in April–May. The timing of ripe, running ripe, and spent fish suggests that frostfish may have a protracted spawning period beginning in mid-winter with a peak from summer until early autumn.

Almost all of the gonad data for frostfish from the west coast South Island come from the winter spawning hoki season. There are no gonad stage data from January to May, or for November. Most fish are immature/resting or maturing. A minority of fish from months where there are data are ripe and spent. There are so few records of running ripe fish for the west coast South Island that they are not discernible on Figure B13. There are, however, a few in July to September visible in Figures B15–16.

Figure B13 for the South Taranaki Bight again shows that at any time of year the majority of fish are immature/resting or maturing. Fish appear to start ripening in September through to April. There are no data available for February or May. No running ripe fish have been observed in the South Taranaki Bight (Figures B14–16).

As with the west coast South Island and the South Taranaki Bight, most fish in the North Taranaki Bight are immature/resting or maturing. There are no available data from February to May, or for August–September.

Figures B15–16 might suggest that frostfish start to spawn on the west coast South Island in winter–early spring and then migrate northwards to the South and North of the Taranaki Bight in spring–summer where they continue to spawn. However it must be noted that there are almost no observations of *any* gonad stage for the Taranaki Bight in winter when there is some observed spawning activity for the west coast South Island. Similarly, in October to January when there is a lot of observed spawning activity around the Taranaki Bight there are no observations of any staged fish on the west coast South Island. This is most likely because most west coast South Island frostfish observations are made during the hoki spawning season, which has finished by October. There are, however, some observations of ripe fish off the North Taranaki Bight in July, suggesting that there is some spawning going on there at the same time as the west coast South Island (Figure B15).

5. FISHERY CHARACTERISATIONS

In this section we begin with an overview of the methods, target species, months and areas where frostfish is caught and on that basis define several key fisheries. We then provide more detailed summaries for those key fisheries.

5.1 Overview

Landings of frostfish are most consistent in quota management areas (QMAs) FRO 7 and FRO 8. Landings in other QMAs have been sporadic and generally much smaller (Figures C1–D7).

Nationally, most frostfish is taken as a bycatch from midwater trawling (MW) targeting hoki (HOK), jack mackerel (JMA) and barracouta (BAR) (Figure C8). A smaller percentage of frostfish has been taken by bottom and midwater trawling targeting squid, and bottom trawling targeting jack mackerel and tarakihi (Figure C8). Direct targeting of frostfish has represented a relatively small proportion of frostfish catches. Most of the frostfish catch has been taken off the west coast of the North and South Islands (statistical areas 034 to 042) in late winter to early summer (Figures C9–10).

The spatial distribution of frostfish catches has varied considerably with target species: catches from hoki and barracouta targeting have been concentrated off the west coast of the South Island (Figure C11, Figure C13); from jack mackerel targeting off the west coast of both the North and South Islands including the South Taranaki Bight (Figure C12); from squid targeting off the Snares Shelf and Canterbury coast (Figure C14), and from targeting for the inshore species tarakihi, gemfish, snapper and trevally mainly off the north-east coasts of the North Island (Figures C15–C18).

The percentage of frostfish catches by method, target species, region (combinations of statistical areas), and month were summarised to identify key, discrete fishing activities (Figure C19). From this summary, six key fisheries were defined (Table 5).

Catches from each of these activities has varied substantially (Figure C20–D21). From 1989–90 to 2001–02 trawling targeting hoki off the west coast (HOK.W) took the majority of frostfish catches. In 1990–91 catches from this activity are estimated to have been close to 2500 t. However, after that year frostfish catches from HOK.W trended downwards and in 2009–10 are estimated to be less than 100 t. In the 2000s, frostfish catches from trawling targeting jack mackerel (JMA.W) increased to over 1000 t in 2009–10. This increase in catch, combined with the decrease from the HOK.W fishery, has meant that the JMA.W fishery now takes over 80% of the frostfish caught nationally. Catches from the other key activities has generally been sporadic.

The TAR|SKI|SNA.NE activity has landed between 30 and 200 t from FRO 1 and FRO 2 combined in each year since 1991–92. Since this activity is a relatively small contributor to national frostfish catches we do not describe them in more detail in this document.

Table 5: Key fishing activities catching frostfish, 1989–90 to 2009–10. Regions are defined on the basis of statistical areas, North-east (NE):001–016; South-east(SE): 020–030; West(W): 034–042.

Label	Target species	Methods	Region	Season
HOK.W	Hoki	Mostly MW	West	June–September
JMA.W	Jack mackerel	Mainly MW, some BT	West	June–July and Sept–January
BAR.W	Barracouta	Mostly MW	West	August–October
FRO.W	Frostfish	Mostly MW	West	August–October
SQU.SE	Squid	MW and BT	South-east	February–May
TAR|SKI|SNA.NE	Tarakihi, gemfish, snapper	Mainly BT, some MW	North-east	All year

5.2 HOK.W fishery

Trawling targeting hoki off the west coast of the South Island was once the main fishery catching frostfish but catches have declined substantially, particularly during the 2000s (Figure C22). This is at least partially due to the decrease in effort (Figure C23) associated with the reduction in TACC for hoki. The frostfish catch from this fishery is highly concentrated in the months August to September and the statistical areas 034 and 035 (Figure C24). Catches of frostfish tend to be more concentrated in the south, towards the Hokitika Canyon, during June–July and spread out towards the north in August–September.

The fishery is predominantly midwater although in 2009–10 there was an increase in the proportion of catch taken by bottom trawling (Figure C26). Virtually all the catch of frostfish is from larger offshore vessels reporting on TCEPR forms (Figure C27).

The spatial and seasonal pattern of frostfish catches has changed little over 20 years, although in the 2008–09 and 2009–10 fishing years a greater proportion of the catch was taken in July than in August or September (Figures D28–D29).

5.3 JMA.W fishery

The fishery targeting jack mackerel off the west coast of the North and South Islands have had highly variable catches of frostfish but since 2004–05 catches have been close to, or above, 1000 t (Figure C30). This is despite little trend in effort (Figure C31). Frostfish catches from this fishery have been relatively spread out both spatially and seasonally but a larger proportion of frostfish has been taken off the South Island (034–036) during winter and early spring and off Taranaki (037, 040–042) in early summer (Figures C32–33).

Over time, an increasing proportion of the catches from this fishery come from FRO 8 (Figure C30) with a greater proportion of frostfish being caught in statistical area 041 during summer and less in 034 and 035 during winter (Figures C36–37). Before 1999–2000 a substantial proportion of frostfish catches from this activity were taken using bottom trawl (Figure C34). However, since then almost all the catch of frostfish has been taken using midwater trawling.

5.4 BAR.W fishery

Catches of frostfish from trawling targeting barracouta off the west coast of the South Island have been sporadic (Figure C38). Most catches were taken during September in statistical areas 034 and 035 (Figures D40–D41). Frostfish catches from this fishery have generally been taken by midwater trawling (Figure C42) and are almost always reported on TCEPR forms (Figure C43).

The spatial distribution of frostfish catches has changed over time with less catch taken in the southern statistical areas 034 and 035 and more taken in areas 036, 040 and other areas since 2004–05 (Figure C44). During the same period the frostfish catch from this fishing activity has become less concentrated on the August to October period (Figure C45).

5.5 FRO.W fishery

Trawling targeting frostfish off the west coast of the South Island has been very sporadic (Figure 46) but in 1998–99 caught over 800 t in FRO 7, which was about 30% of the national frostfish catch in that year (Figure C21). The spatial and seasonal distribution is similar to the BAR.W fishery: most of the frostfish catch is taken in August–October off the west coast of the South Island (Figures D48–49). This distribution has changed little over time (Figures D52–53).

5.6 SQU.SE fishery

This fishery targets squid off the Snares Shelf and Puysegur (FRO 5, mainly statistical areas 028 and 030) and the Canterbury coast (FRO 3, mainly statistical areas 020 and 022). Before 1998–99 most of the frostfish catches from this fishery came from FRO 5, but since that time FRO 3 catches have dominated (Figure C54). The seasonal distribution of effort is similar in both areas, being between February and May (Figures D56–57). The Snares Shelf-Puysegur fishery uses predominately midwater trawling while the Canterbury fishery uses predominately bottom trawling. Frostfish catches from the Snares Shelf fishery (statistical area 028) dominated in the early 1990s but in most years since then have been relatively small (Figure C60).

6. CATCH-PER-UNIT-EFFORT ANALYSES

Catch-per-unit-effort analyses were done for two of the key fishing activities identified in the previous section: trawling off the west coast (a) targeting jack mackerel (JMA.W) and (b) targeting hoki (HOK.W). The other activities were considered too sporadic to be capable of providing useful CPUE indices.

6.1 JMA.W fishery

6.1.1 Data subset and core vessel selection

Catch and effort data from midwater (MW) and bottom (BT) trawling targeting jack mackerel (JMA) in statistical areas 034, 035, 036, 037, 039, 040, 041 and 042 was used. The data was also restricted to TCEPR forms, depth of tow 25–500 m, depth of bottom 25–500 m, net height 1–100 m, net width 10–200 m, tow speed 3–7 knots, and duration 0–15 hrs. This data subset had between 938 and 2926 individual tows per fishing year (Table D1).

Alternative core vessel selection criteria were investigated by considering the reduction in the number of vessels and percentage of catch (Figure D1). The most appropriate combination of criteria to define the core fleet was vessels that had fished for at least three trips in each of at least three years. These criteria resulted in a core fleet size of 18 vessels which took 88% of the catch (Figure D1). There was significant change in the composition of the fleet in the late 1990s when a number of vessels stopped fishing (mostly in 1997–98) and several new vessels started fishing (Figure D3). This change in the fleet composition was related to a company ceasing operations in the fishery and several larger Ukrainian vessels entering (Fu 2013). The proportion of tows with positive frostfish catches and the unstandardised CPUE was similar between core and all vessels (Figures D4–D5).

6.1.2 Selection of error distribution and model terms

A generalised linear model (GLM) was developed for the catch from tows with positive catches of frostfish. Alternative error distributions were evaluated using the Akaike Information Criterion (AIC) as the selection criterion and with the model formula *catch ~ fyear + month + area + vessel + method*. On this basis the log-logistic distribution was selected (Figure E6).

An initial log-logistic model with a fishing year term was fitted followed by forward stepwise selection of terms with the following terms offered: *month, area, area* x *month, vessel, method, poly(log(duration), 3), poly(log(depth), 3), poly(log(bottom), 3), poly(log(height), 3), poly(log(width), 3), poly(log(speed), 3), poly(time, 3), poly(moon, 3)*. The final model included the terms *month, area, area* x *month, vessel, poly(log(duration), 3), poly(log(depth), 3), poly(log(height), 3), poly(log(speed), 3)*, and *poly(time, 3)* and had a pseudo-coefficient of determination (R^2) of 32.5% (Table D3).

6.1.3 Influence of model terms on standardisation

The standardised CPUE index is flatter than the unstandardised index, in particular showing less of an increase during the 2000s (Figure D7). The variable with the highest overall influence on the standardisation was vessel (22% overall influence) followed by tow speed (10%) and duration (10%) (Table D4). The standardisation effect of these three variables appears to be aliasing for the change in fleet composition and fishing behaviour in the late 1990s (Figure D8 right panel). Most model terms show a shift in their distributions in the late 1990s which, in most cases, causes a shift in their influence on the unstandardised CPUE (Figures D9–15).

The coefficients estimated for the area × month interaction term suggest that the seasonality seen in the spatial distribution of catches from this fishery (see Section 6.3) are caused in part by seasonal variation in catch-per-unit-effort and thus potentially seasonal variation in biomass. In the more southern statistical areas 034, 035 and 036, coefficients are highest during spring and lowest during autumn (Figure D16). In the more northern statistical areas 041 and 042, coefficients are highest in summer-autumn and lowest in winter-spring (Figure D18).

6.1.4 Sensitivity test

The shift in fleet composition and associated change in fishing behaviour in the late 1990s may cause problems with the estimation of GLM coefficients. To test the sensitivity of results to this another GLM was fitted with the same model terms but with a data set that was restricted to midwater trawling from 1999–2000 onwards. The resulting CPUE indices were very similar to those from the base GLM (Figure D23). There was also little change in the CPUE index when a lognormal distribution was assumed instead of a log-logistic distribution as in the base case (Figure D25).

6.1.5 CPUE index

Final standardised CPUE indices for the JMA.W fishery from the base-case GLM are provided in Table D5 and Figure 1. For comparison, an unstandardised CPUE index is also provided. There was little difference between the overall trends exhibited by the two indices, although the standardised index is flatter in the period since 2001–02 primarily due to the model accounting for the change in fleet composition around this time.

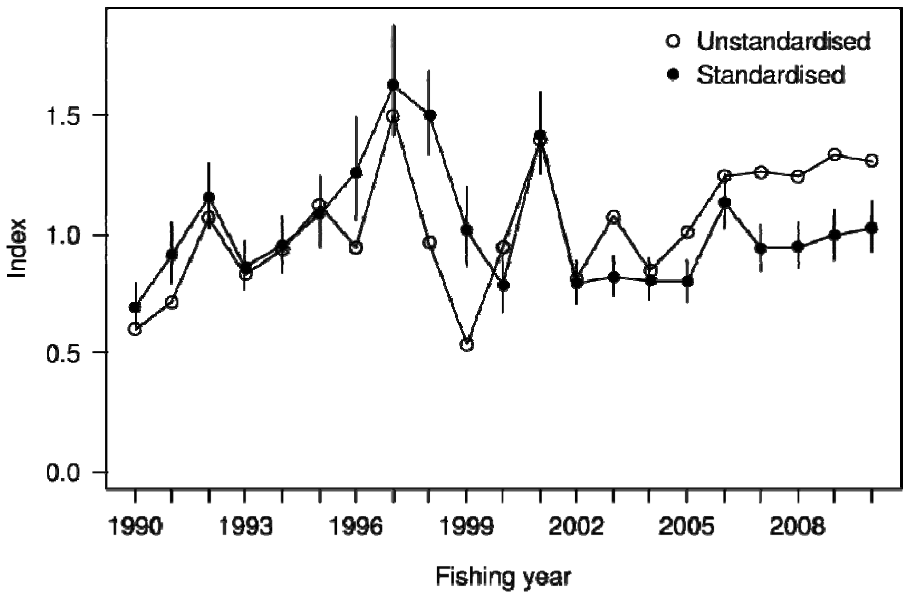

Figure 1:Standardised and unstandardised CPUE indices for frostfish from the western jack mackerel fishery (JMA.W). Fishing years are labelled according the latter calendar year e.g. 1990=1989–90. The standardised index is from the base-case GLM (see text for details). The unstandardised index is based on the geometric mean of the catch per tow and is thus not standardised for changes in fishing effort.

6.2 HOK.W fishery

6.2.1 Data subset and core vessel selection

Catch and effort data from midwater (MW) and bottom (BT) trawling targeting hoki (HOK) in statistical areas 034, 035, 036 during June to September was used. The data was also restricted to TCEPR forms, depth of tow 100–1000 m, depth of bottom 100–1000 m, net height 10–200 m, net width 10–200 m, tow speed 2–6 knots, and duration 0–15 hrs. This data subset had between 680 and 6937 individual tows per fishing year (Table EE1).

For each fishing trip, landings of frostfish were allocated to fishing events on that trip using one of three methods: (1) in proportion to estimated catch, if any, for the trip, otherwise (2) in proportion to effort, if only one method was used on the trip, otherwise (3) equally across events on the trip. It was found that in some years there was a high proportion of trips which used allocation methods 2 or 3 because there was no estimated catch of frostfish on the trip. To remove any potential bias due to allocation method, the data were further restricted to those trips where frostfish catches were estimated and for which allocation method 1 could thus be used.

Alternative core vessel selection criteria were investigated by considering the reduction in the number of vessels and percentage of catch (Figure EE5). The most appropriate combination of criteria was considered to be to define the core fleet as those vessels that recorded frostfish for at least one trip in each of at least three years. These criteria resulted in a core fleet size of 77 vessels which took 74% of the catch (Figure EE5).

6.2.2 Selection of error distribution and model terms

A generalised linear model (GLM) was developed for the catch from tows with positive catches of frostfish. Alternative error distributions were evaluated using the Akaike Information Criterion (AIC) as the selection criterion and with the model formula *catch ~ fyear + month + area + vessel + method*. On this basis the log-logistic distribution was selected (Figure E10).

An initial log-logistic model with a fishing year term was fitted followed by forward stepwise selection of terms with the following terms offered: *month, area, vessel, method, poly(log(duration), 3), poly(log(depth), 3), poly(log(bottom), 3), poly(log(height), 3), poly(log(width), 3), poly(log(speed), 3), poly(time, 3), poly(moon, 3)*. The final model included the terms *vessel, poly(log(bottom), 3), poly(log(duration), 3), poly(log(height), 3)* and *month* and had a pseudo-coefficient of determination (R^2) of 32.7% (Table EE4).

6.2.3 Influence of model terms on standardisation

The standardised CPUE index is similar to the unstandardised index but exhibits a steeper decline (Figure EE11). This is largely due to the model estimating that coefficients for vessel, the variable with the highest overall influence on the standardisation, increased over time (Figure EE12). Note that in 2007–08 and 2008–09 there was a substantial reduction in the number of vessels in the dataset with vessels with high coefficients dominating (Figure EE13). The standardisation effect of other variable included in the GLM is negligible mostly due to the fact that their distributions have changed little (Figures E14–17).

6.2.4 Sensitivity tests

Since the standardisation was highly influenced by the vessel variable several sensitivity tests were done in which the core vessel criteria were changed. Other sensitivity tests were done where early years (due to uncertainty in reporting practices) and the last year (due to the re-entry of several vessels into the fishery) were excluded. None of the sensitivity tests modified the CPUE index substantially over the period 1996–1997 to 2009–10 (Figure EE24).

6.2.5 CPUE index

Final standardised CPUE indices for the HOK.W fishery from the base-case GLM are provided in Table EE6 and Figure 2. There was been a steep decline in the CPUE index between the early 1990s, when it fluctuated around 2, and the early 2000s, when it fluctuated between 0.5 and 1. In 2009–10 there was a drop in both standardised and unstandardised CPUE from the previous year.

Due to uncertainties regarding the reporting of frostfish catches in the hoki fishery it is uncertain whether this CPUE index is reflecting frostfish biomass. The reduction in frostfish CPUE and catches from the hoki fishery may also reflect changes in fishing technology and skill which allows better avoidance of bycatch species.

It is also worth noting that the estimates of frostfish biomass from the *Kaharoa* west coast South Island surveys, although they are unlikely to provide a good estimate of frostfish biomass, exhibit the opposite pattern to the CPUE index from the hoki fishery. The biomass estimates from those trawl surveys increased dramatically from the early 1990s to the early2000s and have remained high (Table 3).

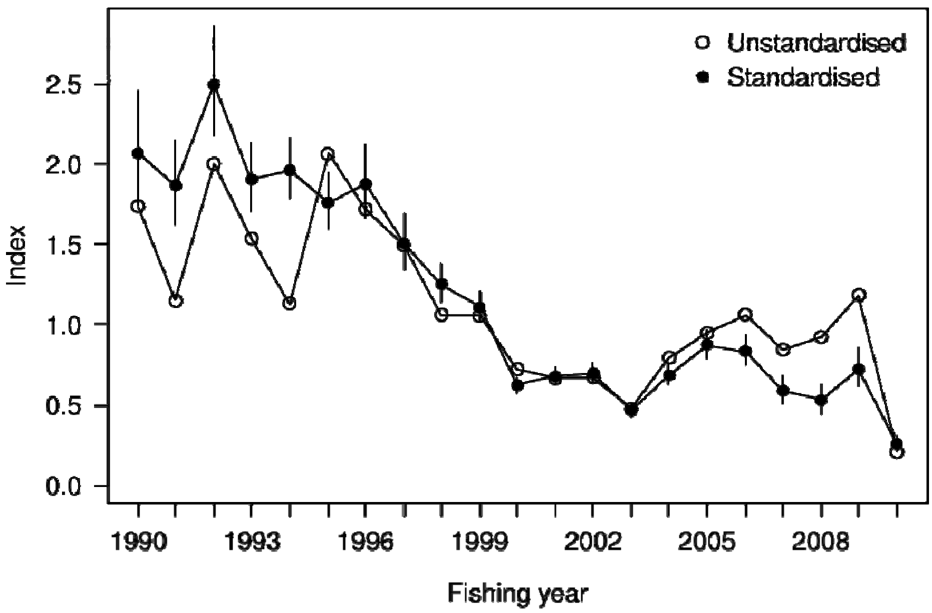

Figure 2:Standardised and unstandardised CPUE indices for frostfish from the western hoki fishery (HOK.W). Fishing years are labelled according the latter calendar year e.g. 1990=1989–90. The standardised index is from the base-case GLM (see text for details). The unstandardised index is based on the geometric mean of the catch per tow and is thus not standardised for changes in fishing effort.

7. SUMMARY AND RECOMMENDATIONS

7.1 Biology

Frostfish are widely distributed in temperate seas, but northern and southern hemisphere populations may be separate biological species. They migrate from near the bottom into midwater at night to feed on crustaceans, small squid and fish. Frostfish are fast growing and short lived with few individuals living more than eight years.

In New Zealand there is little information available on frostfish spawning and stock structure. This study concluded that off the west coast of the North and South Islands, where most catches are taken and the largest populations probably reside, that frostfish probably have a protracted spawning period starting in mid-winter with a peak from summer to early autumn. More research on stock structure is likely to be beneficial for fisheries management.

7.2 Fishery-independent data

There is little fisheries-independent data available for frostfish in New Zealand. No research surveys have been designed with frostfish as a target species. Given that most of the frostfish caught by the commercial fishery is taken by midwater trawling, it could be considered unlikely that bottom trawl surveys provide a good index of biomass. However, it is still worth monitoring the estimates of frostfish biomass from the *Kaharoa* west coast South Island surveys as a potential indicator.

7.3 Fishery-dependent data

Fisheries-dependent data on frostfish are available from the observer programme and commercial catch and effort logbooks. In general, observer sampling of frostfish has been representative of frostfish catches. Off the west coast of the South Island most fish are between 80 and 120 cm. In the North and South Taranaki Bights there are fewer smaller fish.

7.4 Fishery characterisations

Most landings of frostfish come from FRO 7 and FRO 8. Landings from other quota management areas have been sporadic and generally small. Most frostfish is caught as a bycatch to midwater trawling targeting hoki off the west coast of the South Island or jack mackerel in the North and South Taranaki Bights.

Historically most of landings have come from the hoki fishery. In 1990–91, this fishery is estimated to have taken around 2500 t of frostfish. However, during the late1990s, landings from the hoki fishery declined and landings from the jack mackerel fishery increased. In 2009–10, the jack mackerel fishery landed over 1000 t of frostfish, about 80% of national landings. Around 1999–2000 there was a sudden change in fleet composition in the jack mackerel fishery which resulted in a substantial shift in fishing methods towards shorter duration and faster midwater trawling. This appears to have contributed to increased catches of frostfish from that fishery.

7.5 Catch per unit effort analyses

Separate catch per unit effort standardisations were done for the hoki and jack mackerel fisheries. The two CPUE indices exhibit contrasting trends and it uncertain how well either of them tracks frostfish biomass. The index based on the jack mackerel fishery provides the most promise as an index of biomass provided that there are no further substantial shifts in fleet composition and methods.

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APPENDIX A: SUMMARIES OF TRAWL SURVEY DATA

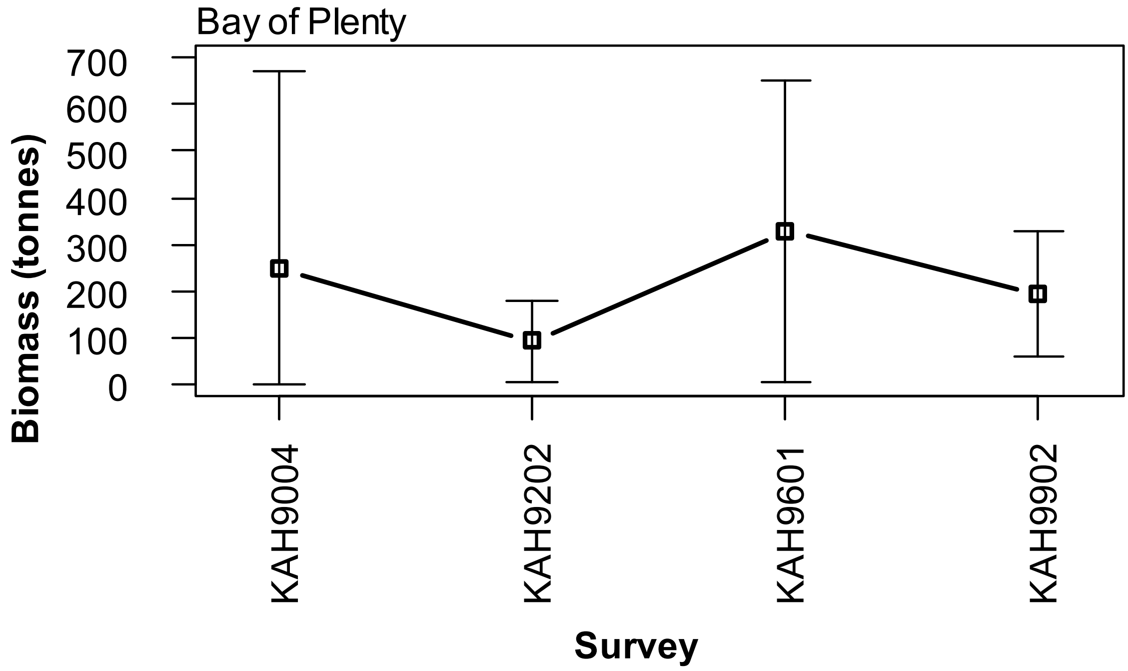


Figure A1: Doorspread biomass estimates of total frostfish from the Bay of Plenty, from *Kaharoa* surveys from 1990 to 1999. NB: data by sex not available.

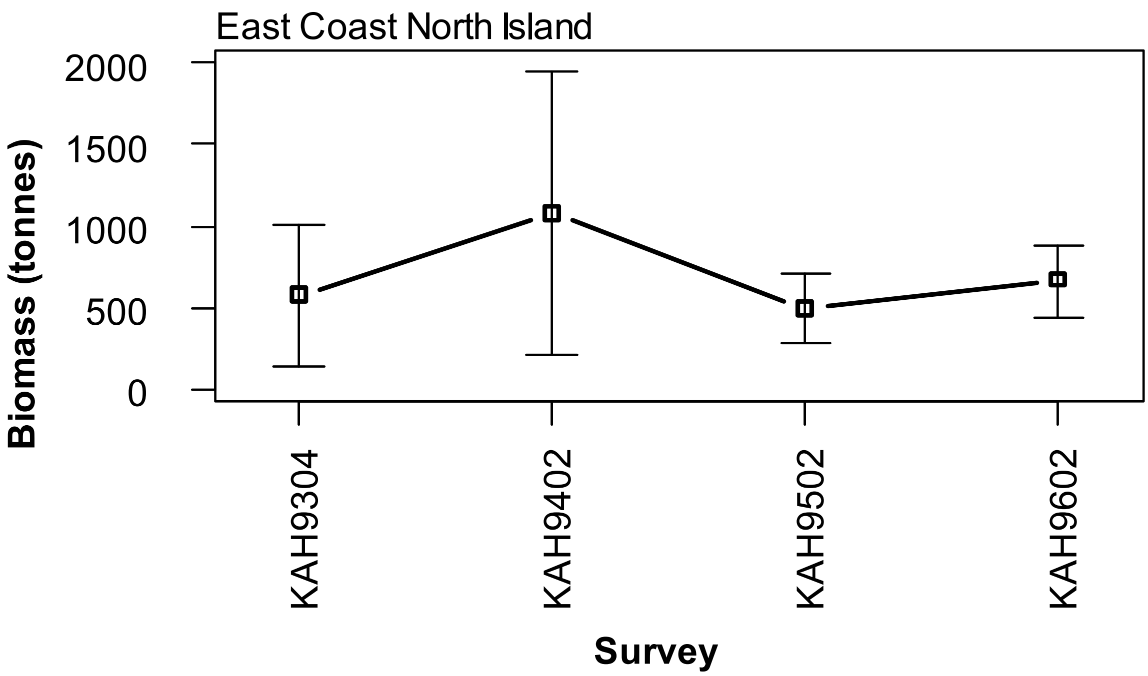


Figure A2: Doorspread biomass estimates of frostfish by sex from the east coast North Island, from *Kaharoa* surveys from 1993 to 1996. NB: data by sex not available.

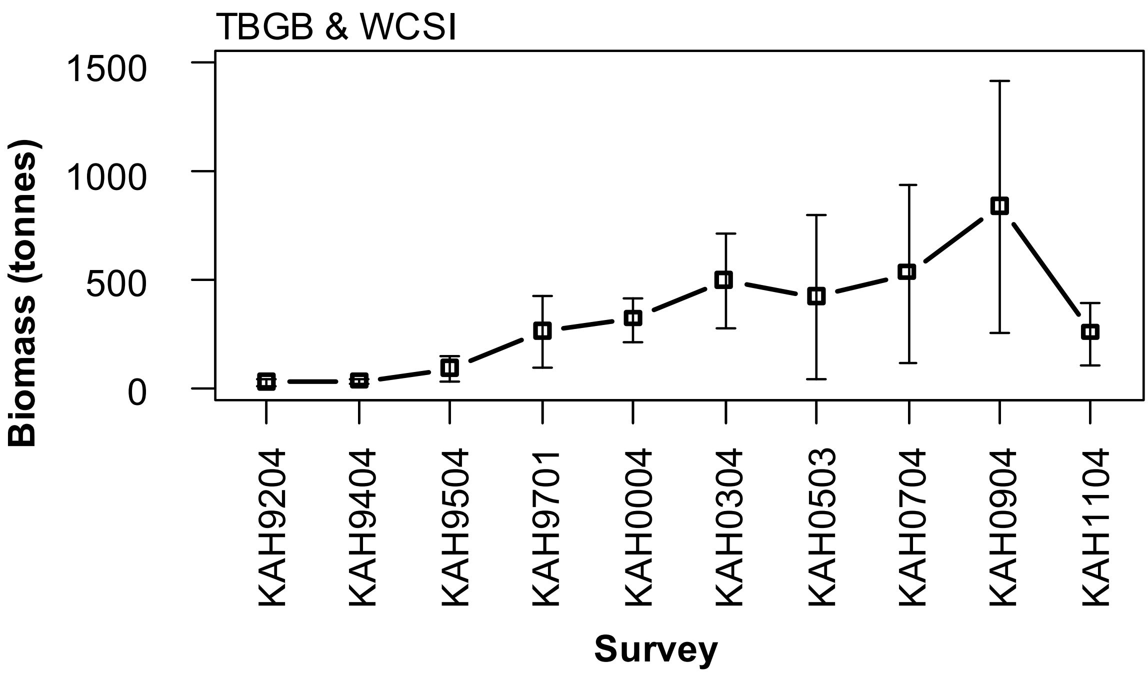


Figure A3: Doorspread biomass estimates of frostfish by sex from the west coast South Island/Tasman & Golden Bays, from *Kaharoa* surveys from 1992 to 2011.

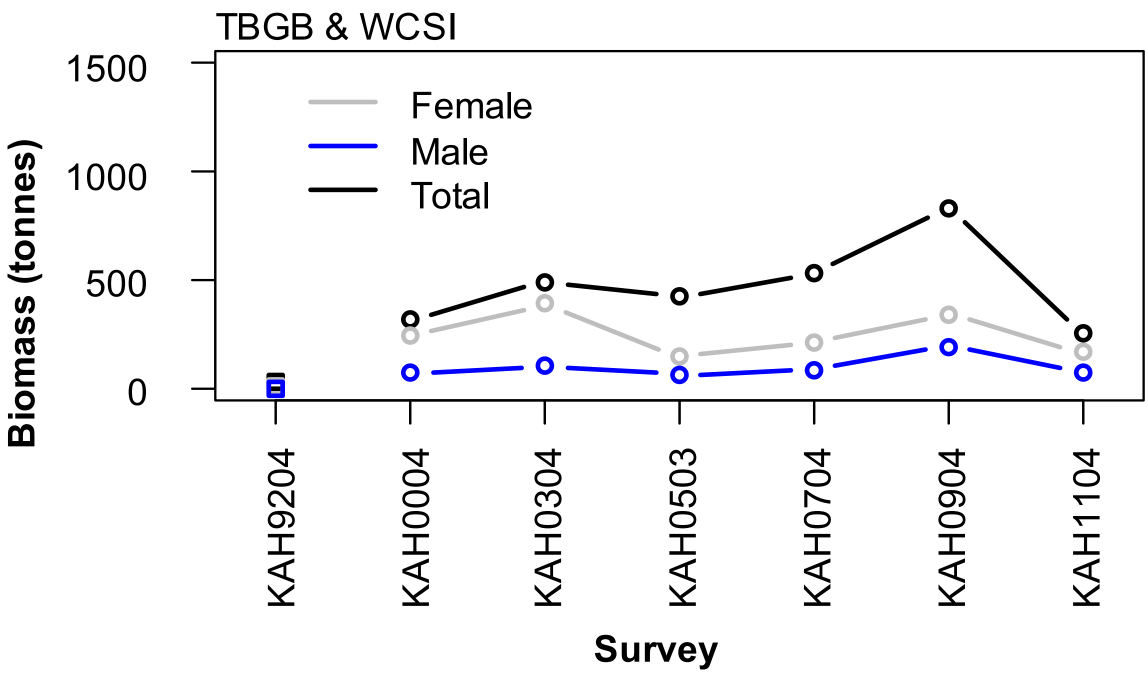


Figure A4: Doorspread biomass estimates of frostfish by sex from the west coast South Island and Tasman andGoldenBays, from *Kaharoa* surveys from 1992 to 2011. NB: data by sex not available for 1994 and 1995. NB2: Total includes unsexed fish as well.

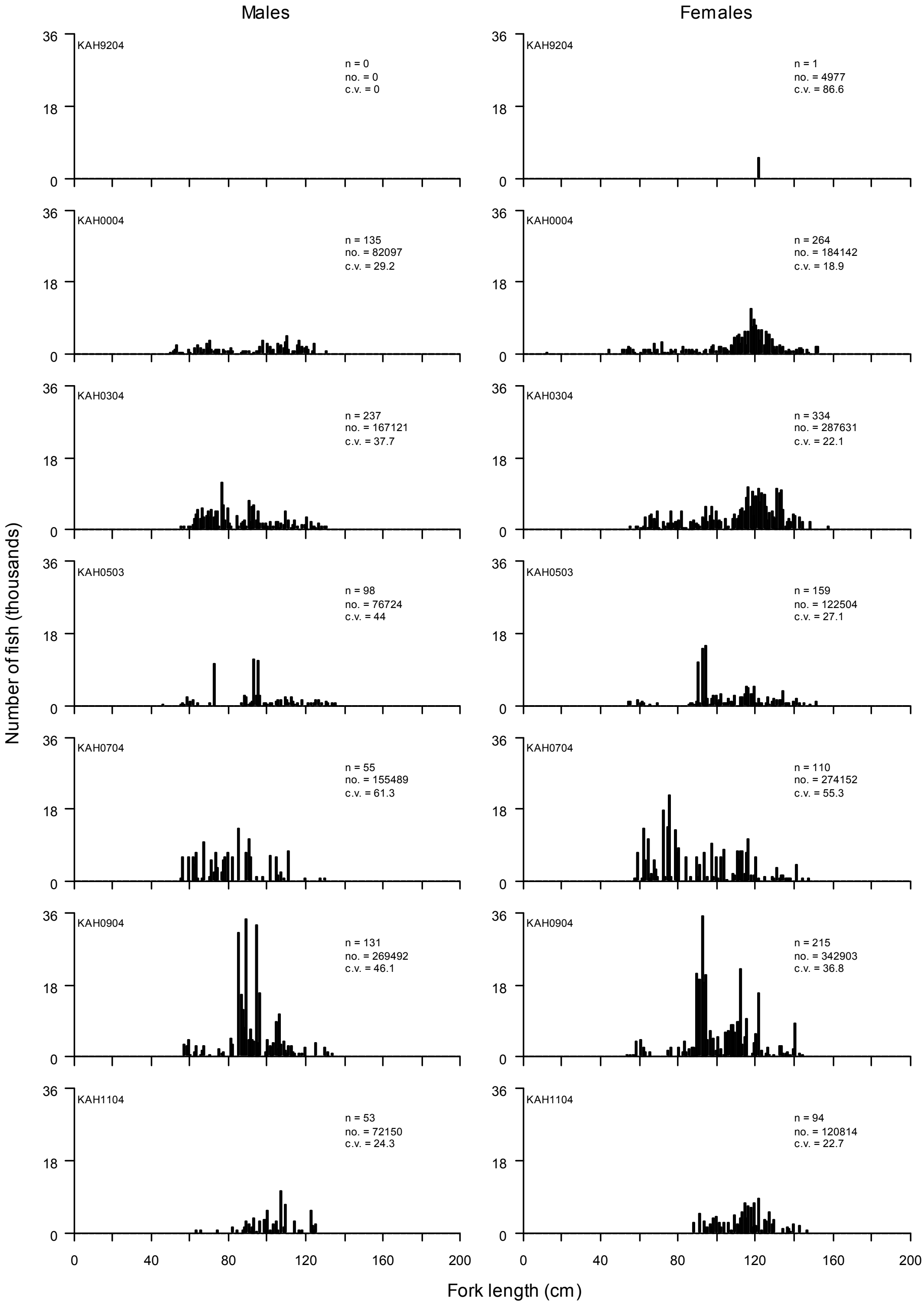


Figure A5: Scaled population length frequencies of male and female frostfish from the west coast South Island and Tasman and GoldenBays, from *Kaharoa* surveys from 1992 to 2011.

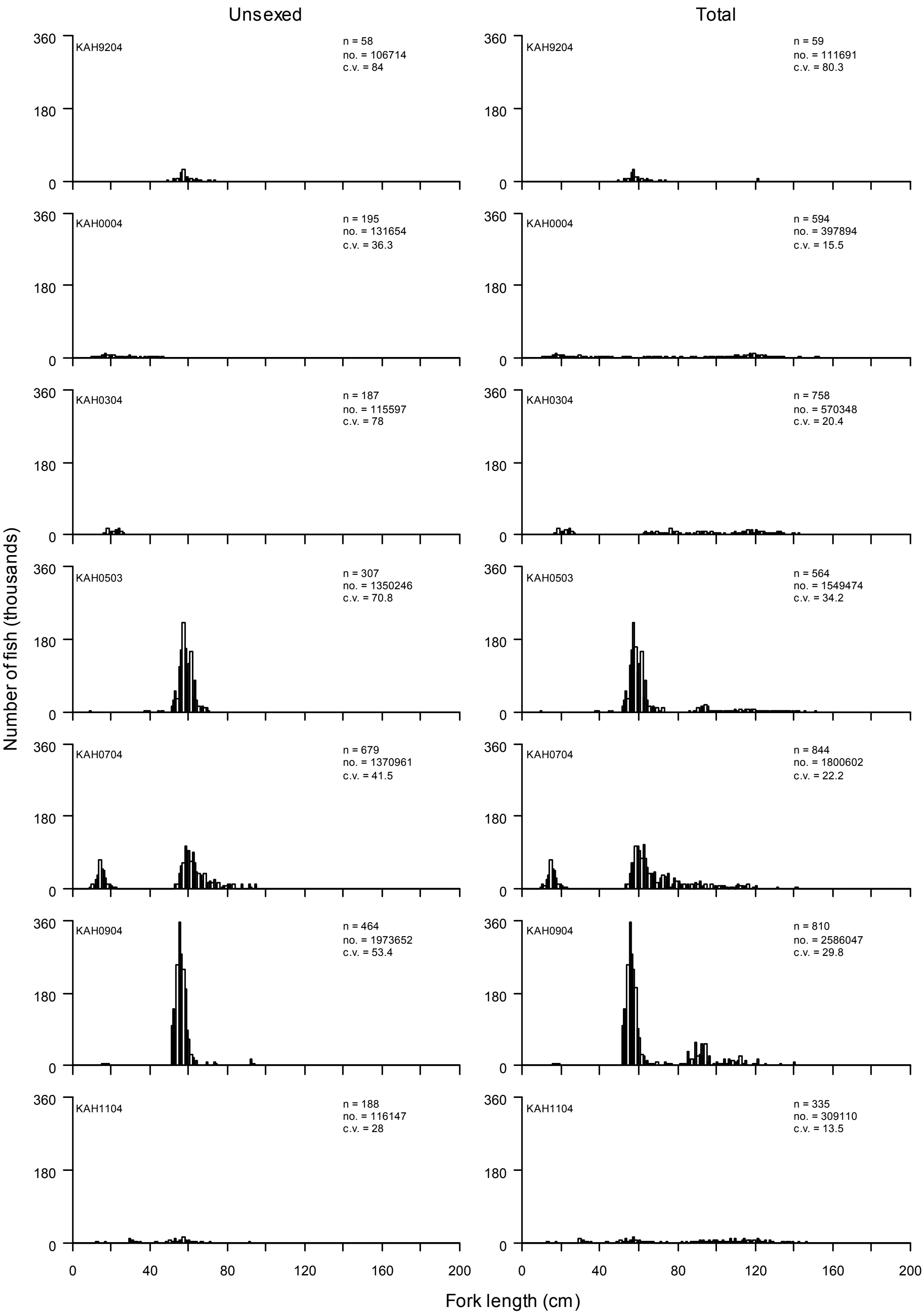


Figure A6: Scaled population length frequencies of unsexed and total frostfish from the west coast South Island and Tasman and GoldenBays, from *Kaharoa* surveys from 1992 to 2011. Note the different y-axis scales between Figure A5 and A6.

APPENDIX B: SUMMARIES OF OBSERVER PROGRAMME DATA

Table B1: Total number of tows by fishing year sampled for frostfish length from each area overall by the observer programme for the fishing years 1994–95, and 1998–99 to 2009–10. WCSI = west coast South Island, STB= South Taranaki Bight, NTB=North Taranaki Bight.

Fishing year	WCSI	STB	NTB	Other	Total
1994–95	-	-	-	2	2
1998–99	9	2	-	1	12
1999–00	153	-	-	18	171
2000–01	106	22	-	13	141
2001–02	99	28	-	6	133
2002–03	122	86	-	31	239
2003–04	82	6	17	13	118
2004–05	34	2	16	15	67
2005–06	24	13	13	13	63
2006–07	46	33	9	9	97
2007–08	57	10	20	1	88
2008–09	53	8	9	3	73
2009–10	12	9	27	8	56
Total	797	219	111	133	1 260

Table B2: Total number of tows by fishing year sampled for frostfish length by month for all areas combined by the observer programme for the fishing years 1994–95, and 1998–99 to 2009–10.

Fishing year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1994–95	-	-	-	-	2	-	-	-	-	-	-	-	2
1998–99	-	-	-	-	1	-	-	-	-	-	-	11	12
1999–00	-	-	-	4	1	2	-	-	1	59	91	13	171
2000–01	7	3	23	-	-	4	-	-	-	24	72	8	141
2001–02	29	-	-	-	-	3	2	-	-	18	73	8	133
2002–03	88	12	-	2	12	6	9	1	-	10	79	20	239
2003–04	3	-	24	6	-	-	-	-	-	19	62	4	118
2004–05	-	8	6	-	1	-	1	2	2	18	20	9	67
2005–06	1	3	10	1	-	-	-	1	12	6	29	-	63
2006–07	8	-	20	18	-	-	6	1	-	6	35	3	97
2007–08	15	-	7	-	-	-	-	-	14	31	21	-	88
2008–09	2	-	14	3	1	-	-	-	1	44	8	-	73
2009–10	13	3	20	-	-	1	-	-	3	10	1	5	56
Total	166	29	124	34	18	16	18	5	33	245	491	81	1 260

Table B3: Total number of tows by fishing year sampled for frostfish length by month for the west coast South Island by the observer programme for the fishing years 1998–99 to 2009–10.

Fishing year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1998–99	-	-	-	-	-	-	-	-	-	-	-	9	9
1999–00	-	-	-	-	-	-	-	-	1	57	83	12	153
2000–01	2	-	-	-	-	-	-	-	-	24	72	8	106
2001–02	2	-	-	-	-	-	-	-	-	18	72	7	99
2002–03	17	-	-	-	-	-	-	-	-	9	78	18	122
2003–04	-	-	-	-	-	-	-	-	-	18	60	4	82
2004–05	-	-	-	-	-	-	-	-	1	12	20	1	34
2005–06	-	-	-	-	-	-	-	-	-	-	24	-	24
2006–07	4	-	1	-	-	-	-	-	-	6	34	1	46
2007–08	-	-	-	-	-	-	-	-	10	26	21	-	57
2008–09	1	-	-	-	-	-	-	-	-	44	8	-	53
2009–10	-	-	-	-	-	-	-	-	1	10	1	-	12
Total	26	-	1	-	-	-	-	-	13	224	473	60	797

Table B4: Total number of tows by fishing year sampled for frostfish length by month for the South Taranaki Bight by the observer programme for the fishing years 1998–99, and 2000–01 to 2009–10.

Fishing year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1998–99	-	-	-	-	-	-	-	-	-	-	-	2	2
2000–01	-	-	22	-	-	-	-	-	-	-	-	-	22
2001–02	27	-	-	-	-	-	-	-	-	-	-	1	28
2002–03	71	12	-	-	-	-	3	-	-	-	-	-	86
2003–04	1	-	1	4	-	-	-	-	-	-	-	-	6
2004–05	-	-	-	-	-	-	-	-	-	2	-	-	2
2005–06	-	-	8	-	-	-	-	-	4	-	1	-	13
2006–07	2	-	8	17	-	-	5	-	-	-	-	1	33
2007–08	3	-	-	-	-	-	-	-	2	5	-	-	10
2008–09	-	-	6	2	-	-	-	-	-	-	-	-	8
2009–10	5	-	1	-	-	1	-	-	2	-	-	-	9
Total	109	12	46	23	-	1	8	-	8	7	1	4	219

Table B5: Total number of tows by fishing year sampled for frostfish length by month for the North Taranaki Bight by the observer programme for the fishing years 2003–04 to 2009–10.

Fishing year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
2003–04	1	-	16	-	-	-	-	-	-	-	-	-	17
2004–05	-	7	6	-	-	-	-	-	1	2	-	-	16
2005–06	-	3	2	-	-	-	-	-	4	4	-	-	13
2006–07	2	-	6	1	-	-	-	-	-	-	-	-	9
2007–08	11	-	7	-	-	-	-	-	2	-	-	-	20
2008–09	1	-	6	1	-	-	-	-	1	-	-	-	9
2009–10	8	3	16	-	-	-	-	-	-	-	-	-	27
Total	23	13	59	2	-	-	-	-	8	6	-	-	111

Table B6: Total number of tows by fishing year sampled for frostfish length by month for all other regions by the observer programme for the fishing years 1994–95, 1998–99 to 2009–10.

Fishing year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1994–95	-	-	-	-	2	-	-	-	-	-	-	-	2
1998–99	-	-	-	-	1	-	-	-	-	-	-	-	1
1999–00	-	-	-	4	1	2	-	-	-	2	8	1	18
2000–01	5	3	1	-	-	4	-	-	-	-	-	-	13
2001–02	-	-	-	-	-	3	2	-	-	-	1	-	6
2002–03	-	-	-	2	12	6	6	1	-	1	1	2	31
2003–04	1	-	7	2	-	-	-	-	-	1	2	-	13
2004–05	-	1	-	-	1	-	1	2	-	2	-	8	15
2005–06	1	-	-	1	-	-	-	1	4	2	4	-	13
2006–07	-	-	5	-	-	-	1	1	-	-	1	1	9
2007–08	1	-	-	-	-	-	-	-	-	-	-	-	1
2008–09	-	-	2	-	1	-	-	-	-	-	-	-	3
2009–10	-	-	3	-	-	-	-	-	-	-	-	5	8
Total	8	4	18	9	18	15	10	5	4	8	17	17	133

Table B7: Number of frostfish measured by fishing year and month sampled from the west coast South Island by the observer programme, for fishing years 1998–99 to 2009–10.

Fishing year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1998–99	-	-	-	-	-	-	-	-	-	-	-	644	644
1999–00	-	-	-	-	-	-	-	-	3	479	958	173	1 613
2000–01	40	-	-	-	-	-	-	-	-	213	1128	64	1 445
2001–02	144	-	-	-	-	-	-	-	-	201	712	70	1 127
2002–03	149	-	-	-	-	-	-	-	-	166	803	170	1 288
2003–04	-	-	-	-	-	-	-	-	-	66	529	17	612
2004–05	-	-	-	-	-	-	-	-	10	104	397	20	531
2005–06	-	-	-	-	-	-	-	-	-	-	381	-	381
2006–07	80	-	20	-	-	-	-	-	-	72	479	5	656
2007–08	-	-	-	-	-	-	-	-	145	569	349	-	1 063
2008–09	10	-	-	-	-	-	-	-	-	892	147	-	1 049
2009–10	-	-	-	-	-	-	-	-	5	200	13	-	218
Total	423	-	20	-	-	-	-	-	163	2 962	5 896	1 163	10 627

Table B8: Number of frostfish measured by fishing year and month sampled from the South Taranaki Bight by the observer programme, for fishing years 1998–99, 2000–01 to 2009–10.

Fishing year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1998–99	-	-	-	-	-	-	-	-	-	-	-	30	30
2000–01	-	-	300	-	-	-	-	-	-	-	-	-	300
2001–02	270	-	-	-	-	-	-	-	-	-	-	10	280
2002–03	671	120	-	-	-	-	29	-	-	-	-	-	820
2003–04	10	-	10	25	-	-	-	-	-	-	-	-	45
2004–05	-	-	-	-	-	-	-	-	-	90	-	-	90
2005–06	-	-	145	-	-	-	-	-	29	-	16	-	190
2006–07	35	-	63	127	-	-	34	-	-	-	-	20	279
2007–08	55	-	-	-	-	-	-	-	20	152	-	-	227
2008–09	-	-	80	32	-	-	-	-	-	-	-	-	112
2009–10	80	-	10	-	-	10	-	-	40	-	-	-	140
Total	1 121	120	608	184	-	10	63	-	89	242	16	60	2 513

Table B9: Number of frostfish measured by fishing year and month sampled from the North Taranaki Bight by the observer programme, for fishing years 2003–04 to 2009–10.

Fishing year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
2003–04	10	-	260	-	-	-	-	-	-	-	-	-	270
2004–05	-	128	81	-	-	-	-	-	7	40	-	-	256
2005–06	-	79	27	-	-	-	-	-	21	41	-	-	168
2006–07	40	-	78	5	-	-	-	-	-	-	-	-	123
2007–08	210	-	142	-	-	-	-	-	20	-	-	-	372
2008–09	5	-	190	20	-	-	-	-	10	-	-	-	225
2009–10	158	60	234	-	-	-	-	-	-	-	-	-	452
Total	423	267	1012	25	-	-	-	-	58	81	-	-	1866

Table B10: Number of frostfish measured by fishing year and month sampled for all other areas by the observer programme, for fishing years 1994–95, 1998–99 to 2009–10.

Fishing year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1994–95	-	-	-	-	6	-	-	-	-	-	-	-	6
1998–99	-	-	-	-	1	-	-	-	-	-	-	-	1
1999–00	-	-	-	17	1	4	-	-	-	2	21	1	46
2000–01	58	4	3	-	-	32	-	-	-	-	-	-	97
2001–02	-	-	-	-	-	19	11	-	-	-	1	-	31
2002–03	-	-	-	5	169	33	54	7	-	5	16	11	300
2003–04	5	-	155	2	-	-	-	-	-	4	11	-	177
2004–05	-	20	-	-	1	-	10	30	-	30	-	18	109
2005–06	1	-	-	1	-	-	-	1	4	2	144	-	153
2006–07	-	-	119	-	-	-	8	12	-	-	20	20	179
2007–08	100	-	-	-	-	-	-	-	-	-	-	-	100
2008–09	-	-	30	-	10	-	-	-	-	-	-	-	40
2009–10	-	-	29	-	-	-	-	-	-	-	-	46	75
Total	164	24	336	25	188	88	83	50	4	43	213	96	1 314

Table B11: Number of female frostfish gonads staged by fishing year and month sampled from the west coast South Island by the observer programme, for fishing years 1998–99 to 2009–10.

Fishing year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1998–99	-	-	-	-	-	-	-	-	-	-	-	373	373
1999–00	-	-	-	-	-	-	-	-	-	303	596	111	1010
2000–01	19	-	-	-	-	-	-	-	-	151	675	38	883
2001–02	86	-	-	-	-	-	-	-	-	131	462	45	724
2002–03	85	-	-	-	-	-	-	-	-	80	520	101	786
2003–04	-	-	-	-	-	-	-	-	-	43	286	15	344
2004–05	-	-	-	-	-	-	-	-	4	60	207	15	286
2005–06	-	-	-	-	-	-	-	-	-	-	205	-	205
2006–07	40	-	14	-	-	-	-	-	-	26	295	4	379
2007–08	-	-	-	-	-	-	-	-	62	365	198	-	625
2008–09	10	-	-	-	-	-	-	-	-	482	83	-	575
2009–10	-	-	-	-	-	-	-	-	4	134	5	-	143
Total	240	-	14	-	-	-	-	-	70	1775	3532	702	6333

Table B12: Number of female frostfish gonads staged by fishing year and month sampled from the South Taranaki Bight by the observer programme, for fishing years 1998–99, 2000–01 to 2009–10.

Fishing year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1998–99	-	-	-	-	-	-	-	-	-	-	-	24	24
2000–01	-	-	153	-	-	-	-	-	-	-	-	-	153
2001–02	116	-	-	-	-	-	-	-	-	-	-	3	119
2002–03	334	76	-	-	-	-	20	-	-	-	-	-	430
2003–04	9	-	6	8	-	-	-	-	-	-	-	-	23
2004–05	-	-	-	-	-	-	-	-	-	37	-	-	37
2005–06	-	-	90	-	-	-	-	-	8	-	8	-	106
2006–07	15	-	37	90	-	-	25	-	-	-	-	5	172
2007–08	36	-	-	-	-	-	-	-	8	62	-	-	106
2008–09	-	-	51	23	-	-	-	-	-	-	-	-	74
2009–10	42	-	7	-	-	6	-	-	12	-	-	-	67
Total	552	76	344	121	-	6	45	-	28	99	8	32	1311

Table B13: Number of female frostfish gonads staged by fishing year and month sampled from the North Taranaki Bight by the observer programme, for fishing years 2003–04 to 2009–10.

Fishing year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
2003–04	5	-	87	-	-	-	-	-	-	-	-	-	92
2004–05	-	42	29	-	-	-	-	-	2	16	-	-	89
2005–06	-	11	-	-	-	-	-	-	7	11	-	-	29
2006–07	18	-	40	5	-	-	-	-	-	-	-	-	63
2007–08	102	-	80	-	-	-	-	-	1	-	-	-	183
2008–09	4	-	79	8	-	-	-	-	-	-	-	-	91
2009–10	82	17	85	-	-	-	-	-	-	-	-	-	184
Total	211	70	400	13	-	-	-	-	10	27	-	-	731

Table B14: Number of female frostfish gonads staged by fishing year and month sampled from all other areas by the observer programme, for fishing years 1994–95, 1998–99 to 2009–10.

Fishing year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1994–95	-	-	-	-	4	-	-	-	-	-	-	-	4
1998–99	-	-	-	-	1	-	-	-	-	-	-	-	1
1999–00	-	-	-	13	1	2	-	-	-	2	15	1	34
2000–01	20	3	3	-	-	26	-	-	-	-	-	-	52
2001–02	-	-	-	-	-	12	8	-	-	-	-	-	20
2002–03	-	-	-	4	121	19	29	3	-	2	9	8	195
2003–04	4	-	50	2	-	-	-	-	-	4	8	-	68
2004–05	-	7	-	-	1	-	3	23	-	8	-	12	54
2005–06	1	-	-	1	-	-	-	1	1	2	87	-	93
2006–07	-	-	56	-	-	-	8	9	-	-	13	8	94
2007–08	56	-	-	-	-	-	-	-	-	-	-	-	56
2008–09	-	-	16	-	4	-	-	-	-	-	-	-	20
2009–10	-	-	18	-	-	-	-	-	-	-	-	36	54
Total	81	10	143	20	132	59	48	36	1	18	132	65	745

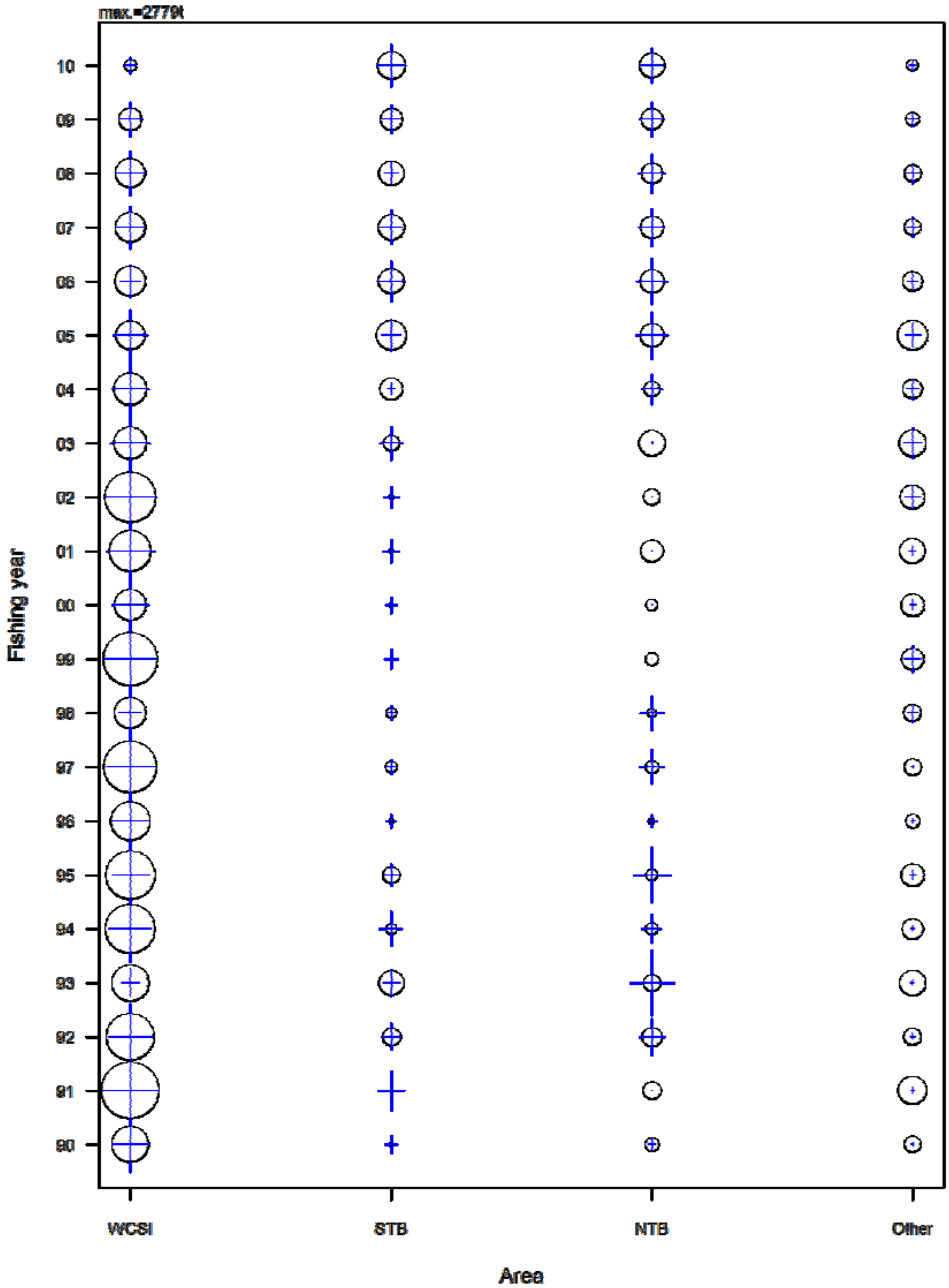


Figure B1: Representativeness of observer sampling of frostfish catch by fishing year and area for fishing years 1989–90 to 2009–10. Circles show the proportion of frostfish catch by area within a fishing year; crosses show the proportion of observed frostfish catch for the same cells. Representation is demonstrated by how closely the cross matches the circle diameter. WCSI = west coast South Island, STB= South Taranaki Bight, NTB=North Taranaki Bight.

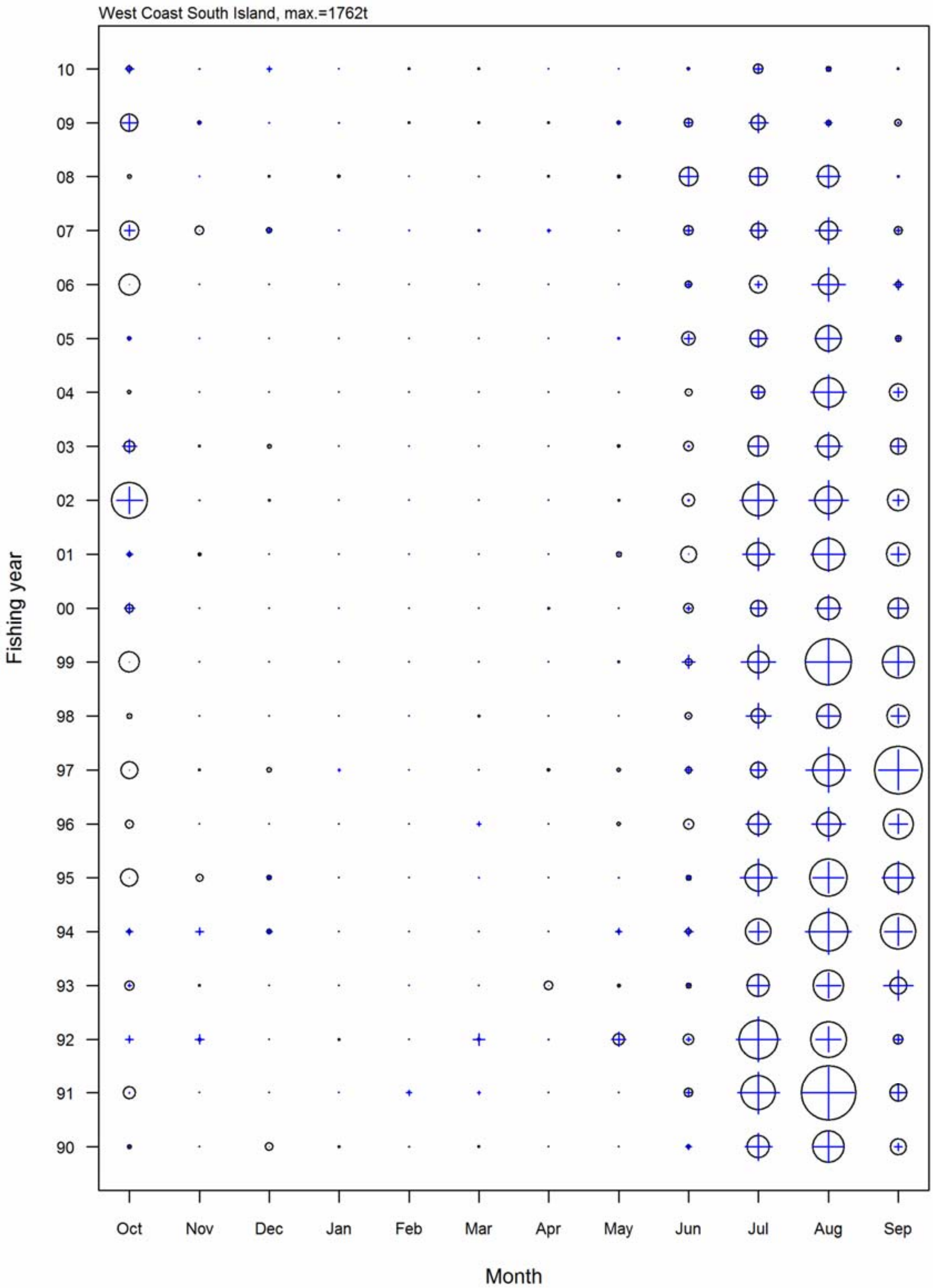


Figure B2: Representativeness of observer sampling of frostfish catch by fishing year and month for the west coast South Island for fishing years 1989–90 to 2009–10. Circles show the proportion of frostfish catch by month within a fishing year; crosses show the proportion of observed frostfish catch for the same cells. Representation is demonstrated by how closely the cross matches the circle diameter.

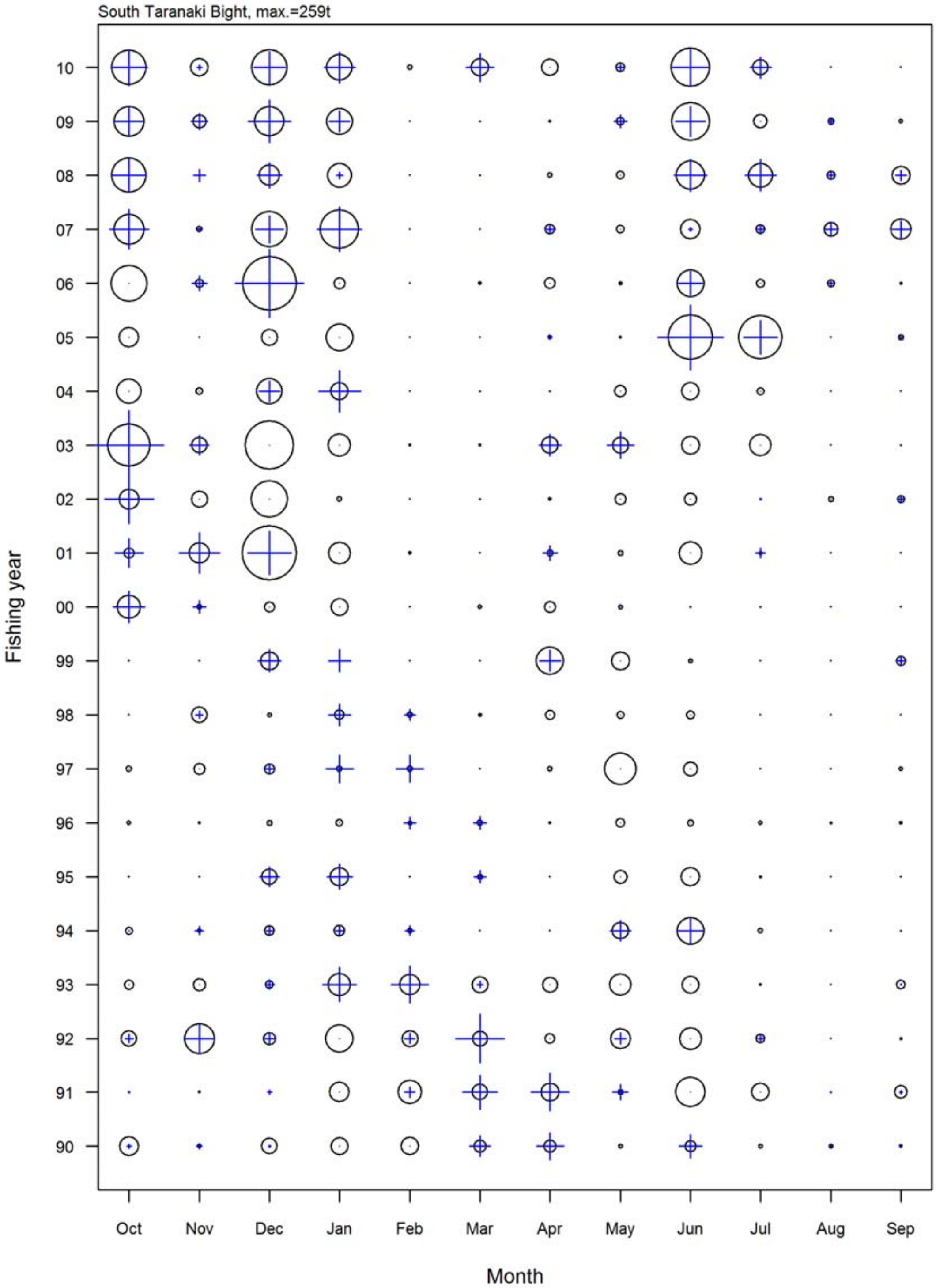


Figure B3: Representativeness of observer sampling of frostfish catch by fishing year and month for the South Taranaki Bight for fishing years 1989–90 to 2009–10. Circles show the proportion of frostfish catch by month within a fishing year; crosses show the proportion of observed frostfish catch for the same cells. Representation is demonstrated by how closely the cross matches the circle diameter.

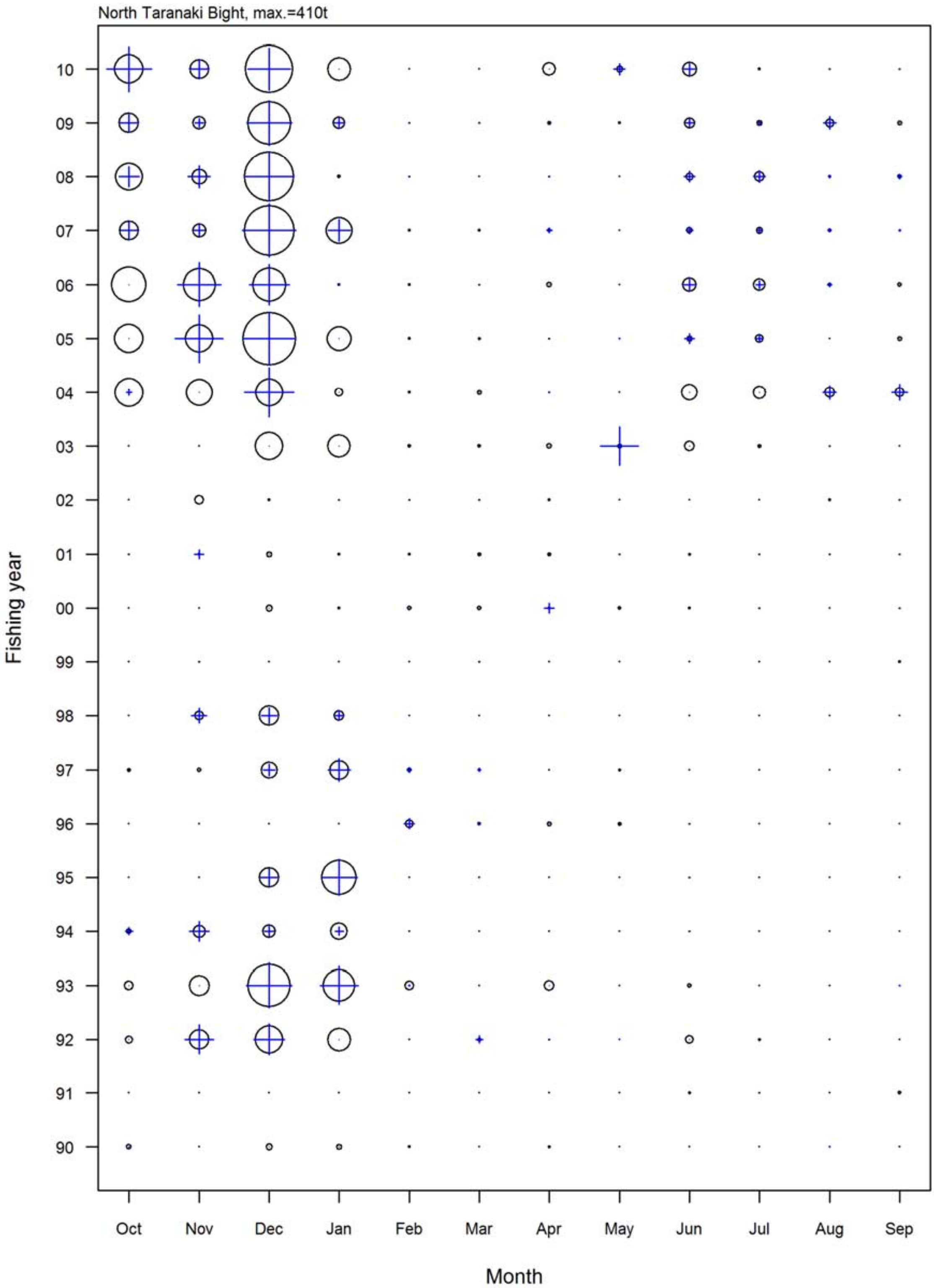


Figure B4: Representativeness of observer sampling of frostfish catch by fishing year and month for the North Taranaki Bight for fishing years 1989–90 to 2009–10. Circles show the proportion of frostfish catch by month within a fishing year; crosses show the proportion of observed frostfish catch for the same cells. Representation is demonstrated by how closely the cross matches the circle diameter.

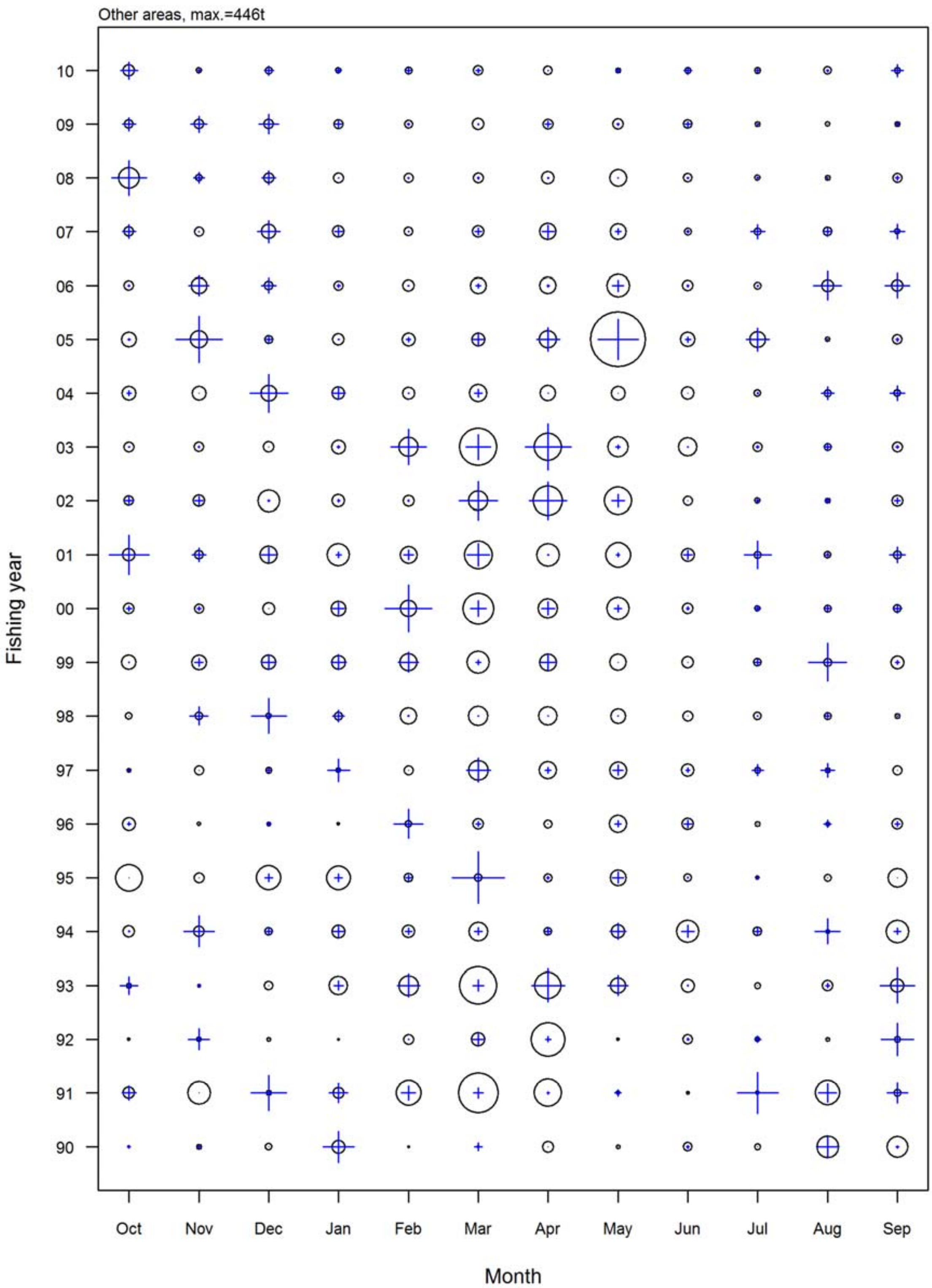


Figure B5: Representativeness of observer sampling of frostfish catch by fishing year and month for all other fishing areas for fishing years 1989–90 to 2009–10. Circles show the proportion of frostfish catch by month within a fishing year; crosses show the proportion of observed frostfish catch for the same cells. Representation is demonstrated by how closely the cross matches the circle diameter.

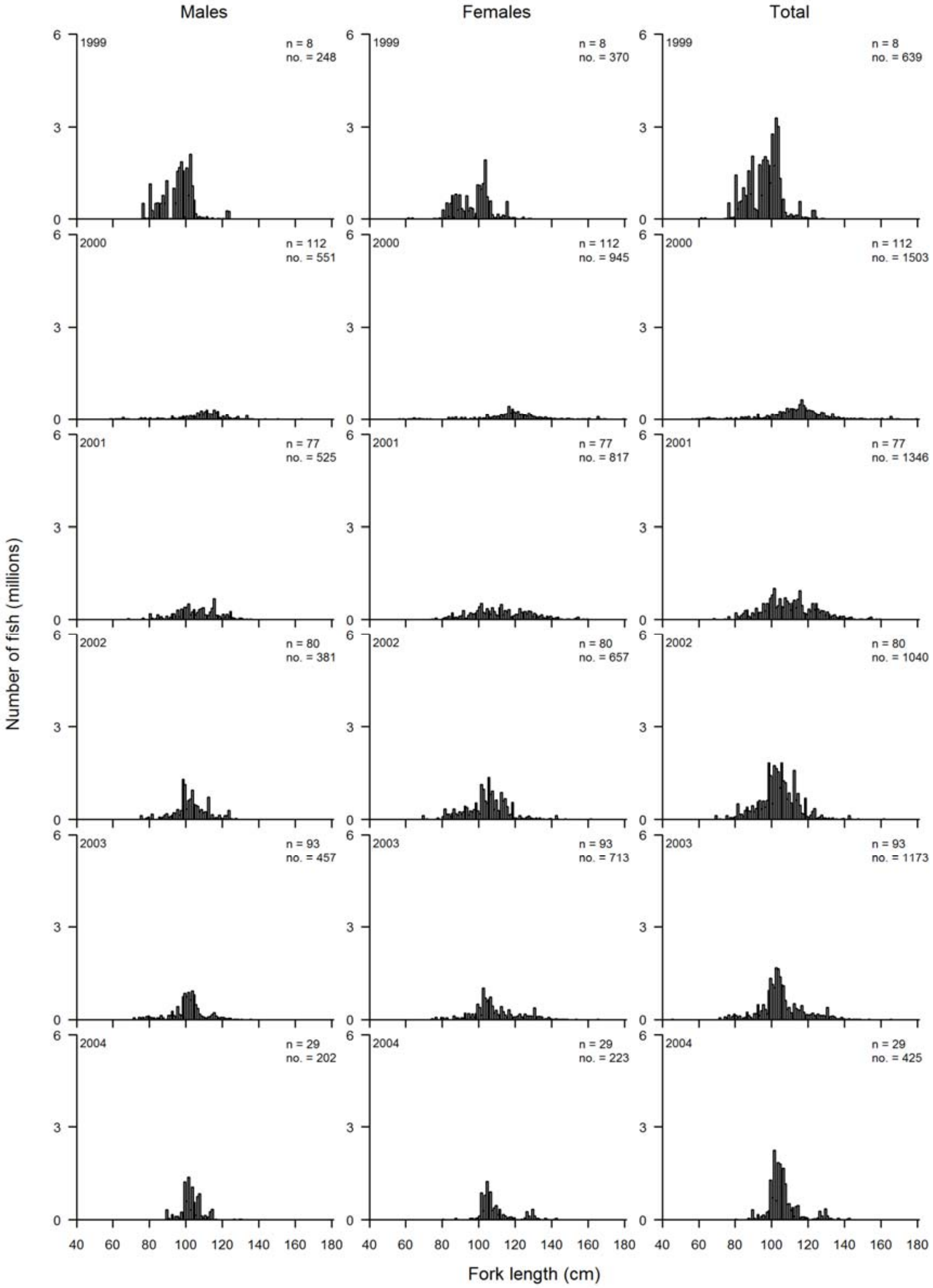


Figure B6: Scaled length frequency of frostfish taken in commercial catches from the west coast South Island fishery by fishing year sampled by the observer programme, for fishing years 1998–99 to 2003–04. n, number of tows sampled; no., number of fish sampled.

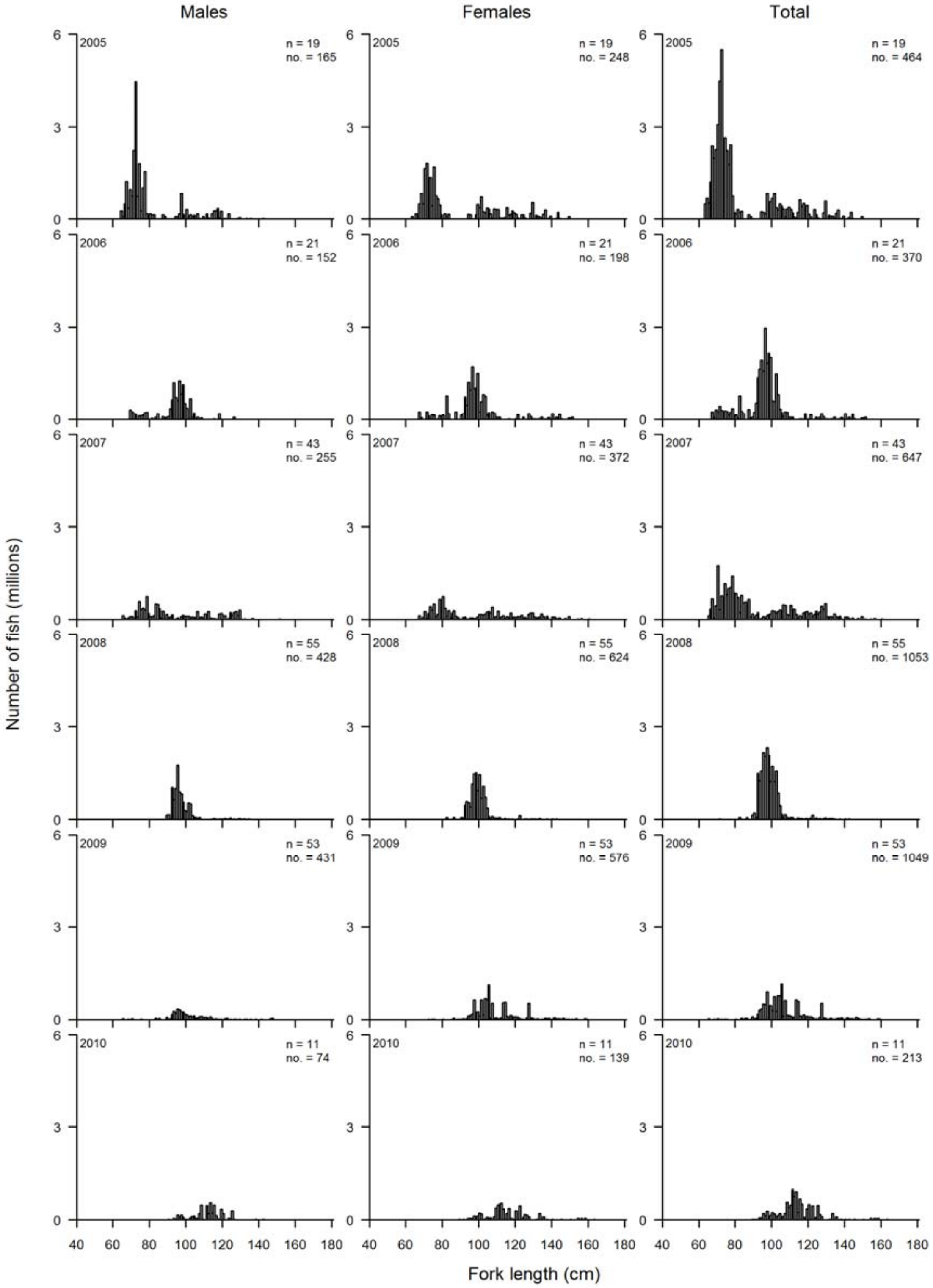


Figure B7: Scaled length frequency of frostfish taken in commercial catches from the west coast South Island fishery by fishing year sampled by the observer programme, for fishing years 2004–05 to 2009–10. n, number of tows sampled; no., number of fish sampled.

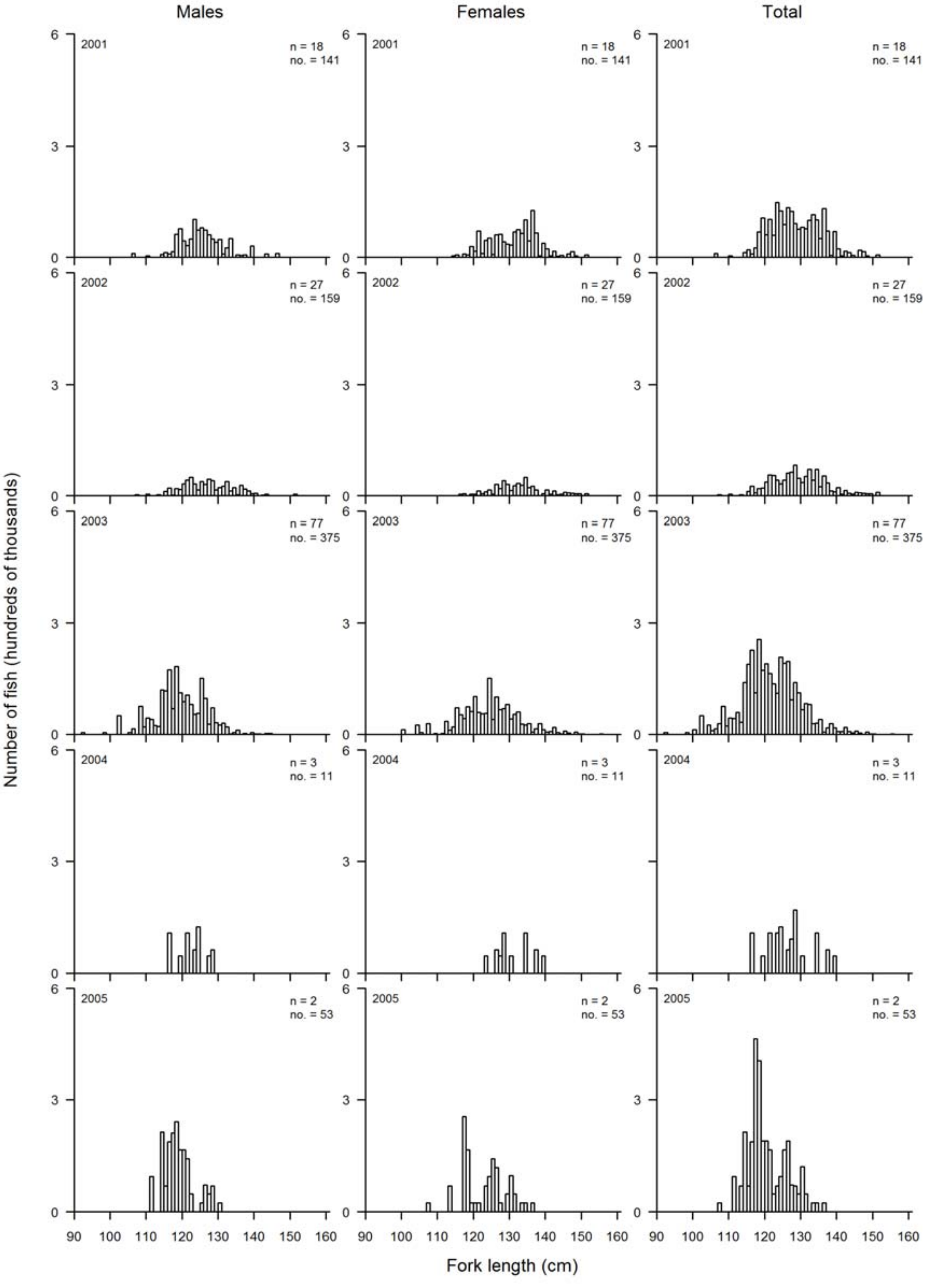


Figure B8: Scaled length frequency of frostfish taken in commercial catches from the Southern Taranaki Bight fishery by fishing year sampled by the observer programme, for fishing years 2000–01 to 2004–05. n, number of tows sampled; no., number of fish sampled.

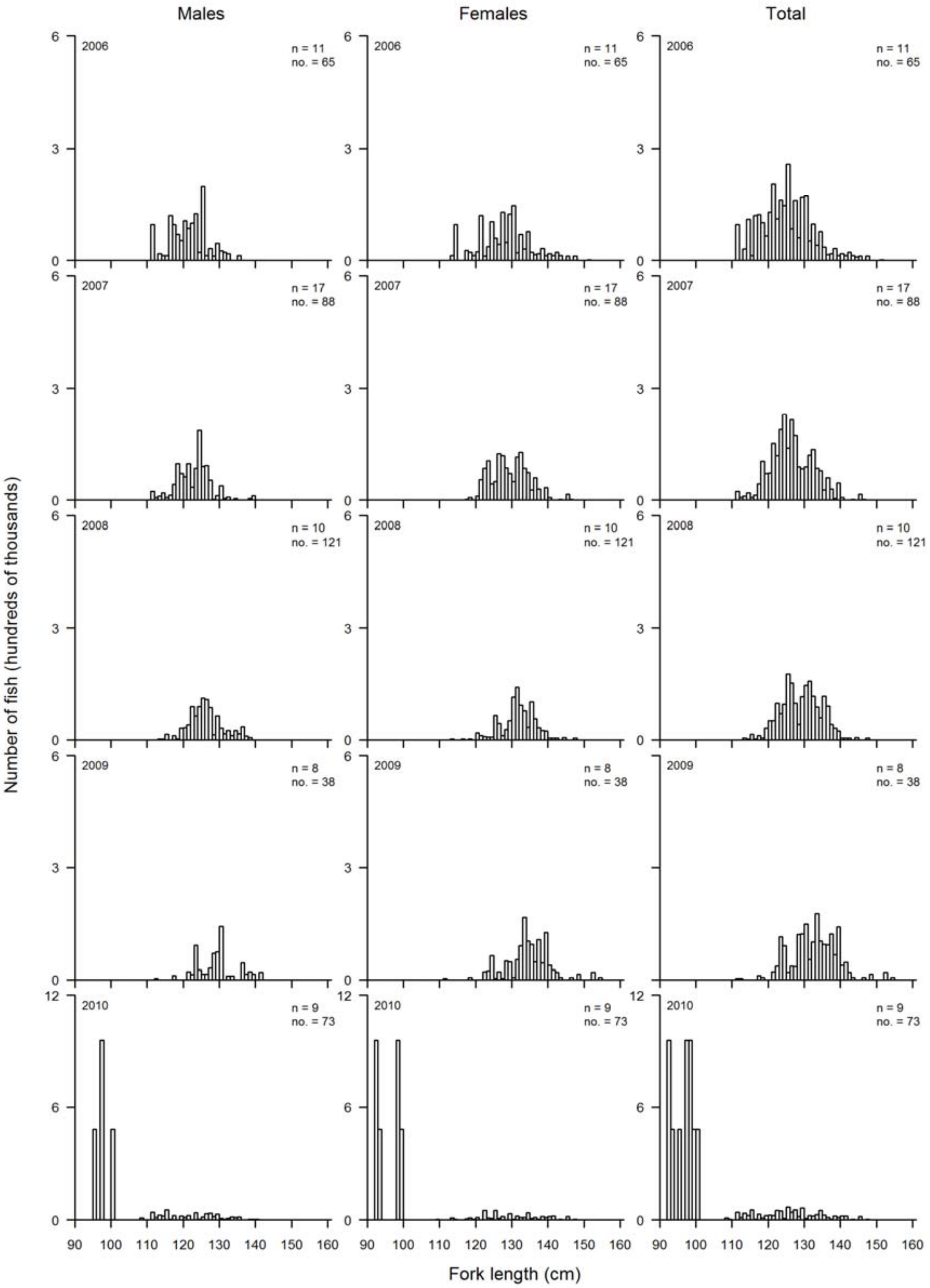


Figure B9: Scaled length frequency of frostfish taken in commercial catches from Southern Taranaki Bight fishery by fishing year sampled by the observer programme, for fishing years 2005–06 to 2009–10. n, number of tows sampled; no., number of fish sampled.

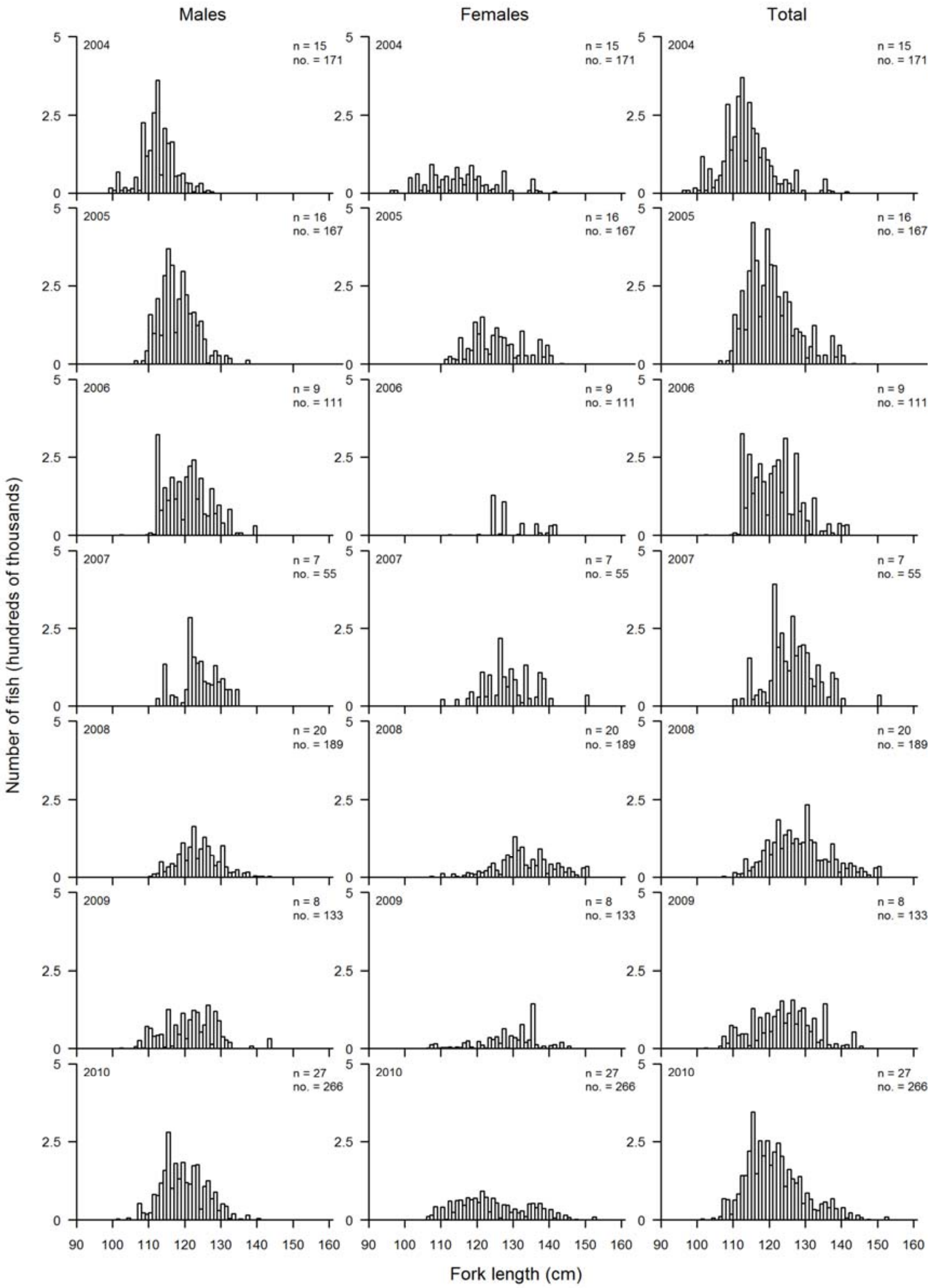


Figure B10: Scaled length frequency of frostfish taken in commercial catches from Northern Taranaki Bight fishery by fishing year sampled by the observer programme, for fishing years 2003–04 to 2009–10. n, number of tows sampled; no., number of fish sampled.

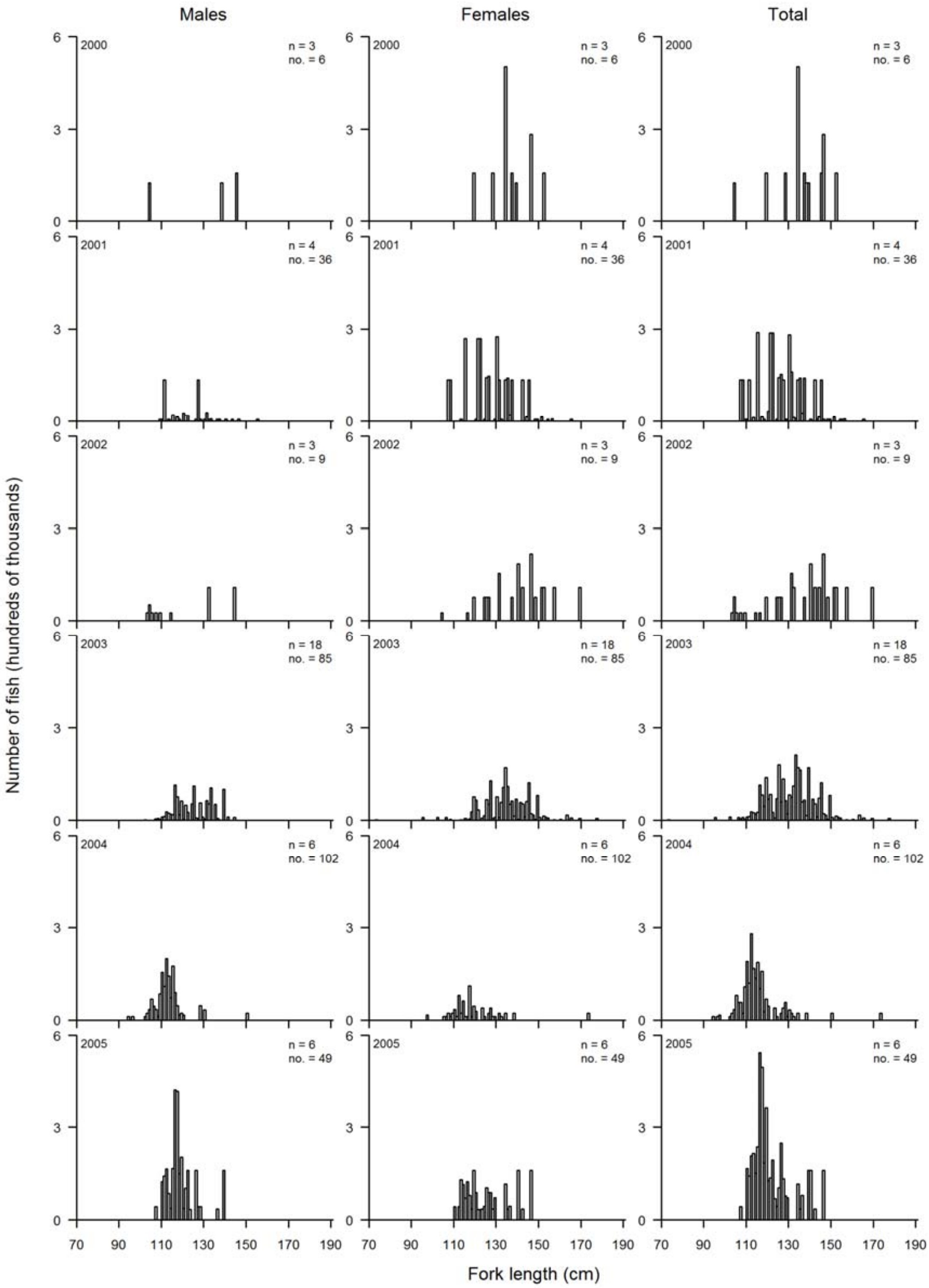


Figure B11: Scaled length frequency of frostfish taken in commercial catches from all other fishery areas by fishing year sampled by the observer programme, for fishing years 1999–00 to 2004–05. n, number of tows sampled; no., number of fish sampled.

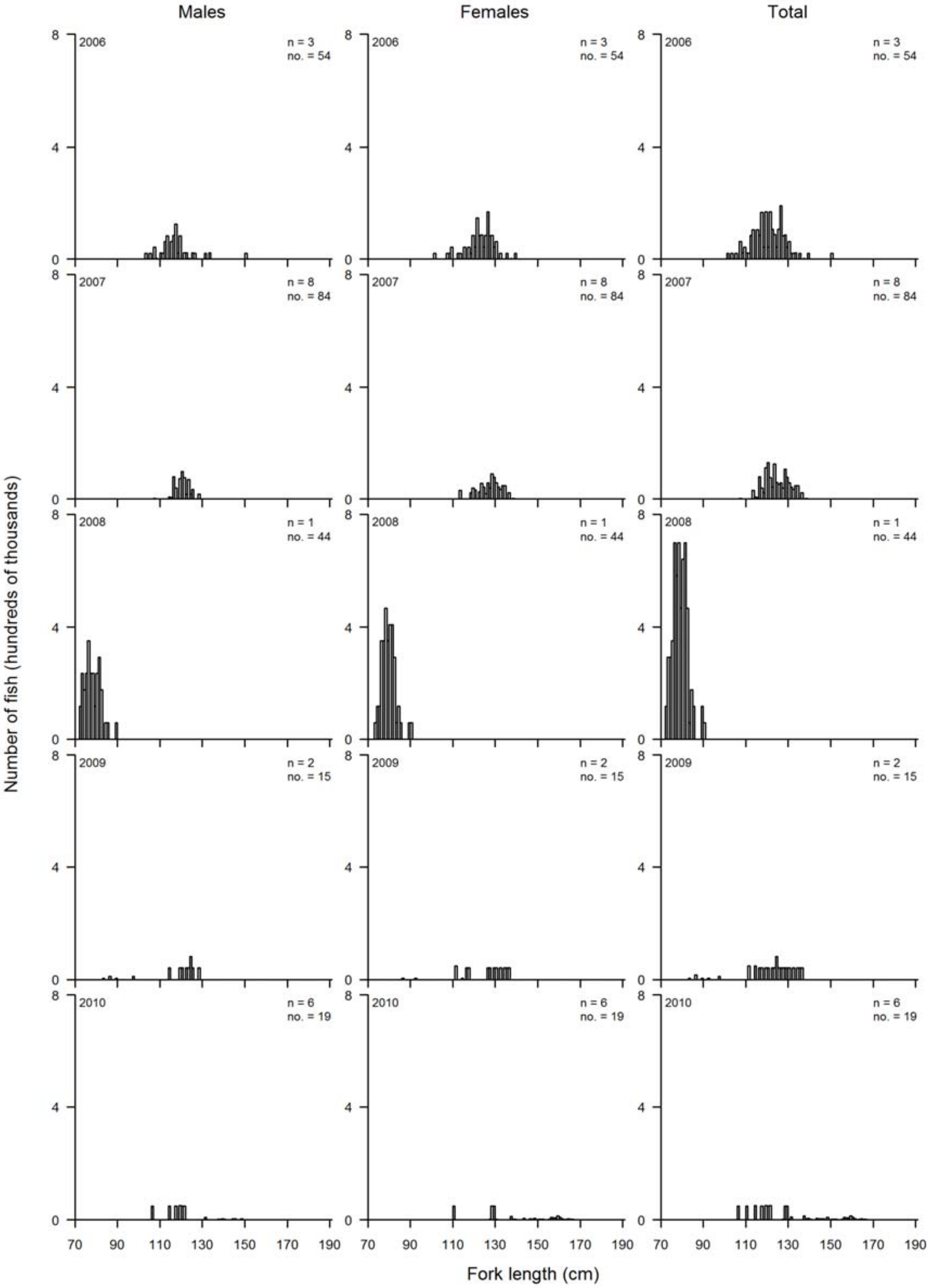


Figure B12: Scaled length frequency of frostfish taken in commercial catches from all other fishery areas by fishing year sampled by the observer programme, for fishing years 2005–06 to 2009–10. n, number of tows sampled; no., number of fish sampled.

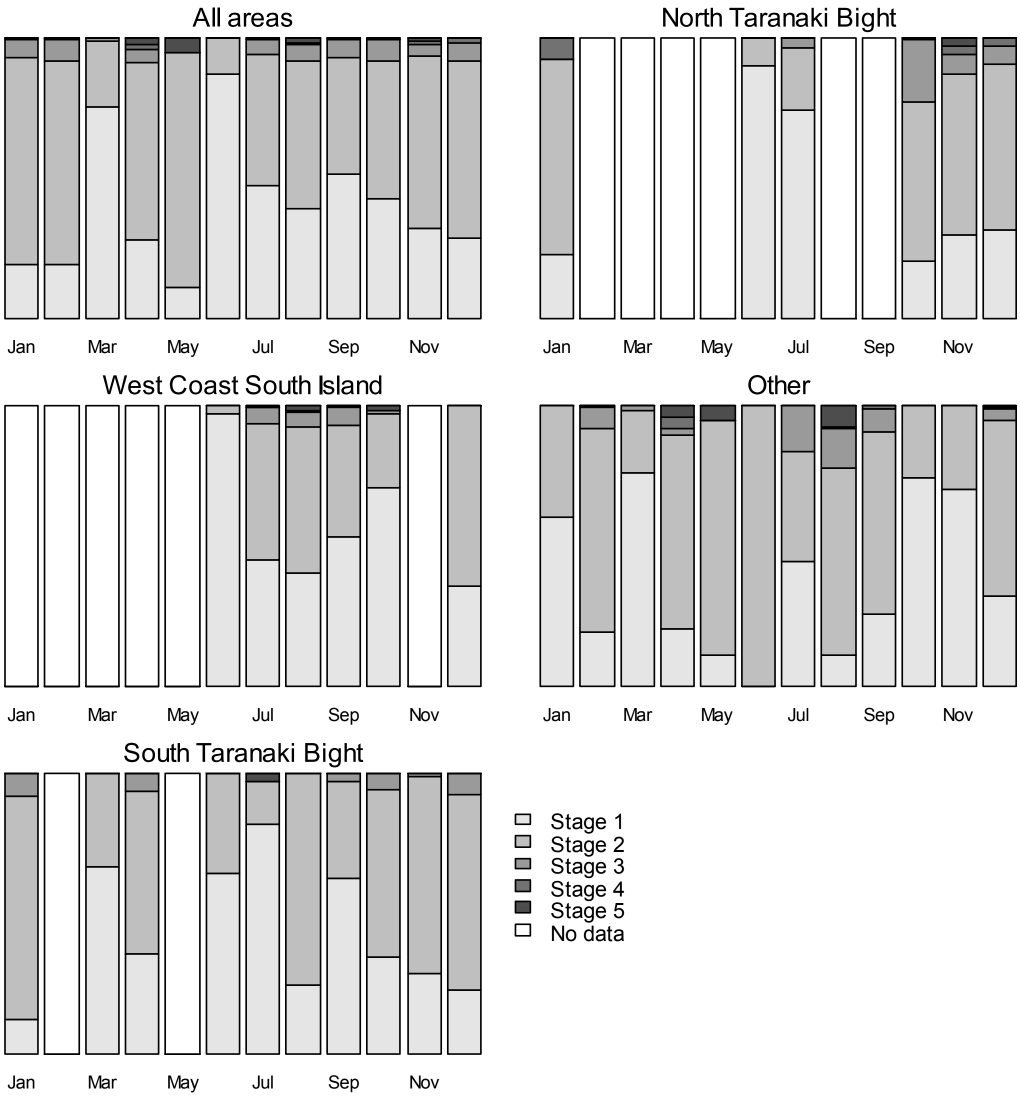


Figure B13: Gonad stages of female frostfish taken in commercial catches, by month and area, sampled by the observer programme, for fishing years 1989–90 to 2009–10. Stages are: 1, resting/immature; 2, maturing; 3, ripe; 4, running ripe; 5, spent. The numbers of observations for each area are given in Table B4.

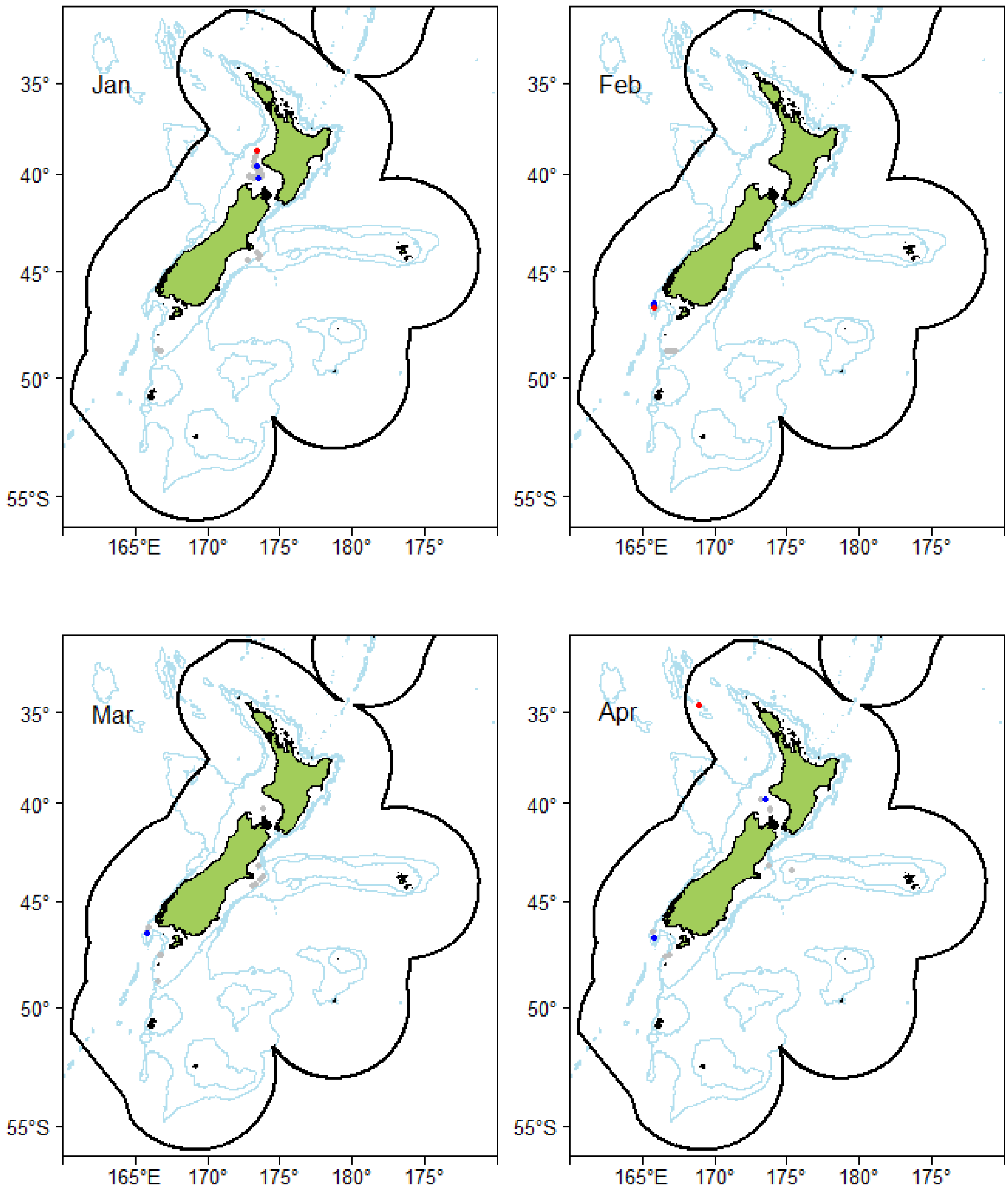


Figure B14: Locations of observed frostfish gonads for all years combined for January to April. Grey dots = immature/resting, maturing, and spent fish; blue dots = ripe fish; red dots = running ripe fish.

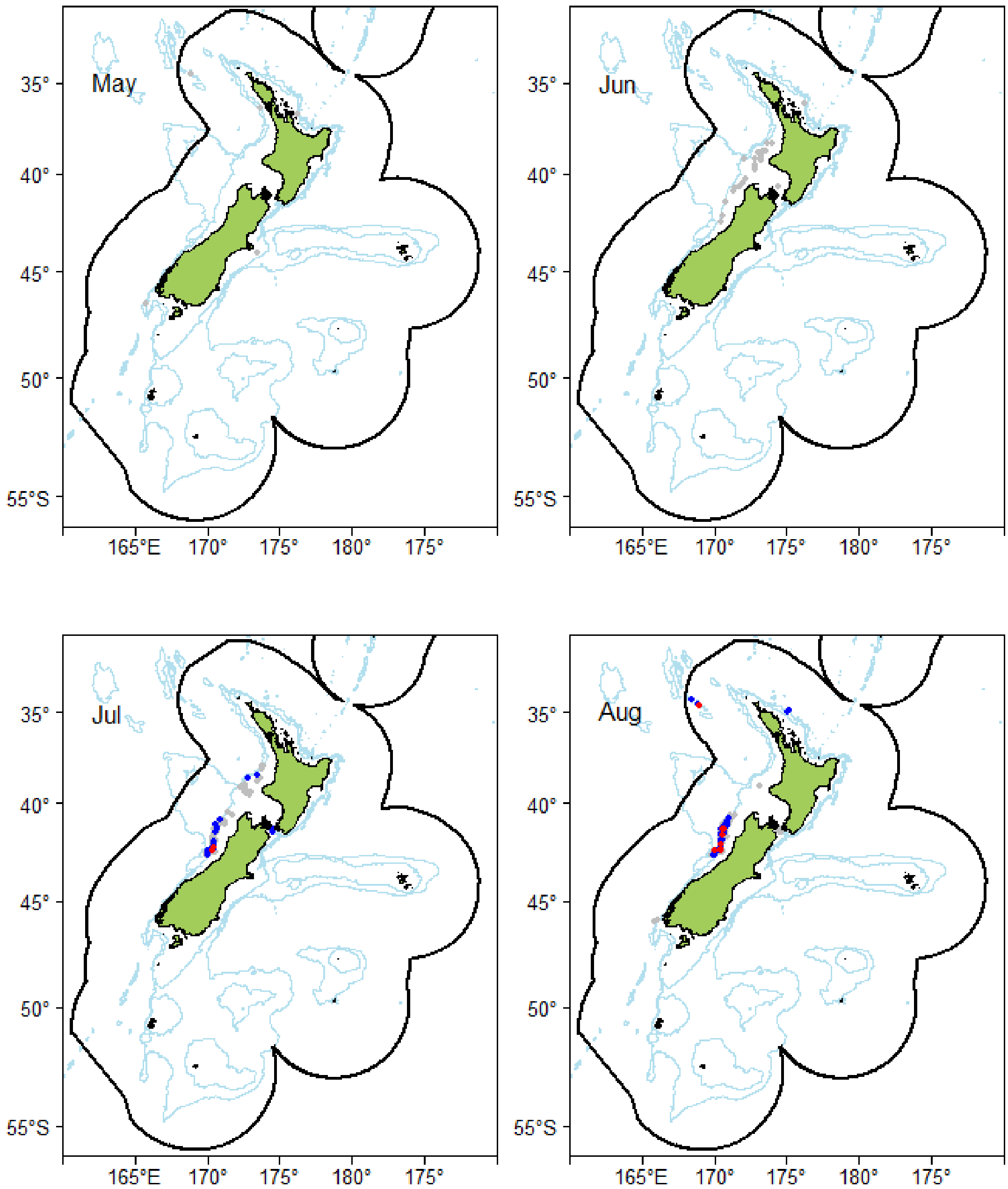


Figure B15: Locations of observed frostfish gonads for all years combined for May to August. Grey dots = immature/resting, maturing, and spent fish; blue dots = ripe fish; red dots = running ripe fish.

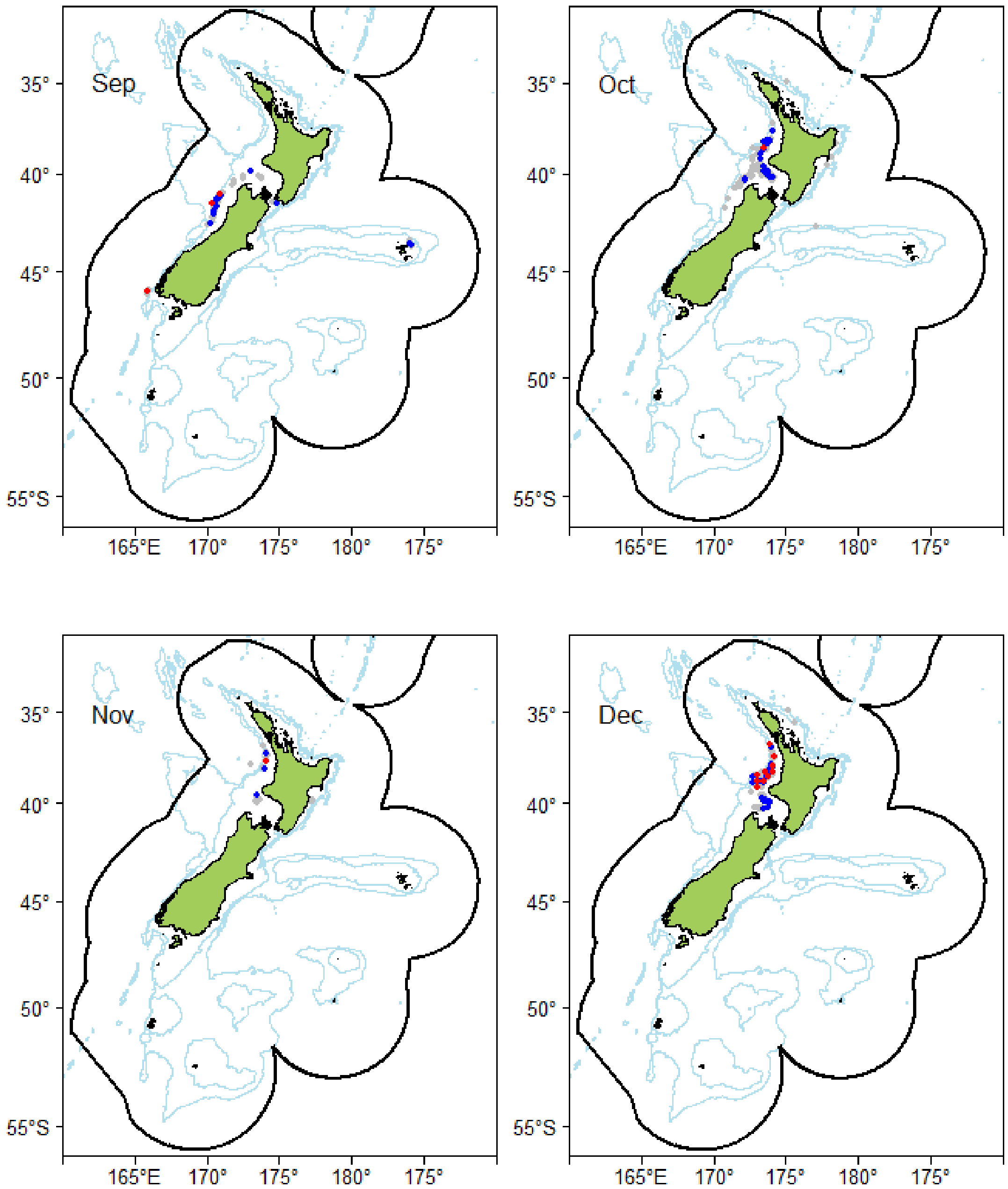


Figure B16: Locations of observed frostfish gonads for all years combined for September to December. Grey dots = immature/resting, maturing, and spent fish; blue dots = ripe fish; red dots = running ripe fish.

APPENDIX C: SUMMARIES OFCATCH AND EFFORT DATA

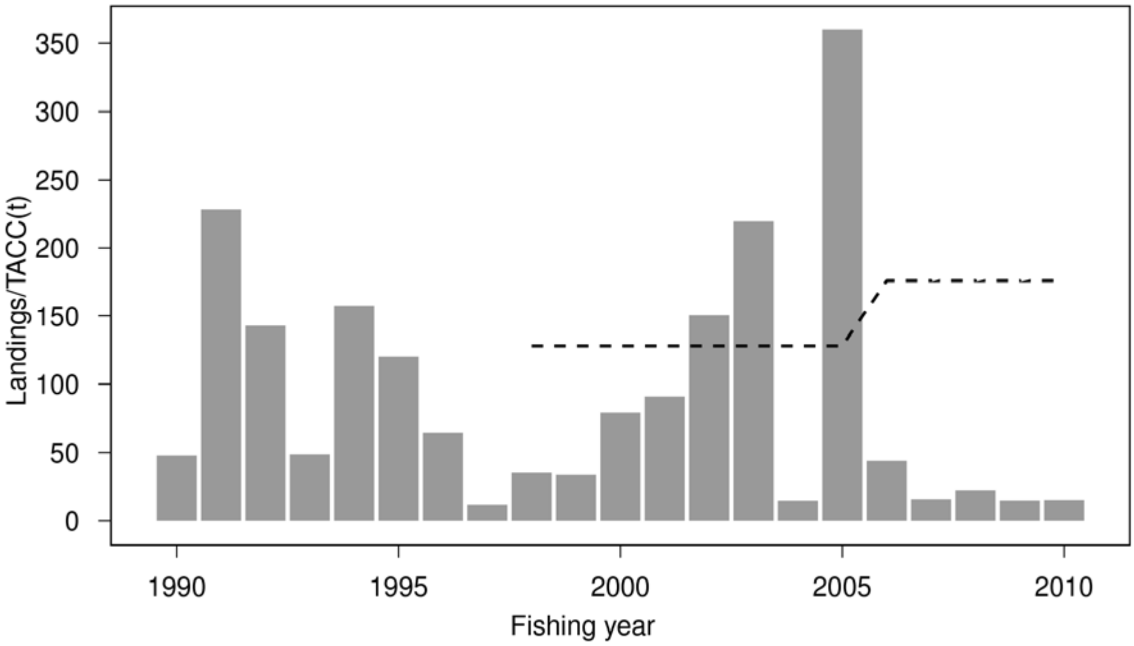


Figure C1: Landings and TACC for FRO 3 by fishing year, 1989–90 to 2009–10.

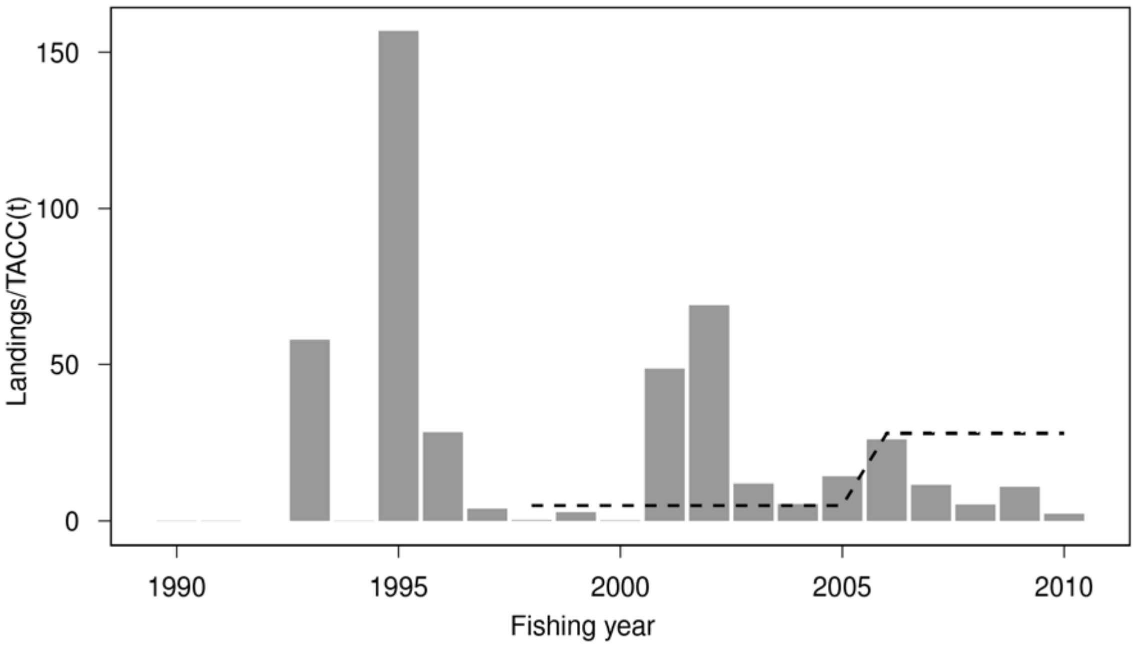


Figure C2: Landings and TACC for FRO 4 by fishing year, 1989–90 to 2009–10.

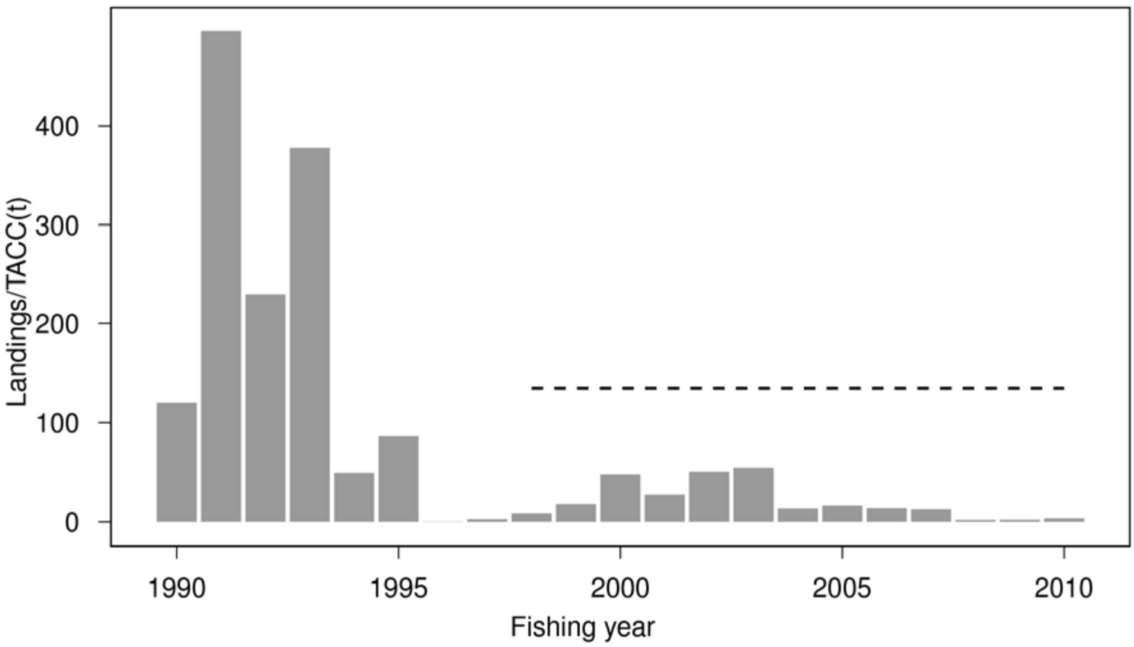


Figure C3: Landings and TACC for FRO 5 by fishing year, 1989–90 to 2009–10.

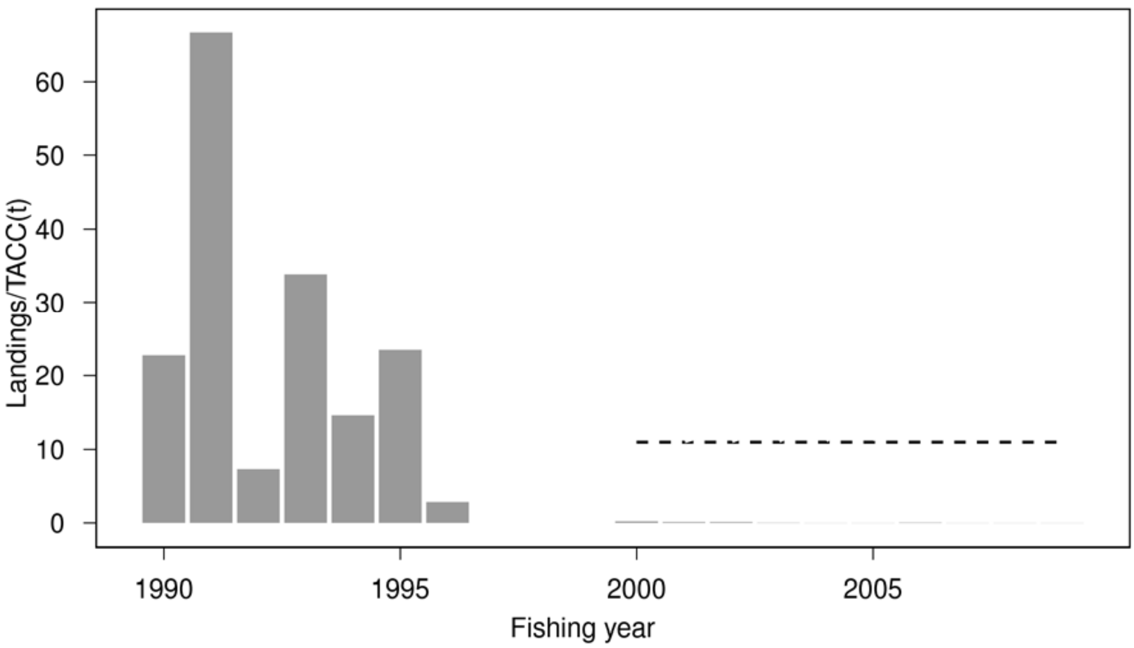


Figure C4: Landings and TACC for FRO 6 by fishing year, 1989–90 to 2009–10.

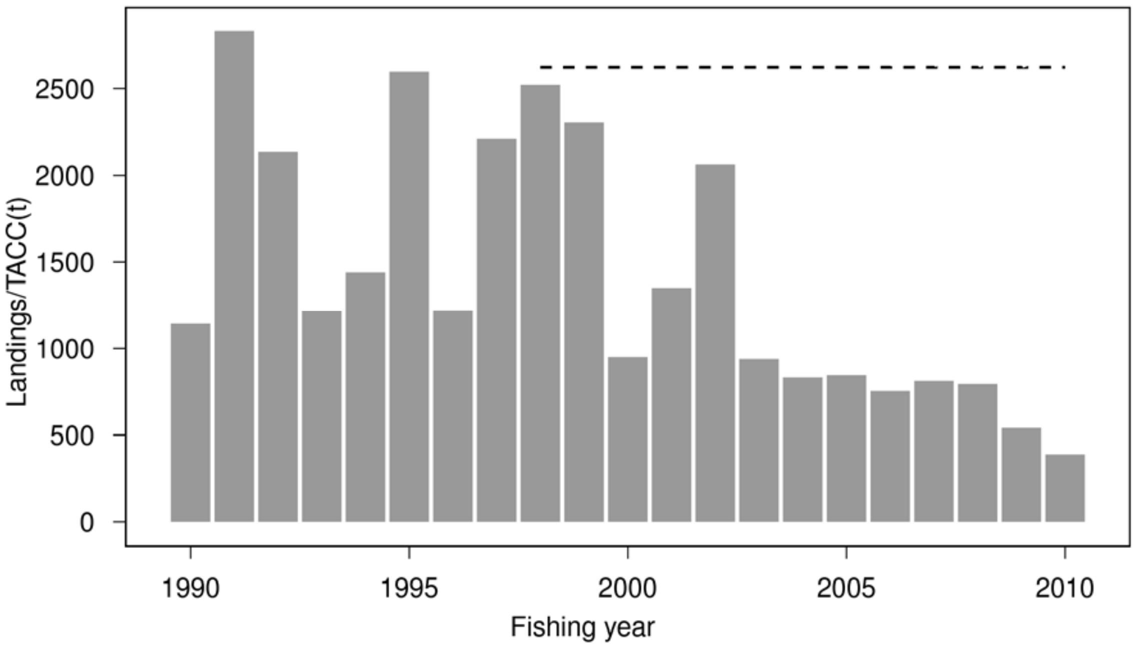


Figure C5: Landings and TACC for FRO 7 by fishing year, 1989–90 to 2009–10.

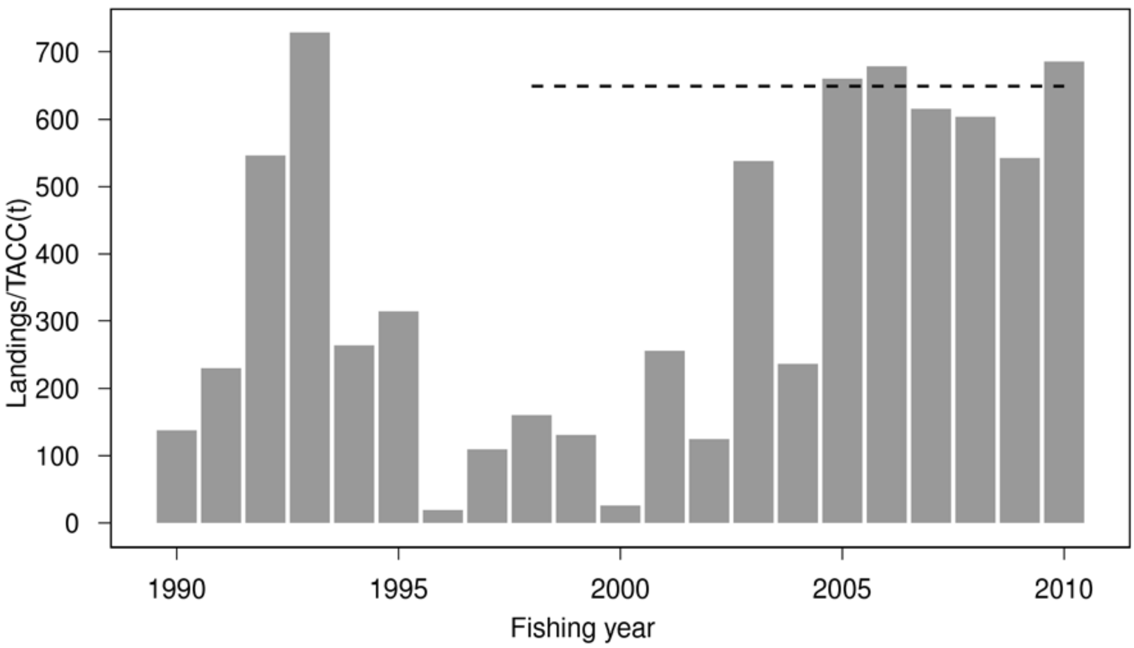


Figure C6: Landings and TACC for FRO 8 by fishing year, 1989–90 to 2009–10.

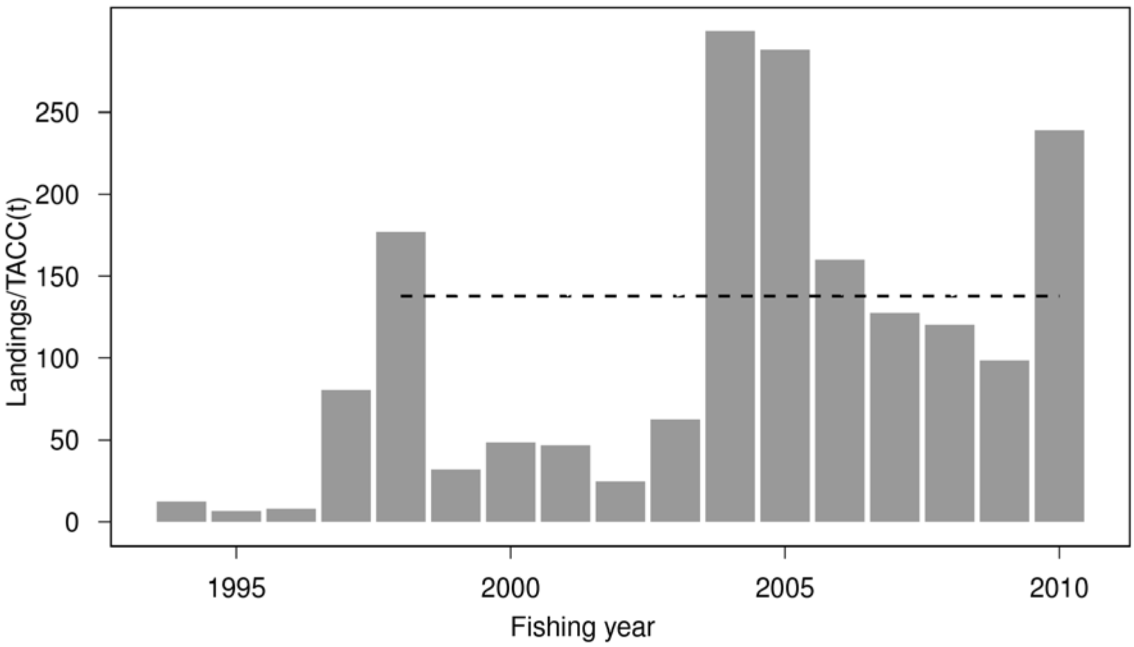


Figure C7: Landings and TACC for FRO 9 by fishing year, 1989–90 to 2009–10.

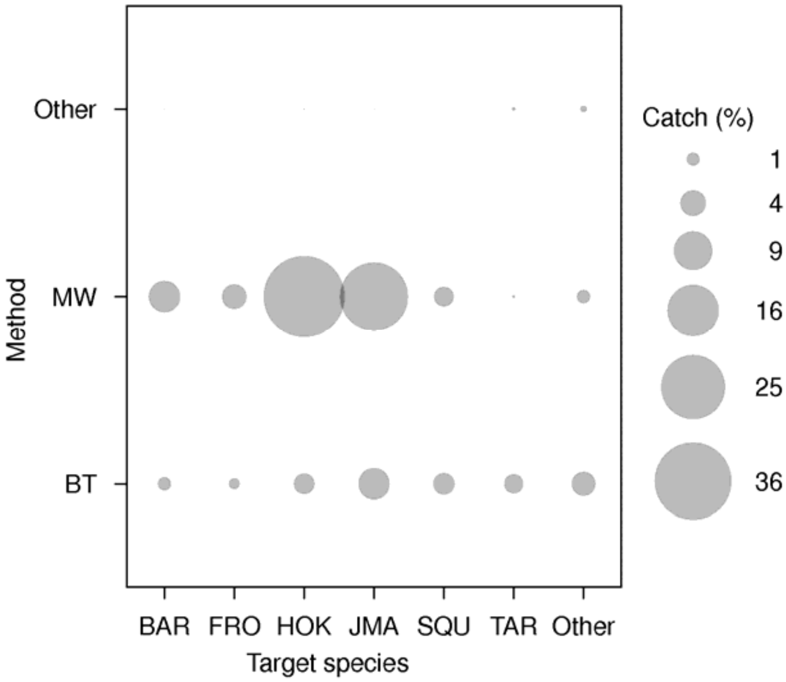


Figure C8: Percentage of catch by method and target species over all QMAs and over all fishing years, 1989–90 to 2009–10.

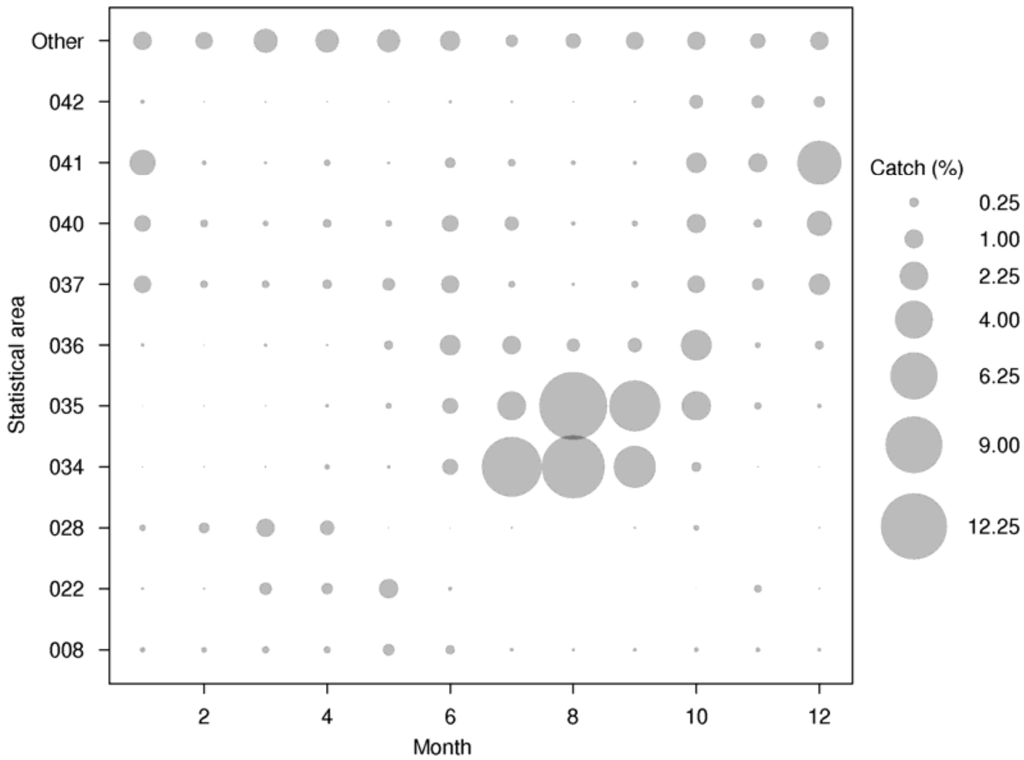


Figure C9: Percentage of catch by statistical area and month over all QMAs and over all fishing years, 1989–90 to 2009–10.

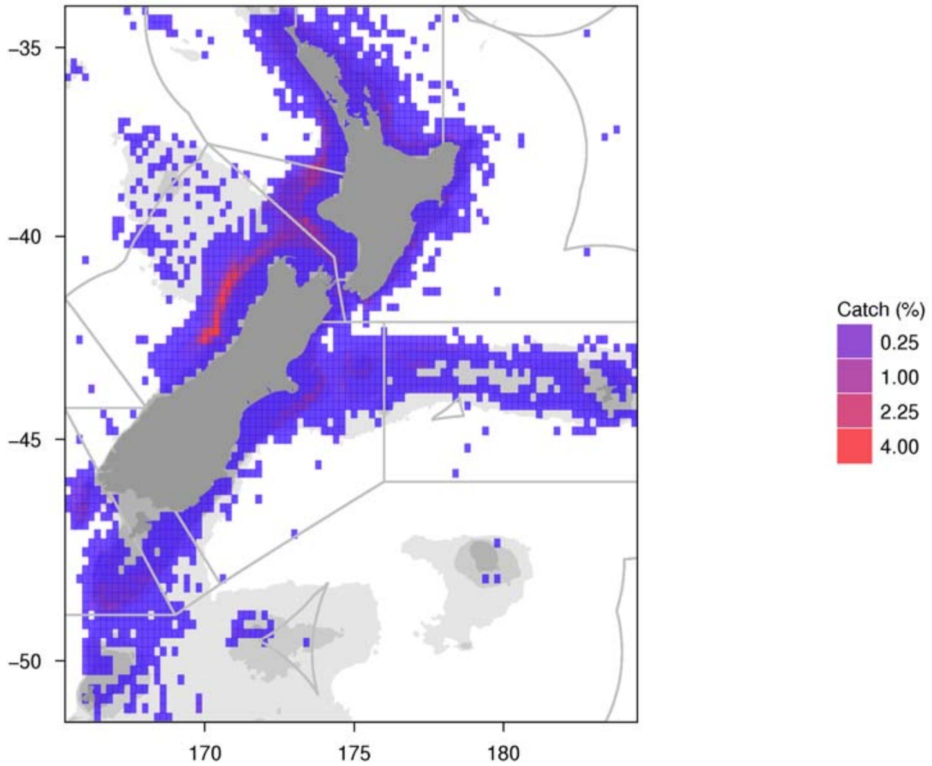


Figure C10: Percentage of total FRO catch by 0.2 degree cell over all fishing years, 1989–90 to 2009–10.

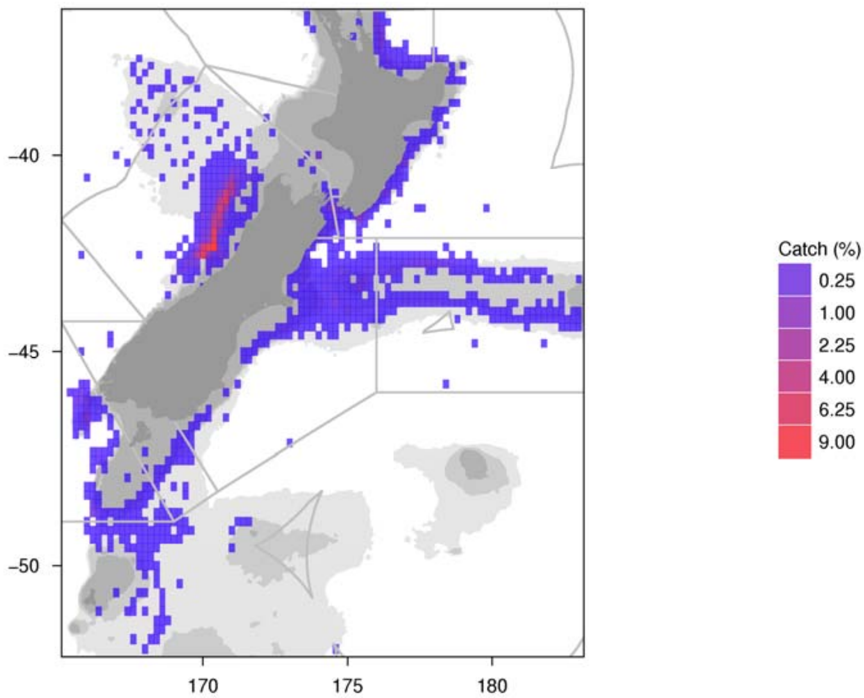


Figure C11: Percentage of total FRO catch by 0.2 degree cell when HOK was the target species over all fishing years, 1989–90 to 2009–10.

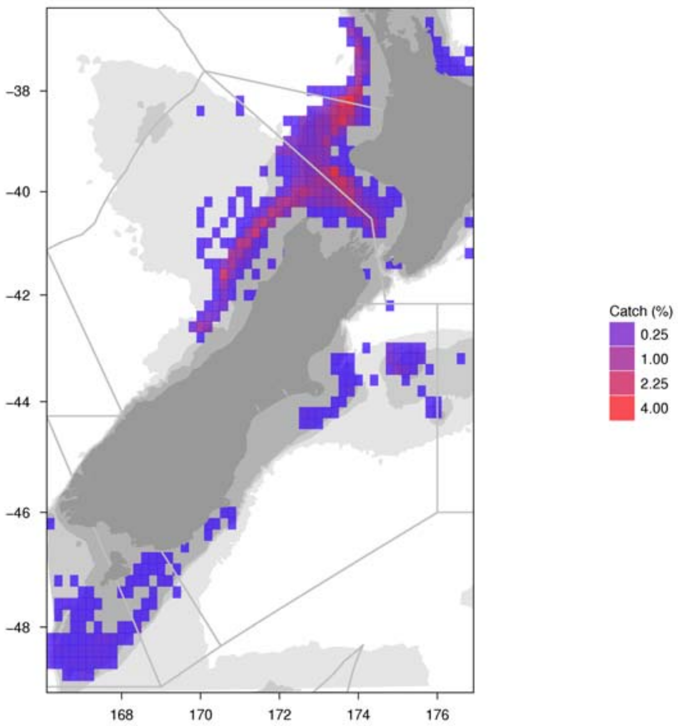


Figure C12: Percentage of total FRO catch by 0.2 degree cell when JMA was the target species over all fishing years, 1989–90 to 2009–10.

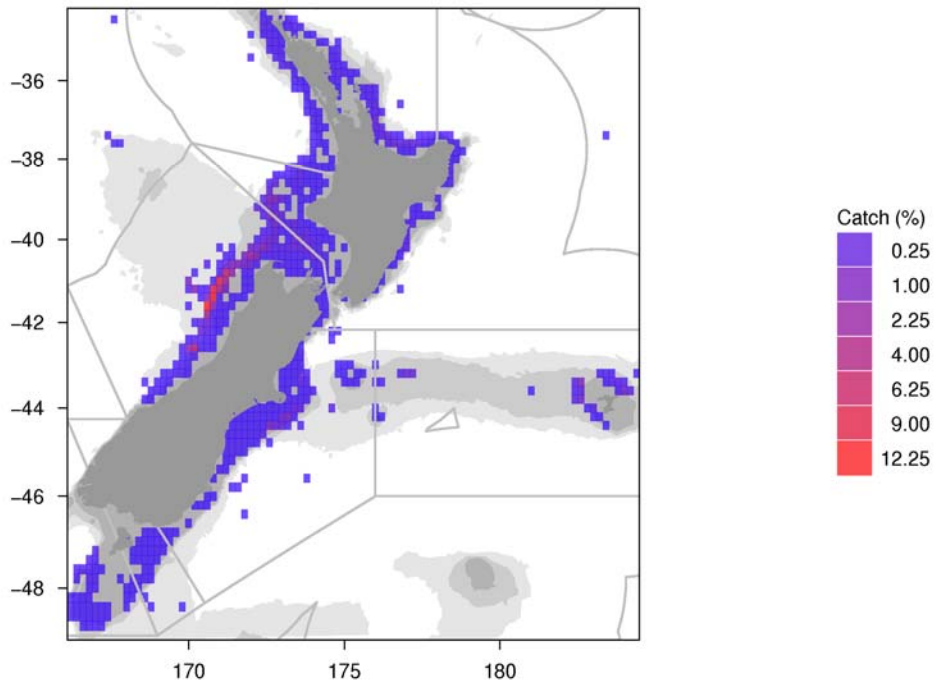


Figure C13: Percentage of total FRO catch by 0.2 degree cell when BAR was the target species over all fishing years, 1989–90 to 2009–10.

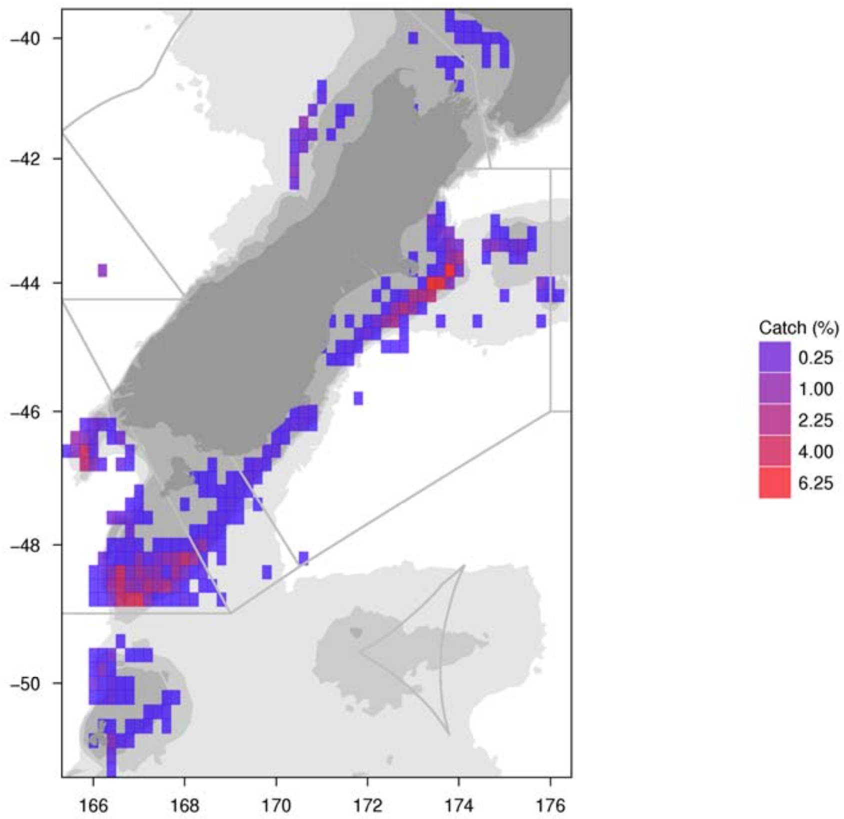


Figure C14: Percentage of total FRO catch by 0.2 degree cell when SQU was the target species over all fishing years, 1989–90 to 2009–10.

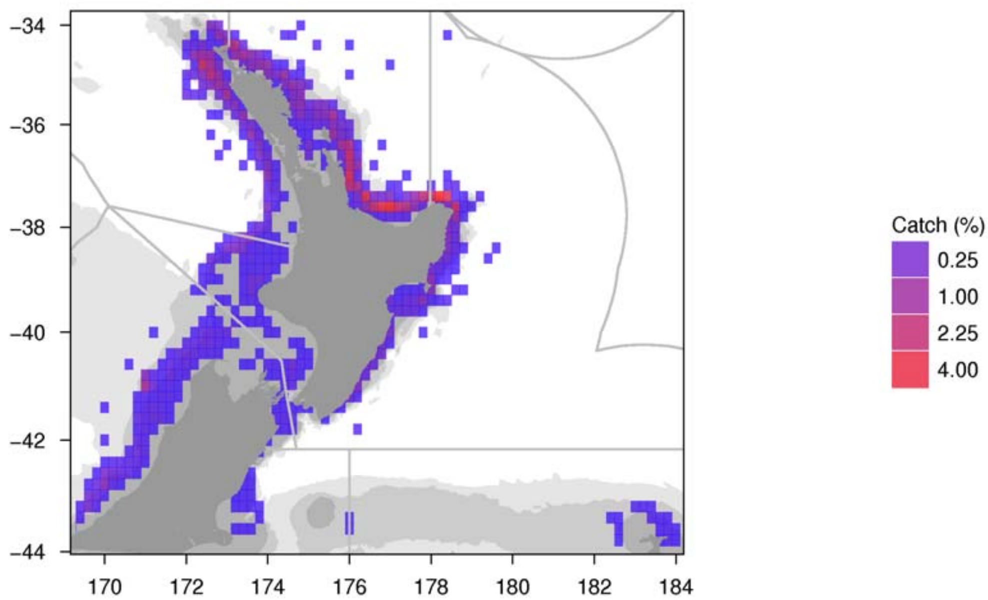


Figure C15: Percentage of total FRO catch by 0.2 degree cell when TAR was the target species over all fishing years, 1989–90 to 2009–10.

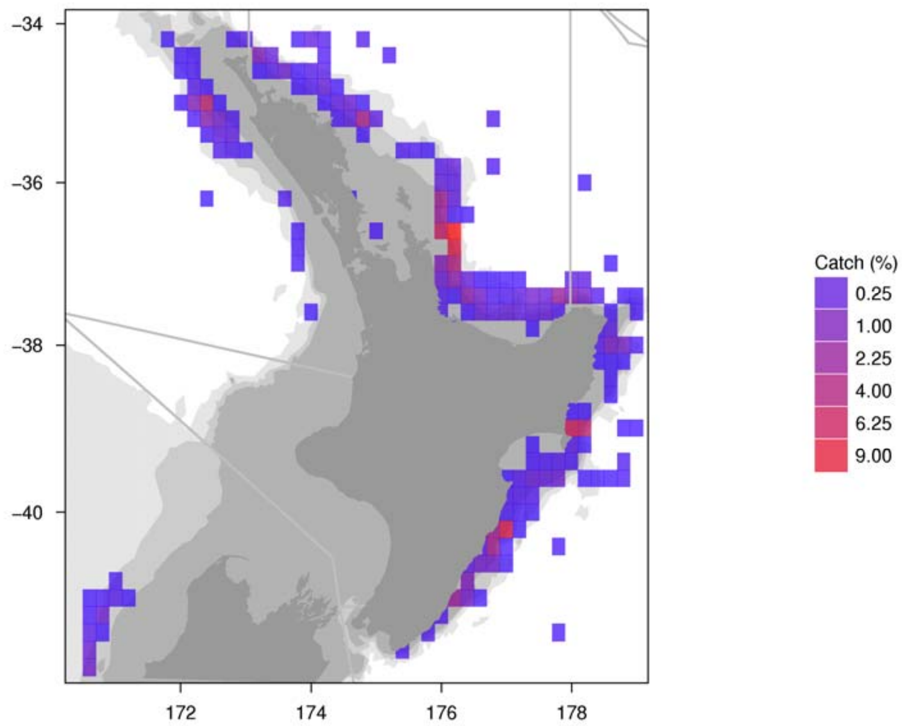


Figure C16: Percentage of total FRO catch by 0.2 degree cell when SKI was the target species over all fishing years, 1989–90 to 2009–10.

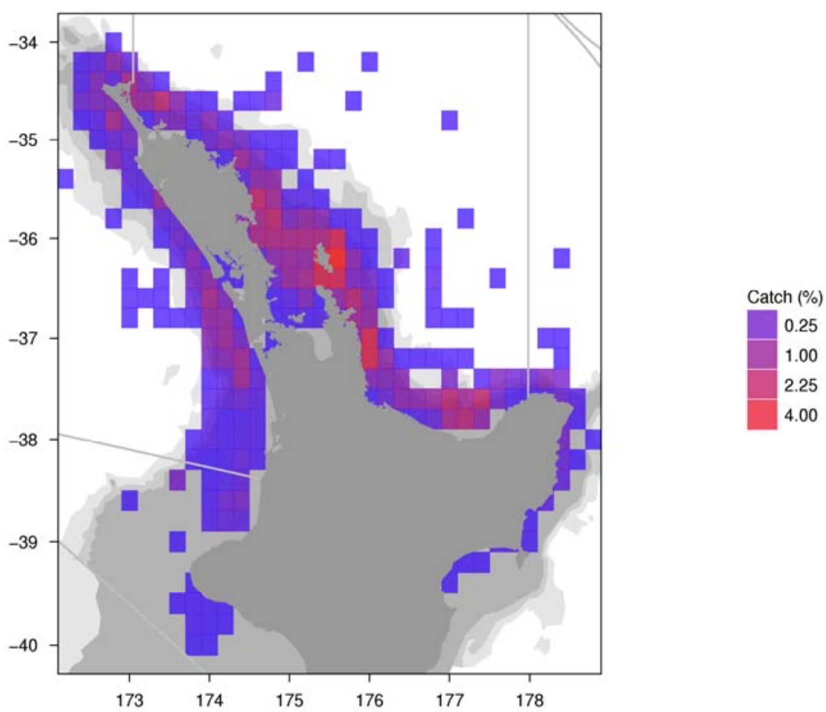


Figure C17: Percentage of total FRO catch by 0.2 degree cell when SNA was the target species over all fishing years, 1989–90 to 2009–10.

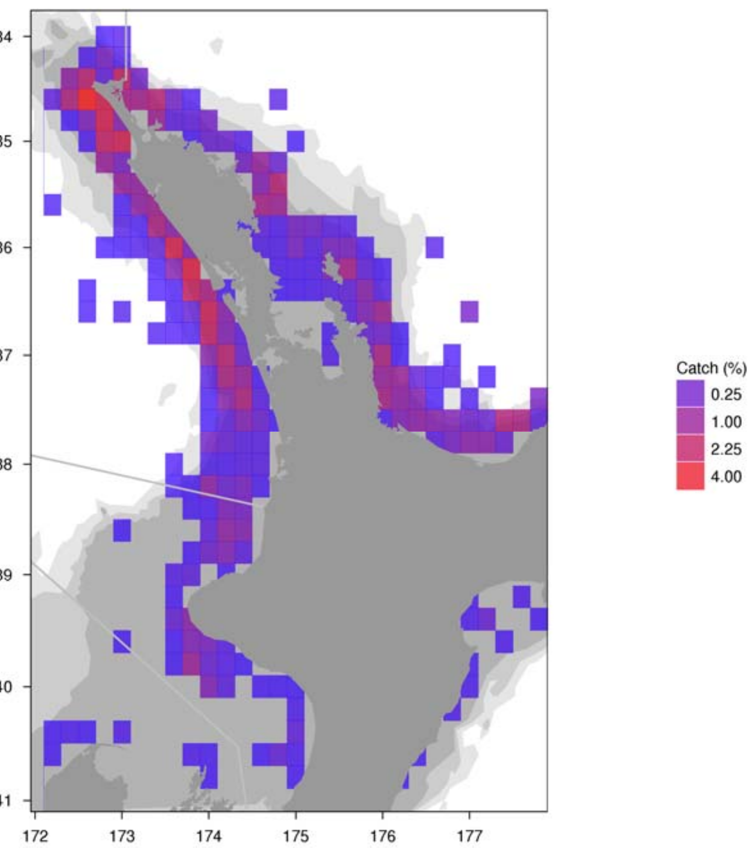


Figure C18: Percentage of total FRO catch by 0.2 degree cell when TRE was the target species over all fishing years, 1989–90 to 2009–10.

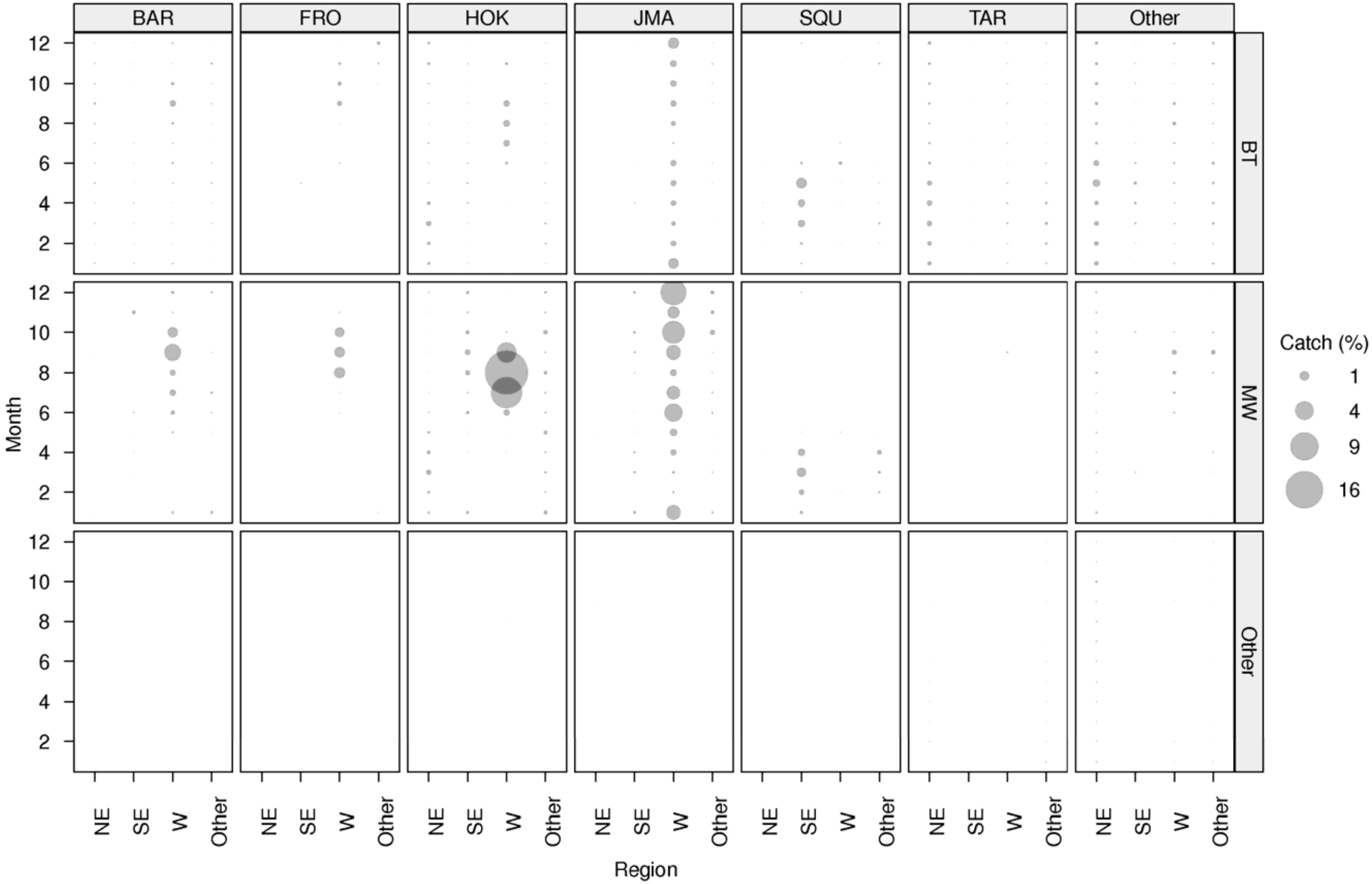


Figure C19: Proportion of frostfish catches by method, target species, month and region over all fishing years, 1989–90 to 2009–10. Regions are defined on the basis of statistical areas, North-east (NE):001–016; South-east(SE): 020–030; West(W): 034–042.

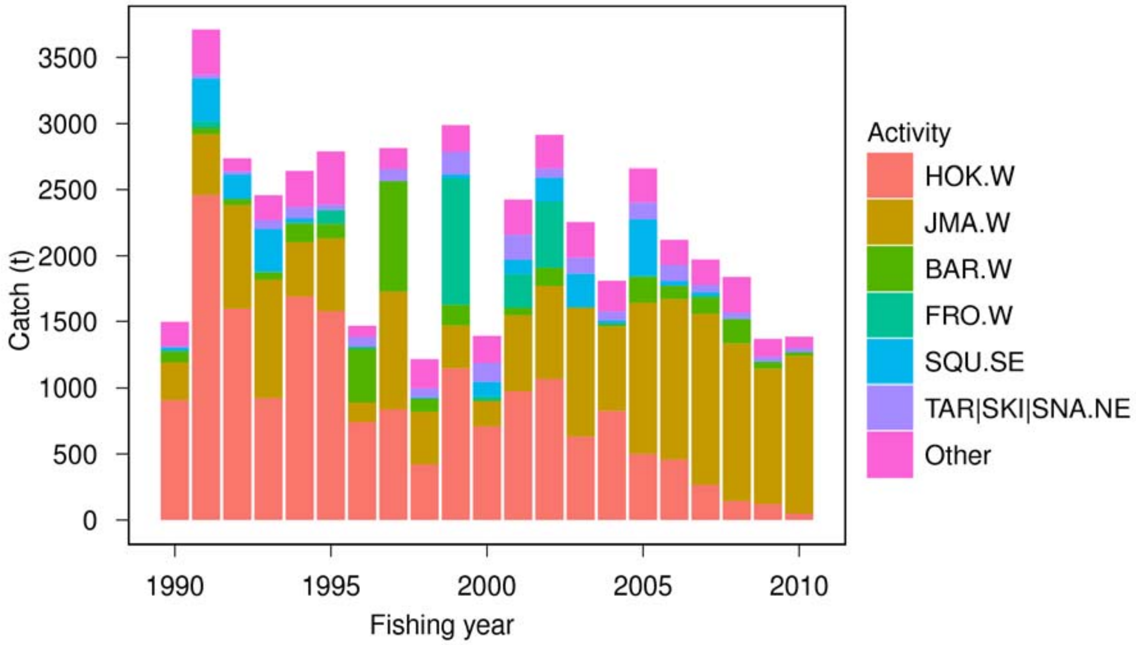


Figure C20: Catches by key fishing activity and fishing year. Labels indicate the combination of target species and region(s) that define the activity. See Table 5 for definitions of each fishing activity.

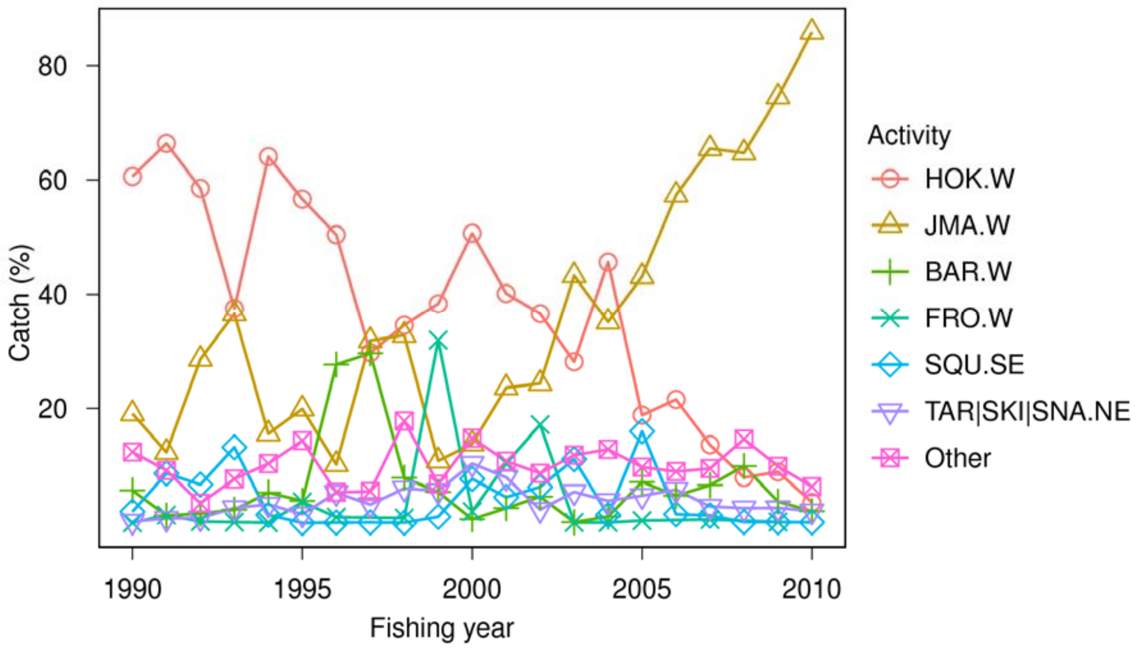


Figure C21: Percentage of catches by activity for each fishing year. Labels indicate the combination of target species and region(s) that define the activity. See Table 5 for definitions of each fishing activity.

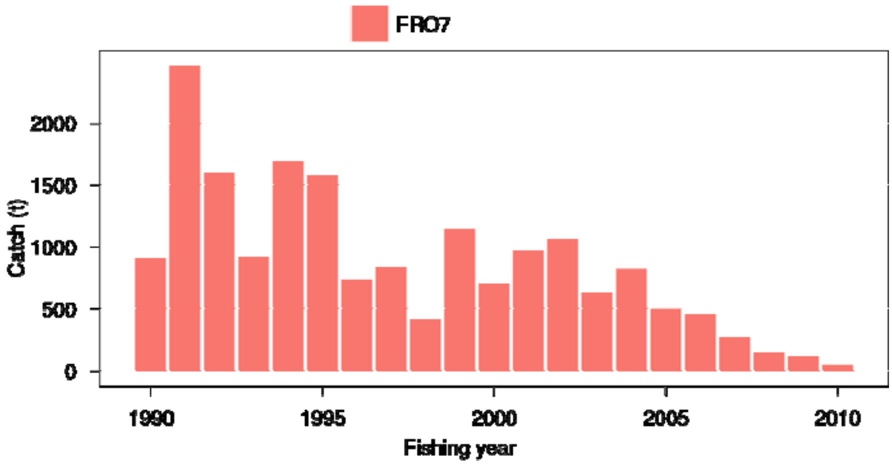


Figure C22: Catch of frostfish by quota management area (QMA) and fishing year for activity HOK.W. QMA is determined on the basis of statistical area. Note that a negligible quantity of FRO 8 was recorded as landed by this activity.

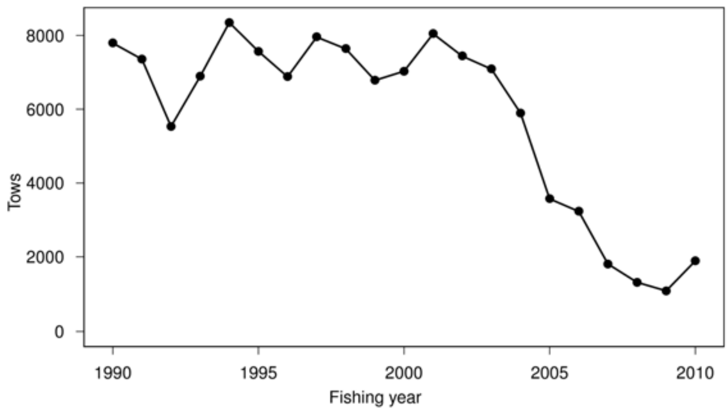


Figure C23: Number of tows by fishing year for activity HOK.W.

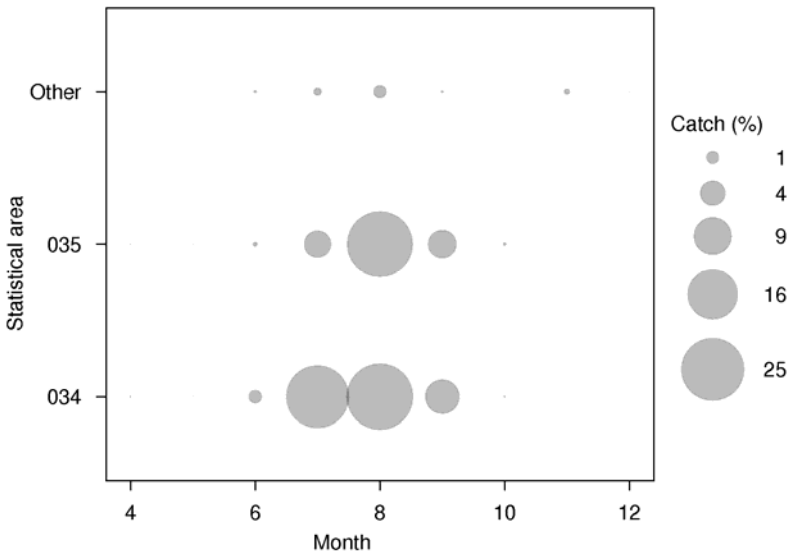


Figure C24: Percentage of catch by statistical area and month for HOK.W over all fishing years, 1989–90 to 2009–10.

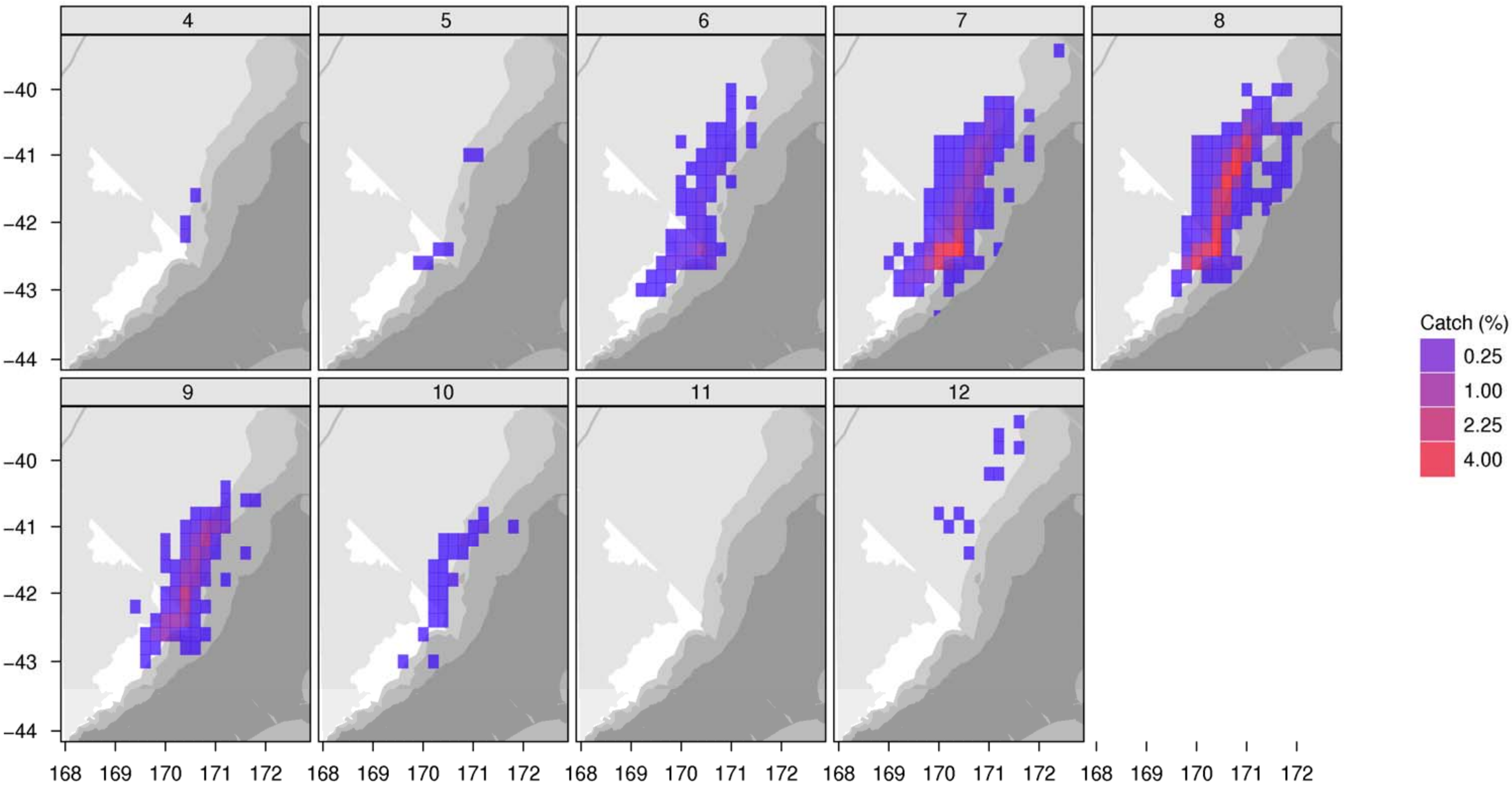


Figure C25: Percentage of frostfish catch by 0.2 degree cell and month from activity HOK.W over all fishing years, 1989–90 to 2009–10.

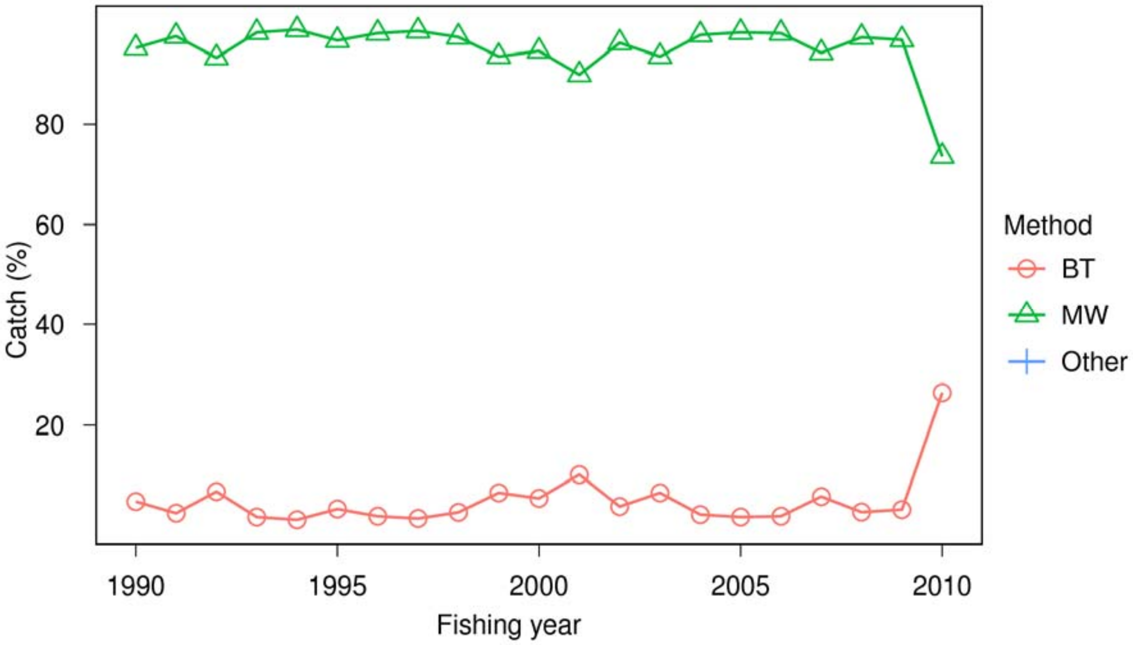


Figure C26: Percentage of frostfish catch by method for each fishing year for activity HOK.W.

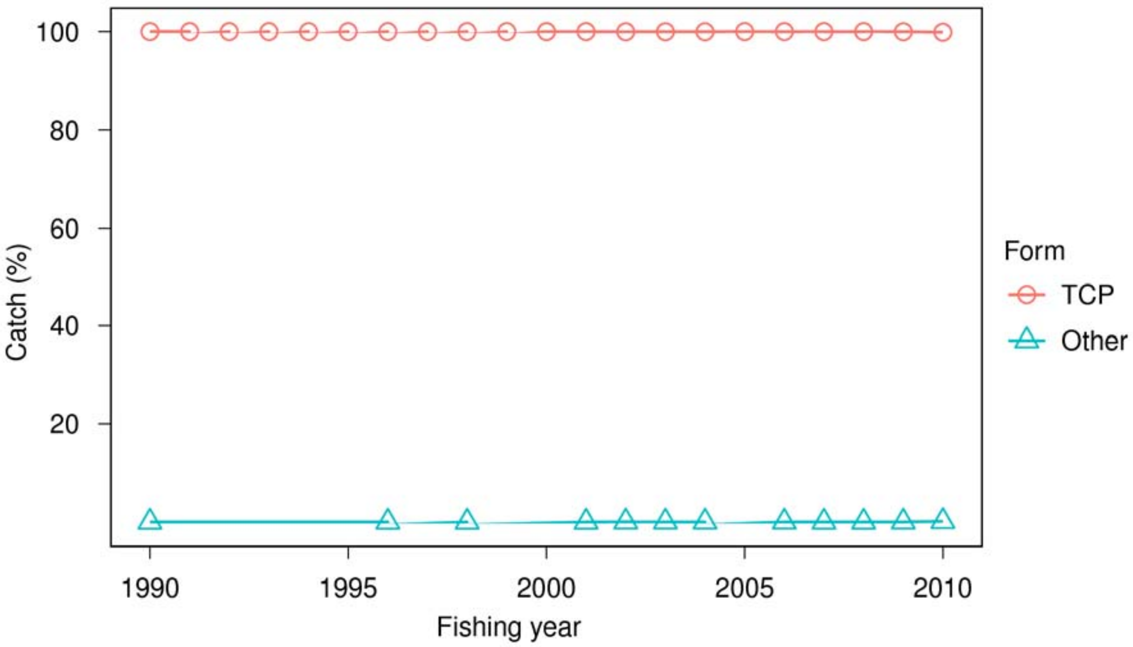


Figure C27: Percentage of frostfish catch by form type for each fishing year for activity HOK.W.

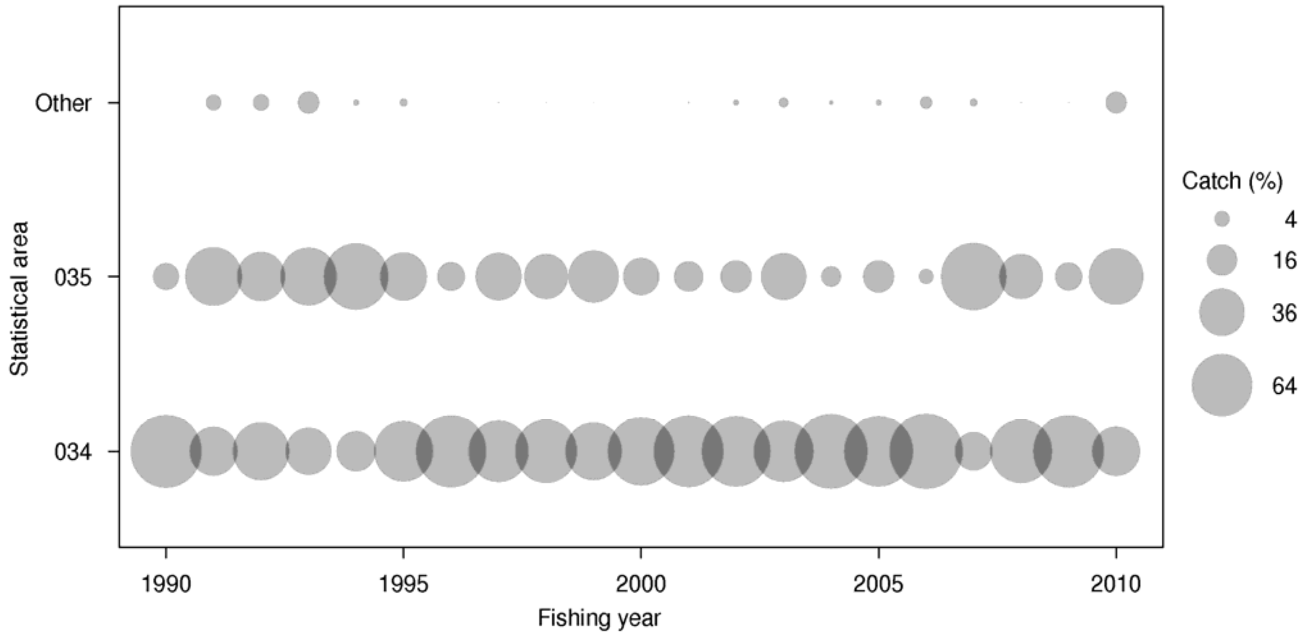


Figure C28: Percentage of frostfish catch by statistical area for each fishing year for activity HOK.W.

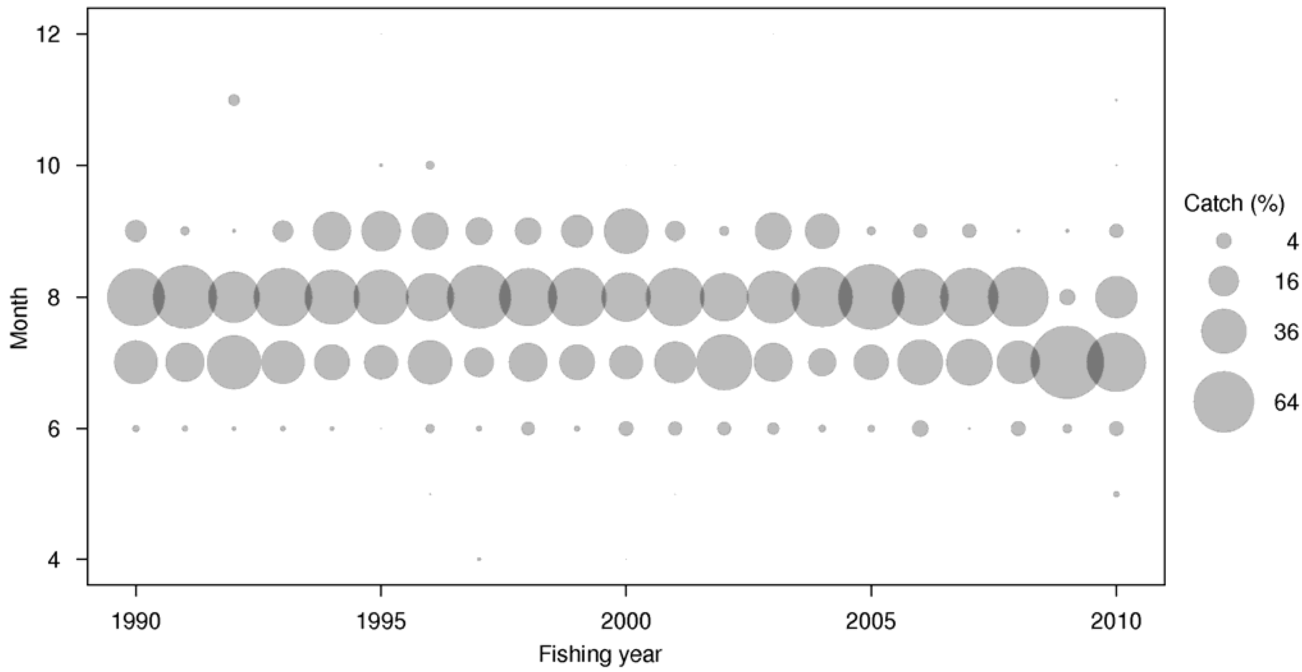


Figure C29: Percentage of frostfish catch by month for each fishing year for activity HOK.W.

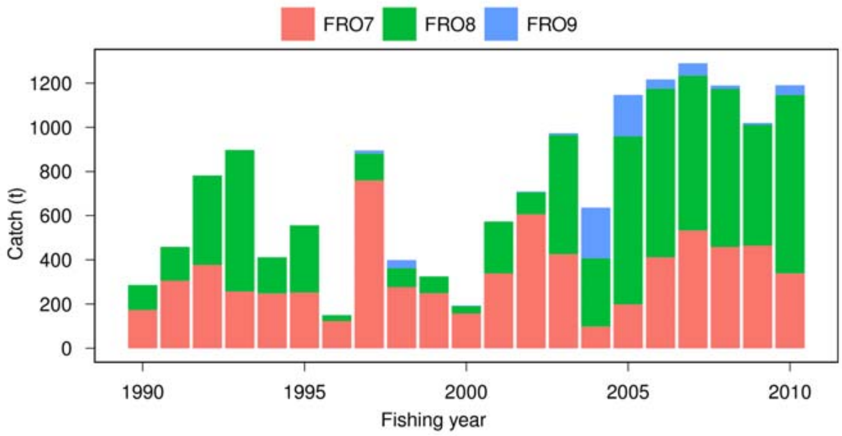


Figure C30: Catch of frostfish by quota management area (QMA) and fishing year for activity JMA.W. QMA is determined on the basis of statistical area.

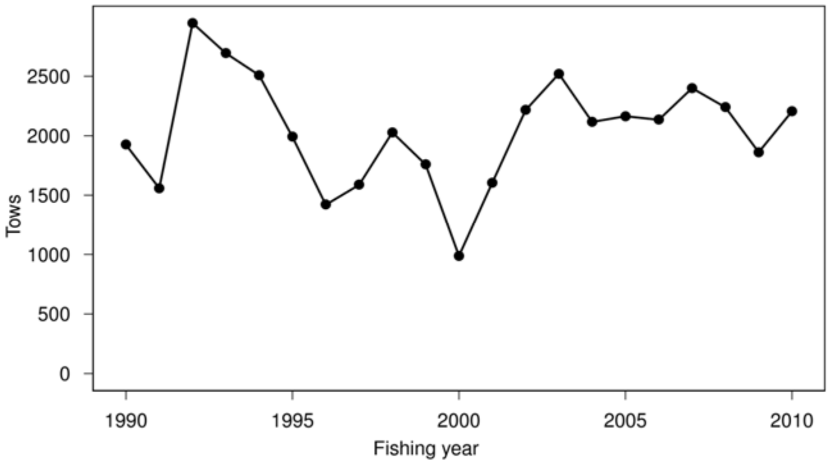


Figure C31: Number of tows by fishing year for activity JMA.W.

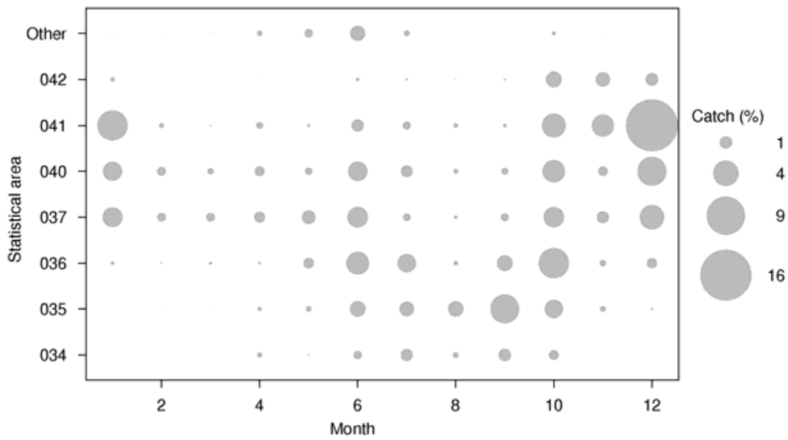


Figure C32: Percentage of catch by statistical area and month for JMA.W over all fishing years, 1989–90 to 2009–10.

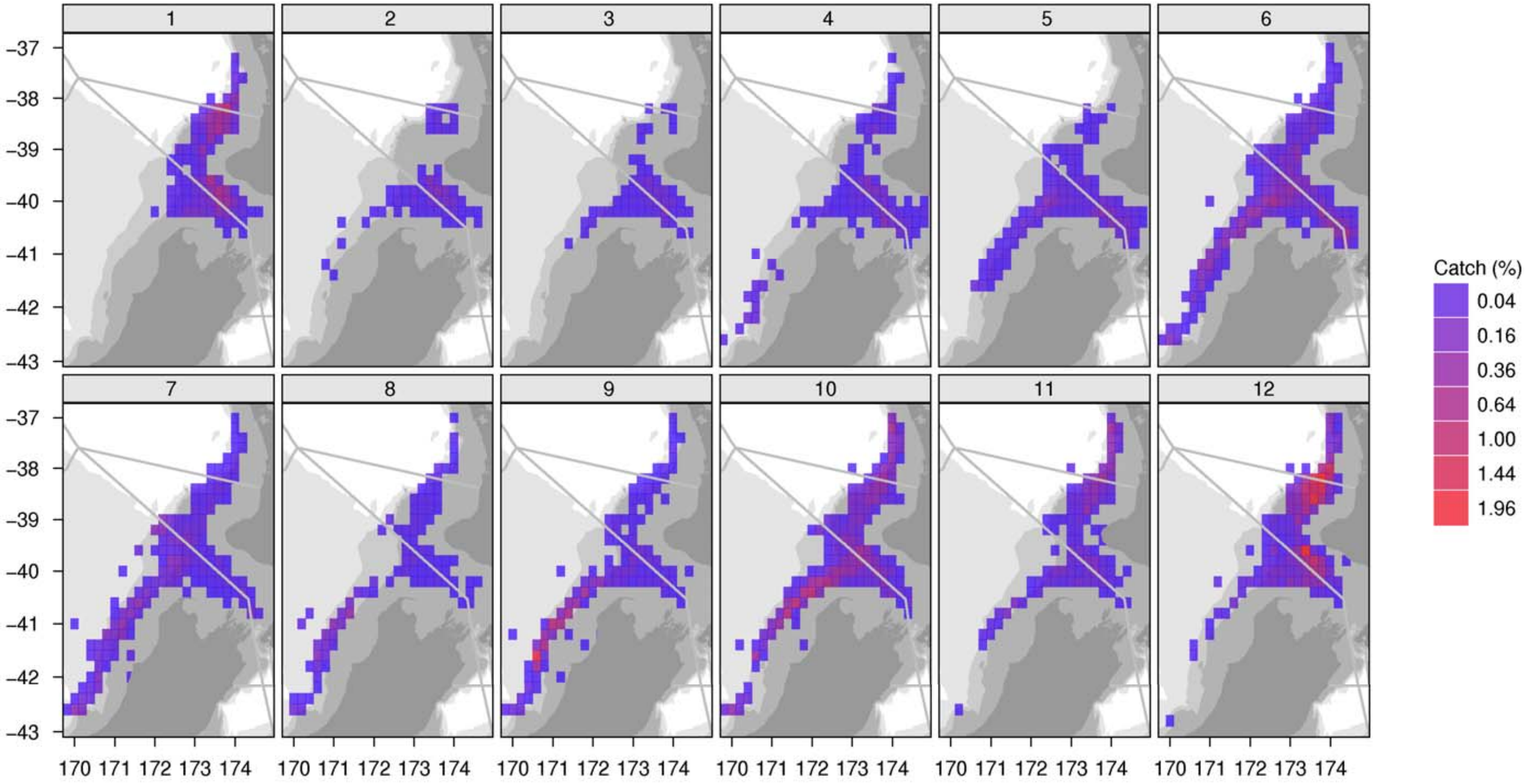


Figure C33: Percentage of frostfish catch by 0.2 degree cell and month from activity JMA.W over all fishing years, 1989–90 to 2009–10.

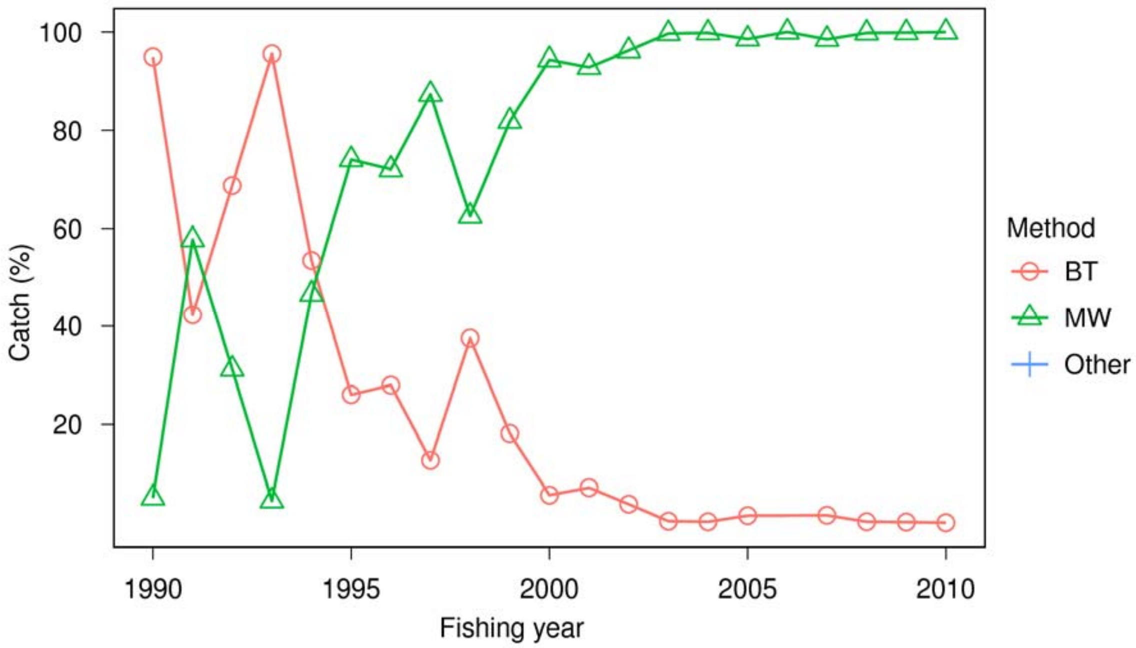


Figure C34: Percentage of frostfish catch by method for each fishing year for activity JMA.W.

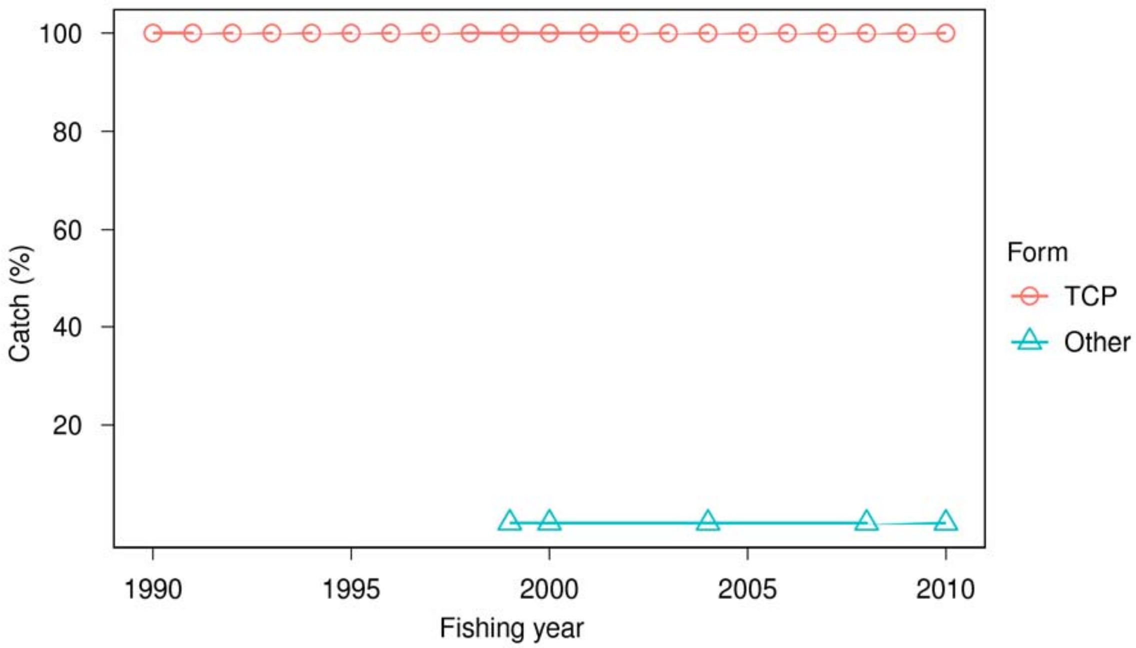


Figure C35: Percentage of frostfish catch by form type for each fishing year for activity JMA.W.

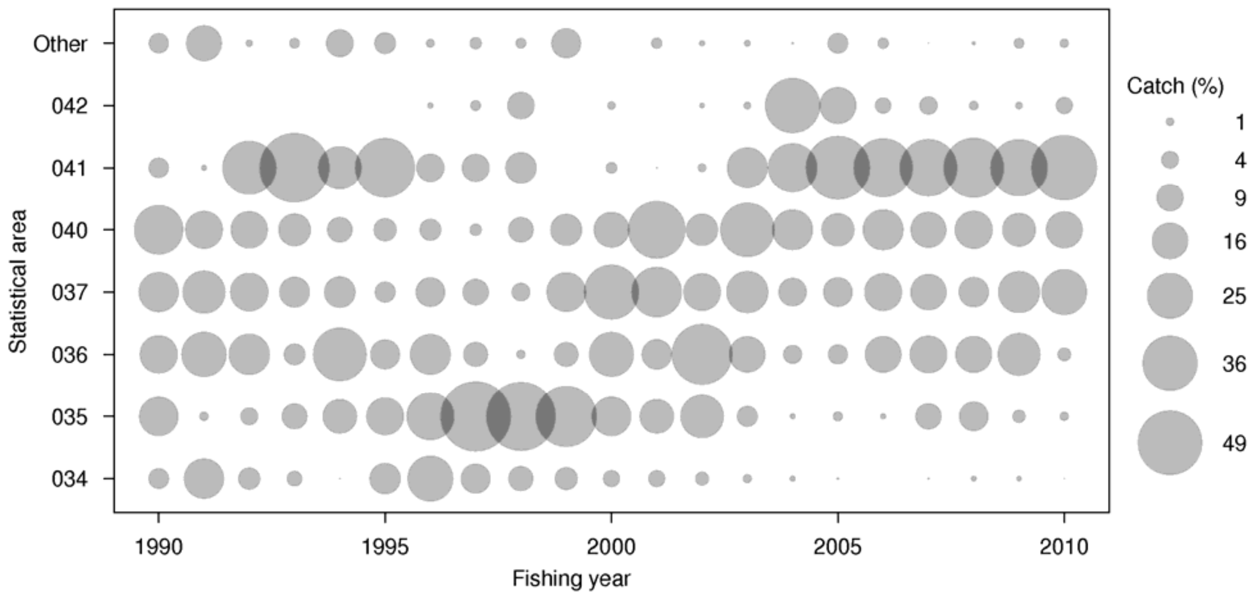


Figure C36: Percentage of frostfish catch by statistical area for each fishing year for activity JMA.W.

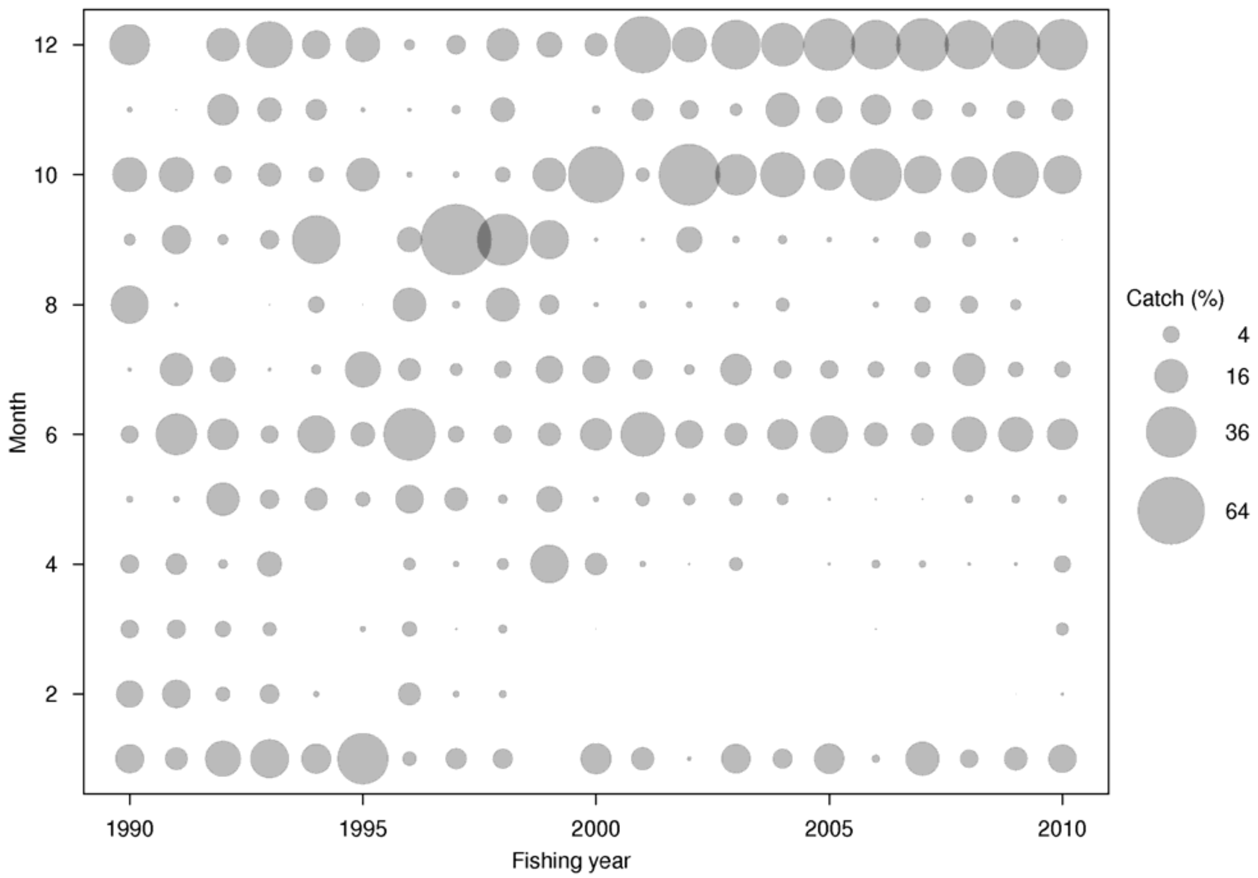


Figure C37: Percentage of frostfish catch by month for each fishing year for activity JMA.W.

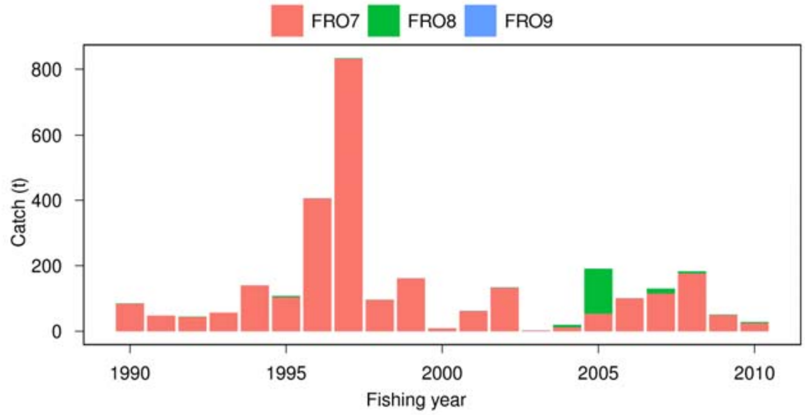


Figure C38: Catch of frostfish by quota management area (QMA) and fishing year for activity BAR.W. QMA is determined on the basis of statistical area. Landings of FRO 9 from this activity were negligible.

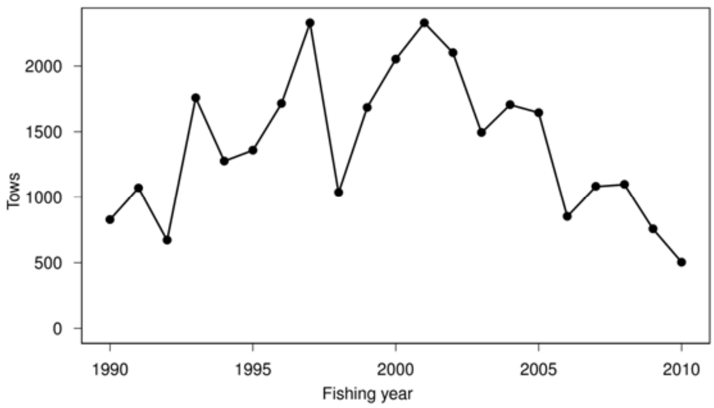


Figure C39: Number of tows by fishing year for activity BAR.W.

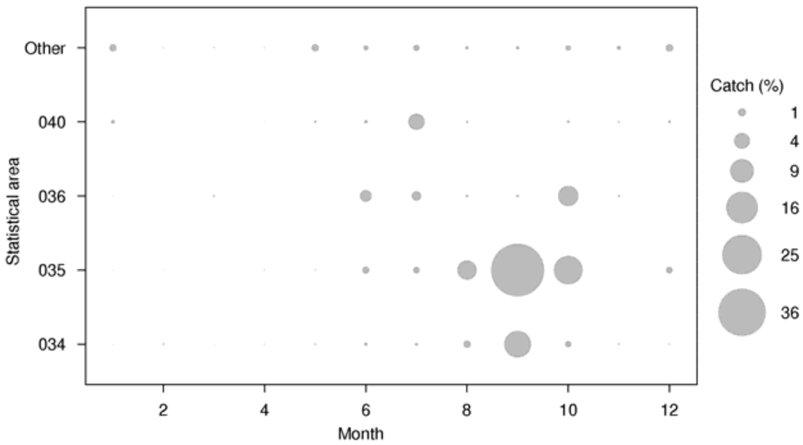


Figure C40: Percentage of catch by statistical area and month for BAR.W over all fishing years, 1989–90 to 2009–10.

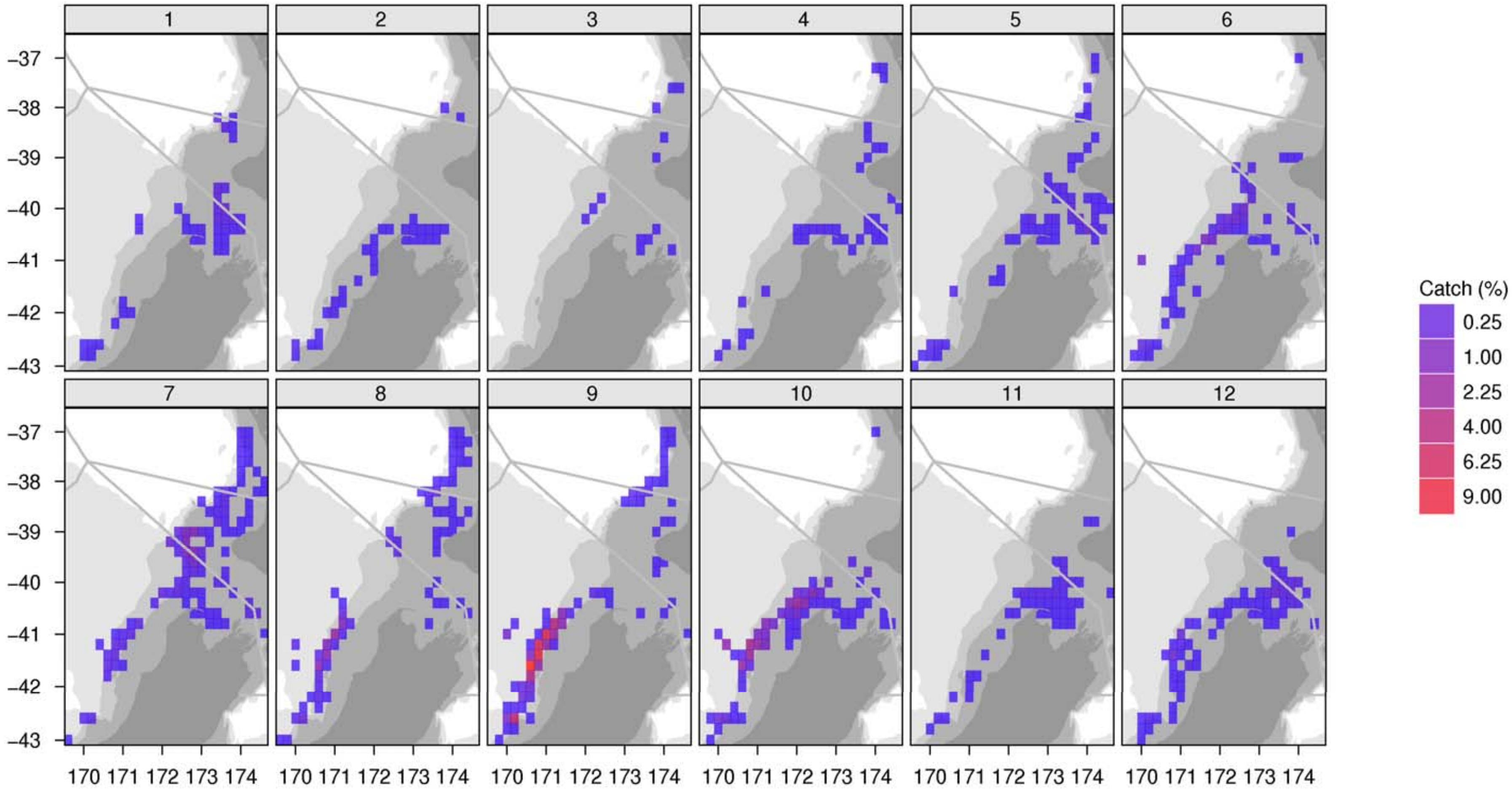
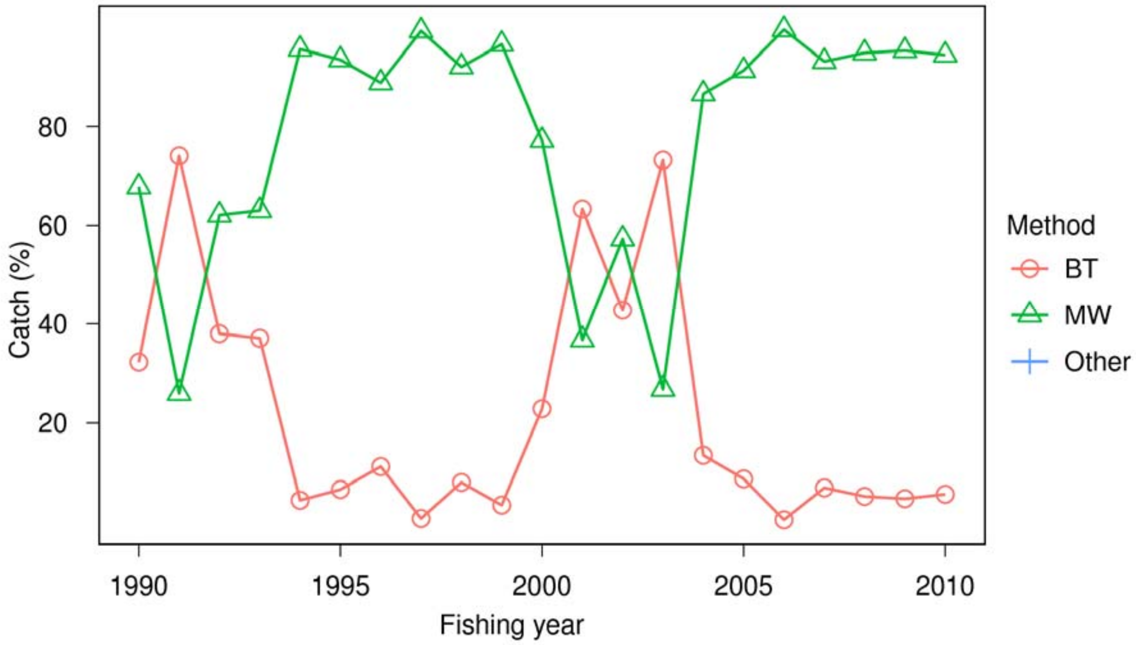
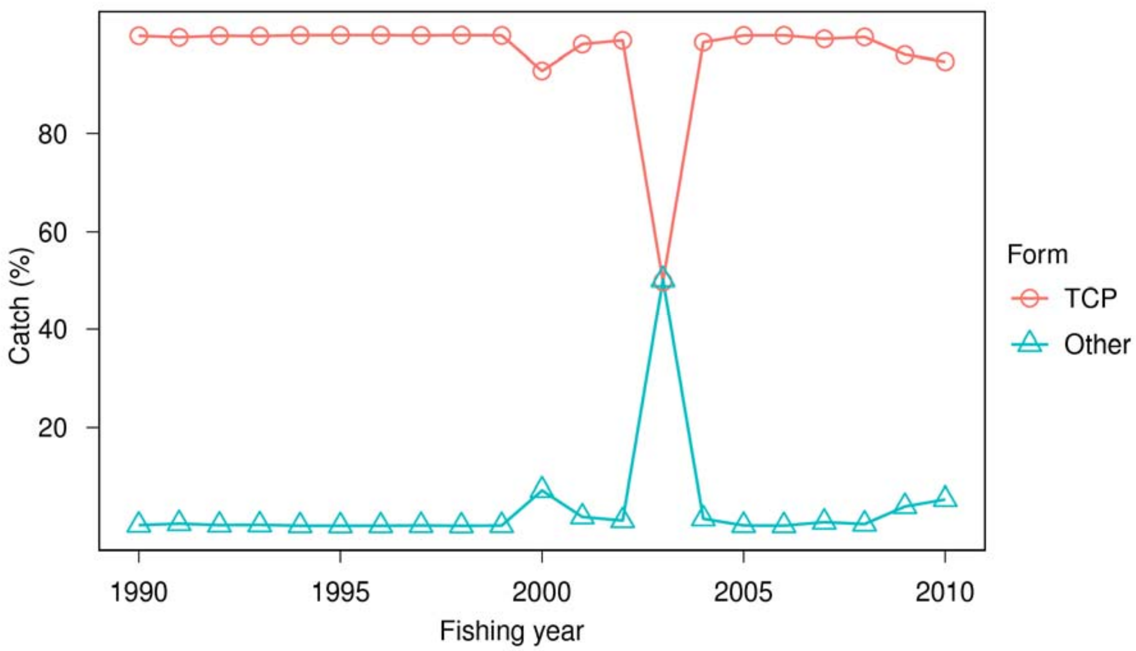


Figure C41: Percentage of frostfish catch by 0.2 degree cell and month from activity BAR.W over all fishing years, 1989–90 to 2009–10.



Figure

Figure C42: Percentage of frostfish catch by method for each fishing year for activity BAR.W.



Figure

Figure C43: Percentage of frostfish catch by form type for each fishing year for activity BAR.W.

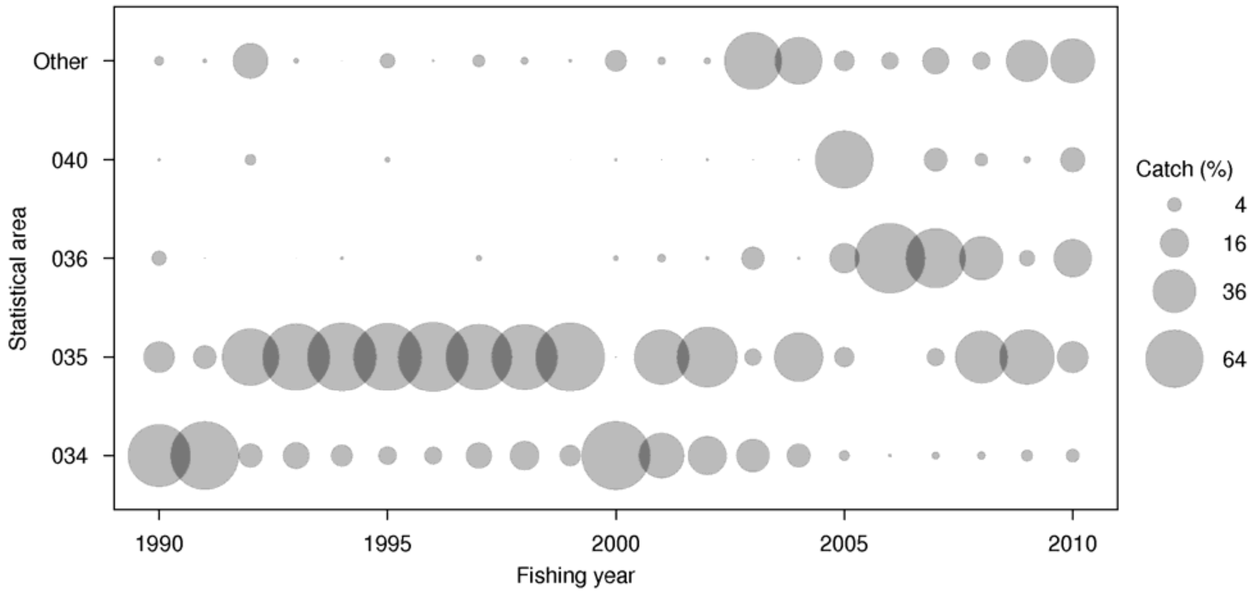


Figure C44: Percentage of frostfish catch by statistical area for each fishing year for activity BAR.W.

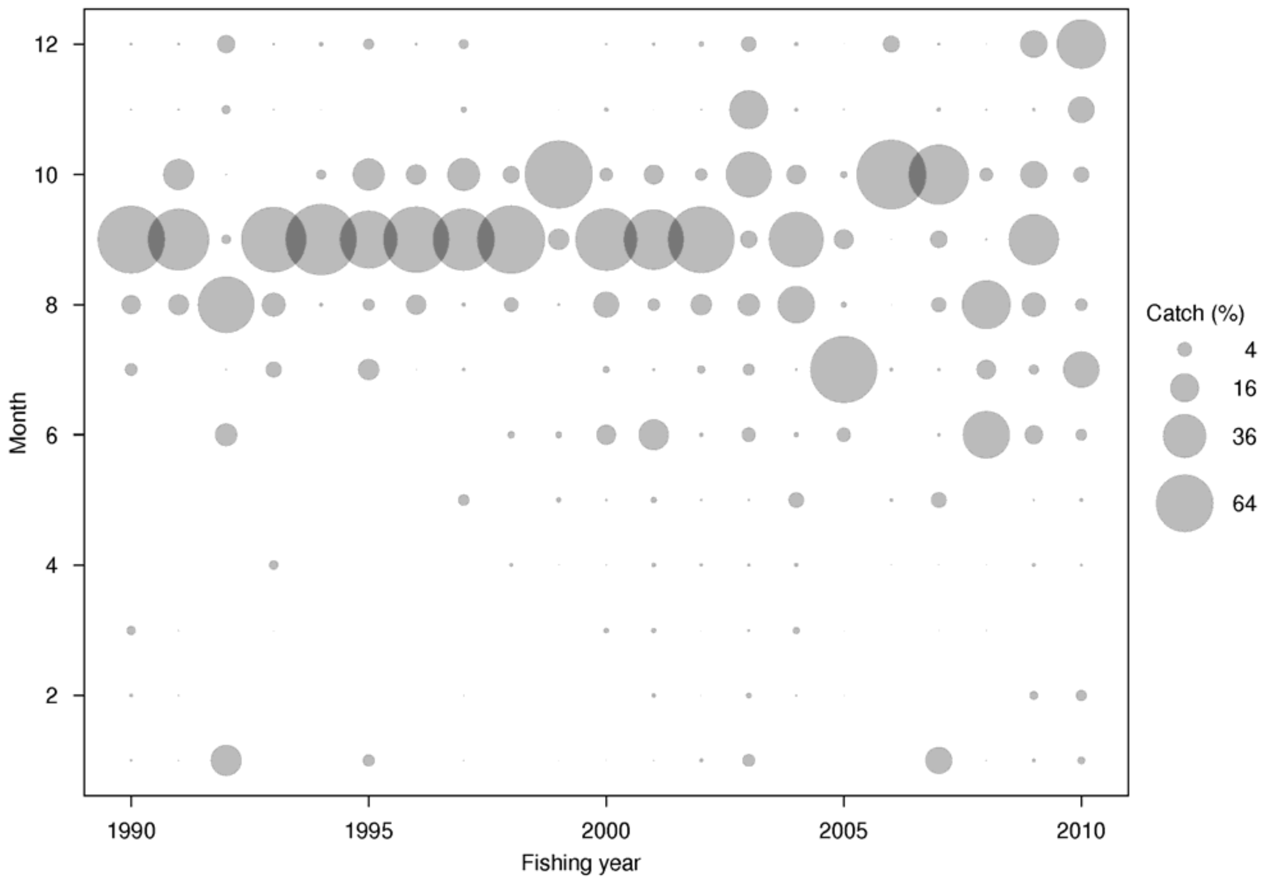


Figure C45: Percentage of frostfish catch by month for each fishing year for activity BAR.W.

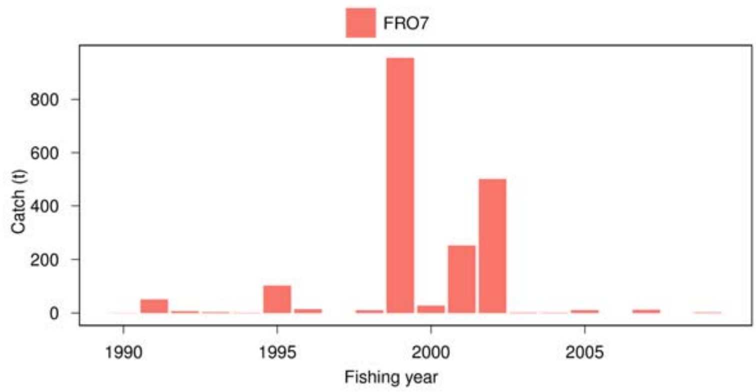


Figure C46: Catch of frostfish by quota management area (QMA) and fishing year for activity FRO.W. QMA is determined on the basis of statistical area.

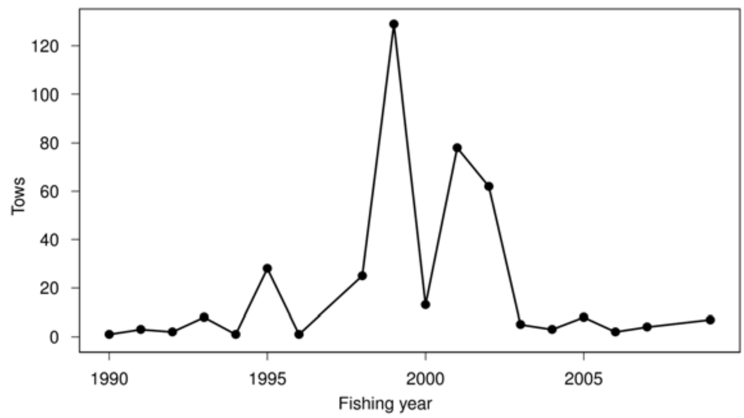


Figure C47: Number of tows by fishing year for activity FRO.W.

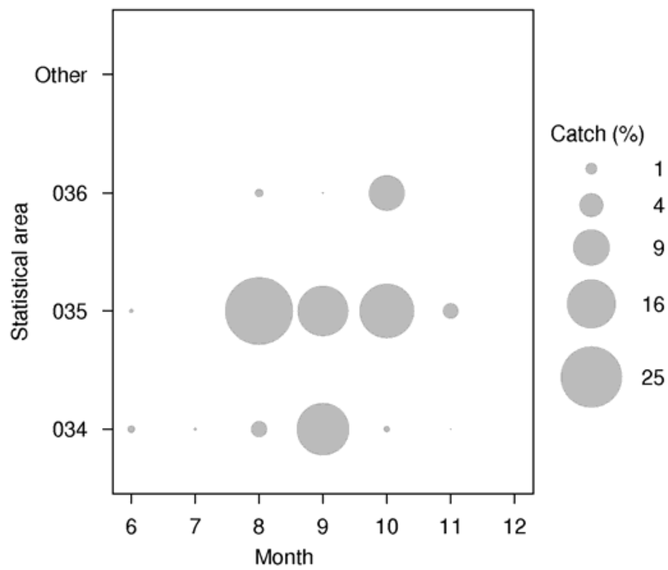


Figure C48: Percentage of catch by statistical area and month for FRO.W over all fishing years, 1989–90 to 2009–10.

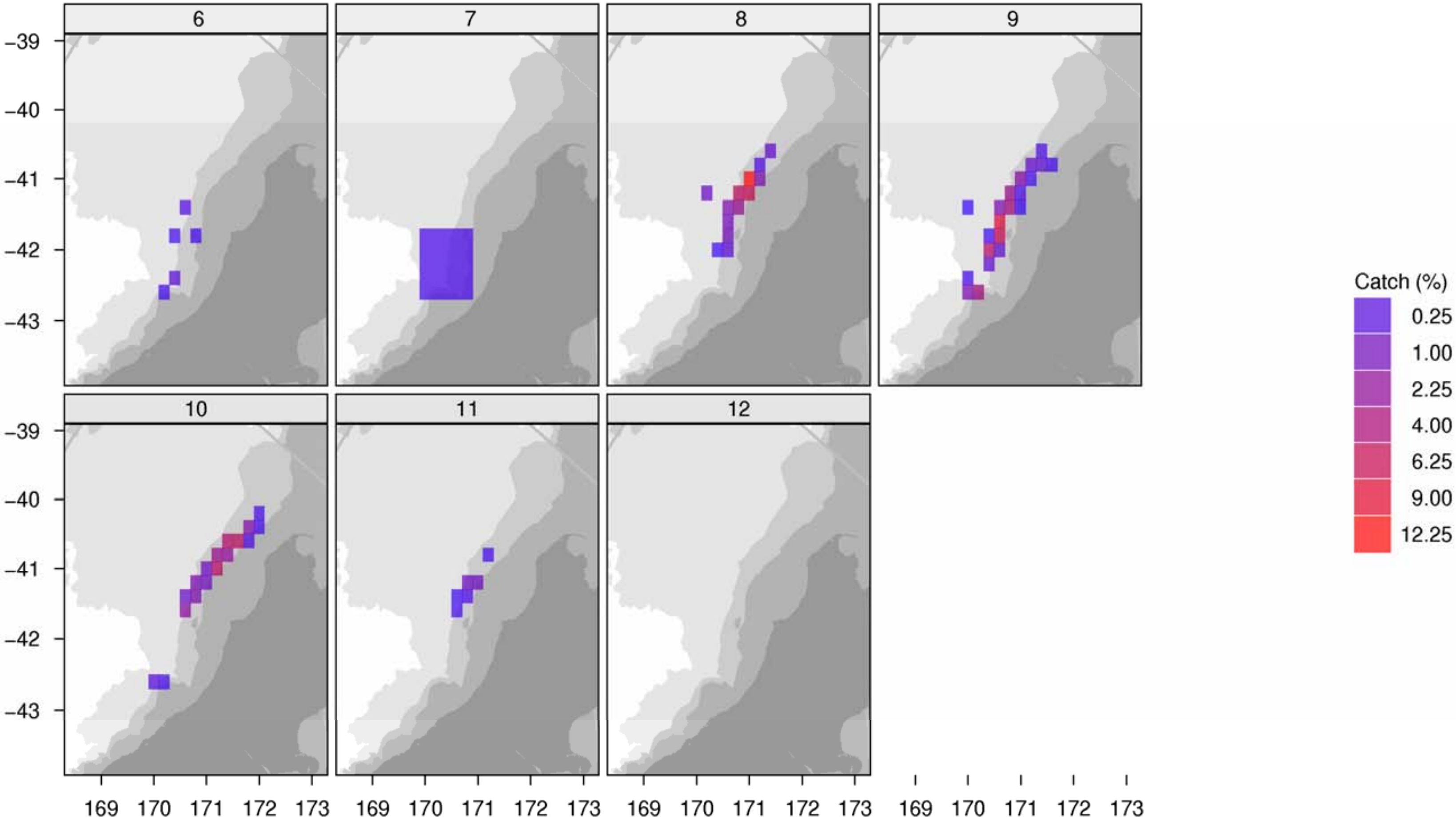


Figure C49: Percentage of frostfish catch by 0.2 degree cell and month from activity FRO.W over all fishing years, 1989–90 to 2009–10.

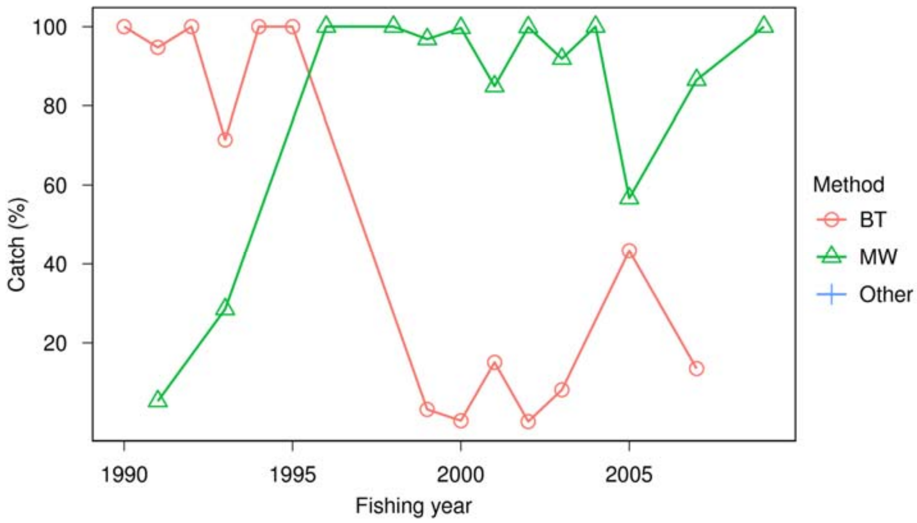


Figure C50: Percentage of frostfish catch by method for each fishing year for activity FRO.W.

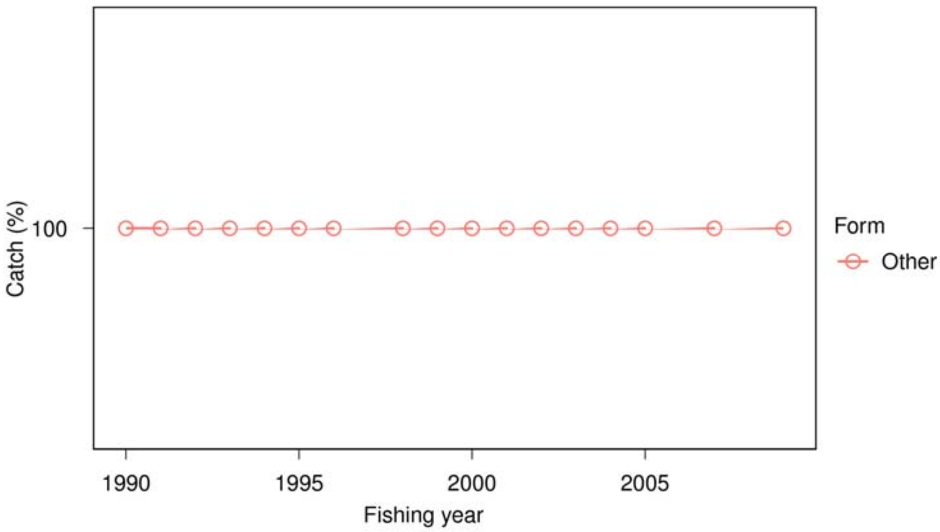


Figure C51: Percentage of frostfish catch by form type for each fishing year for activity FRO.W.

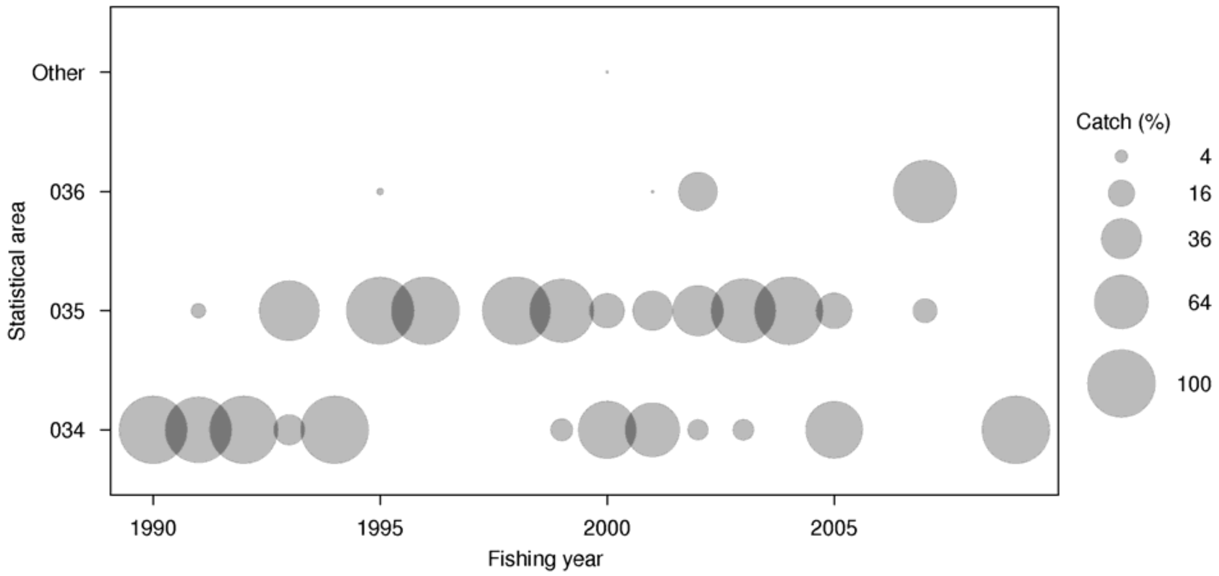


Figure C52: Percentage of frostfish catch by statistical area for each fishing year for activity FRO.W.

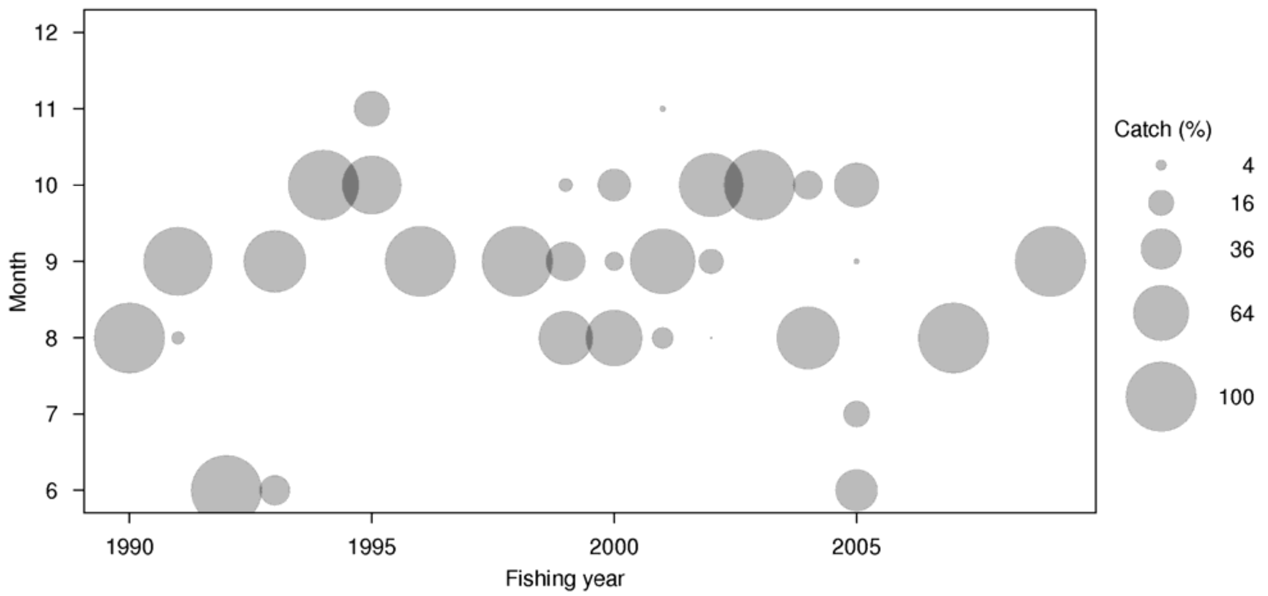


Figure C53: Percentage of frostfish catch by month for each fishing year for activity FRO.W.

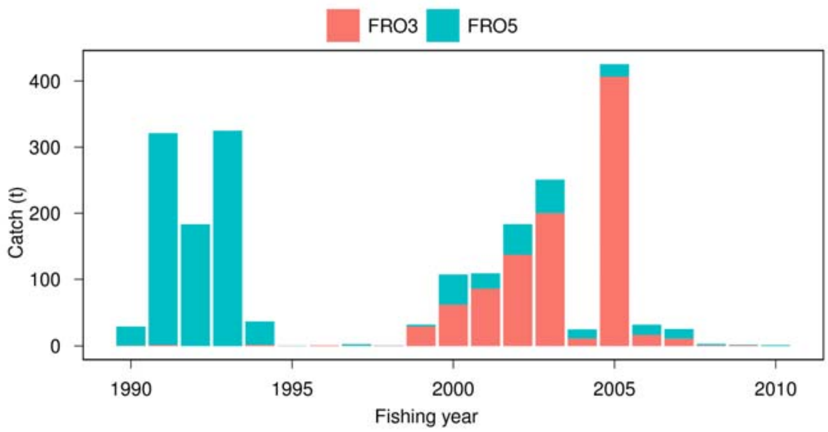


Figure C54: Catch of frostfish by quota management area (QMA) and fishing year for activity SQU.SE. QMA is determined on the basis of statistical area.

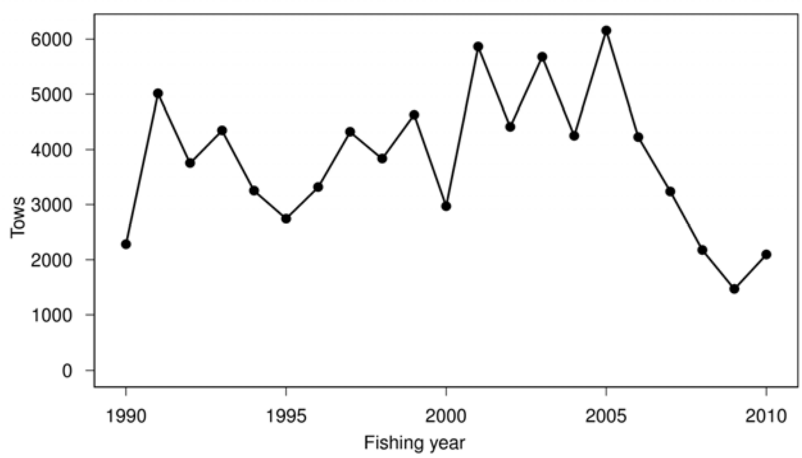


Figure C55: Number of tows by fishing year for activity SQU.SE.

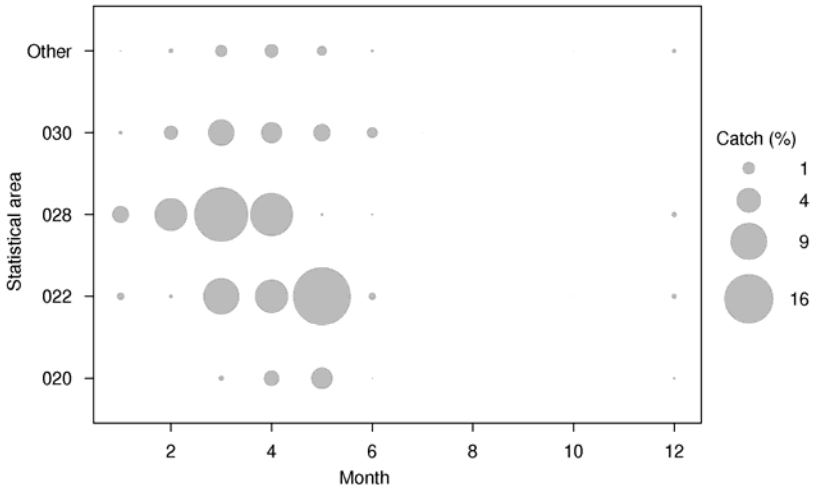


Figure C56: Percentage of catch by statistical area and month for SQU.SE over all fishing years, 1989–90 to 2009–10.

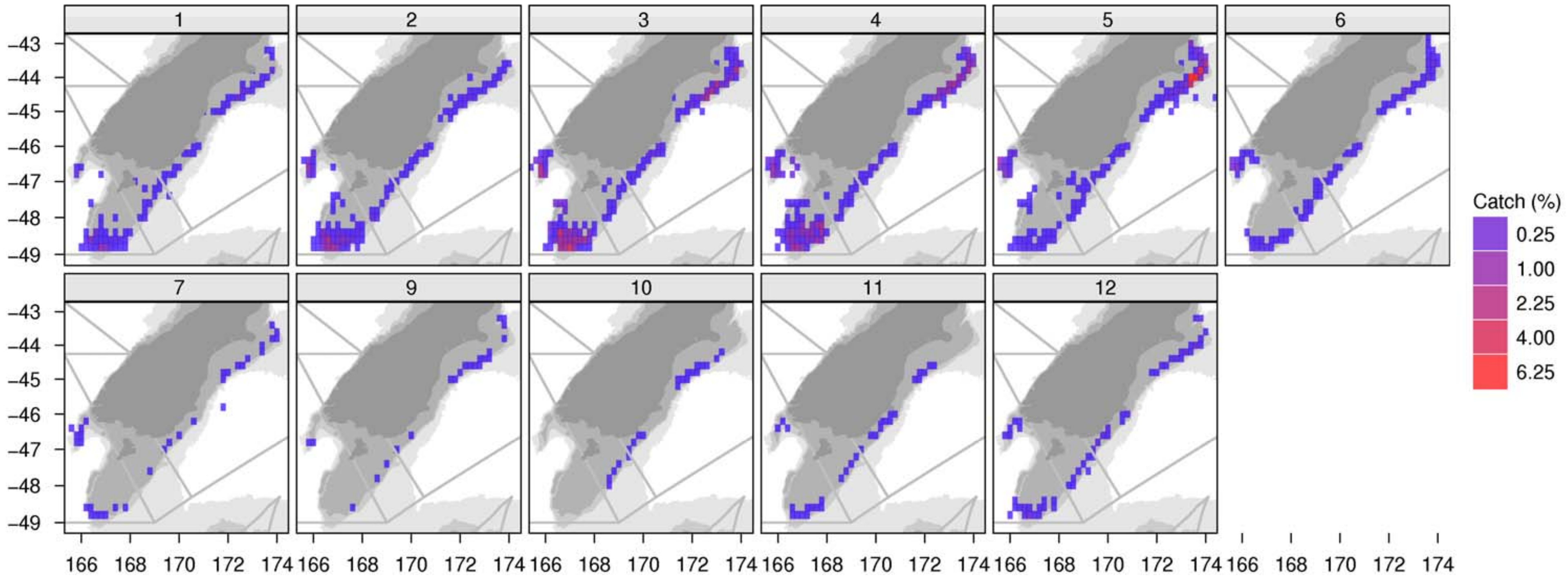


Figure C57: Percentage of frostfish catch by 0.2 degree cell and month from activity SQU.SE over all fishing years, 1989–90 to 2009–10.

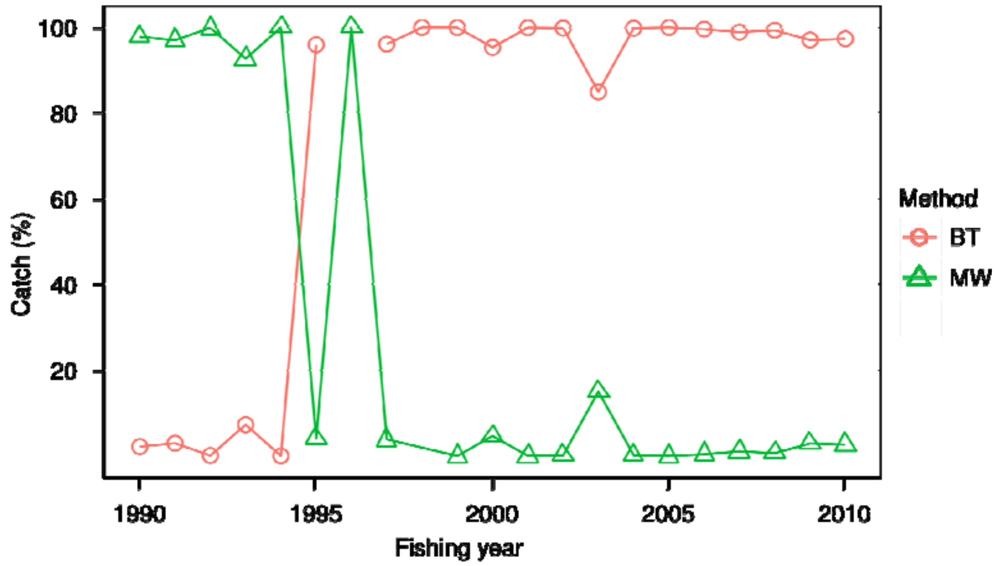


Figure C58: Percentage of frostfish catch by method for each fishing year for activity SQU.SE.

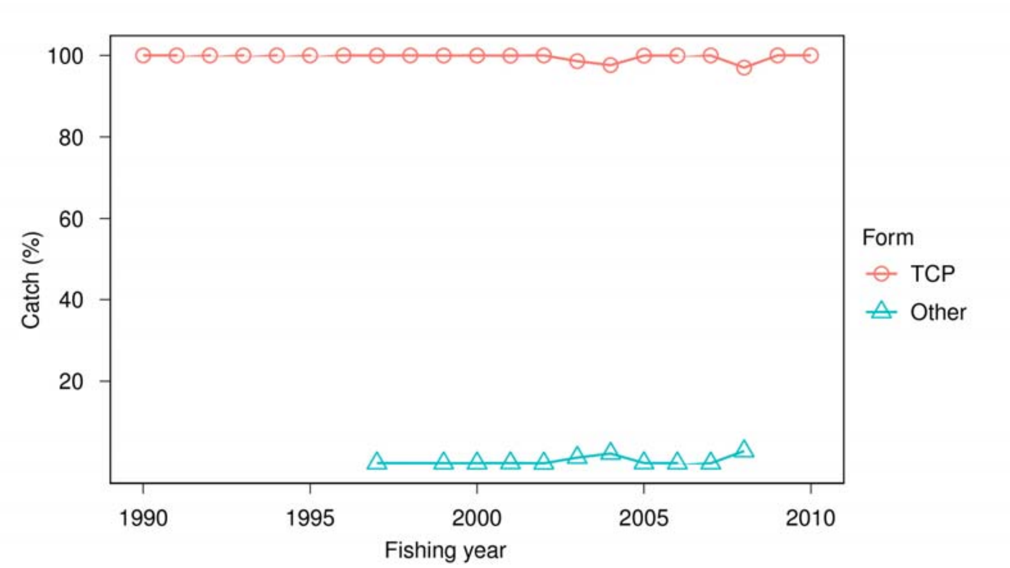


Figure C59: Percentage of frostfish catch by form type for each fishing year for activity SQU.SE.

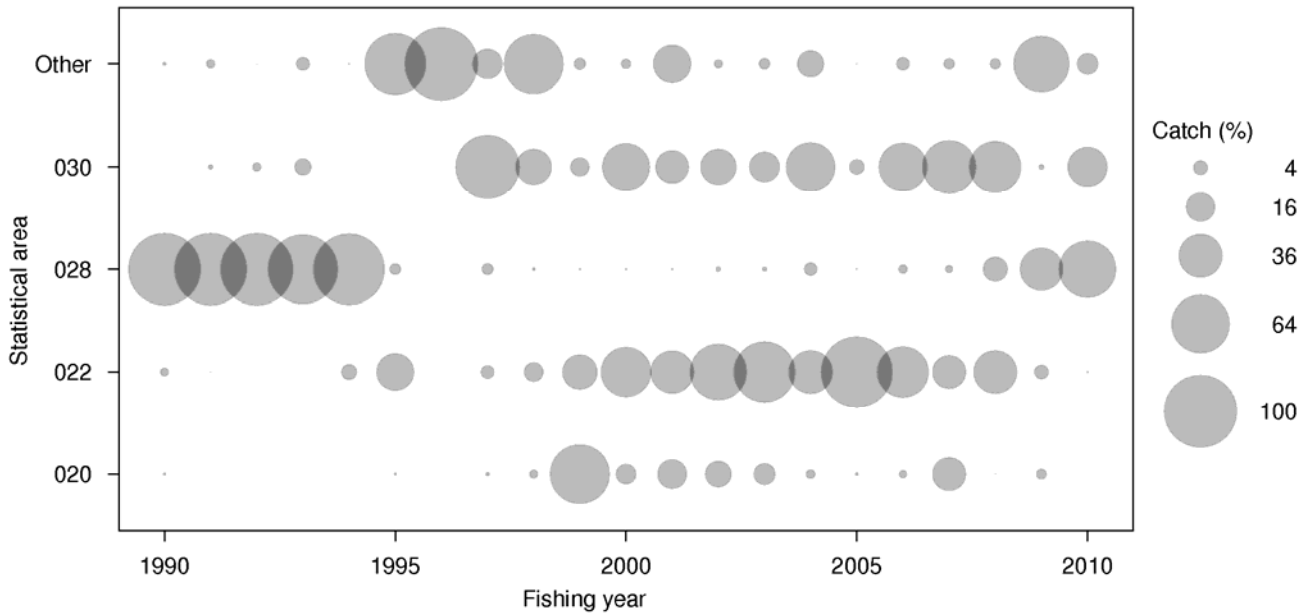


Figure C60: Percentage of frostfish catch by statistical area for each fishing year for activity SQU.SE.

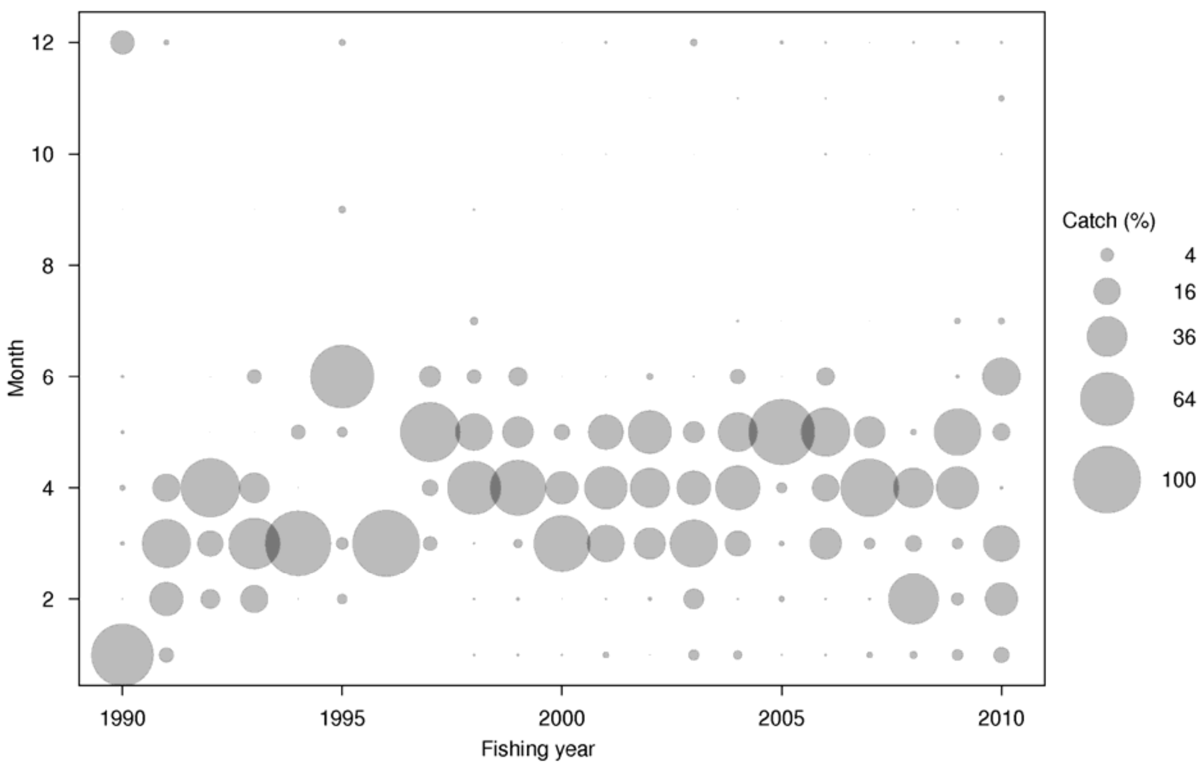


Figure C61: Percentage of frostfish catch by month for each fishing year for activity SQU.SE.

APPENDIX D: CATCH PER UNIT EFFORT FOR TRAWLING TARGETTING JACK MACKEREL (JMA)

Data subsetting and processing

The data used for this CPUE standardisation was defined by the following criteria:

- form type was "TCP";
- method was "MW" or "BT";
- target species was "JMA";
- area was "034", "035", "036", "037", "039", "040", "041", or "042";
- trawl depth was 25–500m;
- bottom depth was 25–500m;
- trawl height was 1–100m;
- trawl width was 10–200m;
- trawl speed was 3–7 kts;
- trawl duration was 0–15hrs.

Table D1 summarises the number of fishing events, vessels, trips, effort and catch in the resultant dataset. The minimum number of vessels was eight in 2006. The percentage of positive catches ranged from 18% to 53%.

In some years there was a high proportion of landings that were retained on board (destination_type R). This causes issues with the use of allocated landings. Thus for these CPUE analyses estimated catches were used.

Table D1: Summary by fishing year of the data subset used for in the CPUE analysis of frostfish caught in trawls targeting jack mackerel..

Fishing year	Events	Vessels	Trips	Effort number	Effort duration (hrs)	Catch (t)	Events with catch (landed,% records)
1990	1 904	20	71	1 904	8 635	325.2	39.18
1991	1 539	30	85	1 539	6 418	418.8	51.40
1992	2 926	31	93	2 926	12 073	974.0	50.92
1993	2 660	27	74	2 660	12 492	849.5	52.56
1994	2 479	27	68	2 479	9 548	843.8	42.84
1995	1 925	34	71	1 925	6 764	624.3	34.91
1996	1 332	24	58	1 332	5 727	182.1	17.64
1997	1 295	30	77	1 295	5 009	1 058.2	41.93
1998	1 888	31	88	1 888	7 195	977.5	37.66
1999	1 531	27	85	1 531	4 767	204.8	22.93
2000	938	13	33	938	2 103	152.6	26.76
2001	1 560	20	52	1 560	4 279	538.9	36.99
2002	2 145	18	60	2 145	6 676	606.9	30.72
2003	2 410	14	59	2 410	7 289	692.7	37.51
2004	2 092	9	47	2 092	6 217	563.0	39.82
2005	2 151	13	46	2 151	6 739	1 107.6	45.14
2006	2 126	8	39	2 126	7 176	1 084.8	50.85
2007	2 387	13	63	2 387	8 989	1 176.2	47.13
2008	2 213	14	57	2 213	8 749	1 105.2	45.46
2009	1 851	13	48	1 851	7 270	952.3	51.22
2010	2 188	11	45	2 188	8 894	1 062.8	53.43

Core vessel selection

Alternative core vessel selection criteria were investigated by considering the reduction in the number of vessels and percentage of catch (Figure D1). The most appropriate combination of criteria was considered to be to define the core fleet as those vessels that had fished for at least three trips in each of at least three years. To qualify, trips were required to have recorded at least 1kg of catch. These criteria resulted in a core fleet size of 18 vessels which took 88% of the catch (Figure D1). A histogram of the number of years in which each core vessel had data in the dataset is provided (Figure D2) as is the overlap of data among core vessels (Figure D3).

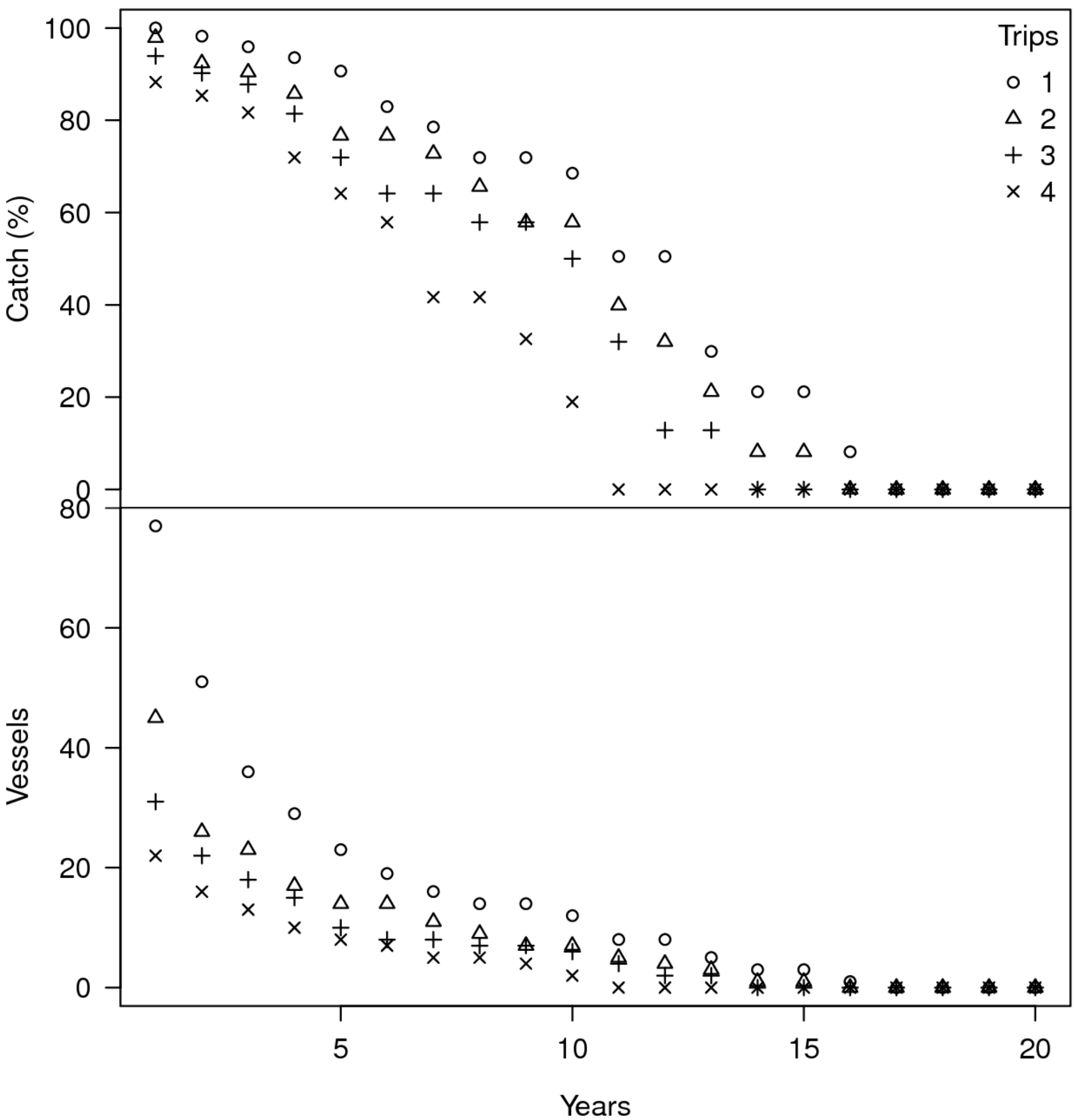


Figure D1: Examination of parameters for defining core vessels.

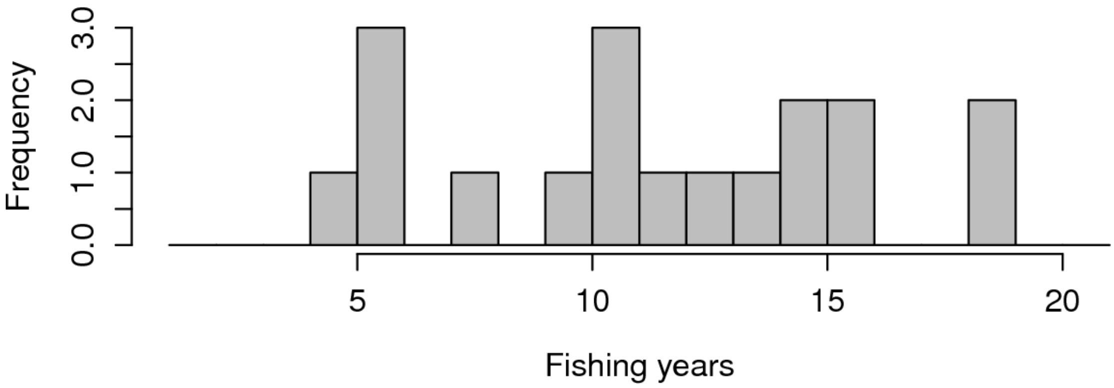


Figure D2: Histogram of the number of years with data for each core vessel.

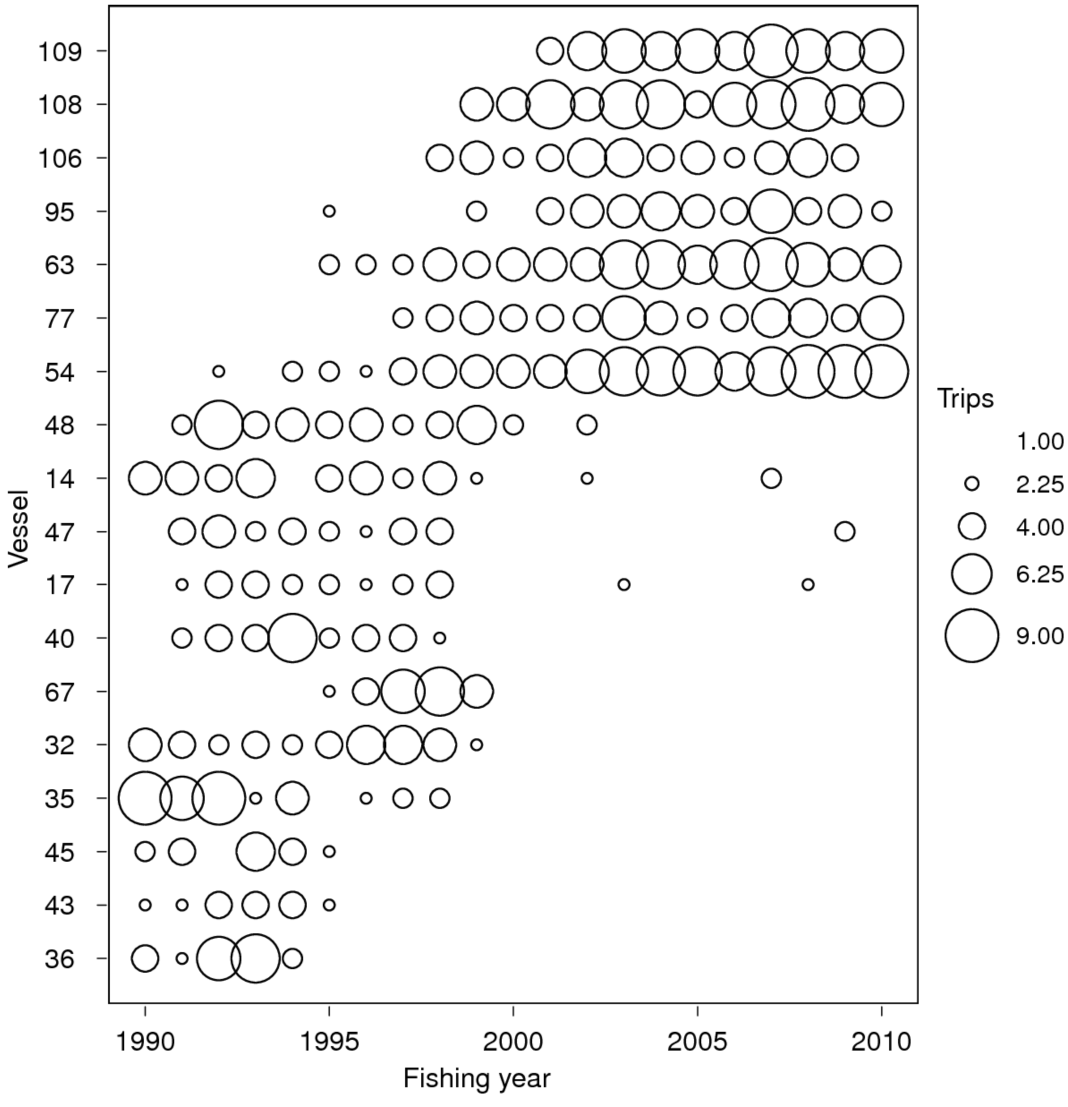


Figure D3: Number of trips by fishing year for core vessels. Area of circles is proportional to the proportion of records over all fishing years and vessels.

Table D2: Summary of core vessel data by fishing year.

Fishing year	Strata	Vessels	Trips	Catch (t)	Effort num	Effort duration (hrs)	Events with catch (% records)	Events	Trips (+ve)	Events (+ve)	Duration (+ve)
1990	1 022	7	29	250.7	1 022	4 236	61.84	1 022	24	632	2 588.8
1991	945	10	36	264.7	945	3 714	60.32	945	22	570	2 094.8
1992	2 021	12	51	826.9	2 021	8 236	61.55	2 021	36	1 244	5 258.9
1993	2 261	12	47	791.5	2 261	10 306	58.25	2 261	36	1 317	5 961.8
1994	2 047	11	43	690.2	2 047	7 839	46.51	2 047	25	952	3 717.0
1995	1 049	13	36	303.8	1 049	3 972	37.56	1 049	14	394	1 692.4
1996	934	11	36	153.4	934	4 202	21.95	934	16	205	994.9
1997	871	12	44	762.5	871	3 679	49.14	871	32	428	2 199.7
1998	1 339	12	51	582.5	1 339	5 205	43.09	1 339	41	577	2 761.2
1999	1 074	12	44	146.1	1 074	2 903	16.67	1 074	30	179	668.9
2000	883	9	28	147.1	883	1 967	27.07	883	18	239	615.8
2001	1 452	11	38	509.8	1 452	3 782	35.26	1 452	29	512	1 397.5
2002	1 858	11	45	538.4	1 858	5 151	26.91	1 858	35	500	1 440.2
2003	2 354	8	51	673.7	2 354	7 053	37.51	2 354	45	883	2 907.7
2004	2 083	8	46	562.3	2 083	6 168	39.70	2 083	35	827	2 497.8
2005	2 119	10	41	1 097.0	2 119	6 500	45.21	2 119	37	958	3 198.6
2006	2 081	7	38	1 081.0	2 081	7 050	51.32	2 081	35	1 068	3 739.3
2007	2 301	9	56	1 111.2	2 301	8 539	47.46	2 301	45	1 092	4 183.2
2008	2 161	10	52	1 104.1	2 161	8 322	46.41	2 161	46	1 003	4 092.6
2009	1 832	9	43	950.4	1 832	7 168	51.58	1 832	39	945	3 938.6
2010	2 179	9	42	1 058.2	2 179	8 841	53.33	2 179	38	1 162	4 955.5

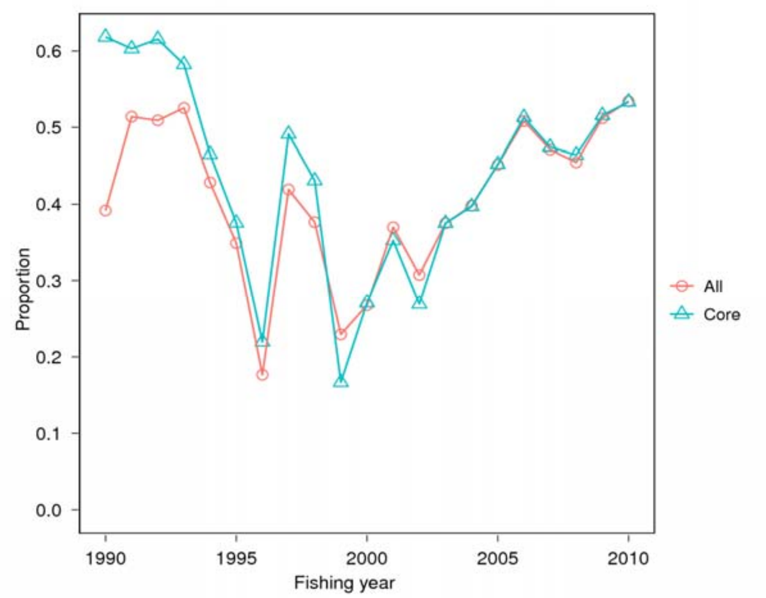


Figure D4: Proportion of positive catches for the entire dataset (All) and core vessels (Core).

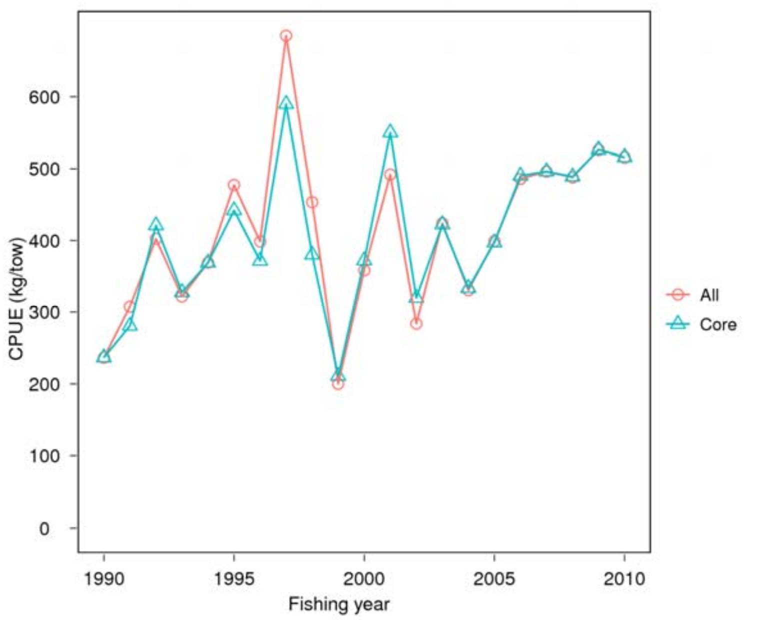


Figure D5: Unstandardised CPUE (geometric mean of positive catches) for the entire dataset (All) and core vessels (Core).

Selection of appropriate error distribution

Alternative assumptions regarding the distribution of model errors were tested by (a) fitting alternative distributions to the data, and (b) fitting simplified GLMs to the data assuming alternative distributions. The criterion used to select the most appropriate distribution was the negative log likelihood of the simplified GLM. On this basis a log logistic distribution was used. The GLM using the gamma distribution failed to converge.

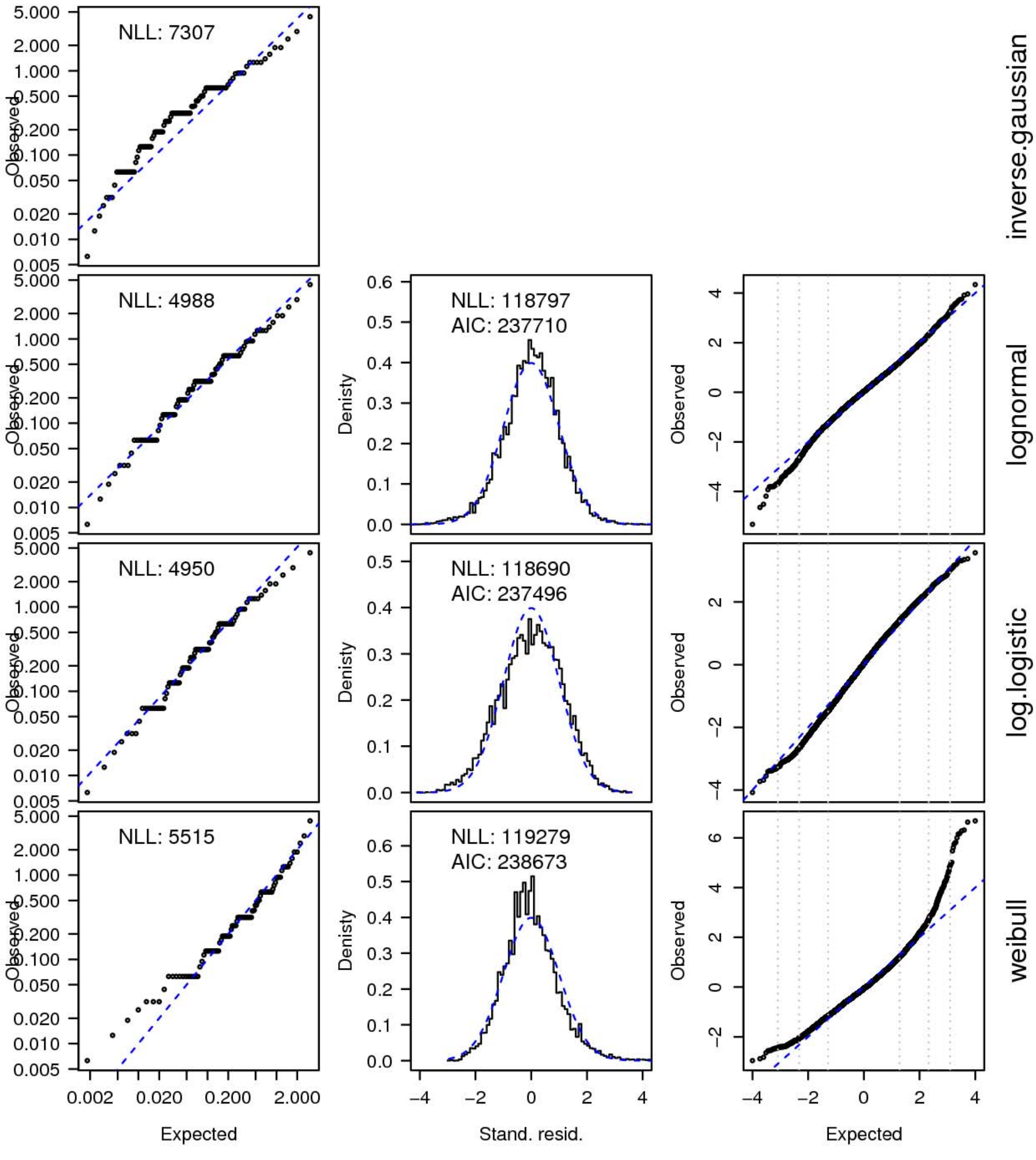


Figure D6: Diagnostics for alternative distributional assumptions for catch. Left: quantile-quantile plot of observed catches (centred (by mean) and scaled (by standard deviation) in log space) versus maximum likelihood fit of distribution (missing panel indicates that the fit failed to converge); Middle: standardised residuals from a generalised linear model fitted using the formula *catch ~ fyear + month + area + vessel + method* and the distribution (missing panel indicates that the model failed to converge); Right: quantile-quantile plot of model standardised residuals against standard normal (vertical lines represent 0.1%, 1% and 10% percentiles). NLL = negative log-likelihood; AIC = Akaike information criterion

Stepwise selection of model terms

Forward stepwise selection of model terms was done on the basis of the Akaike Information Criterion (AIC). The maximal set of model terms offered to the stepwise selection algorithm was:

~ *fyear + month + area + areaMonth + vessel + method + poly(log(duration), 3) + poly(log(depth), 3) + poly(log(bottom), 3) + poly(log(height), 3) + poly(log(width), 3) + poly(log(speed), 3) + poly(time, 3) + poly(moon, 3)*

with the term *fyear* forced into the model. Terms were only added to the model if they increased the percent deviance explained by 0.25 %. Table D3 provides a summary of the changes in the deviance explained and in AIC as each term was added to the model. The final model formula was:

~ *fyear + areaMonth + vessel + poly(log(duration), 3) + poly(log(depth), 3) + poly(log(height), 3) + poly(log(speed), 3) + poly(time, 3)*

Table D3: Summary of stepwise selection. Model terms are listed in the order of acceptance to the model. AIC: Akaike Information Criterion; *: Term included in final model.

Term	DF	Log likelihood	AIC	Deviance pseudo-R^2 (%)	Nagelkerke pseudo-R^2 (%)	
fyear	22	-120 196	240 435	-	5.00	*
areaMonth	108	-119 116	238 447	-	17.22	*
vessel	125	-118 314	236 879	-	25.26	*
poly(log(duration), 3)	128	-117 937	236 130	-	28.77	*
poly(log(depth), 3)	131	-117 725	235 712	-	30.67	*
poly(log(height), 3)	134	-117 612	235 492	-	31.67	*
poly(log(speed), 3)	137	-117 551	235 376	-	32.19	*
poly(time, 3)	140	-117 513	235 307	-	32.52	*
method	141	-117 507	235 295	-	32.58	
poly(moon, 3)	144	-117 500	235 288	-	32.63	
poly(log(bottom), 3)	147	-117 496	235 285	-	32.67	
poly(log(width), 3)	150	-117 493	235 285	-	32.70	

Influence of model terms on annual CPUE indices

Table D4: Summary of the explanatory power and influence of each term in the standardisation model. Coefficients is the number of coefficients associated with the term added. Log likelihood and AIC values are for the fit as each term is successively added. Coefficient of determination (R^2) values represent the change in R^2 from the the previous model. R^2: square of the correlation coefficient between log(observed) and log(fitted).

Term	Coefficients	Log likelihood	AIC	R^2 (%)	Deviance pseudo-R^2 (%)	Negelkerke pseudo-R^2 (%)	Overall influence (%)
intercept	1	-120 598	241 201	-	-	-	-
fyear	20	-120 196	240 435	2.92	-	5.00	-
areaMonth	86	-119 116	238 447	12.08	-	12.22	7.77
vessel	17	-118 314	236 879	9.63	-	8.04	21.57
poly(log(duration), 3)	3	-117 937	236 130	3.59	-	3.51	9.58
poly(log(depth), 3)	3	-117 725	235 712	1.71	-	1.90	3.92
poly(log(height), 3)	3	-117 612	235 492	1.13	-	0.99	7.12
poly(log(speed), 3)	3	-117 551	235 376	0.38	-	0.53	9.79
poly(time, 3)	3	-117 513	235 307	0.31	-	0.33	0.66

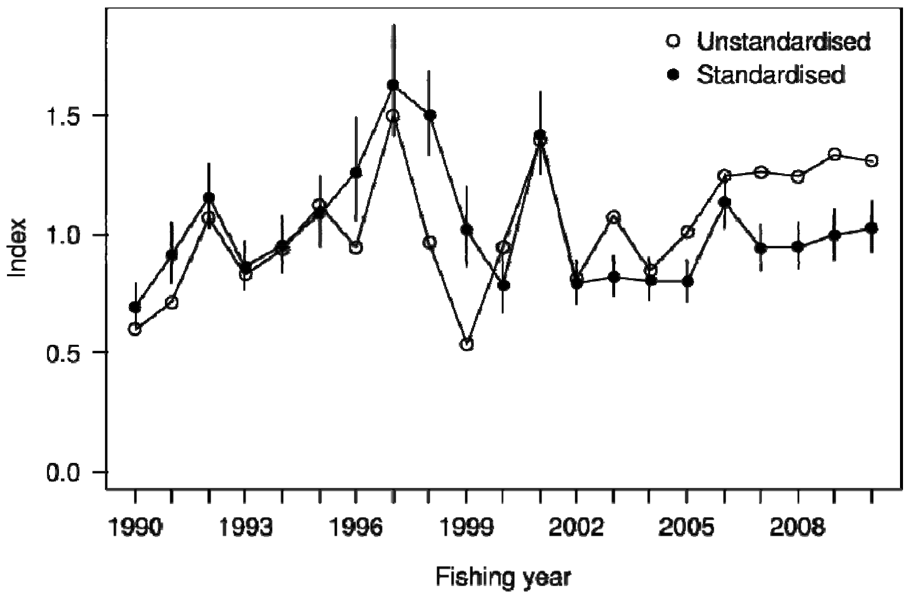


Figure D7: Overall standardisation effect of the model. The unstandardised index is based on the geometric mean of the catch per strata and is not adjusted for effort.

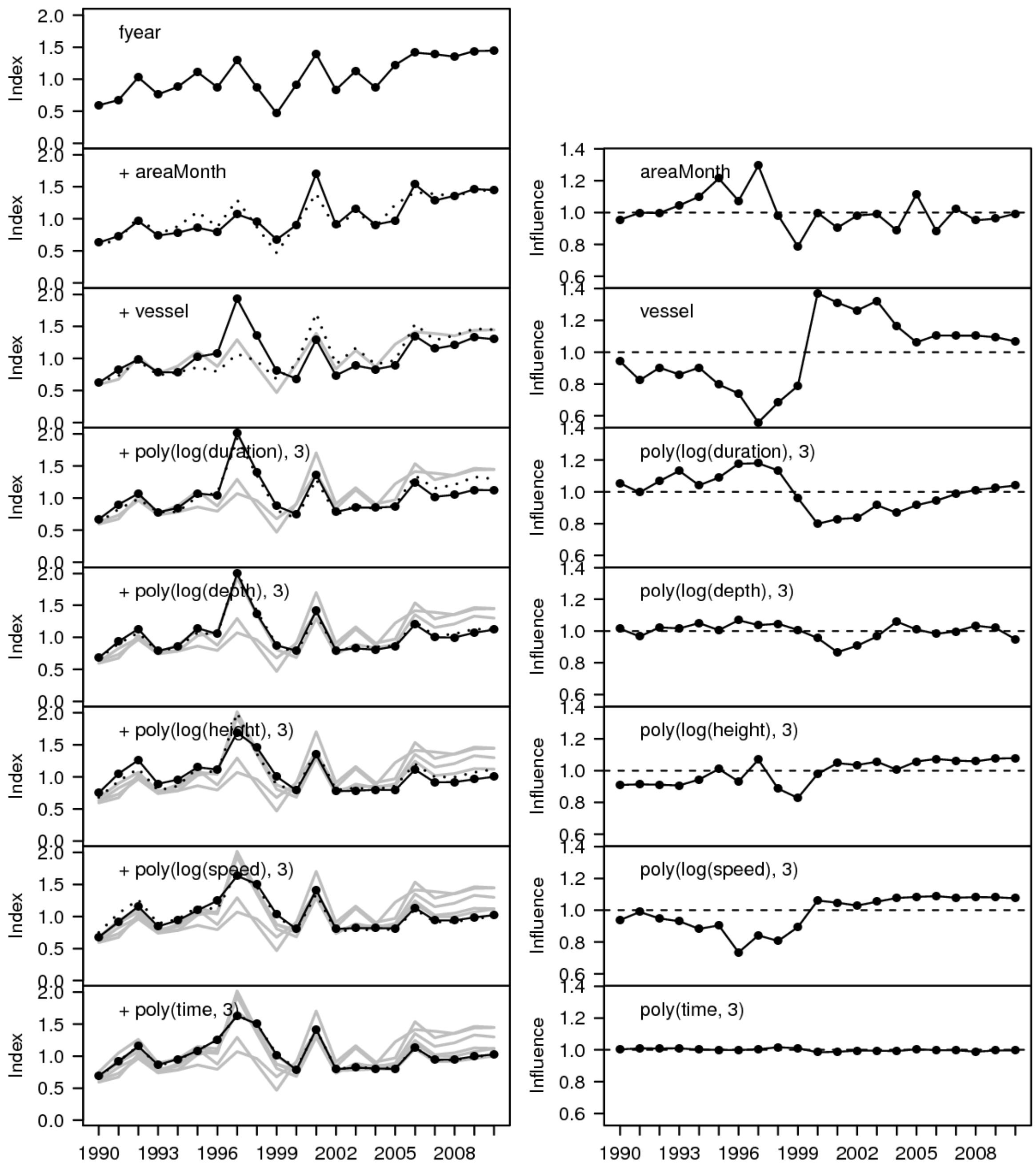


Figure D8: Step and influence plot.

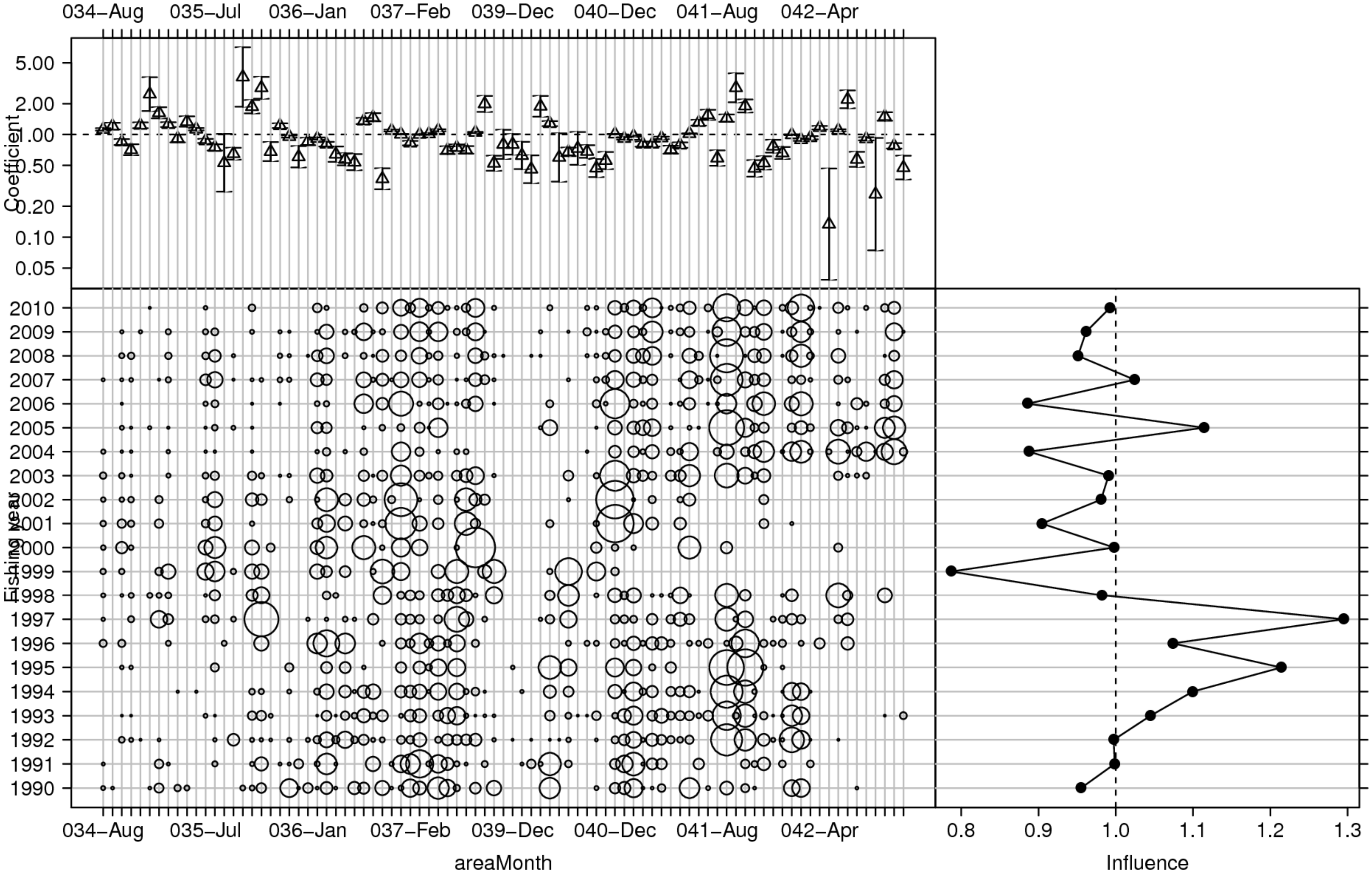


Figure D9: Coefficient-distribution-influence plot for areaMonth.

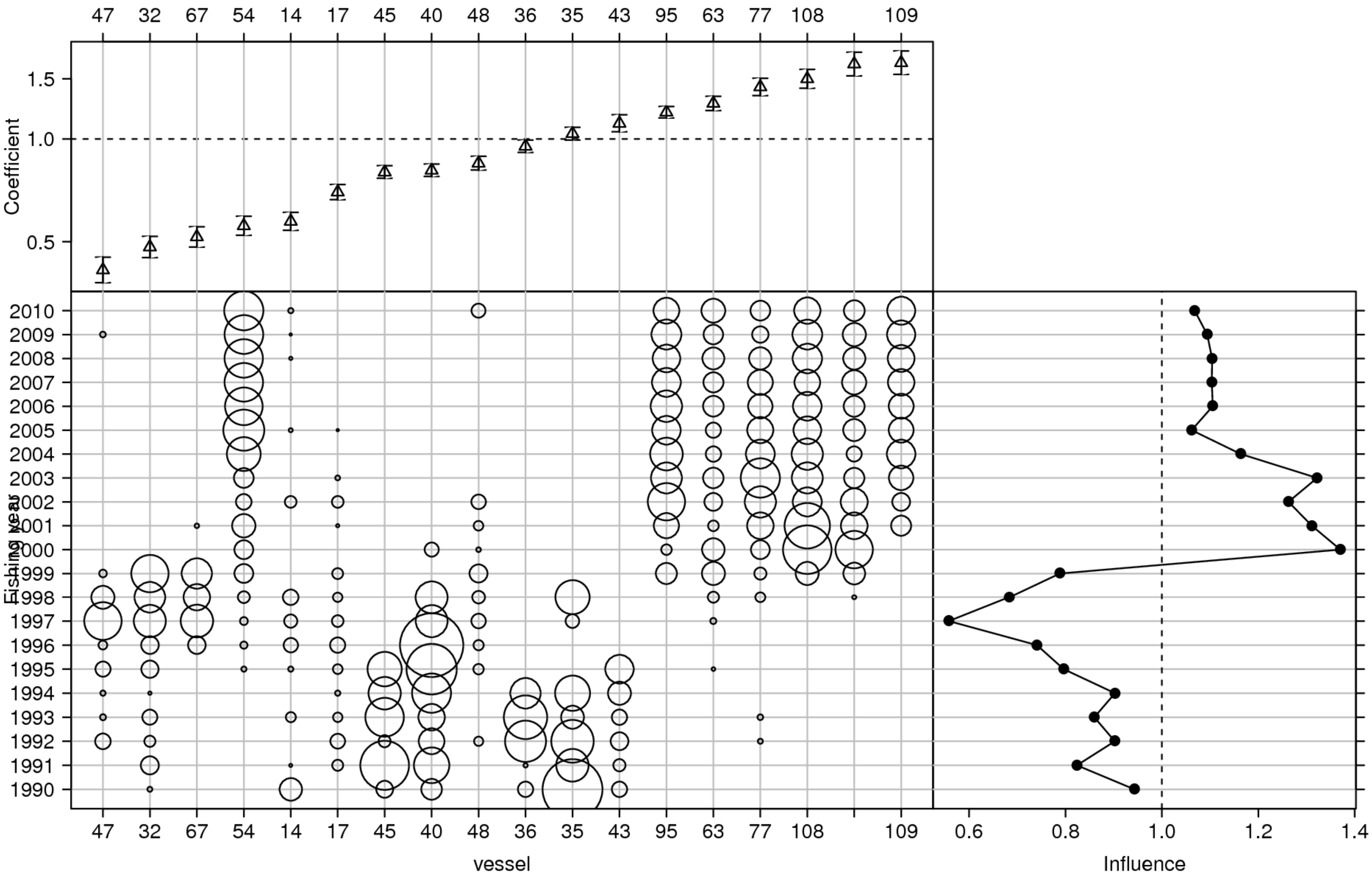


Figure D10: Coefficient-distribution-influence plot for vessel.

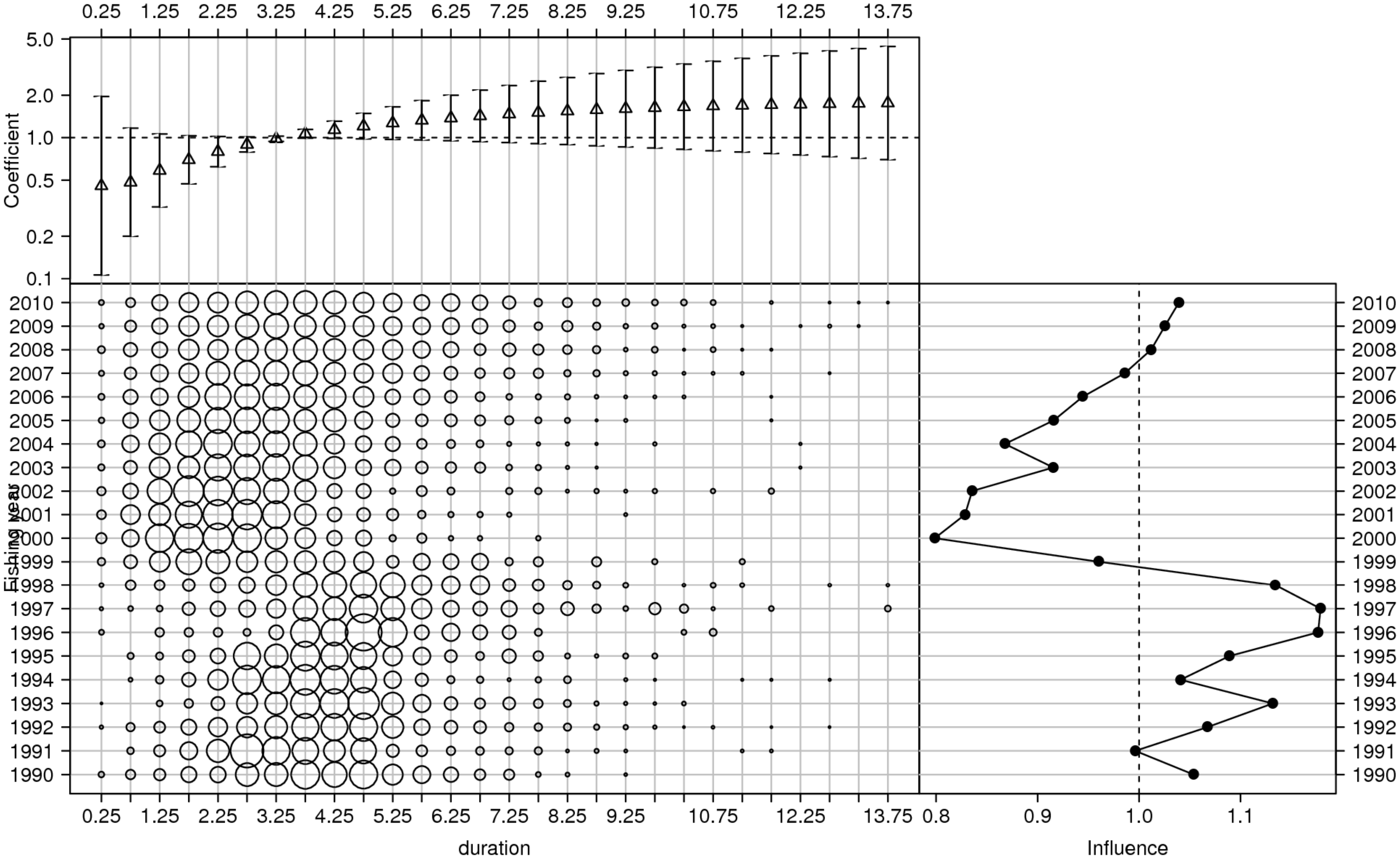


Figure D11: Coefficient-distribution-influence plot for poly(log(duration), 3).

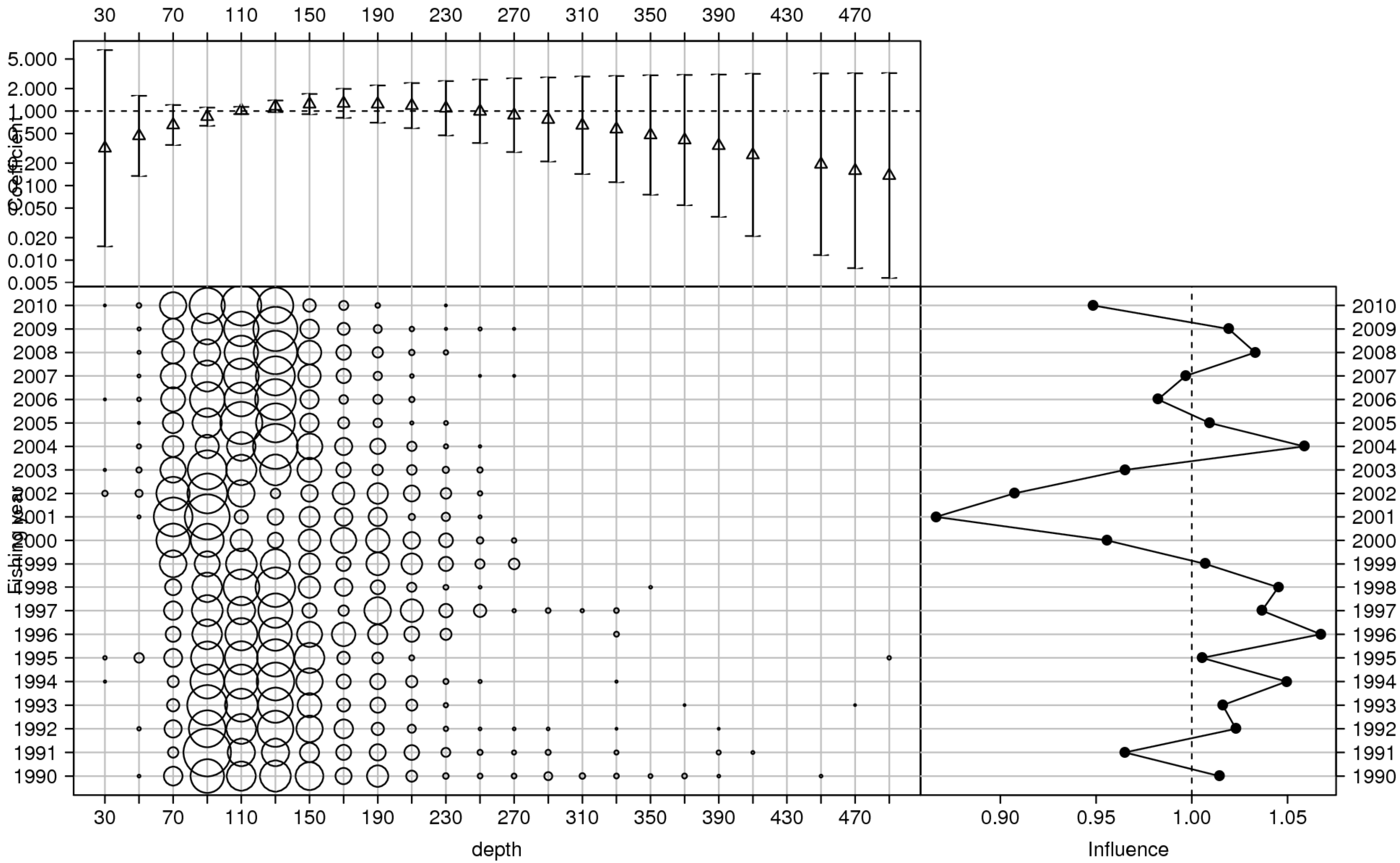


Figure D12: Coefficient-distribution-influence plot for poly(log(depth), 3).

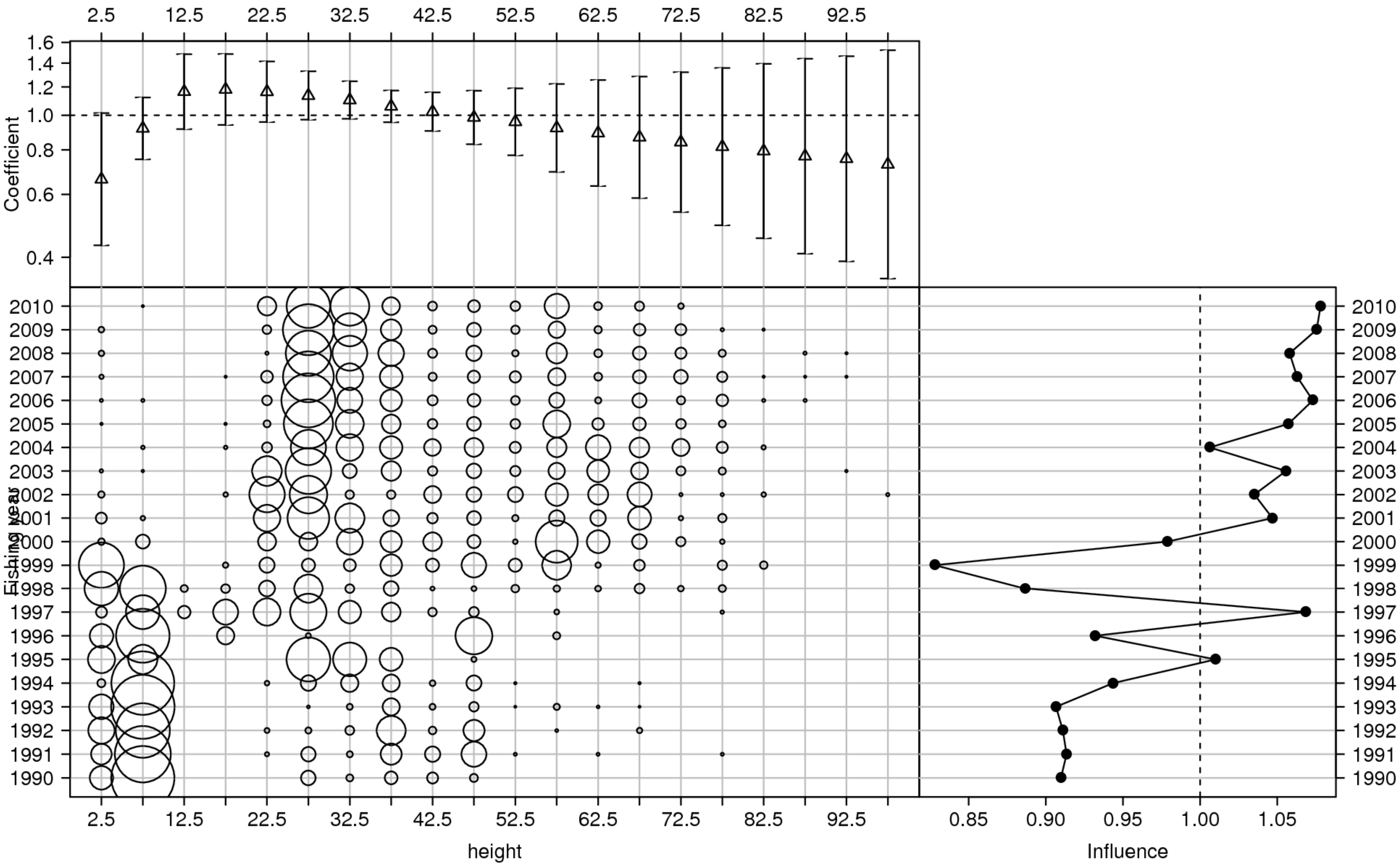


Figure D13: Coefficient-distribution-influence plot for poly(log(height), 3).

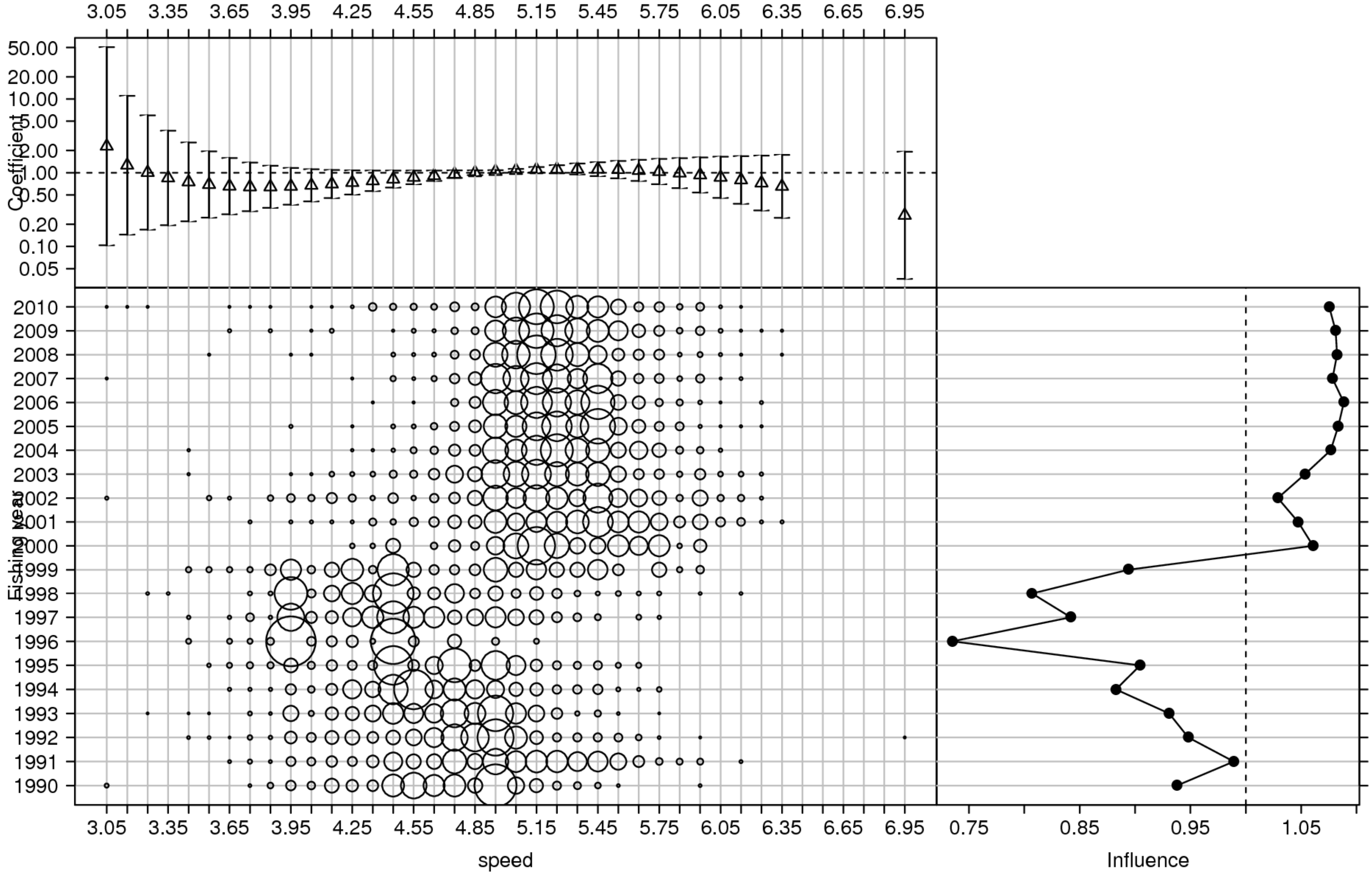


Figure D14: Coefficient-distribution-influence plot for poly(log(speed), 3).

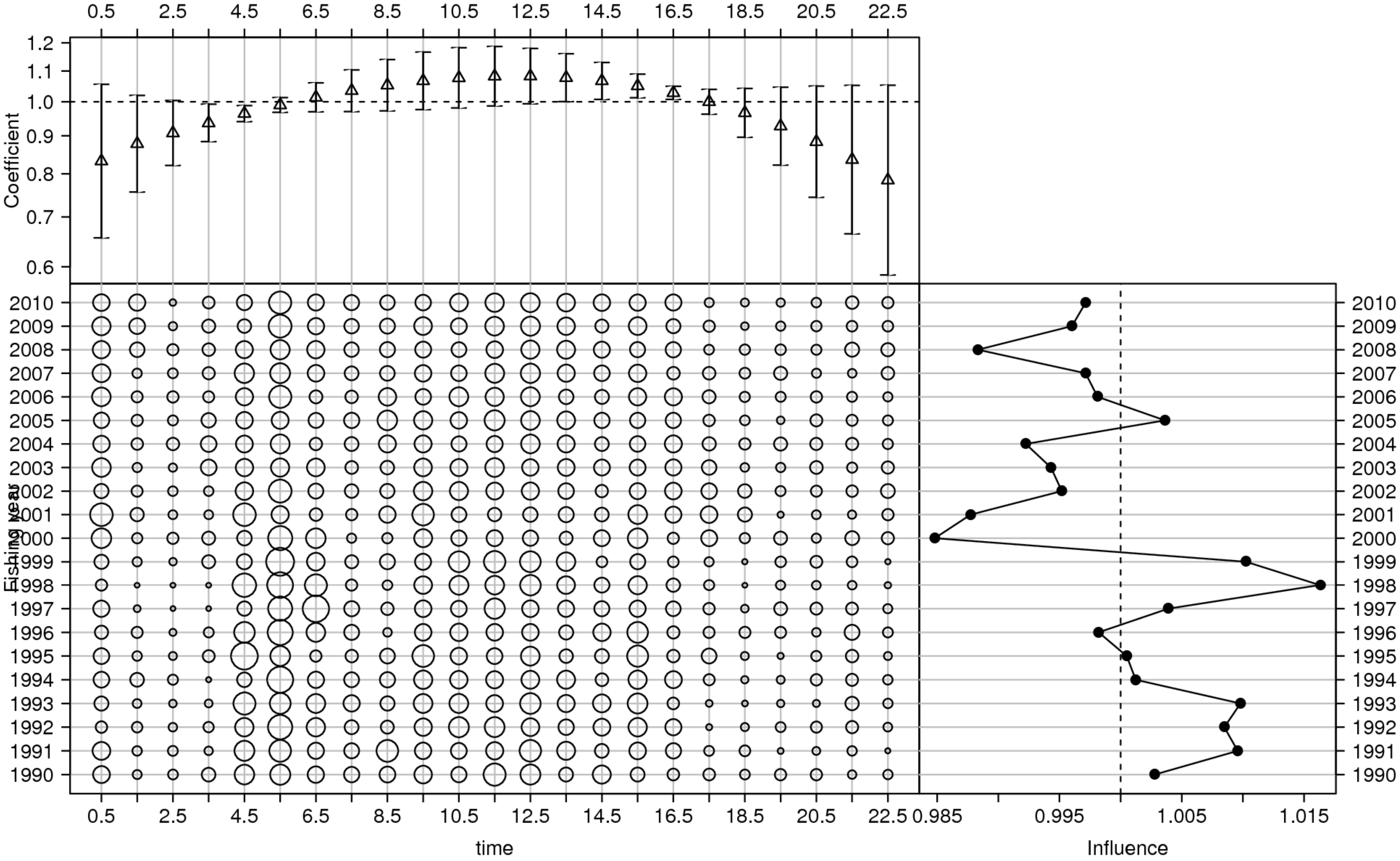


Figure D15: Coefficient-distribution-influence plot for poly(time, 3).

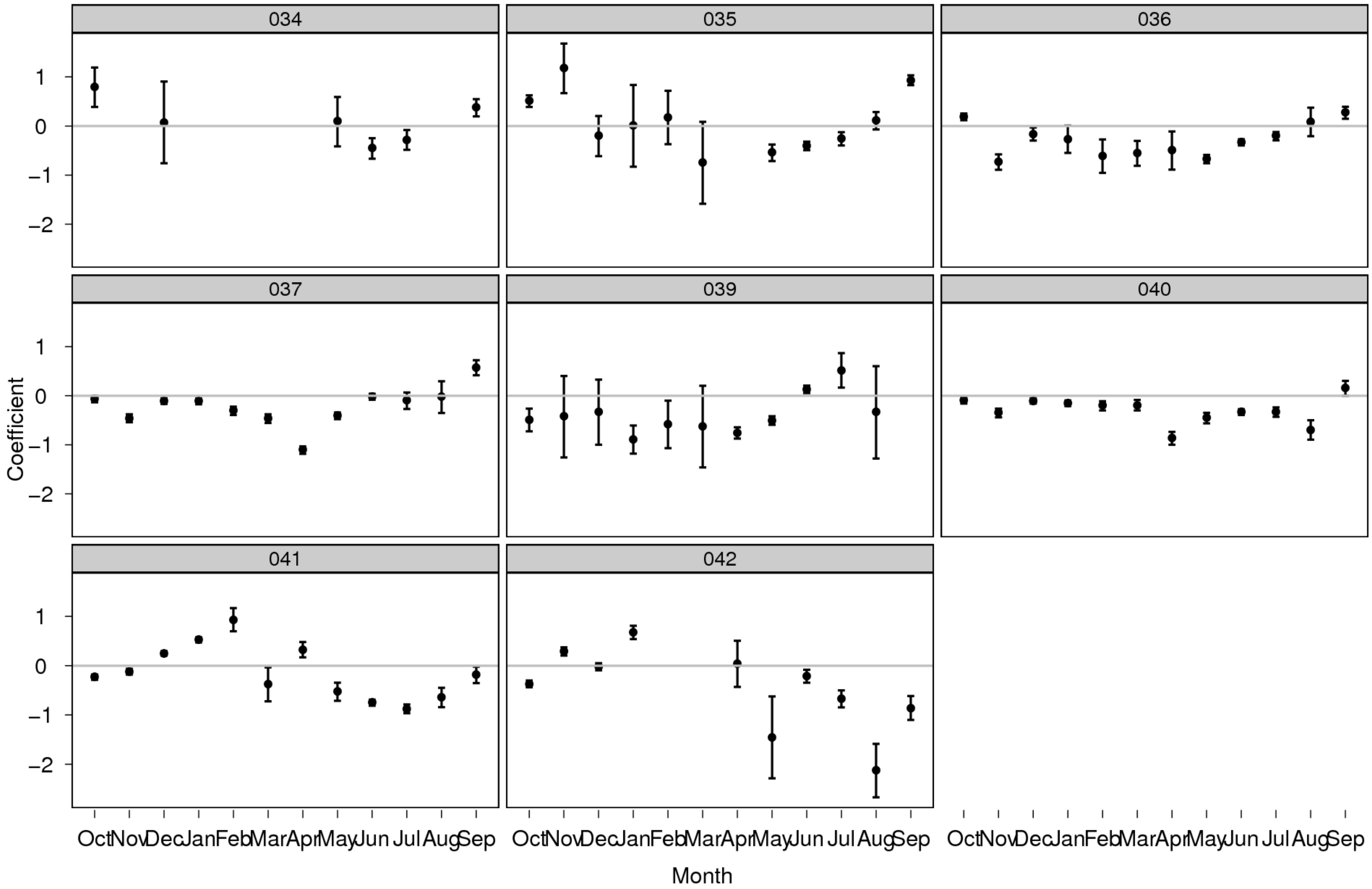


Figure D16: Estimated area × month coefficients (+/- one standard error).

Residual diagostics

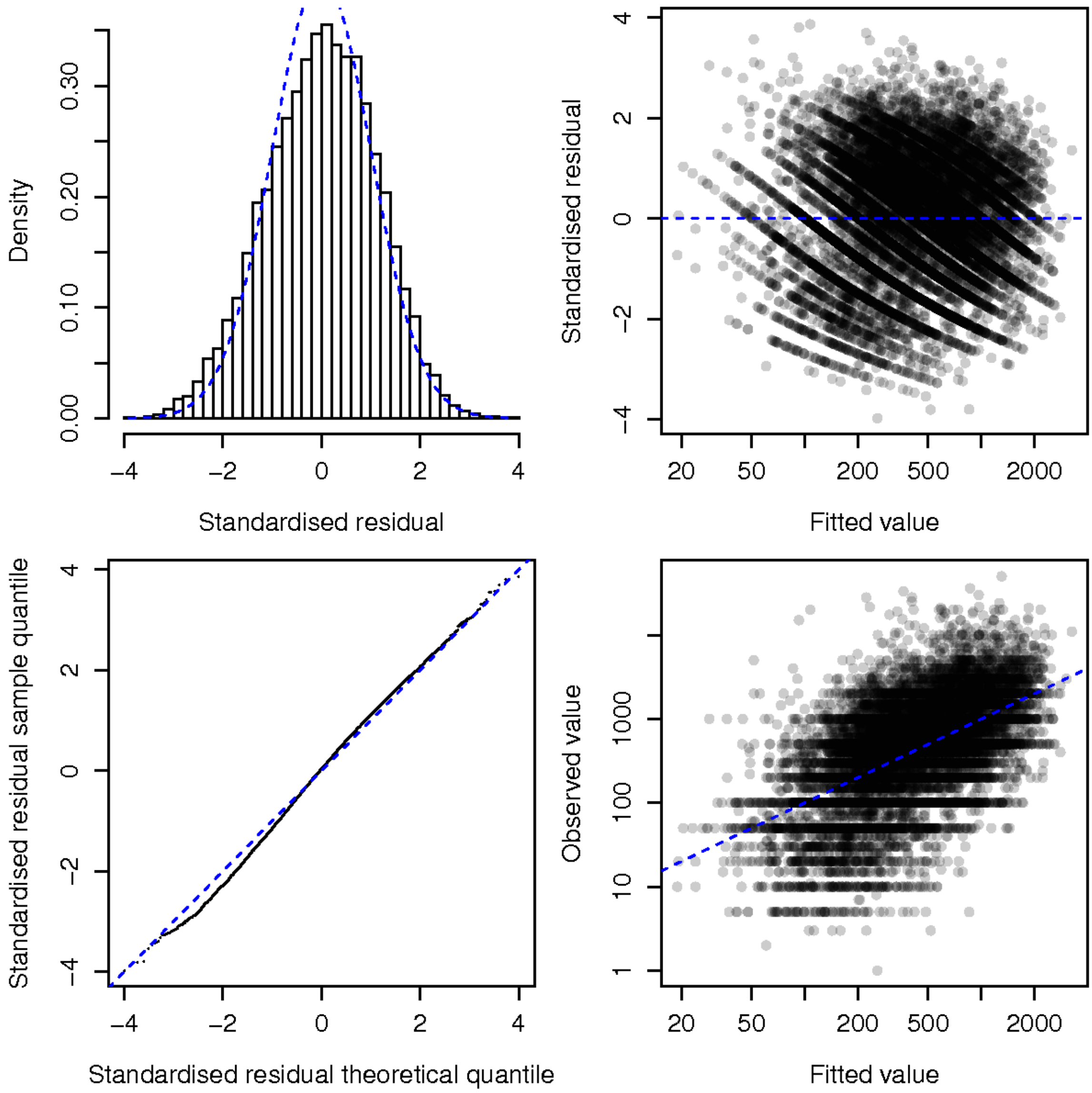


Figure D17: Residual diagnostics. Top left: histogram of standardised residuals compared to standard normal distribution. Bottom left: quantile-quantile plot of standardised residuals. Top right: fitted values versus standardised residuals. Bottom right: observed values versus fitted values.

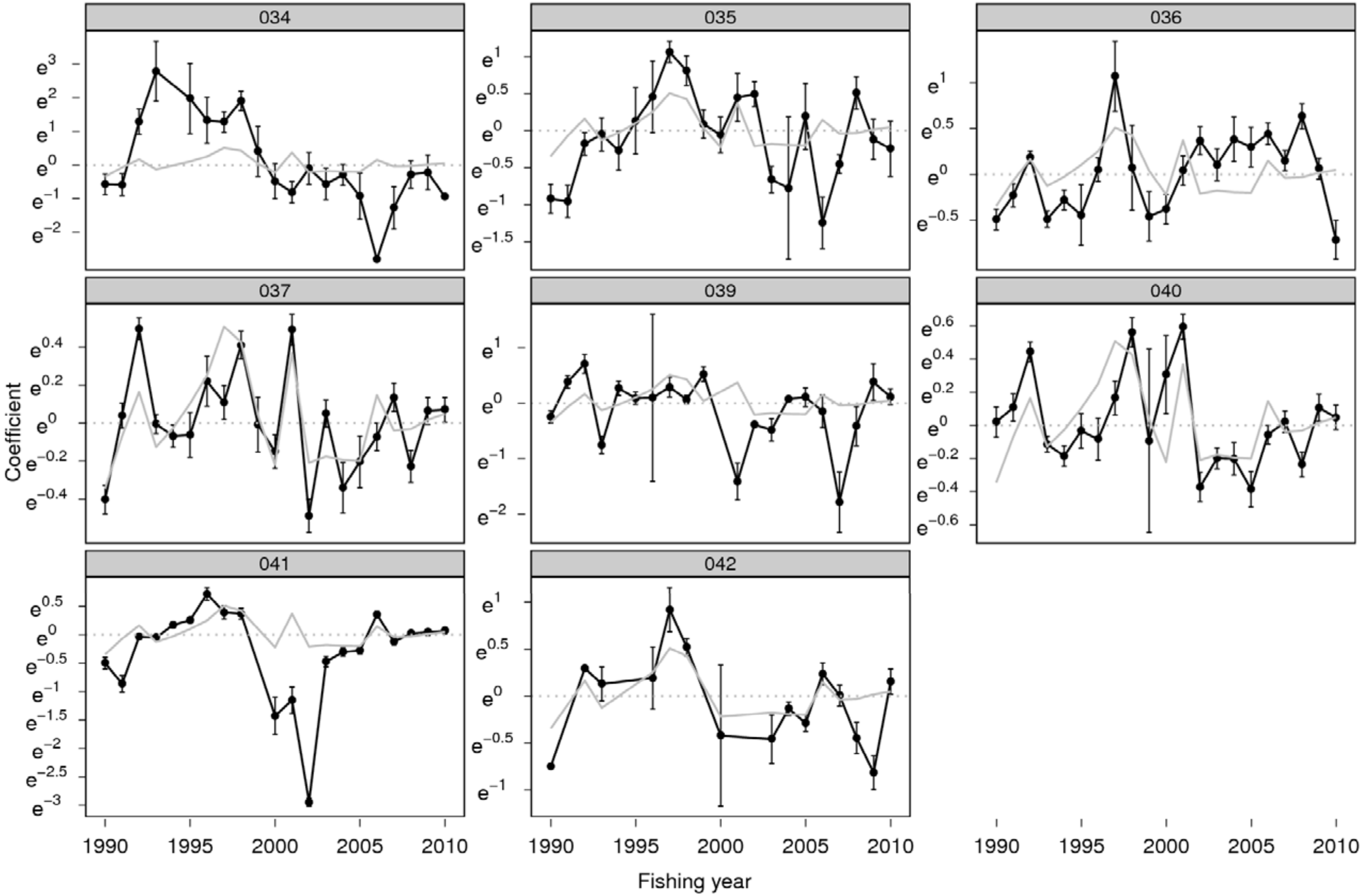


Figure D18: Residual implied coefficients for area × fishing year interactions. Implied coefficients (black points) are calculated as the normalised fishing year coefficient (grey line) plus the mean of the standardised residuals in each fishing year and area. These values approximate the coefficients obtained when an area × year interaction term is fitted, particularly for those area × year combinations which have a substantial proportion of the records. The error bars indicate one standard error of the standardised residuals.

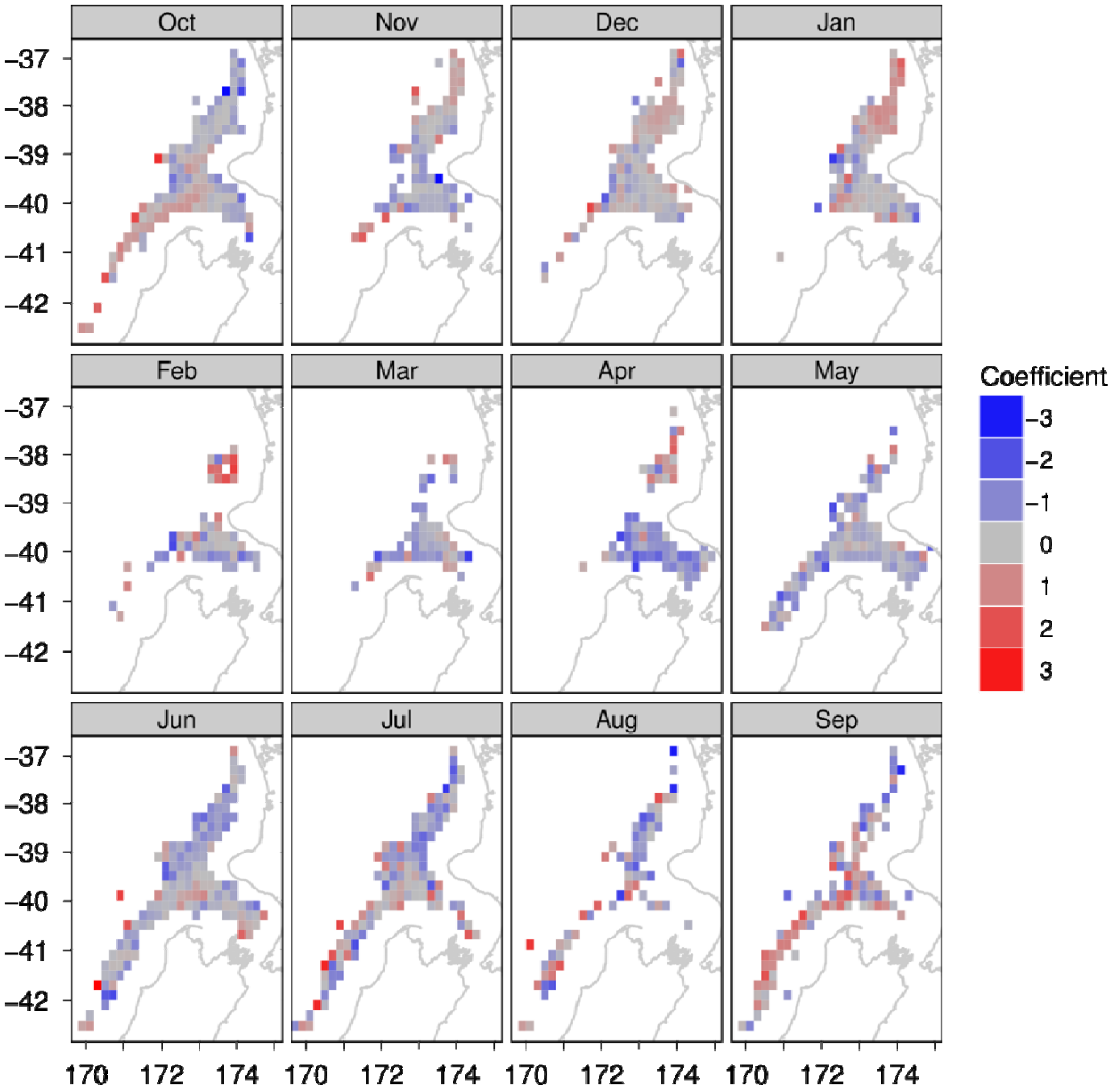


Figure D19: Residual implied coefficients for each position in each month. Implied coefficients are calculated as the sum of the normalised coefficients for any model terms relating to area and month (month, area and area × month terms) plus the mean of the standardised residual for position in each month. This plot is intended to show what the combination of model fit and residuals imply about seasonality in local catch rates.

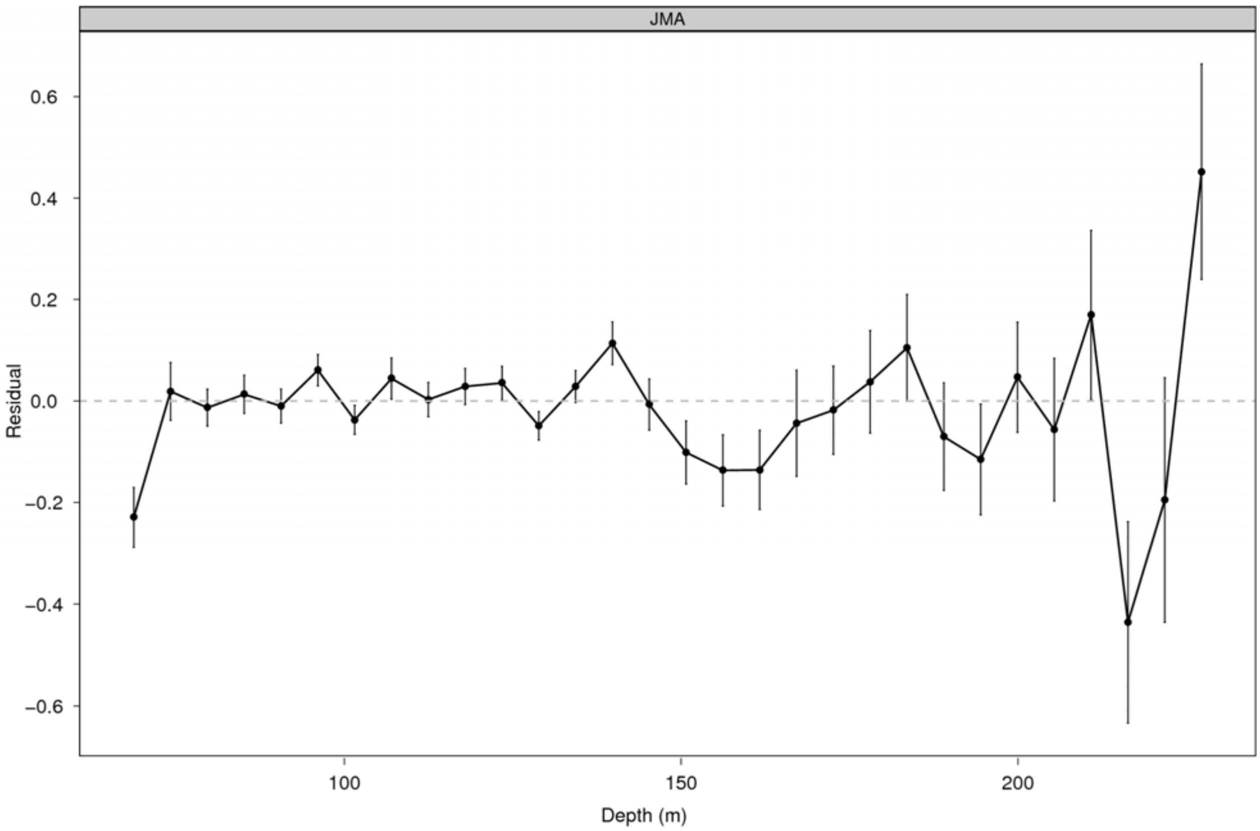


Figure D20: Mean and standard error of residuals by depth and target species.

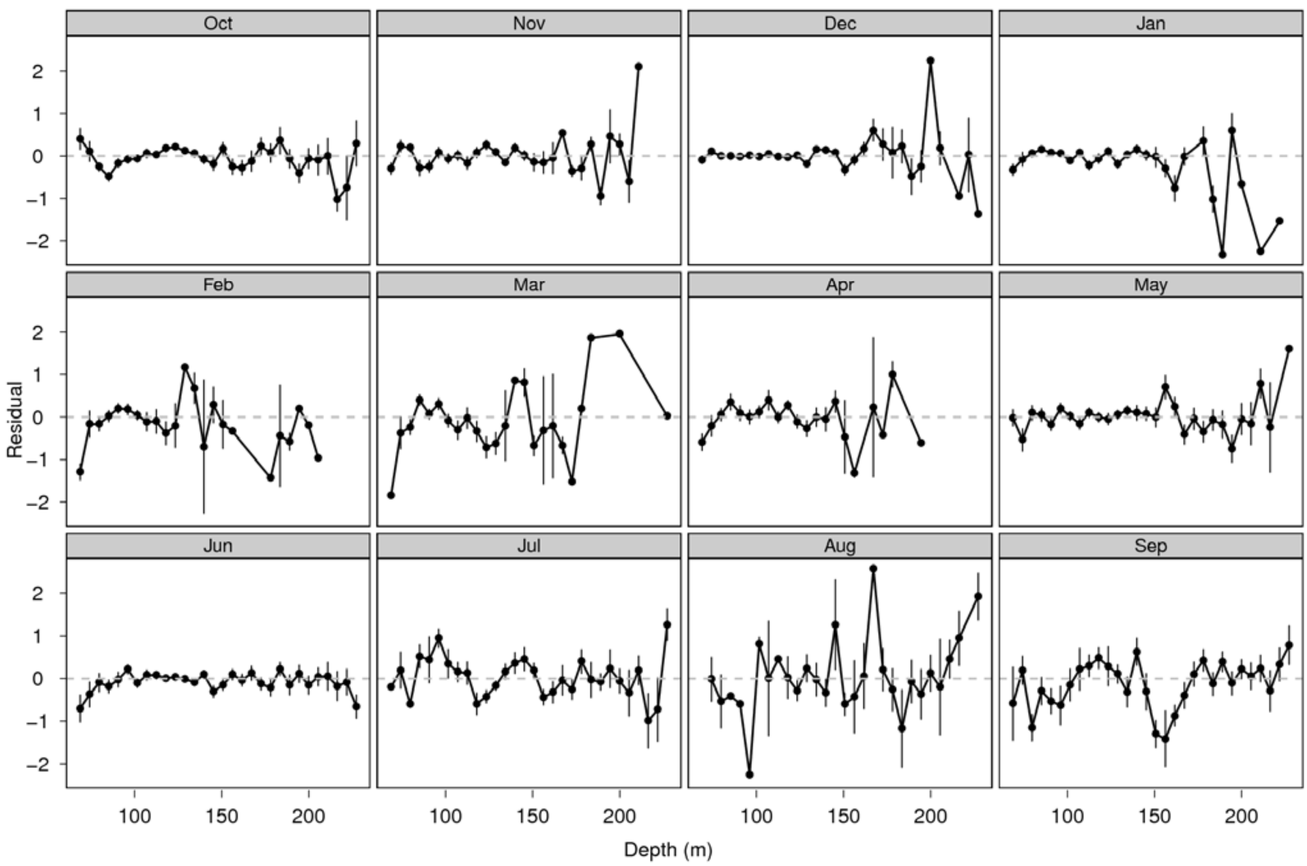


Figure D21: Mean and standard error of residuals by depth and month.

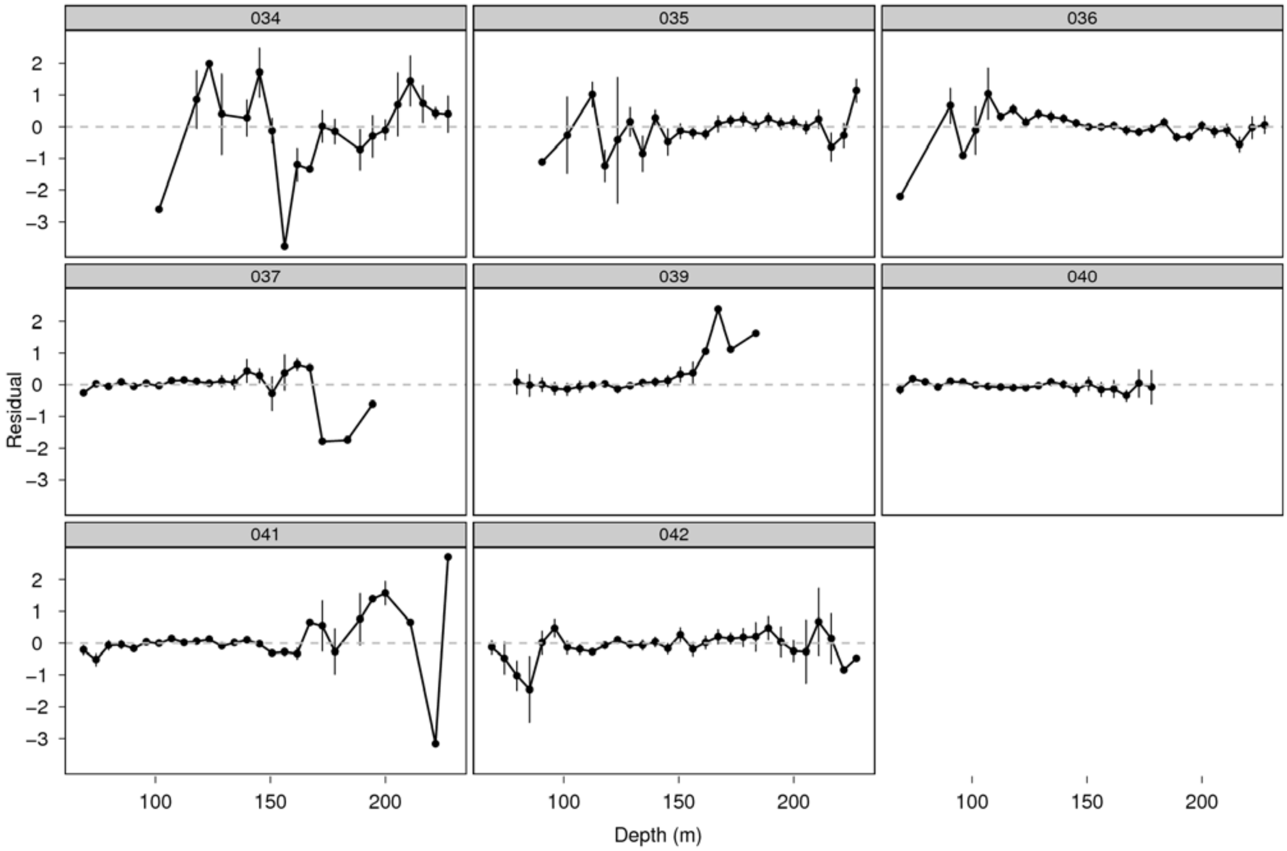


Figure D22: Mean and standard error of residuals by depth and area.

Sensitivity to switch in vessels and fleet

To test the sensitivity of CPUE index to the dramatic shift in fleet and methods in 1999–2000a GLM was fit using the same formula as in the base case but only including data from midwater trawling from 1999–2000 onwards(Figure D23).

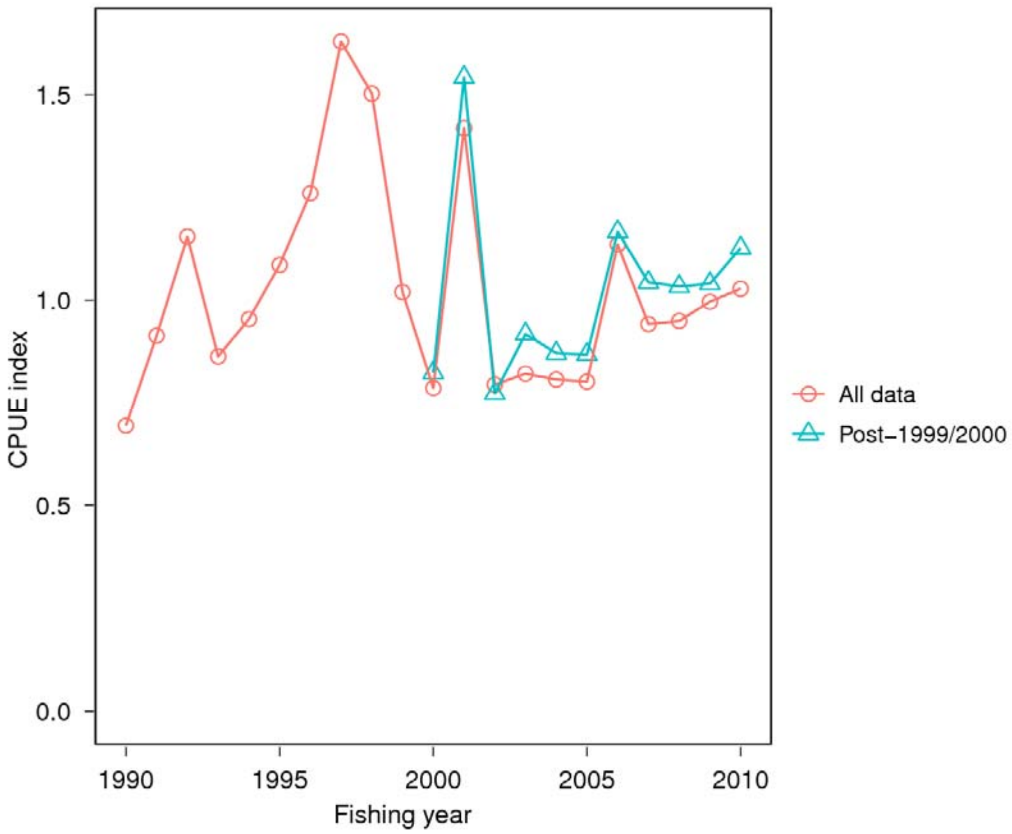


Figure D23: Sensitivity of standardised CPUE to data used.

Summary of CPUE indices

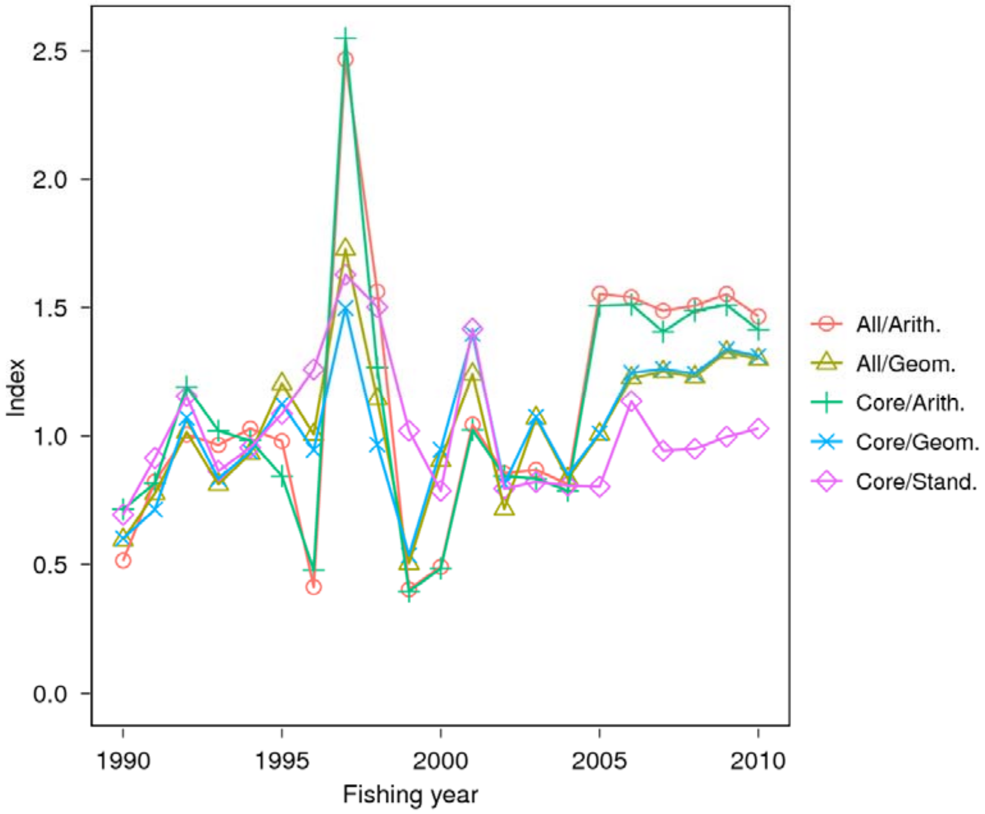


Figure D24: Standardised and unstandardised CPUE indices. All: all vessels, Core: core vessels, Geom.: geometric mean, Arith.: arithmetic mean, Stand.: standardised using GLM.

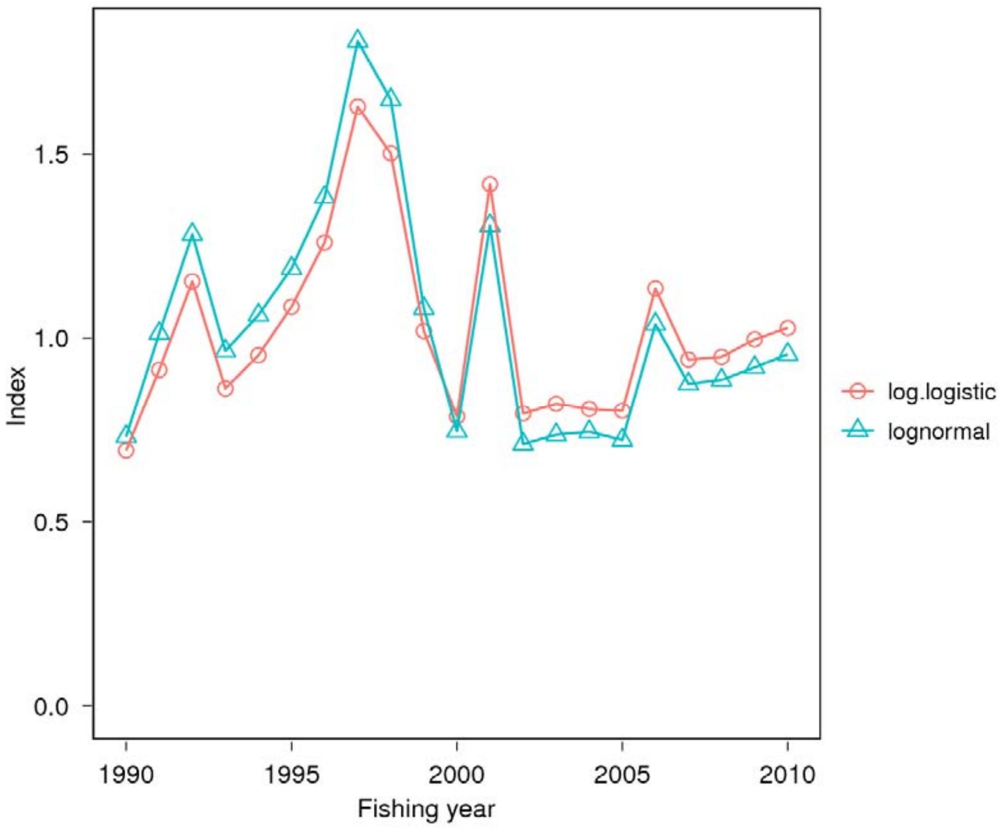


Figure D25: Standardised CPUE obtained from the GLM model when using a log.logistic distribution and a lognormal distribution.

Table D5: Standardised and unstandardised CPUE indices. Fishing year labelled by latter calender year e.g. 1990=1989–90. All: all vessels, Core: core vessels, Geom.: geometric mean, Arith.: arithmetic mean, Stand.: standardised using GLM, SE: standard error.

Fishing year	All/Arith.	Core/Arith.	All/Geom.	Core/Geom.	Core/Stand.	Core/Stand. SE
1990	0.5156	0.7143	0.5962	0.6014	0.6936	0.06826
1991	0.8214	0.8157	0.7757	0.7134	0.9135	0.06873
1992	1.0049	1.1913	1.0144	1.0703	1.1543	0.05920
1993	0.9641	1.0193	0.8112	0.8332	0.8628	0.05964
1994	1.0275	0.9818	0.9307	0.9378	0.9534	0.06151
1995	0.9790	0.8433	1.2038	1.1237	1.0853	0.06947
1996	0.4127	0.4782	1.0051	0.9443	1.2598	0.08598
1997	2.4668	2.5491	1.7276	1.4988	1.6288	0.07207
1998	1.5629	1.2667	1.1436	0.9659	1.5019	0.05865
1999	0.4039	0.3961	0.5044	0.5365	1.0194	0.08196
2000	0.4910	0.4850	0.9038	0.9459	0.7859	0.07860
2001	1.0429	1.0223	1.2407	1.3977	1.4181	0.06157
2002	0.8541	0.8438	0.7156	0.8129	0.7945	0.06014
2003	0.8676	0.8333	1.0693	1.0735	0.8208	0.05313
2004	0.8124	0.7859	0.8333	0.8478	0.8066	0.05668
2005	1.5544	1.5074	1.0066	1.0093	0.8017	0.05483
2006	1.5404	1.5125	1.2256	1.2463	1.1350	0.05147
2007	1.4875	1.4061	1.2508	1.2613	0.9414	0.05097
2008	1.5077	1.4877	1.2306	1.2429	0.9488	0.05237
2009	1.5531	1.5105	1.3271	1.3372	0.9961	0.05312
2010	1.4664	1.4141	1.2996	1.3112	1.0276	0.04997

APPENDIX E: CATCH PER UNIT EFFORT ALAYSES FOR MIDWATER TRAWLING TARGETTING HOKI (HOK)

Data subsetting and processing

The data used for this CPUE standardisation was defined by the following criteria:

- form type was "TCP";
- method was "MW";
- target species was "HOK";
- area was "034", "035", or "036";
- month was 6, 7, 8, or 9;
- trawl depth was 100–1000m;
- bottom depth was 100–1000m;
- trawl height was 10–200m;
- trawl width was 10–200m;
- trawl speed was 2–6kts;
- trawl duration was 0–15hrs.

Table E1 summarises the number of fishing events, vessels, trips, effort and catch in the resultant dataset. The minimum number of vessels was 13 in 2008. The percentage of positive catches ranged from 15% to 49%.

Table E1: Summary by fishing year of the data subset used in the CPUE analysis of frostfish caught in midwater trawls targeting hoki..

Fishing year	Events	Vessels	Trips	Effort number	Effort duration (hrs)	Catch (t)	Events with catch (landed,% records)
1990	6 307	63	139	6 307	28 372	843.85	15.13
1991	5 851	59	151	5 851	25 561	2 381.84	21.43
1992	4 326	55	104	4 326	17 040	1 410.49	29.89
1993	5 122	54	107	5 122	17 550	894.89	21.81
1994	6 937	55	120	6 937	22 633	1 657.85	27.26
1995	6 135	55	123	6 135	23 759	1 509.56	24.06
1996	4 758	53	122	4 758	18 710	677.96	23.35
1997	5 737	65	159	5 737	24 861	748.17	22.40
1998	5 734	57	133	5 734	24 384	917.98	33.31
1999	4 558	53	127	4 558	16 765	878.08	29.68
2000	4 800	50	141	4 800	16 095	633.22	33.27
2001	4 995	59	189	4 995	16 947	718.33	41.54
2002	3 918	54	171	3 918	12 176	869.05	48.62
2003	3 822	46	126	3 822	15 337	501.12	44.06
2004	3 710	47	114	3 710	14 650	671.67	37.47
2005	2 103	37	70	2 103	7 724	424.83	40.23
2006	1 727	33	62	1 727	5 581	386.11	39.61
2007	1 007	29	48	1 007	3 838	222.77	40.91
2008	783	13	29	783	1 681	123.44	27.08
2009	680	15	23	680	2 109	108.44	36.76
2010	1 175	23	47	1 175	3 646	34.79	47.15

There is a generally close relationship between annual allocated landings and annual estimated catches, particularly since 1999–2000 (Figure E1). Preliminary investigations showed that there was a high proportion of events with small allocated landings (i.e less than 100kg) in 2009–2010. Further investigation showed that many of these arose from a single vessel which had a large number of events in that fishing year but which did not record any estimated catches of frostfish. As a result, all the FRO 7 landings for that vessel where allocated to events using method 2 (allocated proportional to effort_num) which results in those landings being spread over many events, and hence, smaller individual allocated landings. However, this issue was not restricted to this vessel and, particularly in earlier years, landing allocated using methods 2 (proportional to effort_num) and 3 (equally) represented a substantial proportion of the records and were often smaller than those allocated using method 1 (proportional to estimated catch) (Figure E2).

To remove any potential for bias, the data was further restricted to those events where allocation method 1 (allocation in proportion to estimated catches) was used (Table E1).This is equivalent to only using data from trips where at least one event had estimated catches of frostfish. As expected, this additional data restriction changes the absolute values of both the proportion of events with positive catches (Figure E3) and the geometric mean of positive catches (Figure E4) but the general pattern of fluctuations are similar for both.

Table E2 summarises the number of fishing events, vessels, trips, effort and catch in the resultant dataset. The minimum number of vessels was 11 in 2008. The percentage of positive catches ranged from 19% to 40%.

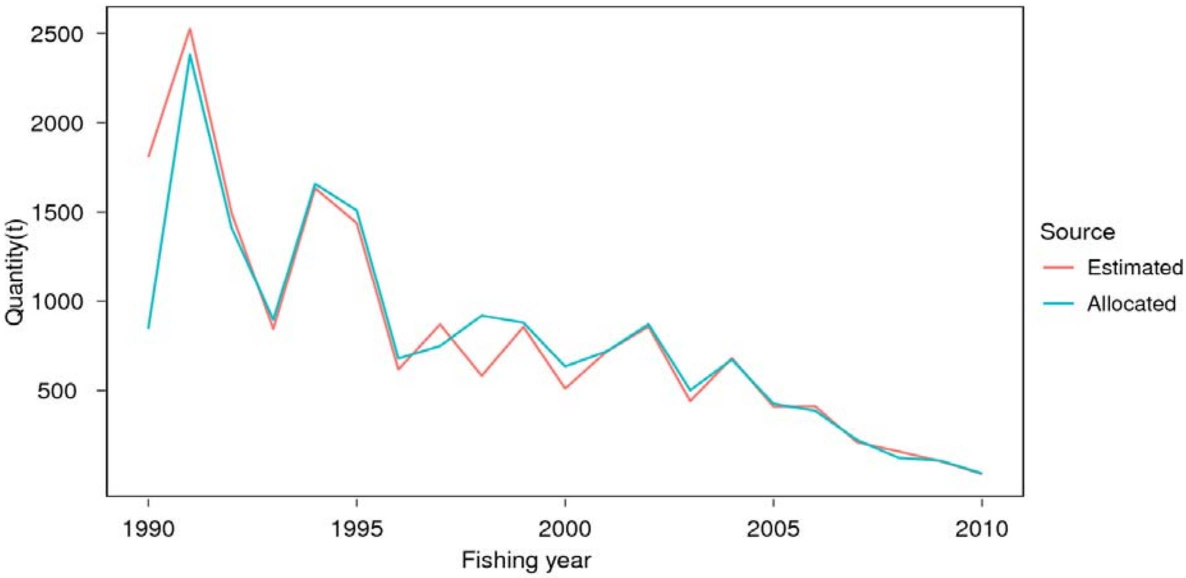


Figure E1: Estimated catches and allocated landings of frostfish by fishing year.

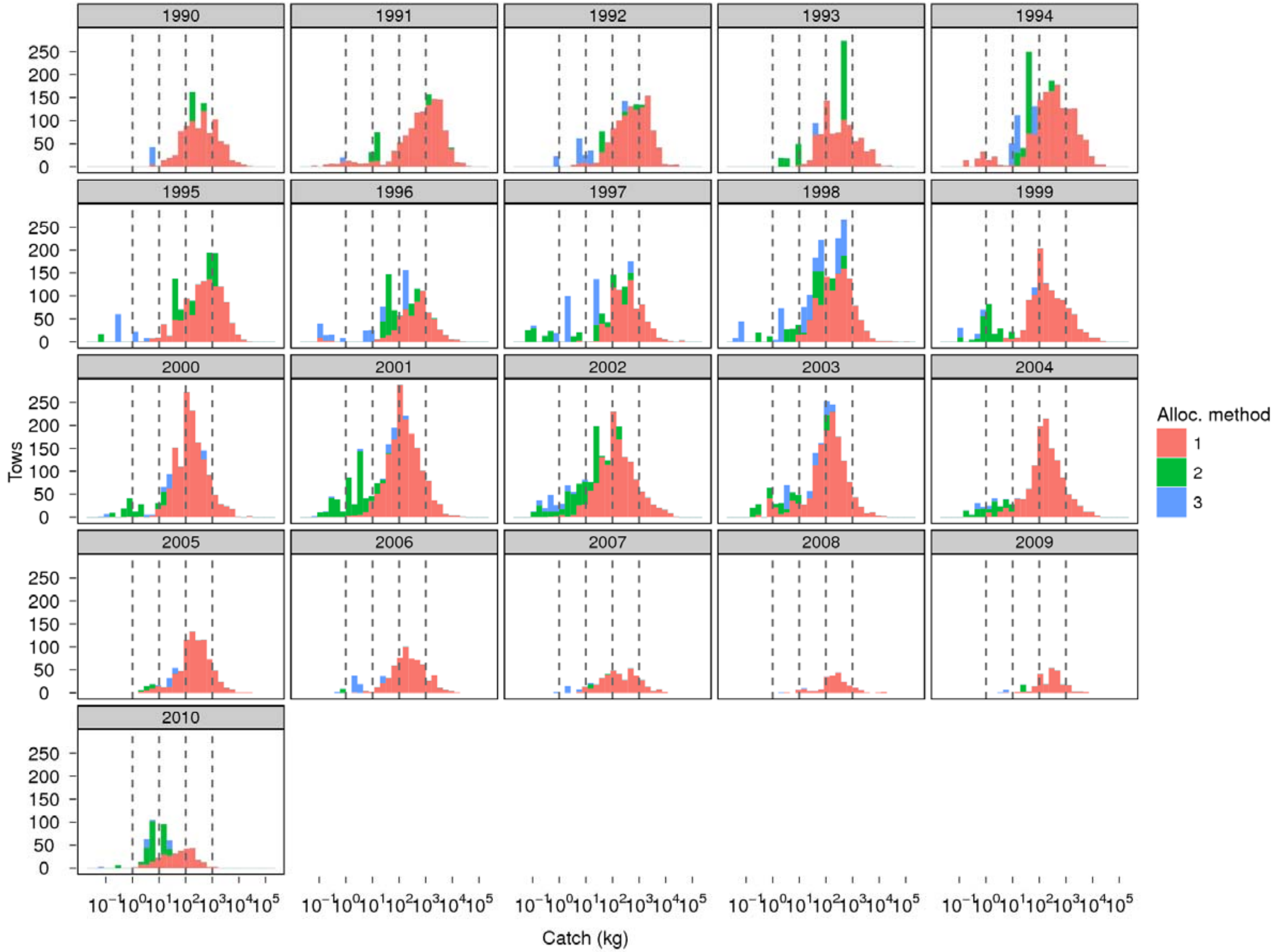


Figure E2: Frequency distributions of catches of frostfish by allocation method by fishing year.

Table E2: Summary by fishing year of the data subset used for this analysis.

Fishing year	Events	Vessels	Trips	Effort number	Effort duration (hrs)	Catch (t)	Events with catch (landed,% records)
1990	2 960	39	58	2 960	12 537	827.96	28.24
1991	3 834	41	77	3 834	15 650	2 337.90	29.63
1992	3 492	42	65	3 492	12 938	1 380.31	30.87
1993	3 836	35	59	3 836	11 669	812.70	21.82
1994	4 958	40	78	4 958	15 671	1 636.51	29.33
1995	4 247	34	61	4 247	15 469	1 361.77	25.88
1996	3 244	38	65	3 244	12 086	634.81	18.93
1997	3 806	47	91	3 806	16 227	712.14	20.20
1998	4 281	45	81	4 281	17 290	824.41	26.14
1999	4 014	45	97	4 014	14 533	876.26	26.66
2000	4 407	42	100	4 407	14 713	619.75	31.20
2001	4 307	51	120	4 307	15 352	712.97	36.68
2002	3 333	47	108	3 333	11 022	858.34	40.29
2003	3 471	41	97	3 471	14 139	489.55	39.44
2004	3 522	43	82	3 522	14 260	671.24	34.61
2005	1 990	33	59	1 990	7 276	423.68	39.75
2006	1 578	30	54	1 578	5 136	385.48	38.21
2007	971	28	42	971	3 719	222.43	38.72
2008	781	11	27	781	1 679	123.42	26.89
2009	657	13	19	657	2 018	108.08	34.55
2010	919	20	35	919	2 808	32.31	32.43

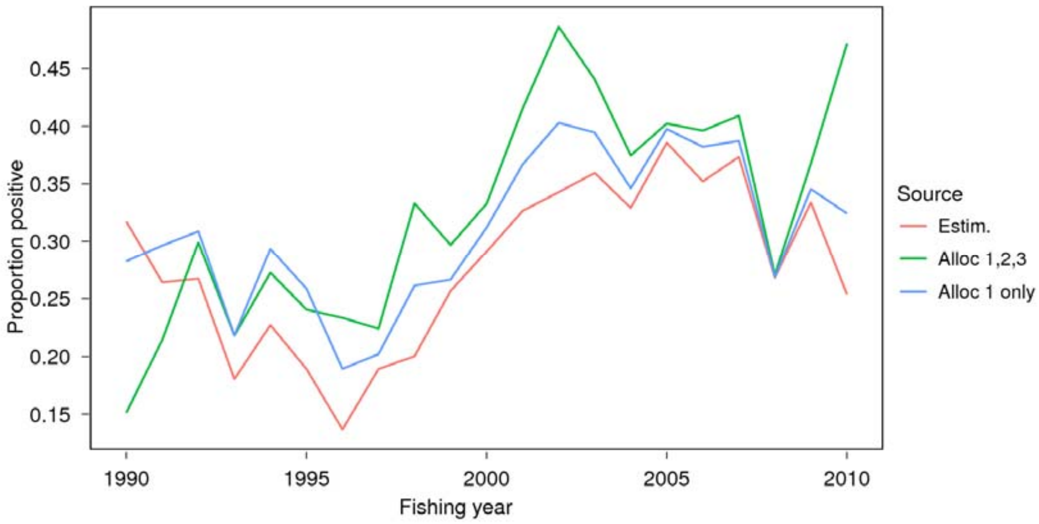


Figure E3: Proportion of events with FRO catches by fishing year from alternative data sources.

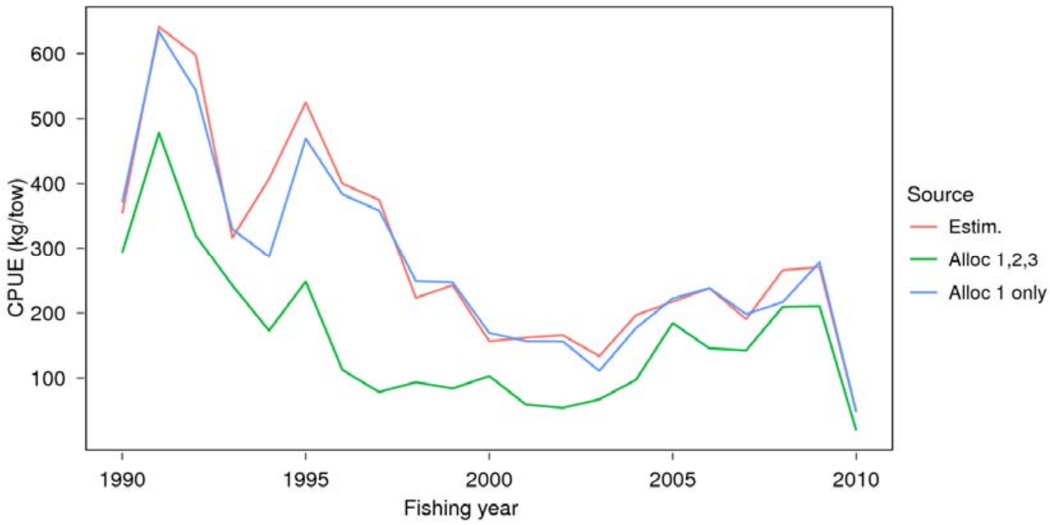


Figure E4: Unstandardised CPUE (geometric mean of positive catches) by fishing year from alternative data sources.

Core vessel selection

Alternative core vessel selection criteria were investigated by considering the reduction in the number of vessels and percentage of catch (Figure E5). The most appropriate combination of criteria was considered to be to define the core fleet as those vessels that had fished for at least one trip in each of at least three years. To qualify, trips were required to have recorded at least 1kg of catch. These criteria resulted in a core fleet size of 77 vessels which took 74% of the catch (Figure E5). A histogram of the number of years in which each core vessel had data in the dataset is provided (Figure E6) as is the overlap of data among core vessels (Figure E7).

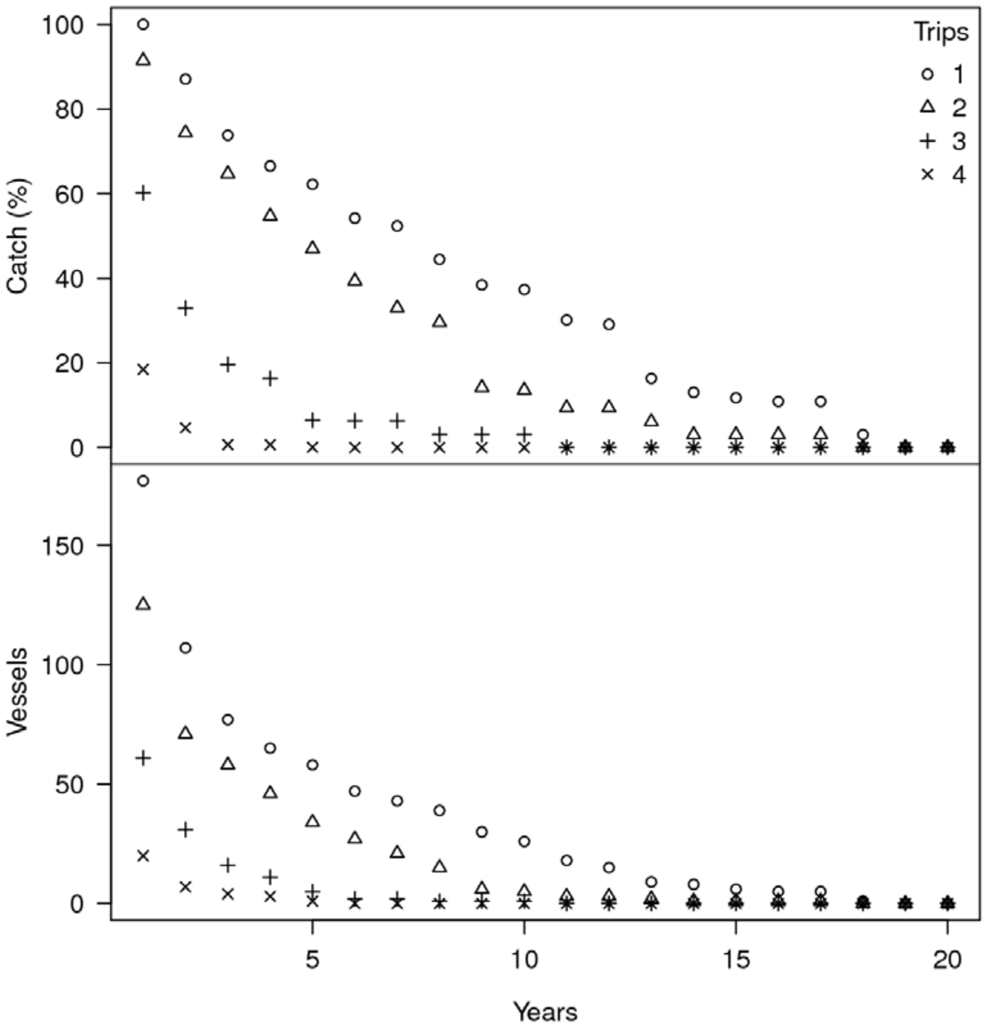


Figure E5: Examination of parameters for defining core vessels.

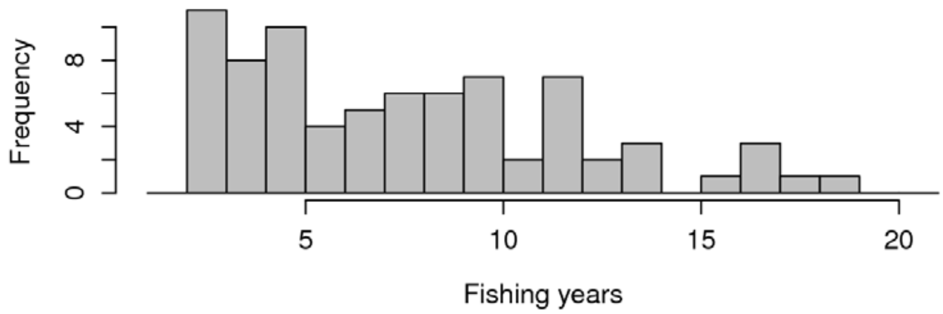


Figure E6: Histogram of the number of years with data for each core vessel.

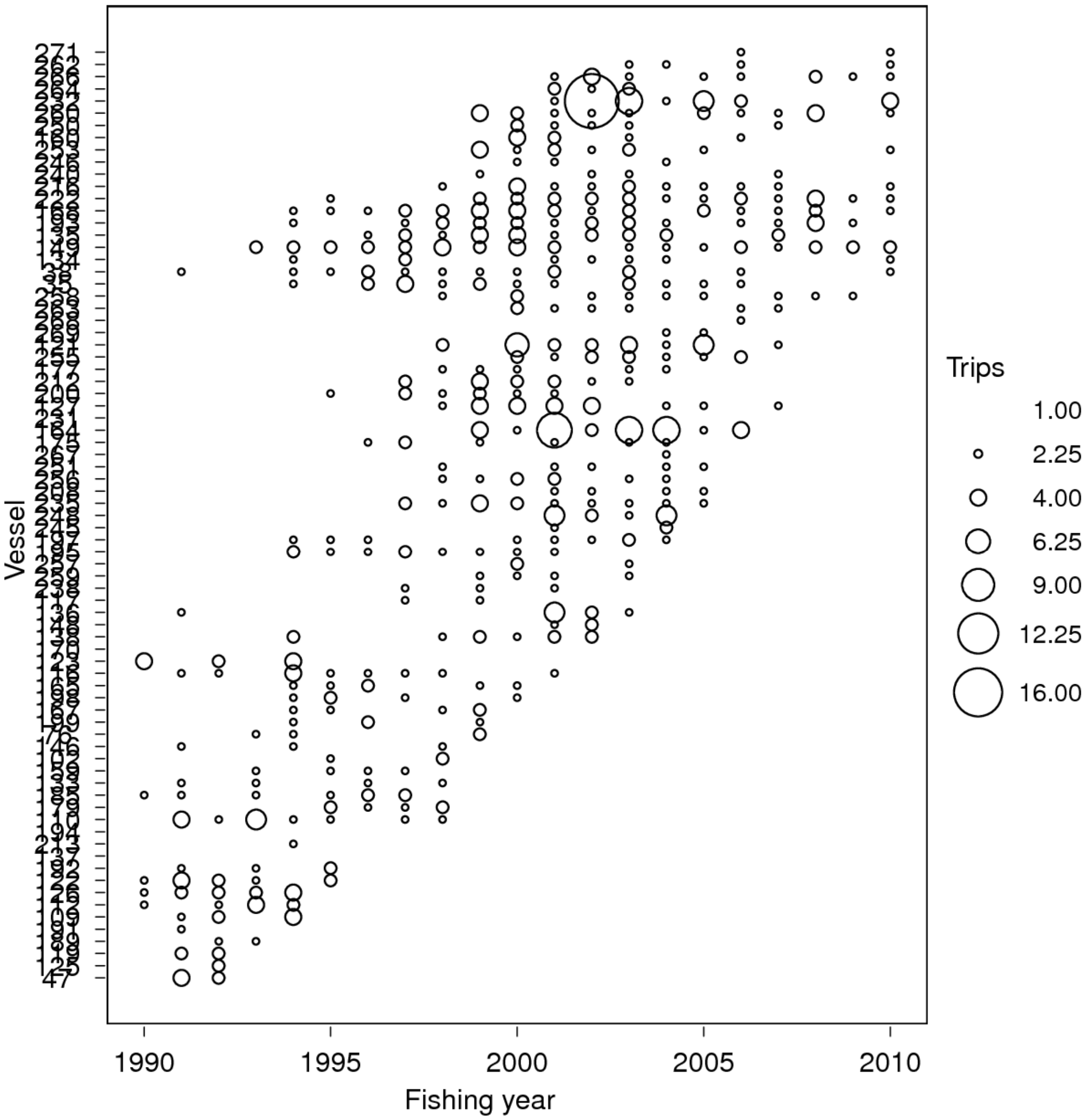


Figure E7: Number of trips by fishing year for core vessels. Area of circles is proportional to the proportion of records over all fishing years and vessels.

Table E3: Summary of core vessel data by fishing year.

Fishing year	Strata	Vessels	Trips	Catch (t)	Effort num	Effort duration (hrs)	Events with catch(% records)	Events	Strata (+ve)	Trips (+ve)	Effort num (+ve)	Effort duration (+ve)
1990	916	13	20	272.14	916	3 988	29.04	916	266	19	266	1 160.6
1991	1 768	19	41	747.27	1 768	7 393	28.00	1 768	495	38	495	2 084.6
1992	1 649	22	40	672.93	1 649	6 620	38.57	1 649	636	39	636	2 509.2
1993	2 511	24	42	652.89	2 511	7 907	27.40	2 511	688	39	688	2 357.9
1994	3 638	30	64	1 092.77	3 638	11 949	28.34	3 638	1 031	62	1 031	3 800.2
1995	3 512	28	51	1 160.51	3 512	12 976	26.85	3 512	943	47	943	3 421.8
1996	2 740	29	50	556.55	2 740	10 098	17.48	2 740	479	42	479	1 875.2
1997	2 877	36	68	501.41	2 877	11 891	19.36	2 877	557	59	557	2 516.9
1998	3 820	40	71	712.41	3 820	15 287	23.95	3 820	915	62	915	3 744.6
1999	3 900	41	92	870.65	3 900	14 070	27.31	3 900	1 065	84	1 065	4 072.6
2000	4 352	40	98	617.88	4 352	14 454	31.34	4 352	1 364	95	1 364	5 140.1
2001	4 149	46	112	678.15	4 149	14 972	36.54	4 149	1 516	105	1 516	6 108.8
2002	3 277	44	103	854.10	3 277	10 784	40.22	3 277	1 318	94	1 318	4 966.8
2003	3 468	40	96	489.55	3 468	14 136	39.42	3 468	1 367	93	1 367	7 020.2
2004	3 391	39	75	670.33	3 391	13 995	35.06	3 391	1 189	72	1 189	6 095.0
2005	1 990	33	59	423.68	1 990	7 276	39.75	1 990	791	56	791	3 841.4
2006	1 513	29	52	382.32	1 513	4 906	38.14	1 513	577	48	577	2 302.5
2007	970	27	41	222.43	970	3 717	38.76	970	376	38	376	1 659.8
2008	781	11	27	123.42	781	1 679	26.89	781	210	19	210	536.8
2009	657	13	19	108.08	657	2 018	34.55	657	227	16	227	818.5
2010	919	20	35	32.31	919	2 808	32.43	919	298	33	298	1 112.8

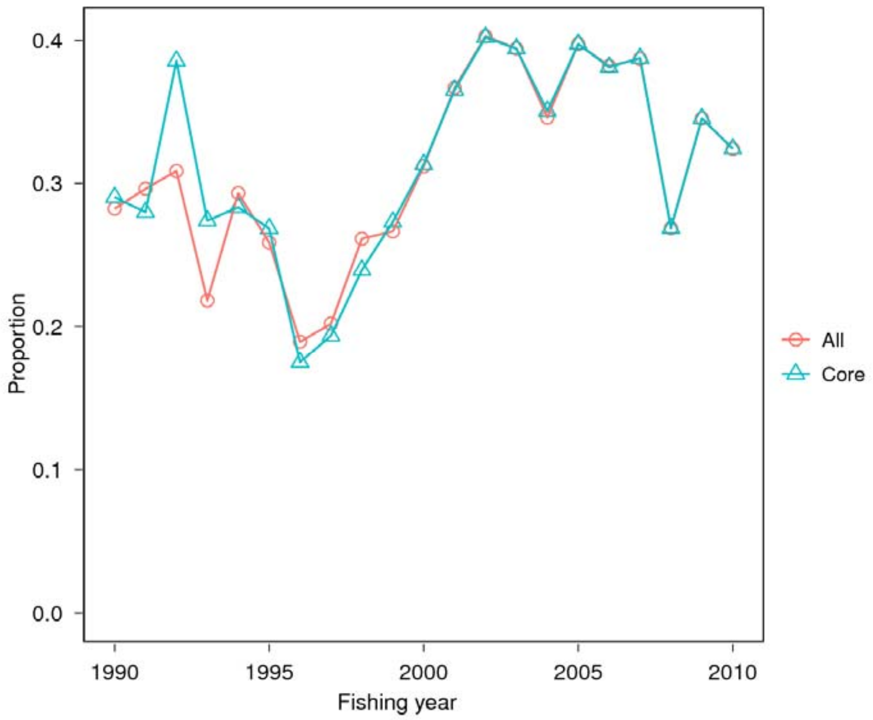


Figure E8: Proportion of positive catches for the entire dataset (All) and core vessels (Core).

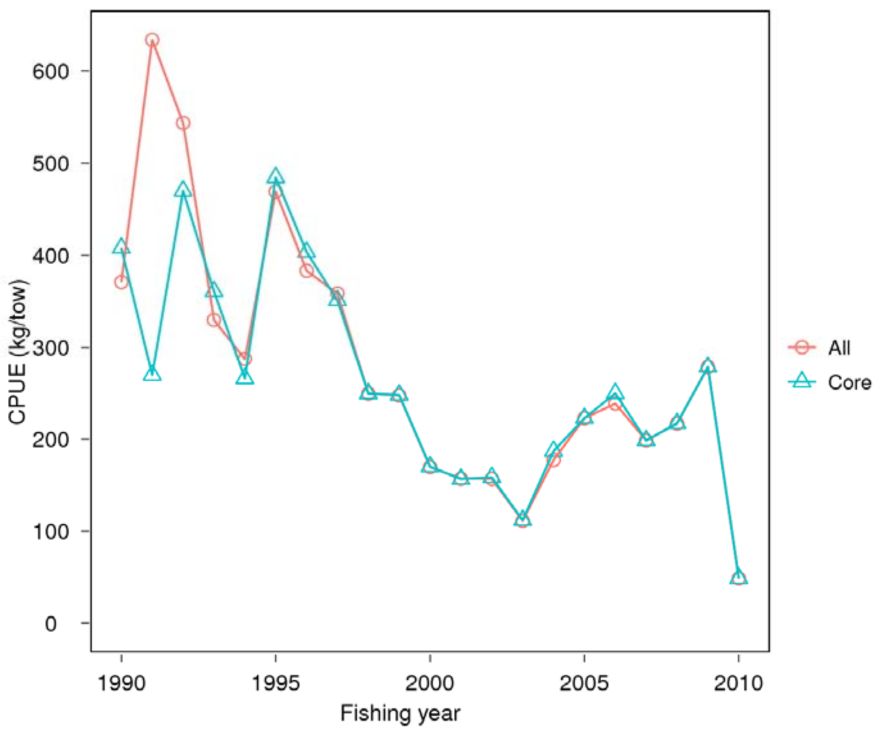


Figure E9: Unstandardised CPUE (geometric mean of positive catches) for the entire dataset (All) and core vessels (Core).

Selection of appropriate error distribution

Alternative assumptions regarding the distribution of model errors were tested by (a) fitting alternative distributions to the data, and (b) fitting simplified GLMs to the data assuming alternative distributions. The criterion used to select the most appropriate distribution was the negative log likelihood of the simplified GLM. On this basis a log-logistic distribution was used.

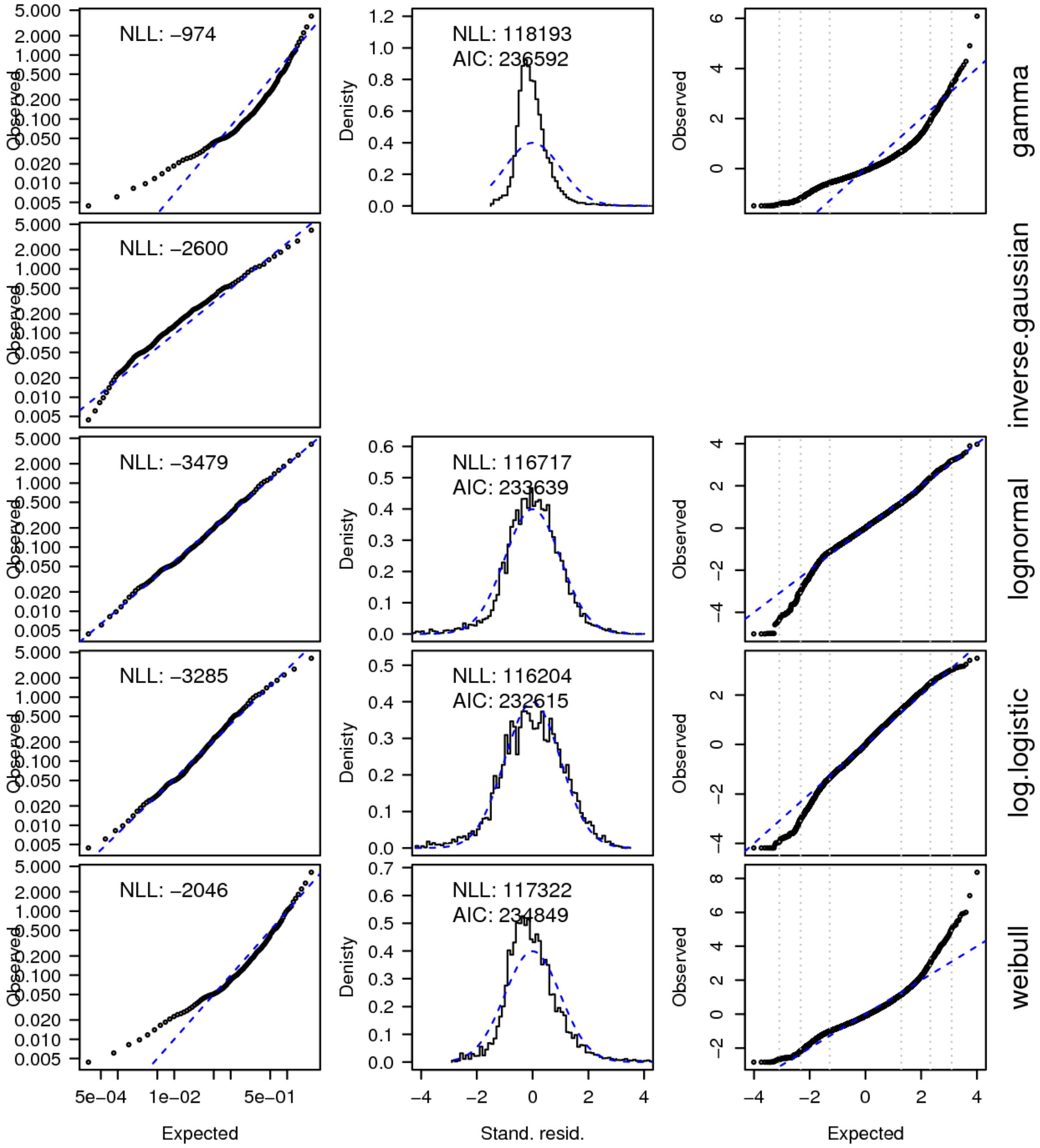


Figure E10: Diagnostics for alternative distributional assumptions for catch. Left: quantile-quantile plot of observed catches (centred (by mean) and scaled (by standard deviation) in log space) versus maximum likelihood fit of distribution (missing panel indicates that the fit failed to converge); Middle: standardised residuals from a generalised linear model fitted using the formula catch ~ fyear + month + area + vessel and the distribution (missing panel indicates that the model failed to converge); Right: quantile-quantile plot of model standardised residuals against standard normal (vertical lines represent 0.1%, 1% and 10% percentiles). NLL = negative log-likelihood; AIC = Akaike information criterion.

Stepwise selection of model terms

Forward stepwise selection of model terms was done on the basis of the Akaike Information Criterion (AIC). The maximal set of model terms offered to the stepwise selection algorithm was:

~ fyear + month + area + vessel + poly(log(duration), 3) + poly(log(depth), 3) + poly(log(bottom), 3) + poly(log(height), 3) + poly(log(width), 3) + poly(log(speed), 3) + poly(time, 3) + poly(moon, 3)

with the term *fyear* forced into the model. Terms were only added to the model if they increased the percent deviance explained by 0.25 %. Table E4 provides a summary of the changes in the deviance explained and in AIC as each term was added to the model. The final model formula was:

~ fyear + vessel + poly(log(bottom), 3) + poly(log(duration), 3) + poly(log(height), 3) + month

Table E4: Summary of stepwise selection. Model terms are listed in the order of acceptance to the model. AIC: Akaike Information Criterion; *: Term included in final model.

Term	DF	Log likelihood	AIC	Nagelkerke pseudo-R^2 (%)	
fyear	22	-118 273	236 589	9.44	*
vessel	98	-116 286	232 768	29.02	*
poly(log(bottom), 3)	101	-116 088	232 377	30.73	*
poly(log(duration), 3)	104	-115 943	232 094	31.95	*
poly(log(height), 3)	107	-115 889	231 992	32.40	*
month	110	-115 856	231 933	32.67	*
poly(time, 3)	113	-115 838	231 901	32.82	
poly(log(depth), 3)	116	-115 822	231 877	32.95	
poly(moon, 3)	119	-115 816	231 869	33.00	
poly(log(width), 3)	122	-115 811	231 866	33.04	
area	124	-115 809	231 865	33.06	

Influence of model terms on annual CPUE indices

Table E5: Summary of the explanatory power and influence of each term in the standardisation model. Coefficients is the number of coefficients associated with the term added. Log likelihood and AIC values are for the fit as each term is successively added. Coefficient of determination (R^2) values represent the change in R^2 from the the previous model. R^2: square of the correlation coefficient between log(observed) and log(fitted).

Term	Coefficients	Log likelihood	AIC	R^2 (%)	Negelkerke pseudo-R^2 (%)	Overall influence (%)
intercept	1	-119 082	238 167	-	-	-
fyear	20	-118 273	236 589	7.13	9.44	-
vessel	76	-116 286	232 768	18.43	19.58	17.04
poly(log(bottom), 3)	3	-116 088	232 377	1.74	1.71	3.99
poly(log(duration), 3)	3	-115 943	232 094	1.09	1.22	3.37
poly(log(height), 3)	3	-115 889	231 992	0.35	0.45	6.12
month	3	-115 856	231 933	0.37	0.27	1.95

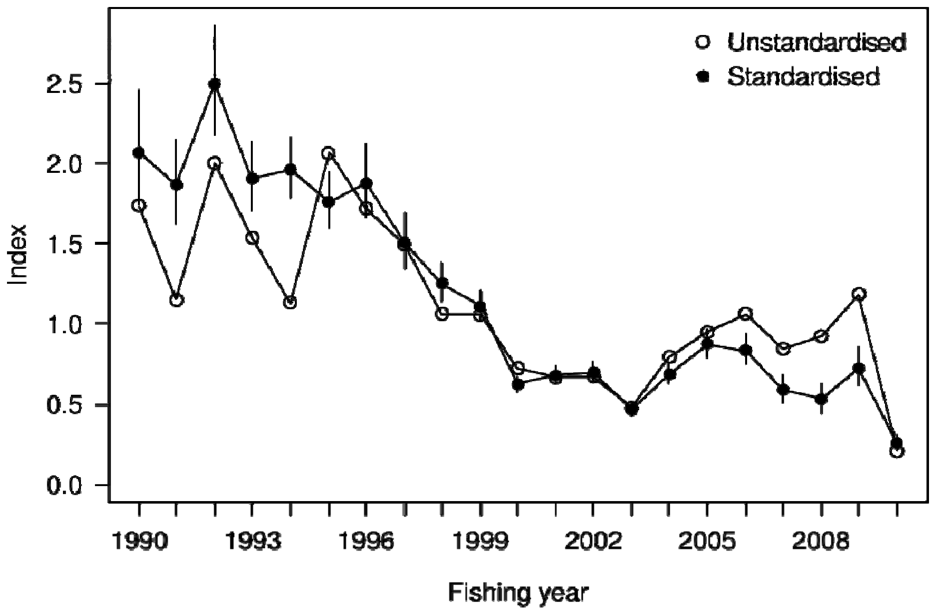


Figure E11: Overall standardisation effect of the model. The unstandardised index is based on the geometric mean of the catch per strata and is not adjusted for effort.

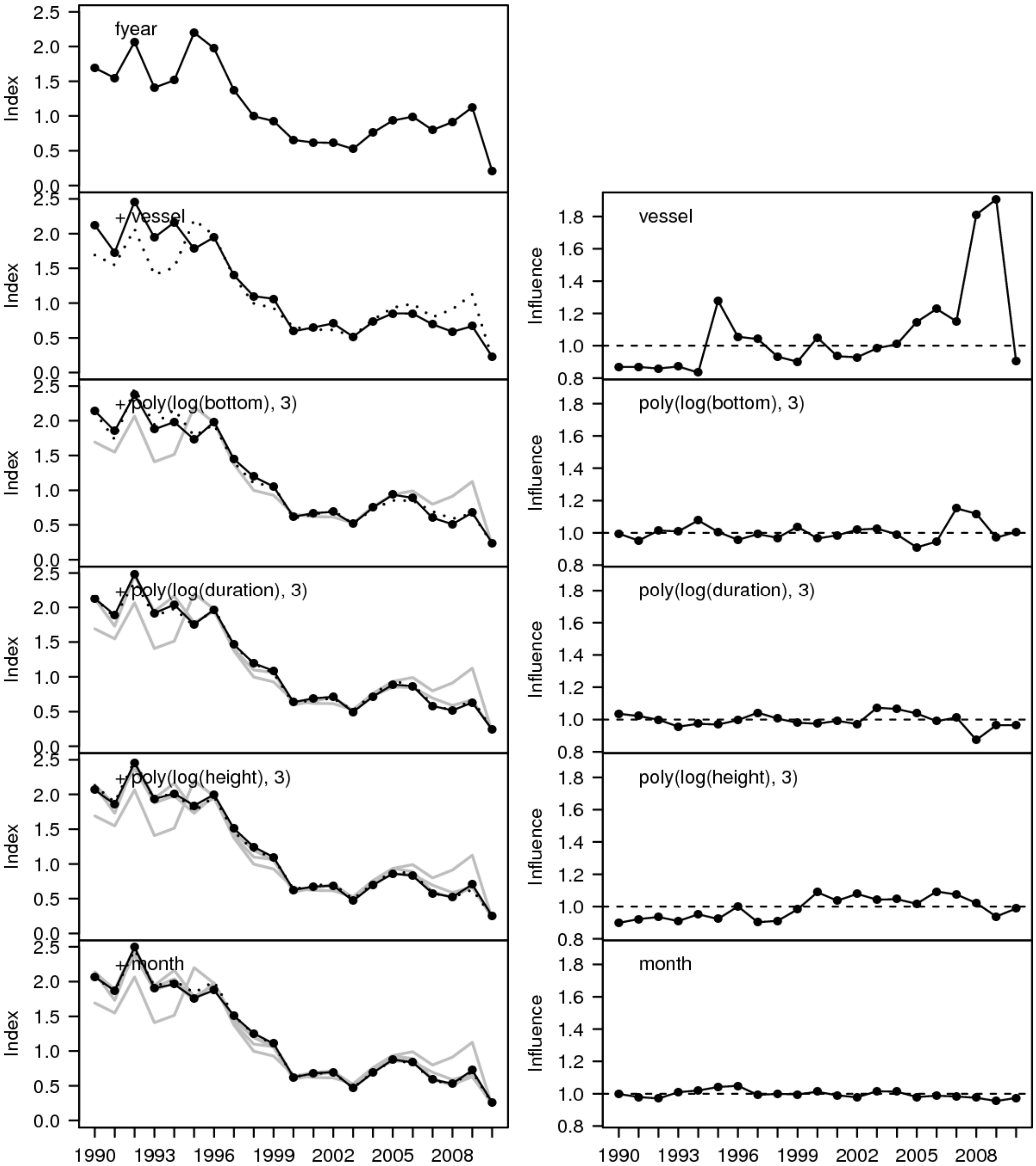


Figure E12: Step and influence plots.

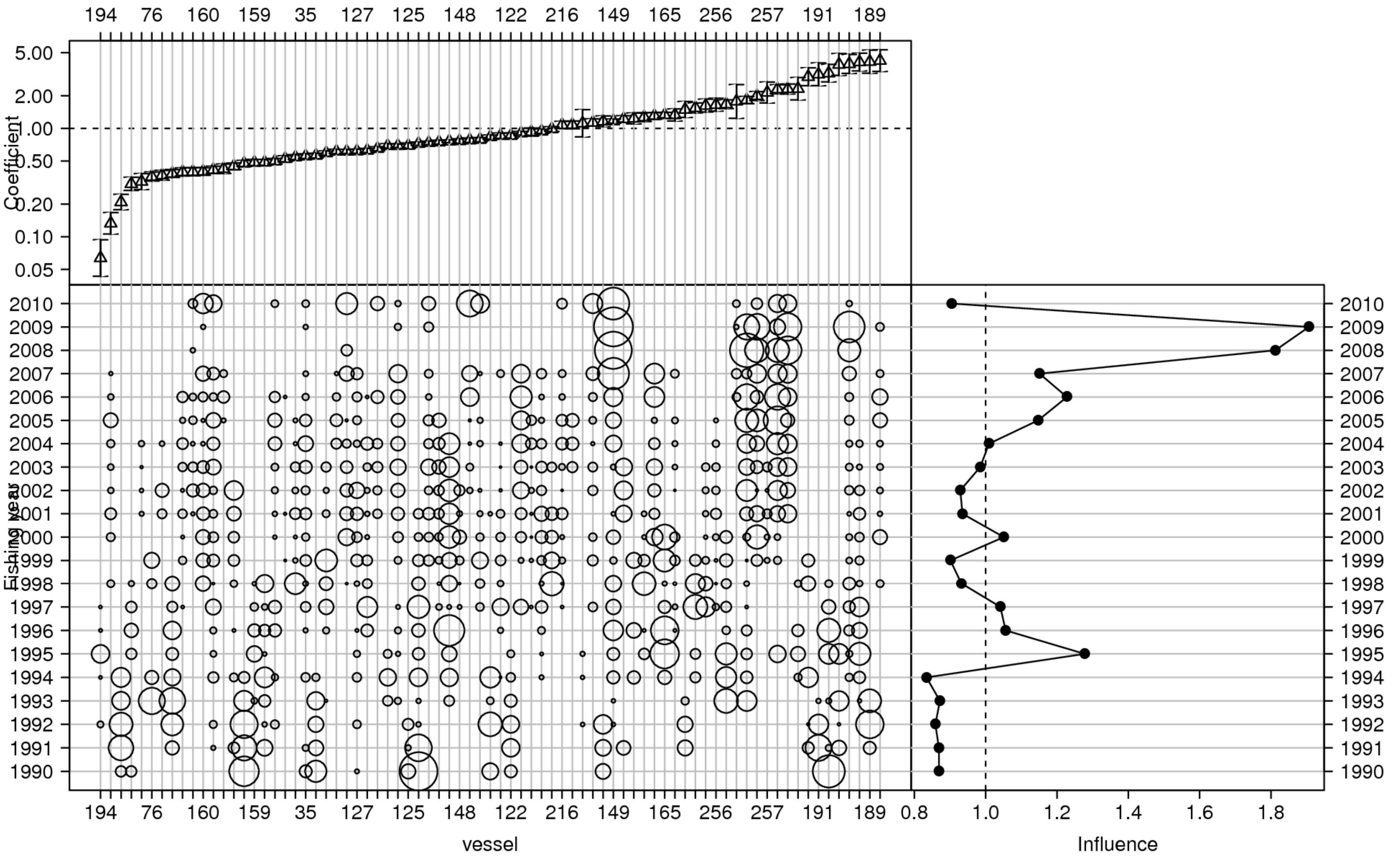


Figure E13: Coefficient-distribution-influence plot for vessel.

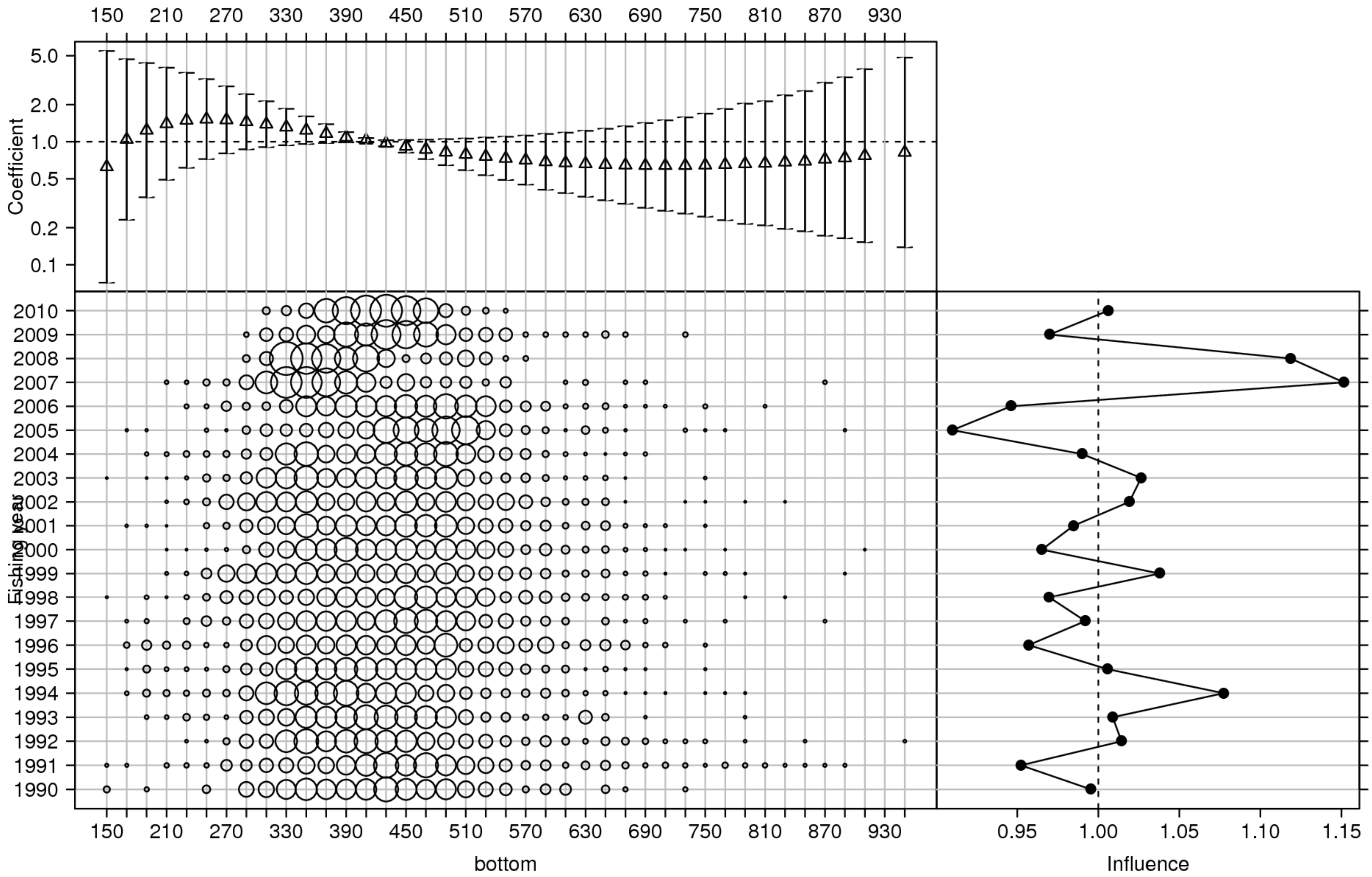


Figure E14: Coefficient-distribution-influence plot for poly(log(bottom), 3).

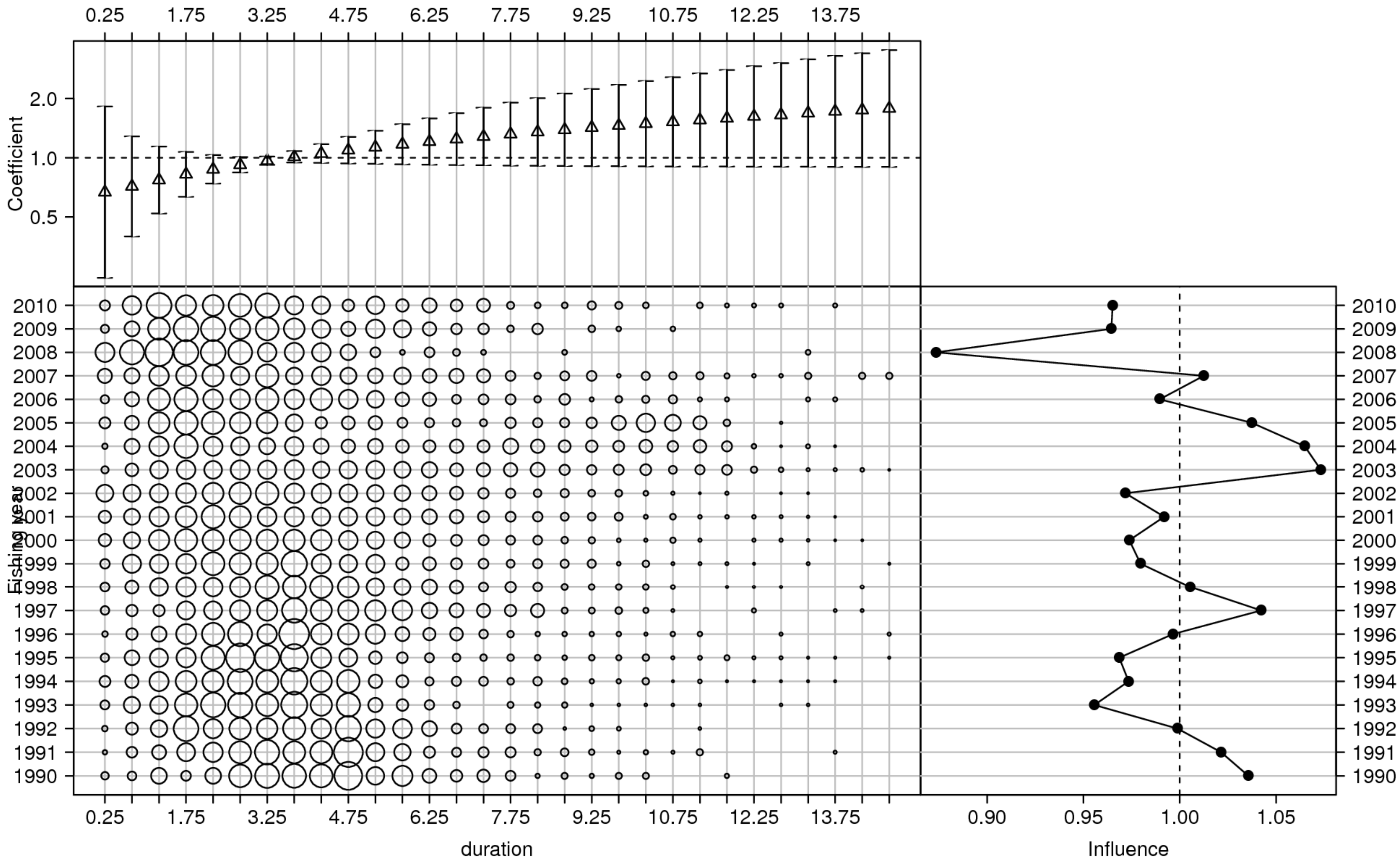


Figure E15: Coefficient-distribution-influence plot for poly(log(duration), 3).

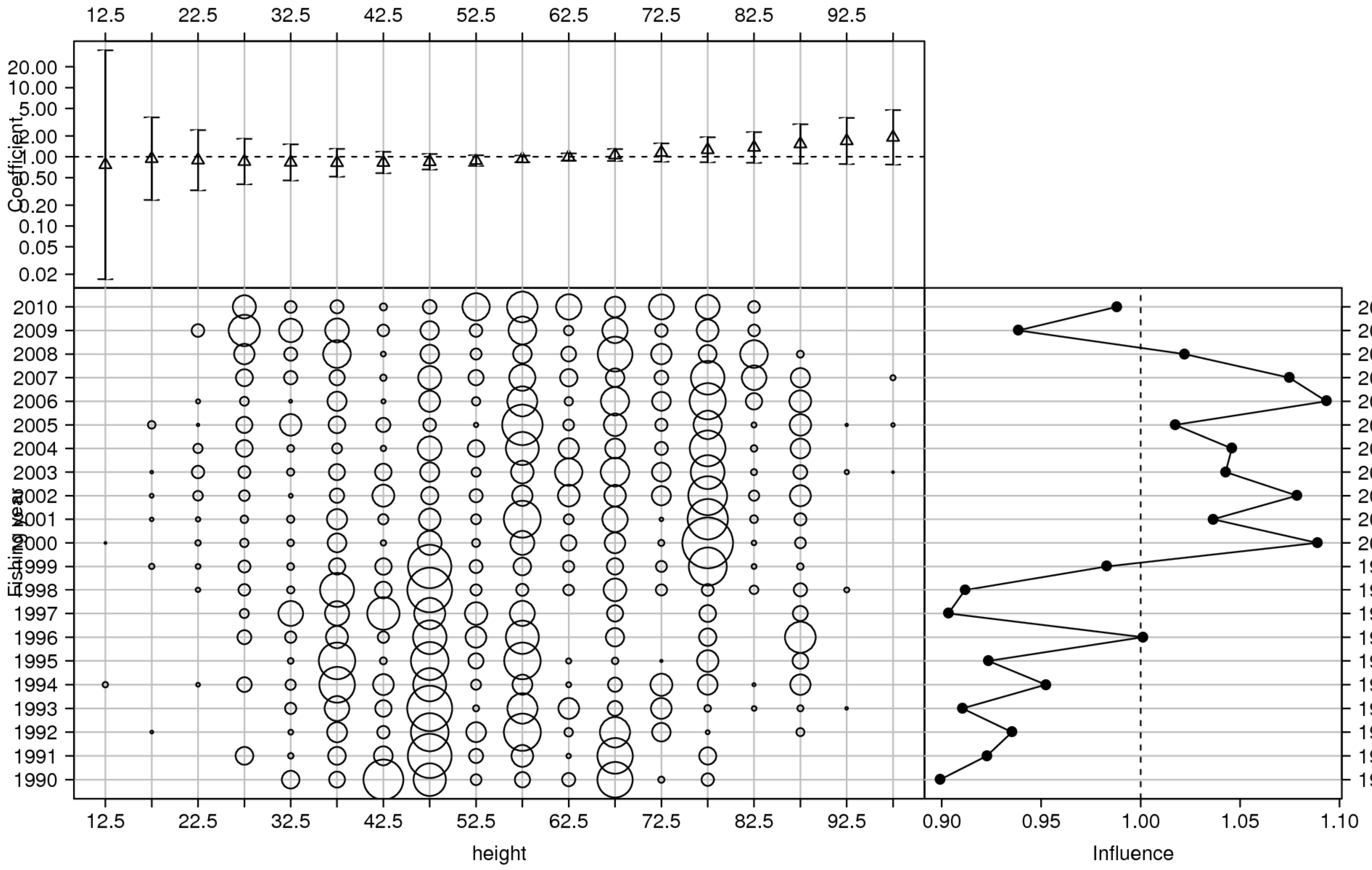


Figure E16: Coefficient-distribution-influence plot for poly(log(height), 3).

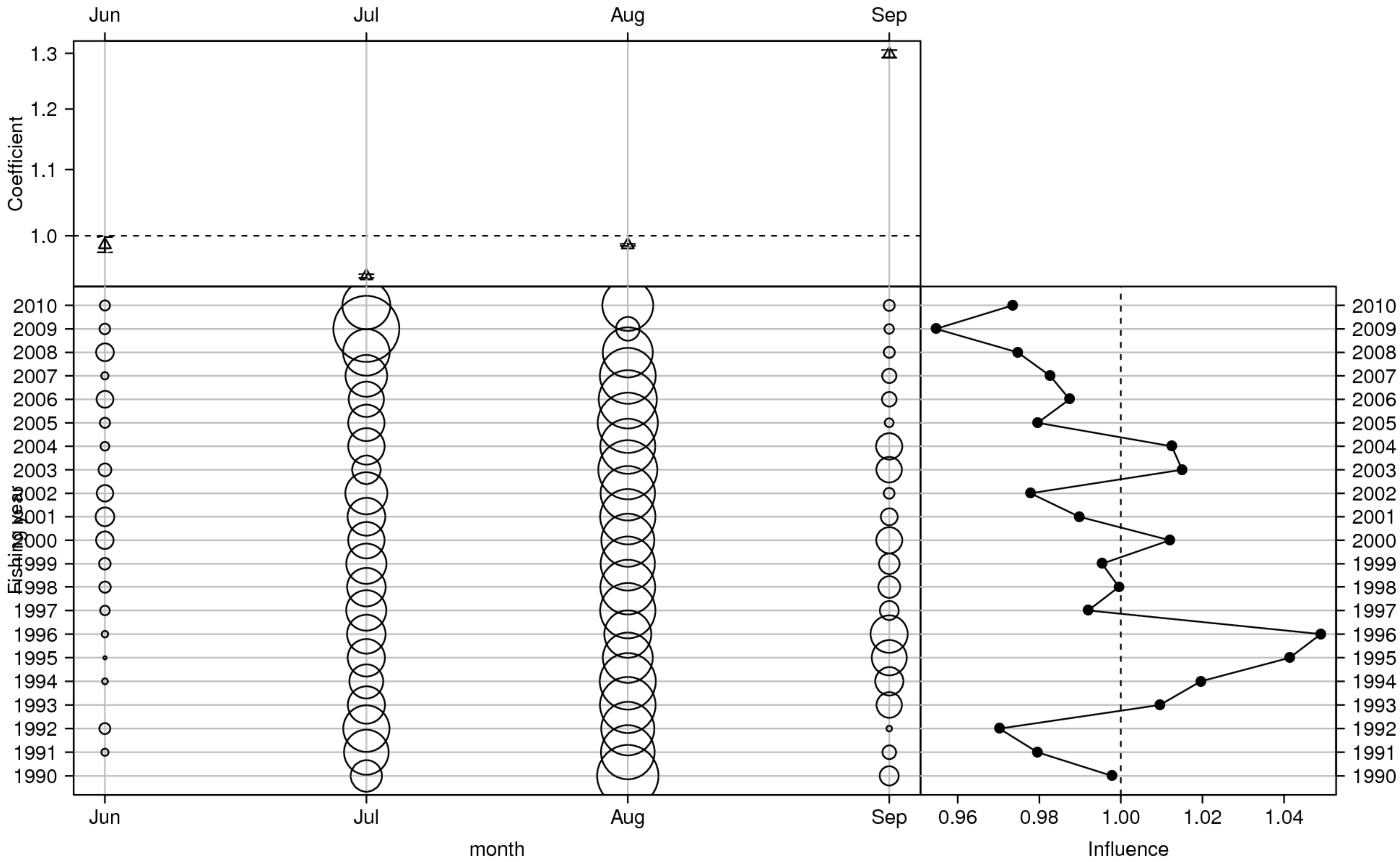


Figure E17: Coefficient-distribution-influence plot for month.

Residual diagostics

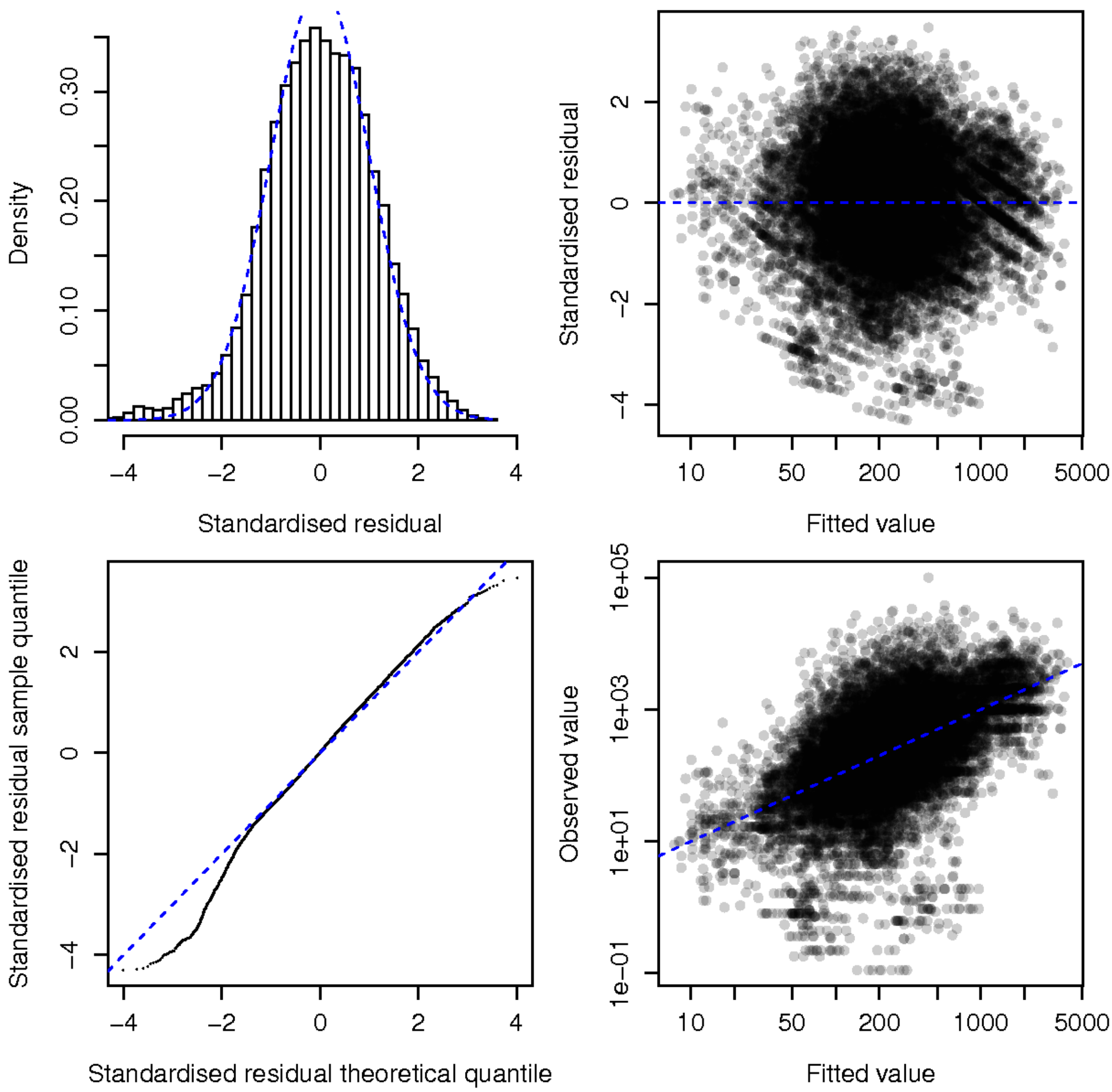


Figure E18: Residual diagnostics. Top left: histogram of standardised residuals compared to standard normal distribution. Bottom left: quantile-quantile plot of standardised residuals. Top right: fitted values versus standardised residuals. Bottom right: observed values versus fitted values.

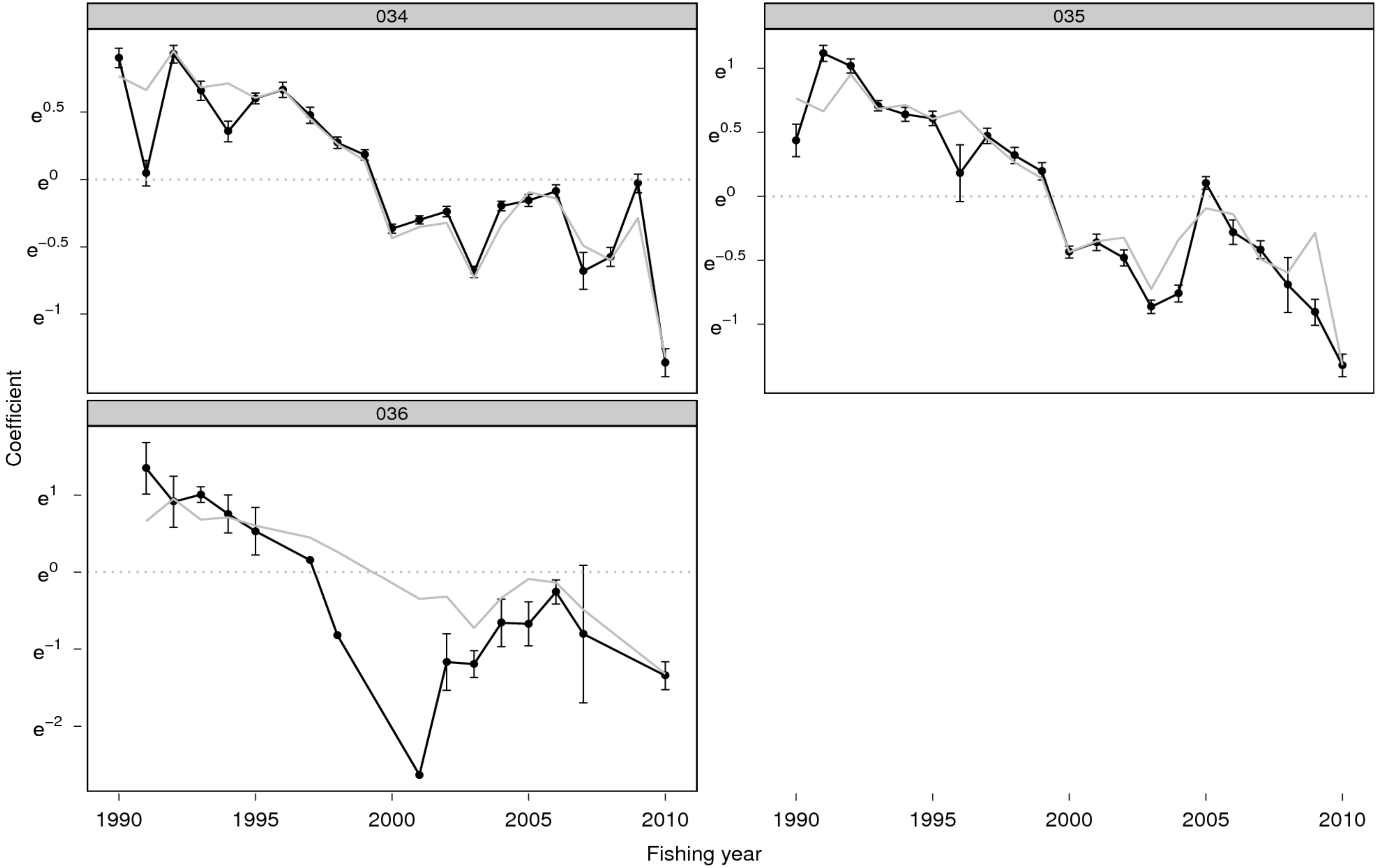


Figure E19: Residual implied coefficients for area × fishing year interactions. Implied coefficients (black points) are calculated as the normalised fishing year coefficient (grey line) plus the mean of the standardised residuals in each fishing year and area. These values approximate the coefficients obtained when an area × year interaction term is fitted, particularly for those area × year combinations which have a substantial proportion of the records. The error bars indicate one standard error of the standardised residuals.

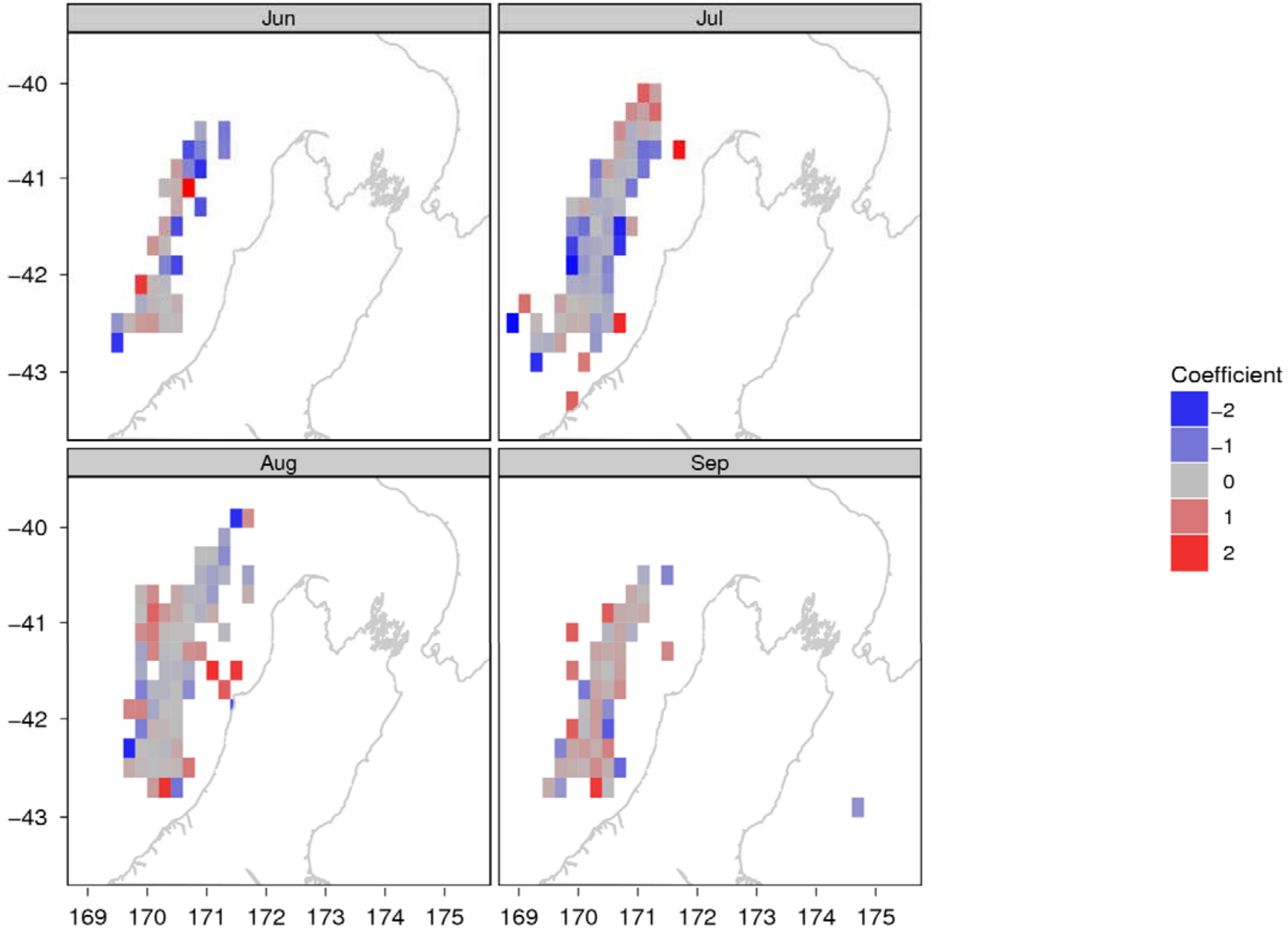


Figure E20: Residual implied coefficients for each position in each month. Implied coefficients are calculated as the sum of the normalised coefficients for any model terms relating to area and month (month, area and area × month terms) plus the mean of the standardised residual for position in each month. This plot is intended to show what the combination of model fit and residuals imply about seasonality in local catch rates.

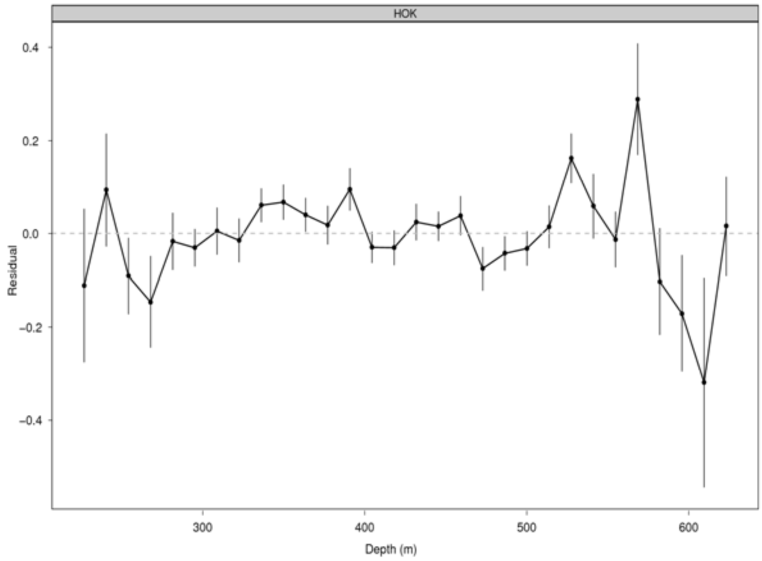


Figure E21: Mean and standard error of residuals by depth and target species.

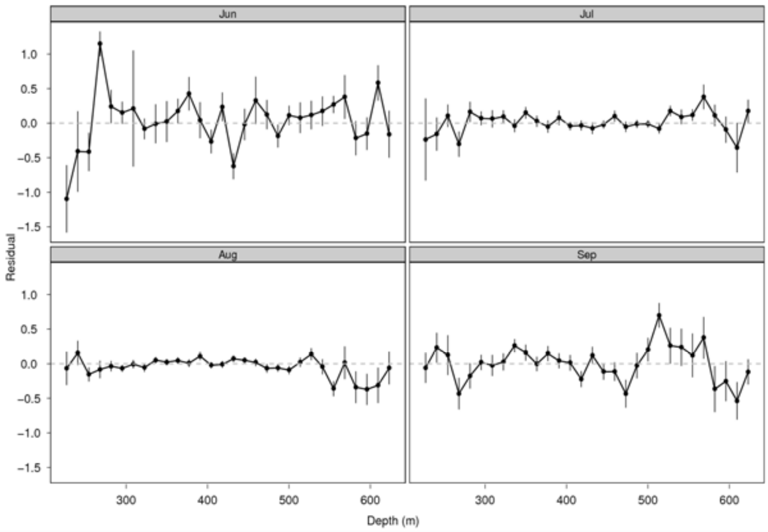


Figure E22: Mean and standard error of residuals by depth and month.

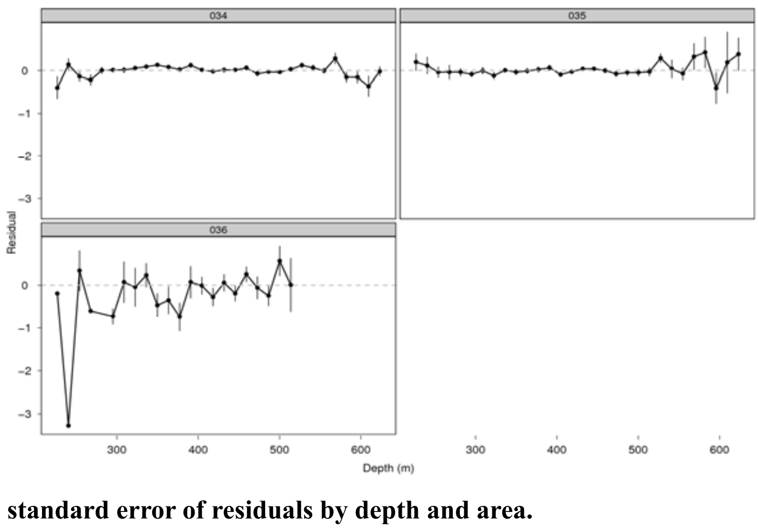


Figure E23: Mean and standard error of residuals by depth and area.

Sensitivity to data selection

Vessel was a highly influential variable in the GLM standardisation model. A concern was that the unusually low catch rates in 2009–2010, coupled with the re-entry of several vessels into the fishery in that year may be have been unduly influencing the estimated vessel coefficients. A sensitivity was done where data from 2009–2010 was excluded. Other sensitivities were done excluding early fishing years (1989–90 to 1994–95) and alternative core vessel definitions (Figure E24).

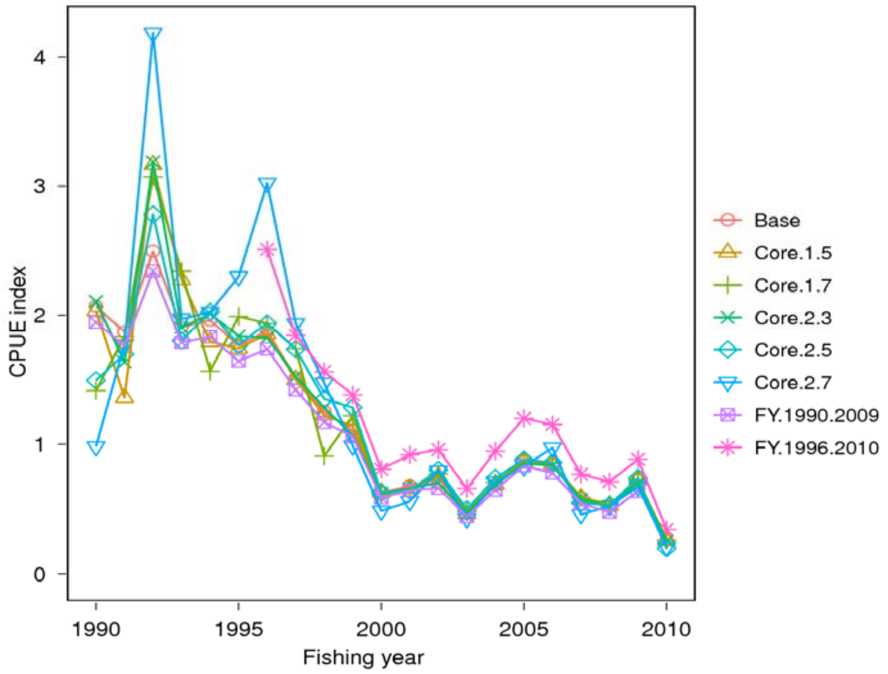


Figure E24: Sensitivity of standardised CPUE to data used. Base: base, core data, Core.X.Y: core vessels defined on basis of X trips in Y years, FY.X.Y: only fishing years X to Y used.

Summary of CPUE indices

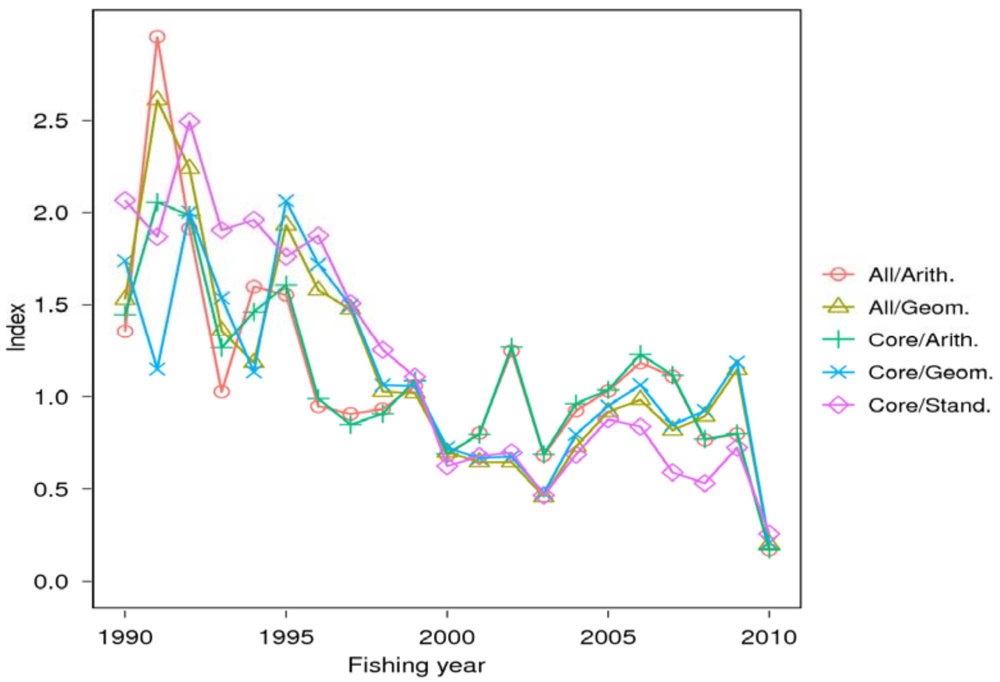


Figure E25: Standardised and unstandardised CPUE indices. All: all vessels, Core: core vessels, Geom.: geometric mean, Arith.: arithmetic mean, Stand.: standardised using GLM.

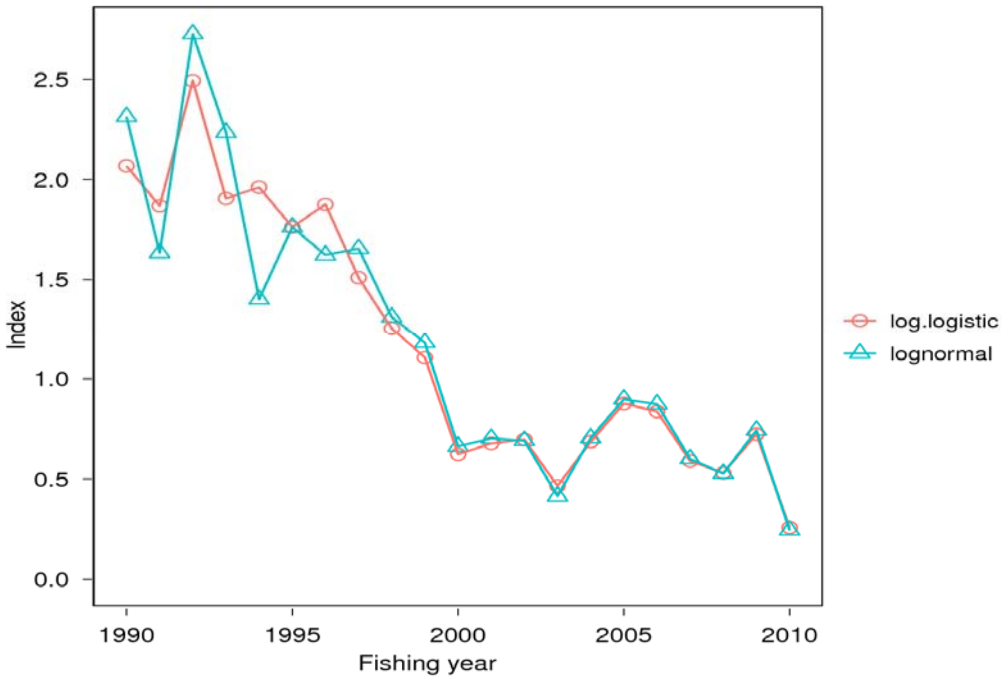


Figure E26: Standardised CPUE obtained from the GLM model when using a log.logistic distribution and a lognormal distribution.

Table E6: Standardised and unstandardised CPUE indices. Fishing year labelled by latter calendar year e.g. 1990=1989–90. All: all vessels, Core: core vessels, Geom.: geometric mean, Arith: arithmetic mean, Stand.: standardised using GLM, SE: standard error.

Fishing year	All/Arith.	Core/Arith.	All/Geom.	Core/Geom.	Core/Stand.	Core/Stand. SE
1990	1.3549	1.4457	1.5283	1.7388	2.0678	0.08611
1991	2.9537	2.0567	2.6111	1.1494	1.8684	0.07155
1992	1.9147	1.9857	2.2396	2.0029	2.4943	0.06837
1993	1.0262	1.2652	1.3582	1.5379	1.9052	0.05595
1994	1.5988	1.4617	1.1833	1.1333	1.9615	0.04753
1995	1.5531	1.6079	1.9327	2.0644	1.7612	0.04914
1996	0.9479	0.9884	1.5794	1.7200	1.8759	0.06069
1997	0.9063	0.8481	1.4769	1.4962	1.5083	0.05603
1998	0.9328	0.9075	1.0273	1.0626	1.2537	0.04936
1999	1.0574	1.0863	1.0192	1.0566	1.1069	0.04368
2000	0.6812	0.6909	0.6984	0.7246	0.6234	0.03888
2001	0.8018	0.7953	0.6462	0.6665	0.6776	0.03796
2002	1.2474	1.2683	0.6453	0.6745	0.6976	0.04096
2003	0.6832	0.6869	0.4578	0.4760	0.4651	0.04021
2004	0.9232	0.9619	0.7294	0.7961	0.6862	0.04123
2005	1.0313	1.0360	0.9169	0.9486	0.8768	0.04844
2006	1.1833	1.2296	0.9824	1.0639	0.8371	0.05590
2007	1.1096	1.1158	0.8174	0.8456	0.5895	0.07036
2008	0.7655	0.7690	0.8936	0.9244	0.5305	0.08568
2009	0.7968	0.8005	1.1466	1.1862	0.7235	0.08559
2010	0.1703	0.1711	0.2011	0.2080	0.2571	0.07740