Ministry for Primary Industries
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Fishery characterisation and catch-per-unit-effort analyses for sea perch (*Helicolenus spp.*) in New Zealand, 1989–90 to 2009–10

New Zealand Fisheries Assessment Report 2014/27

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ISSN 1179-5352 (online)

ISBN 978-0-478-43225-1 (online)

May 2014

New Zealand Government

Growing and Protecting New Zealand

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EXECUTIVE SUMMARY

Bentley, N., Kendrick, T.H., MacGibbon, D.J. (2014). Fishery characterisation and catch-per-unit-effort analyses for sea perch *(Helicolenus spp.)* in New Zealand, 1989–90 to 2009–10.

***New Zealand Fisheries Assessment Report 2014/27.* 181 p.**

Sea perch (Sebastiae *Helicolenus spp*) occur on the continental shelf and slope, seamounts and ridges of the temperate Pacific, Atlantic and Indian Oceans. In the south-west Pacific, it is likely that there are four, closely related species, of *Helicolenus* (Smith et al. 2009). In this study we found evidence that supports the hypothesis that three of these species occur, and are caught in, New Zealand waters. The depth distribution of sea perch catch rates and catches suggests that these species are separated by depth and/or geography.

Sea perch was introduced into the quota management system in the 1998–99 fishing year. The majority of sea perch is caught in quota management areas SPE 3 (FMA 3) and SPE 4 (FMA 4) as bycatch in bottom trawl fisheries targeting species such as hoki, red cod and barracouta.

Ageing studies have provided natural mortality and growth parameter estimates for both the Canterbury coast and Chatham Rise populations. Fishery independent data is available from the Chatham Rise *Tangaroa* surveys and the east coast South Island *Kaharoa* surveys.

Two catch per unit effort standardisations were done for the Canterbury coast: one using aggregated data from bottom trawling targeting inshore species and one using data from individual tows in depths under 250 m. These two resulting CPUE indices were similar and consistent with the biomass index from the winter east coast South Island *Kaharoa* inshore trawl survey time series. Of the two CPUE indices the one based on aggregated data is considered more reliable because it contains more data prior to the 2007–08 fishing year.

Two catch per unit effort standardisations were done for the Chatham Rise (including part of SPE 3) using individual tows data from depths 250–1000 m. In the first standardisation data from tows targeting a variety of species but principally hoki, hake and scampi were used. In the second standardisation, due to concerns about a lack of data in the early-1990s and changes in targeting, only data from hoki targeted tows since the 1994–95 fishing year were used. There was close correspondence among the two CPUE indices and the biomass index from the *Tangaroa* summer trawl survey time series.

1. INTRODUCTION

Sea perch (*Helicolenus spp*) are a genus of Sebastids (rockfish, rockcods, thornyheads) occurring on the continental shelf and slope, seamounts and ridges of the temperate Pacific, Atlantic, and Indian Oceans. In the south-west Pacific, it is likely that there are four, closely related species, of *Helicolenus* (Smith et al. 2009). In this study we found evidence that supports the hypothesis that three of these species occur, and are caught in, New Zealand waters. However, due to prior uncertainty regarding speciation, and because it is difficult to distinguish among species based on morphological characteristics, there is no species discrimination in fisheries catch reporting. Nor is there any species discrimination in fisheries management with a single species, *Helicolenus percoides*, introduced into the Quota Management System (QMS) from 1 October 1998, with all sea perch (SPE) catch counted against the total allowable catch (TAC).

In New Zealand, the majority of sea perch is caught in quota management areas SPE 3 and SPE 4 (FMA 3 and FMA 4 respectively) as bycatch in bottom trawl fisheries targeting species such as red cod, barracouta, and hoki (Ministry for Primary Industries 2012). Sea perch landings are not a valuable component of commercial fishing operations and as such have had relatively little monitoring or research. However, from 1 October 2001, SPE 3 was entered into the Adaptive Management Programme (AMP) and thus has been the subject of several comprehensive reviews of available data (SeaFIC 2002, SeaFIC 2004, Starr et al. 2006, Starr et al. 2008). In addition, in response to increased landings during the early 2000s, a characterisation of the catches in SPE 4 was undertaken (Beentjes et al. 2007).

Under the 10 year Research Programme for Deepwater Fisheries (Ministry of Fisheries 2010) the sea perch 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 sea perch, 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 appendices: A, Summaries of trawl survey data; B, Summaries of observer data; C, Summaries of catch and effort data; D, CPUE for Canterbury coast using aggregated data; E, CPUE for Canterbury coast using tow data; F CPUE for Chatham Rise using tows targeting various species; G, CPUE for Chatham Rise using tows targeting hoki.

2. FISHERY SUMMARY

2.1 Commercial fisheries

Prior to the introduction of sea perch to the QMS in the 1998–99 fishing year, information on the magnitude of landings is scant. Historically, relatively small quantities of sea perch have been landed for sale on the domestic market (Ministry for Primary Industries 2012). Foreign vessels fishing within the New Zealand Exclusive Economic Zone (EEZ) since the 1960s probably recorded sea perch in the "mixed" or "other finfish" categories and are likely to have discarded most (Ministry for Primary Industries 2012).

Most of the commercial catch is taken as bycatch by bottom trawling targeting inshore species such as red cod, barracouta and tarakihi off the Canterbury coast (SPE 3) and targeting hoki, hake and scampi off the Chatham Rise (SPE 4). Catches from targeted bottom trawling are relatively minor. Sea perch is also caught as a bycatch of bottom longlining targeting ling in SPE 3, SPE 4 and SPE 5. Plots of commercial catches and total allowable commercial catch (TACC) by quota management area are provided in Appendix C.

2.2 Recreational fisheries

Sea perch are mostly caught as bycatch in recreational fisheries targeting species such as blue cod. The highest reported catches for sea perch from recreational fishing surveys come from QMAs 2, 3 and 7 (Ministry for Primary Industries 2012).

2.3 Customary non-commercial fisheries

No estimates of customary non-commercial landings were reviewed in this study.

2.4 Illegal landings

No estimates of illegal landings are available. Given the relatively low value of sea perch it is unlikely to be substantial.

2.5 Other source of mortality

There is likely to be some discarding of sea perch by commercial vessels, particularly of small fish, although this has not been quantified (Ministry for Primary Industries 2012).

3. BIOLOGY

3.1 Speciation

There is regional variation in morphology and colouration of sea perch in New Zealand waters and historically two species have been described: *Helicolenus percoides* (Richardson) and *Helicolenus barathri* (Hector). Both species are reported from waters off Australia and New Zealand but there have been recent, conflicting, conclusions as to whether these are actually separate biological species.

Based on morphometric analyses of New Zealand specimens of Sea perch, Paulin (1989) concluded that "*Helicolenus barathri* is a valid species and not a junior synonym of *H. percoides* as considered by earlier authors". He re-described both species noting that *H. barathri* has a larger orbit diameter (for a given length) and is found in deeper water than *H. percoides*. Similar morphological and colour differences between shallow and deep *Helicolenus* are also found off New South Wales (Park 1993). There, the shallow sea perch (80–350 m) are considered to be *H. percoides* and are known as "reef ocean perch" or "inshore ocean perch", whereas the sea perch found in deeper water (250–800 m) are considered to be *H. barathri* and are known as “bigeye ocean perch” or “offshore ocean perch” (New South Wales Department of Primary Industries 2012).

However, analysis of allozymes has not supported the thesis that shallow and deep *Helicolenus* are different species. The study of Smith et al. (1998) suggested that there was only one species of *Helicolenus* in New Zealand. In Australia, Daley et al. (1998) found that the inshore and offshore morphs were reproductively isolated but there were no fixed allelic differences which would be typical of discrete species.

More recently, mitochondrial DNA was used by Smith et al. (2009) to study genetic differences among sea perch in the south-western Pacific using sea perch specimens from numerous locations in the region (including off Australia, the Norfolk, Kermadec, and Louisville Ridges, and New Zealand). They concluded that there are probably four species of *Helicolenus* in the south-west Pacific, two of which are undescribed (referred to hereafter as *H. sp. A* and *H. sp B*).

During this study we found evidence which supports the conclusion of Smith et al. (2009) that there are three species of sea perch in New Zealand waters. Based on a synthesis of the literature (including, importantly figure 3 from Smith et al. 2009) and results from this study we have developed the following working hypothesis of speciation of *Helicolenus* in the south-west Pacific:

- *H. barathri* occurs in 300–1000 m with a peak abundance around 600 m (based on analysis of catch rate by depth in this study). It occurs off eastern Australia, on the Challenger Plateau and off the west coast of the South Island.

- *H. percoides* occurs in 0–250 m with a peak abundance around 150 m (based on analysis of catch rate by depth in this study). It occurs off eastern Australia, in the Tasman Sea and around New Zealand including Chatham Rise. There are two reasons to suspect that *H. percoides* extends as far west as the Chatham Rise and in particular Mernoo Bank. First, Smith et al. (2009) found that one specimen collected from the Chatham Rise fell into the *H. percoides* branch (see their figure 3). Second, there are some, albeit relatively minor, catches of sea perch on the Chatham Rise in depths less than 250 m. This is outside of the depth range of *H. sp.* A, the other sea perch species found on the Chatham Rise (see below). Note however, that there is relatively little area of water less than 250 m on the Chatham Rise, so the biomass there is likely to be small compared to other areas.

- *H. sp. A* (corresponding to the “CR-KR-NR” clade in Smith et al.’s figure 3) occurs in 250–700 m with a peak abundance around 300 m (based on analysis of catch rates in this study) from Norfolk Ridge to the Chatham Rise including the Kermadec Ridge, the Bay of Plenty and the east coast of the North and South Island. Smith et al. (2009) did not analyse specimens from the Bay of Plenty or the East Coast of the North Island, however in this study we found that in those areas the depth profile of sea perch catch rates was consistent with that observed on the Chatham Rise for *H. sp A*.

- *H. sp. B* (corresponding to the “FS-LR” clade in Smith et al.’s figure 3) occurs on the Louisville Ridge and Foundation Seamounts.

Further evidence that *H. sp. A* is distinct from *H. percoides* comes from differences in growth rates, mortality and implied year class strengths between the east coast South Island (ECSI) and Chatham Rise (CR) populations of sea perch. Paul & Horn (2009) found differences in growth curves between these areas with sea perch from the Chatham Rise growing to a larger size. Of the two estimated growth curves, the one from ECSI population is most similar to that estimated for *H. percoides* from south-east Australia (Withell & Wankowski 1988). Based on maximum observed ages they estimated quite different rates of mortality for the two areas: 0.12 (ECSI) and 0.07 (CR). Based on age and length-frequencies from the surveys, Paul & Horn (2009) also found strong evidence for different year class strength between the two areas. These observed differences in sea perch populations on the ECSI and CR may arise for numerous reasons including differences in exploitation history and separate stocks. However, they are not inconsistent with, and provide supporting evidence for, the above species hypothesis.

This species hypothesis is also summarised in Figure 1. Note that this hypothesis is based to some degree on circumstantial evidence and is provided here mainly as a point of reference for understanding the spatial, depth and temporal patterns observed in catch rates of sea perch in New Zealand. However, even if these are not biologically discrete species, the differences in depth preferences, maximum ages, growth rates and biomass trends suggest that these are at least biologically discrete stocks.

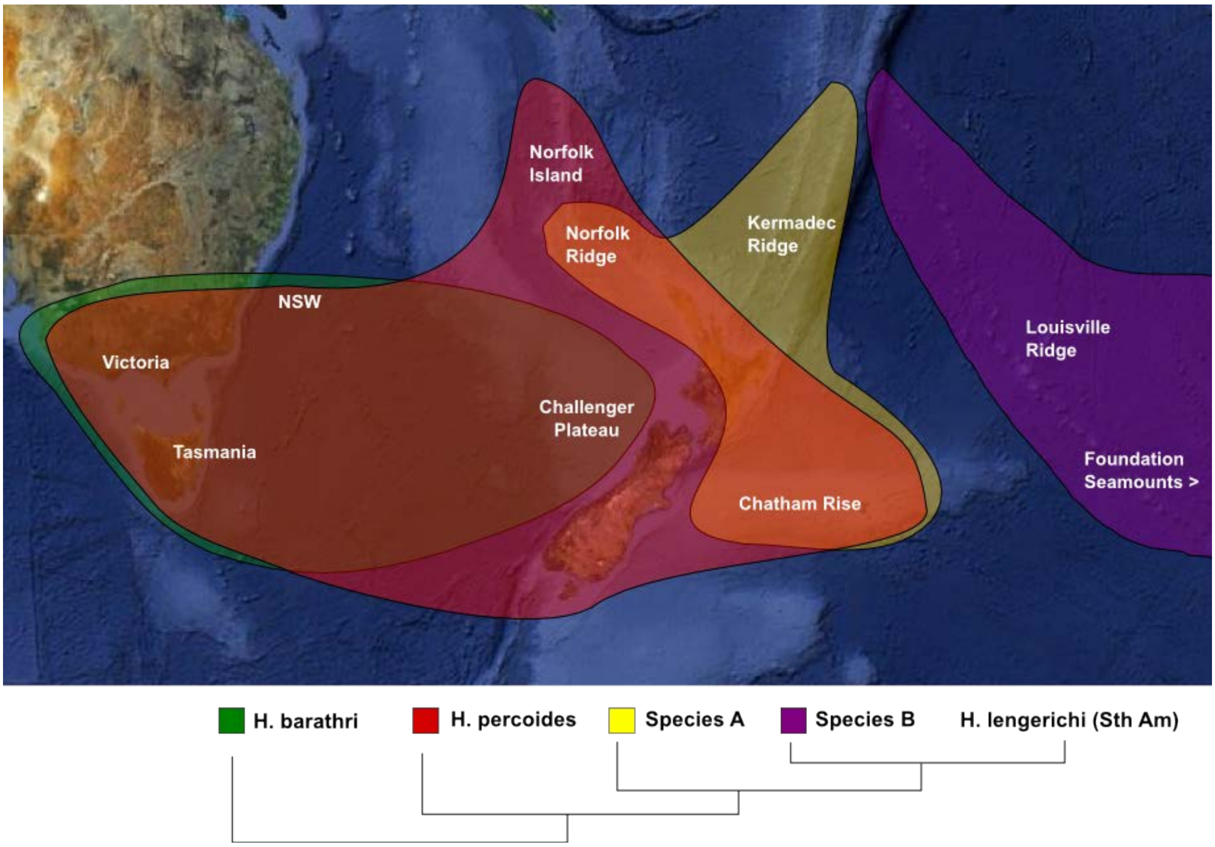


Figure 1: Schematic diagram of a hypothesis for *Helicolenus* speciation in the south-west Pacific. The species distributions drawn are intended to be indicative only. Also shown below the map is the relative genetic relatedness of species based on the mitochondrial DNA analysis of Smith et al. (2009). This includes *H. lengerichi* which is described from southern South America. Note that there is a longitudinal pattern to relatedness.

3.2 Feeding

Sea perch of the genus *Helicolenus* are have been found to feed on a variety of benthic and benthopelagic crustaceans, fish and squid (e.g. Consoli et al. 2010, Neves et al. 2012, Baeck et al.

2013). Variation in the diet of *H. percoides* among locations suggests that it is an opportunistic feeder. Off eastern Tasmania the diet of *H. percoides* has been found to be dominated by salps and fish (Blaber & Bulman 1987). Off the Wairarapa coast, decapod prawns and crabs dominated the diet although salps and fish were still important (Jones 2009). On the Chatham Rise, Horn et al. (2012) noted an ontogenetic shift in diet from small crustaceans such as mysids and galatheids to larger crustaceans such as scampi and crabs.

3.3 Spawning

Sea perch are viviparous, extruding small larvae in floating jelly-like masses (Ministry for Primary Industries 2012).

3.4 Ageing and growth

A reliable ageing method for New Zealand sea perch has been described by Paul & Horn (2009). Using trawl survey data from the east coast South Island and Chatham Rise surveys, they observed that annual formation of growth increments was confirmed by the observed year class progression in comparable samples from three years. The progression of length modes in several consecutive years also matched growth curves estimated from survey age and length data. Further, oxytetracycline injection used in captive fish also found annual growth increments in sea perch, at least for older fish.

Ageing and growth studies have also been done in Australia and results from these for the three species of *Helicolenus* thought to occur in New Zealand are summarised in Table 1.

3.5 Natural mortality

Paul & Francis (2002) estimated natural mortality for sea perch on the east coast of the South Island and the Chatham Rise at 0.13 and 0.10 (using the Hoenig method) and 0.07−0.09 (using the Chapman-Robson estimator). Paul & Horn (2009) estimated natural mortality rates of 0.12 and 0.07 respectively for these areas based on maximum observed ages.

3.6 Maturity

Males mature at 19–25 cm (about 5−7 years) and females mature at 15–20 cm (about 5 years) (Paul & Francis 2002).

3.7 Length-weight relationship

Length-weight parameters for sea perch are available from trawl surveys (e.g. Schofield & Livingston 1996).

Table 1: Estimates of von Bertalanffy growth parameters and maximum observed age for the three *Helicolenus* species assumed to occur in New Zealand. *=maximum observed age across both sexes

Species	Location	Sex	L_{inf}	k	t_0	Max age	Reference
H. percoides	ECSI	Male	42.13	0.119	-0.79	35	Paul & Horn (2009)
		Female	38.70	0.123	-1.05	28	
	Eastern Bass Strait, Australia	Male	43.19	0.115	0.29	42*	Withell & Wankowski (1988)
		Female	44.68	0.107	0.17		
	Bass Strait and NSW, Australia	Both	34.70	0.16	-0.78	17	Knuckey & Curtain (2001)
H. sp. A	Chatham Rise	Male	45.47	0.074	-2.51	59	Paul and Horn (2009) Chatham Rise “*H. percoides*”
		Female	46.34	0.062	-3.93	58	
H. barathri	Bass Strait and NSW, Australia	Both	42.87	0.07	-5.96	62	Knuckey & Curtain (2001)

4. FISHERY INDEPENDENT DATA

4.1 Research trawl surveys

4.1.1 Biomass estimates

There have been no trawl surveys designed specifically to estimate sea perch abundance. The annual summer Chatham Rise *Tangaroa* bottom trawl survey time series, started in 1991, is the longest running ongoing survey that has consistently caught and measured sea perch in New Zealand. Other ongoing bottom trawl surveys that catch and measure sea perch are the autumn west coast South Island time series (started in 1997, run every 2–3 years), and the winter east coast South Island time series started in 1991 (with a hiatus from 1996 until 2007, now run every 2–3 years) and carried out by *Kaharoa*. Discontinued survey series that have caught sea perch include the *Tangaroa* surveys of Southland in February/March from 1993 to 1996 and *Kaharoa* summer surveys of the east coast South Island from 1996 to 2000. The ongoing summer Sub-Antarctic survey by *Tangaroa* catch very few sea perch**.** Trends in biomass and length frequencies from these surveys are presented in Table 2 and Appendix A (Figures A1–A28).

Biomass estimates for the Chatham Rise time series range from 1 498 t to 8 417 t (Figure A1). These are the highest estimates of sea perch for any time series in New Zealand. Coefficients of variation are low, never exceeding 14% for the time series. Male biomass is slightly higher than female biomass in most years but not greatly so (Figure A2). This survey covers the appropriate depth range of the species and probably monitors abundance well. The peak biomass estimates in 2002–2003 are thought to reflect real increases in abundance and match increased commercial catches in SPE 4 during the same period (Beentjes at al. 2007). Beentjes et al. also analysed the Chatham Rise trawl survey biomass estimated from those stations west of 176° which constitutes SPE 3. There was no increase in biomass estimates west of 176°, nor was there an increase in commercial catches from SPE 3 from 2002–2003.

Biomass data from the Chatham Rise time series was also divided into regions east and west of 176° east (Figures A3–6) as was done by Beentjes at al. Biomass from the eastern Chatham Rise is consistently greater than from the western Chatham Rise, with an average east:west biomass ratio of 11:1 for the series. In both the east and west regions, male biomass contributes slightly more to the total biomass than females in most years but not greatly so.

Biomass estimates for the Southland time series are much lower than for the Chatham Rise and are relatively flat at 443–481 t (Figure A7). Coefficients of variation are higher, ranging from 26–32%. Males again contribute to slightly more of the total biomass than females but not greatly so (Figure A8). This time series was discontinued in 1996 and consisted of just four surveys. As such it is not recommended for use in monitoring sea perch abundance.

Biomass estimates for the east coast South Island winter series range from 1 444 to 2 984 t (Figure A9). Coefficients of variation are reasonable ranging from 21–31%. Biomass appears to increase slightly from 1991 to 1993 then decline until 1996. When the time series resumed in 2007, biomass was similar to 1996, and has been relatively flat since. Males again contribute slightly more of the total biomass than females (Figure A10). The time series probably provides a reasonable index of abundance for the area.

Biomass estimates for the east coast South Island summer series fluctuate more and are higher than for the winter series, ranging from 1 638 to 4 046 t (Figure A11). These higher values are associated with higher coefficients of variation as well (range 19–47%). Males and females contribute about equally to the biomass except in 1996 when males are more abundant (Figure A12). The series was discontinued in 2000 and should not be used to monitor abundance on the east coast South Island.

Biomass estimates for the west coast South Island autumn series are the lowest overall of any time series in New Zealand ranging from 76 to 667 t (Figure A13). Coefficients of variation range from 14–38% but are usually around 19–22%. Abundance appears to decline from 1995 to 2003 but has been increasing since. As in other areas, males contribute slightly more of the biomass than females (Figure A14).

4.1.2 Length frequencies

Numbers of individual sea perch measured for length frequencies on the Chatham Rise time series range from 1 065 to 4 596. Sex ratios are about even with a mean male:female ratio of 1.08 for the time series (range 0.87–1.76). For all fish combined, total length ranges from 9–58 cm (Figures A15–A17). Most fish of both sexes are 15–40 cm, usually with a peak at around 25 cm. There does not appear to be a difference in maximum size between the sexes. Mean length has decreased slightly from 28.8 cm at the beginning of the time series to 26.2 cm in 2010. Tracking cohorts through time is difficult but in some years juvenile modes at around 10–15 cm appear and can sometimes be tracked in later years. Otoliths have been collected from three Chatham Rise trawl surveys: TAN0201 (n = 624), TAN0301 (n = 441), and TAN0601 (n = 842). Length frequency modal progression from the Chatham Rise and east coast South Island trawl surveys are in agreement with von Bertalanffy growth curves (Beentjes et al. 2007, Paul & Horn 2009). The development of a catch-at-age history is quite likely to be possible. From the three Chatham Rise surveys where sea perch otoliths were collected, fish aged 14 to 17 years were dominant, but fish aged to 30 years were still relatively common. The maximum observed age was 59 years.

As was done for biomass, length frequency data from the Chatham Rise was analysed by eastern and western divisions, split at 176° east. Fish lengths between the two areas appear to be very similar (Figures A18–23). Mean sex ratios for the two regions are also similar to each other with a mean male:female ratio of 1.07 (range 0.76–1.74) and 1.09 (range 0.77–1.55) for the eastern and western Chatham Rise regions respectively. Scaled population numbers are much lower for the western Chatham Rise than the eastern Chatham Rise. This is unsurprising given that fish are similar sizes between the two regions, but biomass is much lower on the Western Chatham Rise.

Numbers of individual sea perch measured for length frequencies on the Southland time series range from 501–843. Sex ratios are about even with a mean male:female ratio of 1.18 for the time series (range 1.06–1.36). For both sexes, fish range from 10–57 cm total length (Figures A24). Most fish of both sexes are 15–40 cm, similar to the Chatham Rise but usually with a larger peak at around 35 cm. It appears that more males than females grow to more than 40 cm. If exploitation of sea perch is lighter in Southland than for the east coast South Island and Chatham Rise then this may explain why the peak of length distributions are further to the right in the former. However, this time series only consisted of four surveys and the distributions are patchy, making it difficult to track any cohorts that may exist. Otoliths were not collected from the series either and a catch-at-age history cannot be developed for the region.

Numbers of individual sea perch measured for length frequencies on the winter east coast South Island time series range from 1 878 to 4 112. Sex ratios are about even with a mean male:female ratio of 1.16 for the time series (range 0.95–1.39). For both sexes, fish range from 9–50 cm total length (Figures A25–26). Most fish of both sexes are 15–35 cm, usually with a peak at around 20–25 cm. Fewer fish appear to grow beyond 40 cm here compared with Southland and the Chatham Rise. There does not appear to be a difference in maximum size between the sexes. Mean length for the time series has essentially remained the same through the time series at 24.5 cm in 1991 and 24.9 cm in 2009. Apart from the presence of small juvenile modes (10–20 cm) there are no obvious cohorts to track through time. Otoliths have been collected from sea perch on this survey since 2007 making it potentially possible to develop a catch-at-age history for the region. It has been suggested that the smaller size of fish here compared with the Chatham Rise indicate that this may be an important nursery area for sea perch and/or that they are separate stock (Beentjes et al. 2007). Differences in von Bertalanffy growth curves between the Chatham Rise and the east coast South Island also suggest that they are different stocks. However the east coast South Island survey doesn't sample deeper than 400 m and sea perch are found as deep as 800 m. It may be that this survey doesn't adequately sample the size range if their distribution is not fully covered by it and sea perch have been shown to be larger at deeper depths (Beentjes et al. 2007). Alternatively, if the hypothesis discussed in Section 3.1 is true, the east coast South Island series may be sampling mainly *H. percoides* while the Chatham Rise survey may be sampling mainly *H. sp. A*. It is thought that *H. percoides* are found from 0–250 m in depth, with a peak at around 150 m, a range essentially covered by the east coast South Island trawl survey (30–400 m). *H. sp. A* is thought to occur from 250–700 m, a depth range fully covered by the Chatham Rise survey (200–1300 m). The differences in size and growth curves between sea perch caught on the east coast South Island and the Chatham Rise may be due to each survey sampling different species. Numbers of individual sea perch measured for length frequencies on the summer east coast South Island time series range from 1 912–3 183. This is the only time series where there are overall fewer males than females, though not drastically so with a mean male:female ratio of 0.94 for the time series (range 0.85–1.20). For both sexes, fish range from 6–50 cm total length (Figure A27). There appear to be a higher number of fish less than 20 cm compared to the winter time series of the same area, although 1996 is the only comparable year between the two surveys. Most fish of both sexes are 15–35 cm, usually with a peak at around 20–25 cm, similar to the winter time series of the same area. There does not appear to be a difference in maximum size between the sexes, and few fish exceed 40 cm. Mean length decreased slightly over the time series from 26.9 cm in 1996 to 25.7 cm in 2000. Length frequencies are mainly unimodal but in some years there appears to be a juvenile mode at around 10–15 cm.

Numbers of individual sea perch measured for length frequencies on the autumn west coast South Island time series range from 741–2 383. Sex ratios are slightly higher for males with a mean male:female ratio of 1.32 for the time series (range 1.09–1.57). For both sexes, fish range from 5–41 cm total length (Figure A28). Most fish of both sexes are 10–30 cm, usually with a peak at around 16–18 cm, considerably smaller than fish in all other survey areas. There does not appear to be a difference in maximum size between the sexes. Mean length has decreased slightly from 19.8 cm in 1997 to 18.5 cm in 2011. Tracking cohorts through time is difficult, and there doesn't appear to be the juvenile mode at 10–15 cm that is seen in some years for other survey areas. Otoliths are not collected from sea perch on this time series so creating a catch-at-age history is not currently possible. The noticeably smaller size of sea perch on the west coast may indicate that this is a nursery ground for other areas, or that it may be a separate stock. The west coast South Island is also quite geographically distinct and the difference in size may be due to the survey sampling more *H. barathri* rather than *H. percoides* (see Section 3.1). The survey ground covers depth ranges and geographical areas where both hypothesized species are thought to occur.

Table 2: Biomass estimates (t) and their coefficients of variation (c.v.) for sea perch from Tangaroa (TAN) and *Kaharoa* (KAH) trawl surveys (Assumptions: areal availability, vertical availability and vulnerability = 1).

Trip code	Date	Biomass estimate (t)	c.v. (%)
Chatham Rise			
TAN9106	Dec 91–Feb 92	3 085	12
TAN9212	Dec 92–Feb 93	3 124	9
TAN9401	Jan-94	3 919	11
TAN9501	Jan–Feb 95	1 498	9
TAN9601	Dec 95–Jan 96	3 006	10
TAN9701	Jan–Jan 97	2 773	14
TAN9801	Jan–Jan 98	3 397	14
TAN9901	Jan–Jan 99	4 842	9
TAN0001	Dec 99–Jan 00	4 776	8
TAN0101	Dec 00–Jan 01	6 310	10
TAN0201	Dec 01–Jan 02	8 417	8
TAN0301	Dec 02–Jan 03	6 904	8
TAN0401	Dec 03–Jan 04	5 786	13
TAN0501	Dec 04–Jan 05	4 615	11
TAN0601	Dec 05–Jan 06	5 752	10
TAN0701	Dec 06–Jan 07	4 736	10
TAN0801	Dec 07–Jan 08	3 170	14
TAN0901	Dec 08–Jan 09	5 149	13
TAN1001	Jan-10	5 594	12
Southland (summer)			
TAN9301	Feb–Mar 93	469	32
TAN9402	Feb–Mar 94	443	26
TAN9502	Feb–Mar 95	450	26
TAN9604	Feb–Mar 96	481	28
East Coast South Island (winter)			
KAH9105	May–Jun 1991	1 553	29
KAH9205	May–Jun 1992	1 934	27
KAH9306	May–Jun 1993	2 948	31
KAH9406	May–Jun 1994	2 342	28
KAH9606	May–Jun 1996	1 671	25
KAH0705	May–Jun 2007	1 954	21
KAH0806	May–Jun 2008	1 944	23

Trip code	Date	Biomass estimate (t)	c.v. (%)
KAH0905	May–Jun 2009	1 444	25
East Coast South Island (summer)			
KAH9618	Dec 96–Jan 97	4 046	47
KAH9704	Dec 97–Jan 98	1 638	24
KAH9809	Dec 98–Jan 99	3 889	40
KAH9917	Dec 99–Jan 00	2 206	26
KAH0014	Dec 00–Jan 01	1 792	19
West Coast South Island			
KAH9204	Mar–Apr 92	242	22
KAH9404	Mar–Apr 94	426	17
KAH9504	Mar–Apr 95	667	22
KAH9701	Mar–Apr 97	338	14
KAH0004	Mar–Apr 00	302	22
KAH0304	Mar–Apr 03	76	25
KAH0503	Mar–Apr 05	150	19
KAH0704	Mar–Apr 07	163	19
KAH0904	Mar–Apr 09	336	19
KAH1104	Mar–Apr 11	558	38

5. FISHERY DEPENDENT DATA

5.1 Observer programme data

5.1.1 Length and age sampling

The Ministry for Primary Industries Observer Programme has collected sea perch length, weight, female gonad stage, and otoliths since 1986. Tables and figures summarising observer data are provided in Appendix B (Tables B1–12, Figures B1–18).

Most tows from which sea perch have been measured for length have come from the northern Chatham Rise (205), followed by Canterbury (164), western Chatham Rise (130), southern Chatham Rise (103), Southland (56), eastern Chatham Rise (52), west coast South Island (41), and east coast North Island (17) (Table B1). 60 tows from all other regions combined have also measured sea perch for length.

Table B2 shows the number of tows by month and fishing year that measured sea perch for all areas combined. For the Canterbury region tows measuring sea perch have been fairly sporadic (Table B3). Sea perch have been sampled from the eastern Chatham Rise in only six years (Table B4). For years where there is available data it appears that fewer tows measure sea perch in winter months when vessels target hoki in Cook Strait and west coast South Island. A similar pattern is seen for the other three regions that the Chatham Rise was divided into for this study (Tables B5–7). Observed tows measuring sea perch for Southland are also mainly from late spring to early autumn, with none from June to October (Table B8). For the west coast South Island observed tows are restricted almost exclusively to winter and very early spring during the hoki spawning season (Table B9). Just 17 sporadically sampled tows over six years gives little indication of any pattern to when sea perch are most likely to be sampled from the east coast North Island (Table B10). No lengths have been taken for sea perch from the Marlborough region.

The representativeness of observer coverage of sea perch 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 B1–11). 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 the Marlborough region had low coverage until the last four years (note that catch was observed but biological measurements not taken). Aside from a few years in the early 1990s the Canterbury region is generally well covered. Most other regions fluctuate but in general coverage is adequate.

5.1.2 Length and age frequencies

Scaled length frequencies were determined using the ‘Catch at Age’ software (Bull 2002). This process scales the length frequency sample from each tow up to the total 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 sea perch were estimated from catch weights using the length-weight relationship calculated by Schofield & Livingston (1996).

Sampling of fish for lengths from the Canterbury region has been patchy and inconsistent (Figure B12–13). A number of years have not sampled sea perch for length at all (e.g. pre-1998, 2000, and 2009). Years where fish are measured have typically only sampled a few tows (3–19 tows per year) and low numbers of fish (37–381 fish per year). Length frequency plots are usually unimodal and occasionally bimodal but the tracking of cohorts through time is difficult. Most fish of both sexes are 20–40 cm total length (TL). There are more females than males growing larger than 40 cm. Very few fish of either sex grow longer than 50 cm.

Length frequencies from the observer programme for the northern Chatham Rise are presented in Figures B14–15. The number of observed tows sampling sea perch from the northern Chatham Rise was 10–32 tows per year. Modes are more distinct than for the Canterbury region and often more than one mode is present (i.e., 2003 to 2005). Larger numbers of fish were sampled from 2003 to 2005, consistent with the peak biomass estimates from the Chatham Rise trawl survey, and increased commercial landings at this time. However the number and size of samples is still small and what appears to be a mode in one year could potentially be the result of a single tow catching fish of a particular size class rather than the existence of a true mode. The northern Chatham Rise also seems to catch more fish under 20 cm TL and in a number of years a mode from about 11–19 cm is present (i.e., 2004, 2005, 2007). As for the Canterbury region most fish of both sexes are 20–40 cm TL but there appears to be little difference between sexes for fish growing larger than 40 cm. Few fish of either sex are longer than 50 cm.

Scaled length frequencies from the southern and western areas of the Chatham Rise are shown in Figures B16–17. The fish from the southern Chatham Rise appear to be larger than elsewhere with most fish being 30–50 cm as opposed to 20–40 cm elsewhere. Sea perch from the western Chatham Rise appear to be mainly 20–40 cm TL as they are in other regions. However, both areas have small sample sizes and patchy distributions. There are no obvious cohorts than can be tracked and this data should be treated with caution.

Table B12 gives the number of sea perch otoliths collected by QMA and fishing year by the observer programme. Currently, the rate of collection of sear perch otoliths is likely to be too low to create a catch-at-age history. However, observer coverage is reasonably high in the target hoki fishery which accounts for much of the sea perch catch. This, combined with the methodology for ageing sea perch developed by Paul & Horn (2009), means that there is potential to develop a catch-at-age history using otoliths collected by the observer programme if collection rates were increased.

5.1.3 Female maturity

Observer collected data on female maturity stage has used a 5-stage gonad scale (immature/resting, maturing, ripe, running ripe, spent). The majority of samples have come from the northern Chatham Rise (1 547), followed by Canterbury (922), southern Chatham Rise (551), western Chatham Rise (486), other areas (315), east coast North Island (282), eastern Chatham Rise (186), Southland (171), and west coast South Island (145). No gonad information has been collected from the Marlborough region.

The proportions of each gonad stage by month for all years combined are plotted in Figure B18. At most times of the year for all areas combined most fish are immature/resting or maturing. Ripe or running ripe fish appear to be present from September through May with peaks in September/October and February/May. Spent fish are most prevalent from September to December and in April.

Based on gonad data from the Northern and western Chatham Rise it appears that sea perch spawning takes place from late spring to early summer (Figure B18). Sea perch from Canterbury appear to have two spawning peaks; one in early spring and another in mid to late summer. Data from other areas are too sparse (often completely absent) to draw confident comparisons but spawning activity is seen in spring for the eastern and southern Chatham Rise, summer in Southland, winter/spring for the west coast South Island (the only period for which there is data for this area), and spring for the east coast North Island.

6. FISHERY CHARACTERISATIONS

6.1 Overview

The vast majority of sea perch landed in New Zealand is taken from SPE 3 and SPE4 (Figure 2). Roughly equal quantities have come from these two quota management areas, although landings from SPE 4 rose substantially, and thus represented a greater proportion of landings, during the early 2000s. Landings from other QMAs are minor in comparison.

In both SPE 3 and SPE 4, the majority of catch is taken by bottom trawling (Figure 3). However, the main target species differ between areas. Although hoki is an important target species in both areas, in SPE 3 a significant proportion of sea perch is also taken by targeting of inshore species such as red cod, barracouta and tarakihi, whereas in SPE 4 targeting of deeper water species such as hake and scampi results in more bycatch of SPE. In both areas, sea perch is also caught as a bycatch of bottom longlining targeting ling.

The difference in target species in SPE 3 and SPE 4 appears to reflect differing depth preferences of sea perch in those areas and the fact that in SPE 4 there is relatively little bottom trawling and almost no midwater trawling, in depths of less than 300 m. To examine the relationship between sea perch catch rates and depth, we calculated unstandardised catch-per-unit-effort by 20 m depth intervals for all QMAs across all years (Figure 4). There is a peak in CPUE at around 400 m in all areas apart from SPE 7. SPE 3 is distinctive in having a secondary peak in CPUE at around 100 m, and SPE 7 is distinctive in having a broad plateau of CPUE centred around 600 m. This separation by depth can also be seen in the spatial distribution of catches (Figure 5). Catches of sea perch in less than 250 m are highly concentrated off the east coast of the South Island, particularly off Canterbury, whereas catches in depths greater than this occur predominately on the Chatham Rise but also off the Wairarapa, Bay of Plenty and the west and east coasts of the South Island.

The observed spatial pattern in catch rates by depth when combined with the genetic analyses of Smith et al. (2009) forms the basis for the speciation and species distribution hypothesis suggested in Section 3.1. *H. percoides* appears to occur in depths less than 250 m primary off the Canterbury coast, *H. sp. A* occurs in depths greater than 250 m primarily on the Chatham Rise but also off the east coast of the South Island and the east and north-east coast of the North Island, *H. barathri* occurs in depths of 400 m or more off the west coast of the South Island.

We examined annual trends in CPUE in different depths and areas to further investigate (a) whether the populations of sea perch in different depths represented different stocks and thus potentially also different species, and (b) whether the populations in the same depths in different areas may be the same stocks and thus potentially the same species. A generalised linear model (GLM) was fitted to all catches of sea perch from bottom trawling targeting sea perch, hoki, red cod, ling, hake, scampi, squid, barracouta, tarakihi or flatfish. Only data from TCEPR or TCER forms where depth and latitude/longitude are available were used. Because this was an exploratory GLM, we assumed a lognormal error distribution and there was no stepwise selection of model terms. For the analysis, areas were defined based on latitude longitude boxes which captured geographically distinct areas of sea perch catch (Figure 6). A fishing year (*fyear*) by area interaction term was fitted so that annual trends could be compared across areas. The model formula was: *log(catch) ~ fyear:area + month:area + vessel + target + poly(log(depth),3)* and was fitted separately to tows from shallow(less than 250 m) and deep (greater than 250 m) water.

For shallow tows, assumed to represent catches of *H. percoides*, satisfactory CPUE indices could be obtained for the Bay of Plenty (BOP), Canterbury South (CAS), Otago (OTA) and Snares (SNA) (Figure 7). For other areas, including Canterbury North (CAN), there was insufficient data either because there is little fishing in shallow depths, or because prior to 2007–08 depth data is not available for inshore vessels using CELR forms. The annual trends for BOP, CAS, OTA and SNA show similar trends with a decline in CPUE during the 1990s, a nadir in the early to mid-2000s, followed by a subsequent modest increase. The similarity in these trends suggests that these are the same stock of *H. percoides*.

For deep tows, assumed to represent *H. barathri* off the WCSI and *H. sp. A* elsewhere, satisfactory CPUE indices could be obtained for most areas (Figure 8). The BOP and WAI (Wairarapa) indices show similar trends although for both there is a paucity of data in the early-1990s. There was a strong similarity in the indices from the four Chatham Rise areas, CRW, CRN, CRS and CRE (Chatham Rise West, North, South and East respectively). Note that CRW is a part of SPE 3 and the other Chatham Rise areas are all a part of SPE 4. The OTA and SNA indices show very similar trends and differ markedly from the Chatham Rise trends. The index for the west coast South Island (WEC) area, assumed to represent *H. barathri*, differs from all other areas exhibiting a strong increasing trend. The differences in trends between areas suggests that there may be separate stocks and/or species of *Helicolenus* in deeper waters. Note that there are no strong similarities between any of the shallow water indices and the deep water indices.

In the following subsections we characterise the catch of sea perch in each of four regions defined on the basis of statistical areas: Canterbury Coast (020, 022, 024), Chatham Rise (021,023,401–412,049–051), West Coast (033–036) and Kaikoura (018). It is necessary to define the regions on the basis of statistical area because the location of catches by latitudes and longitudes is not universally available prior to 2007–08. These regions do not attempt to reflect quota management areas but rather capture the primary areas where each of the three species of *Helicolenus* are caught according to the evidence presented earlier. We have separated off Kaikoura from the Canterbury Coast region because it is unique in having had a significant proportion of its landings from a target sea perch fishery.

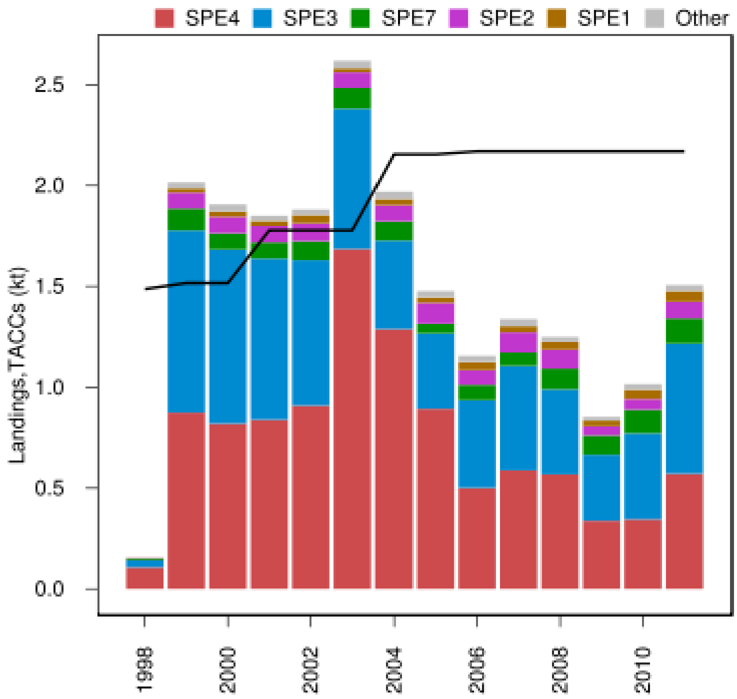


Figure 2: Commercial landings by QMA and combined total TACC for sea perch, for the 1997–98 to 2010–11 fishing years.

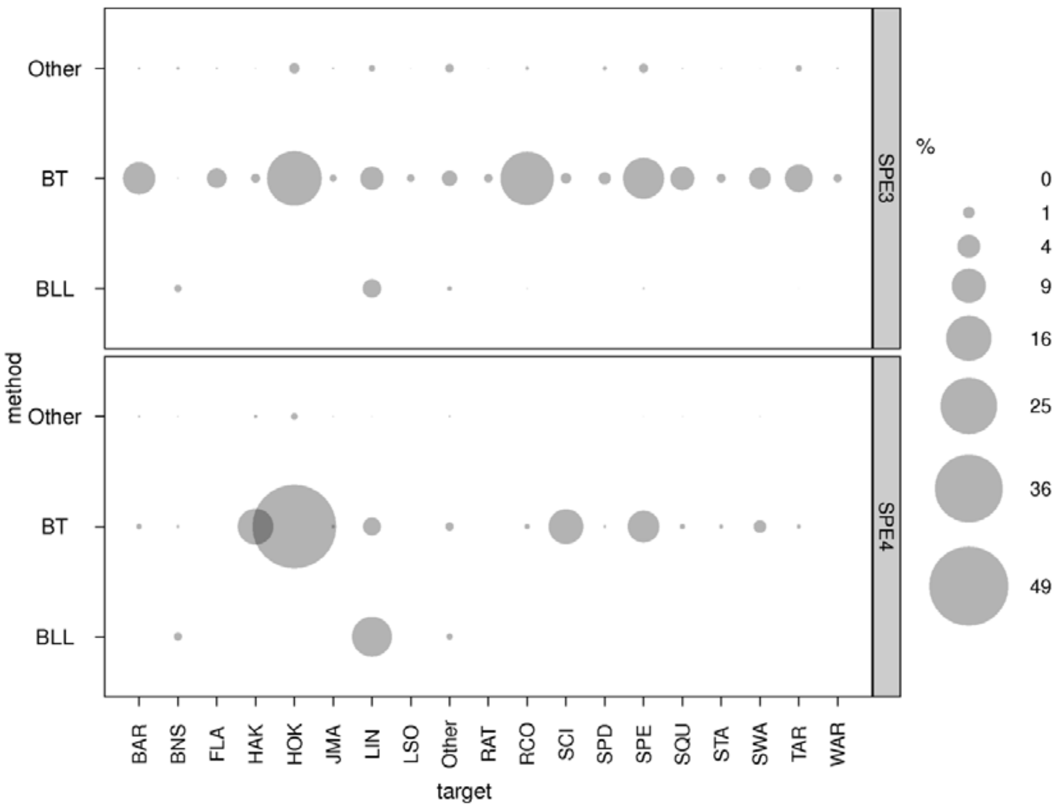


Figure 3: Proportion of sea perch catch taken by target species and method for SPE 3 and SPE 4 for the 1989–90 to 2009–10 fishing years. The area of each circle is proportional to the percentage of the total catch taken within each quota management area by each method/target combination.

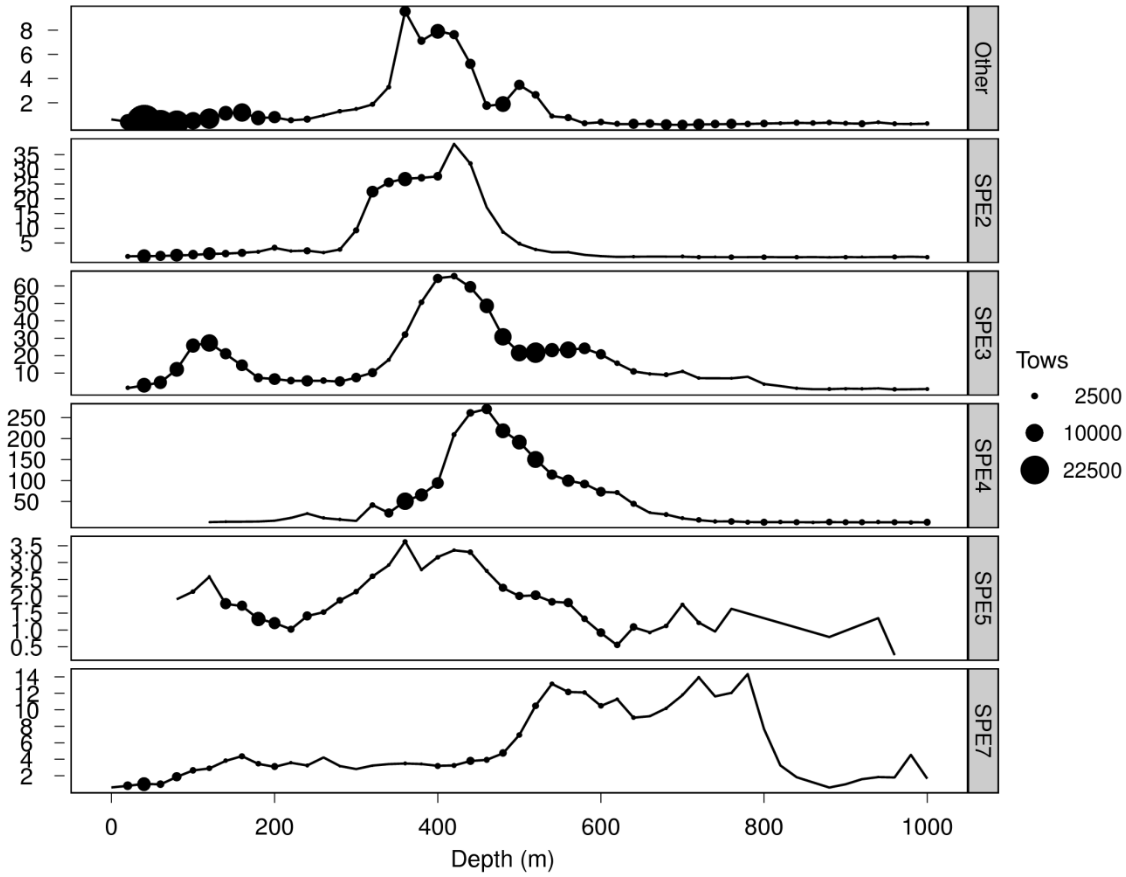
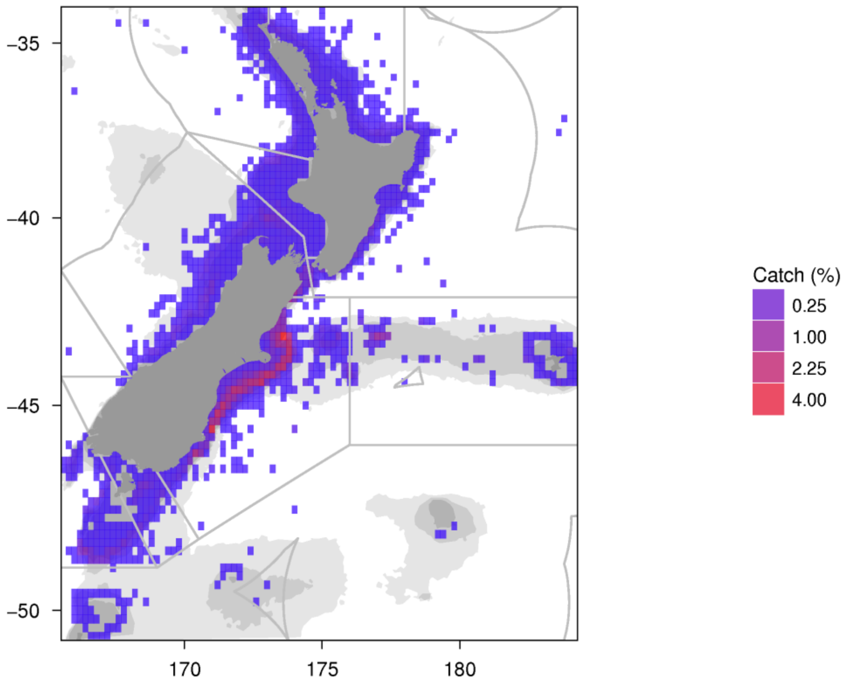


Figure 4: Catch per unit effort of sea perch from trawling by 20 m depth band for each quota management area. The size of the circles is proportional to the number of tows. CPUE is calculated as the geometric mean of sea perch catch per tow. Points are only shown if the number of tows represented is at least 300.

A



B

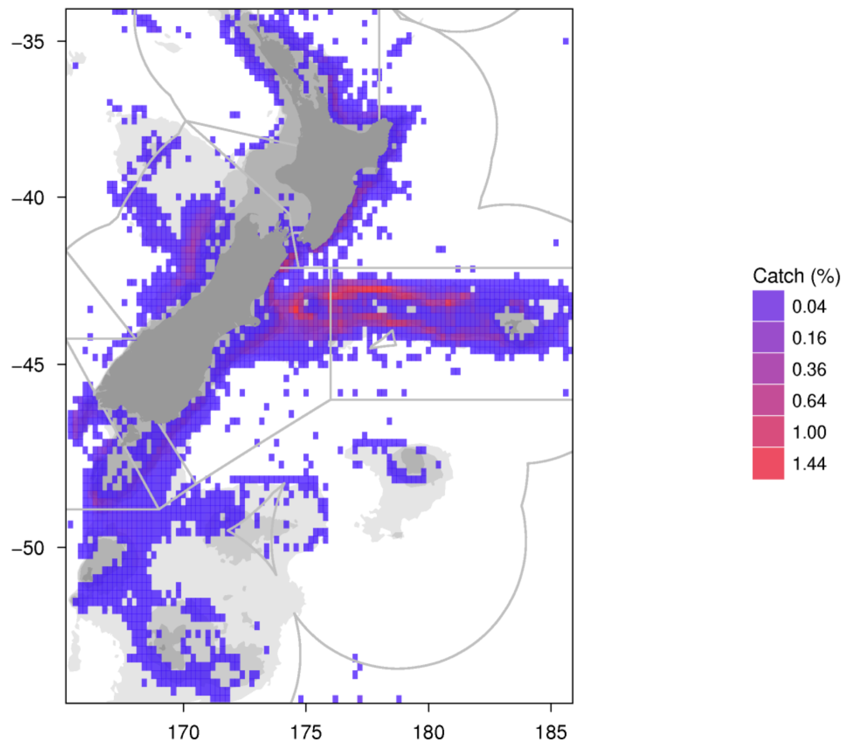


Figure 5: Spatial distribution of sea perch catches in (A) depths less than, or equal to, 250 m, and (B) depths greater than 250 m. Each cell represents a 0.2 degree square. In each panel the colour of each cell represents the percentage of catch taken in that cell over all fishing years, 1989–90 to 2009–10.

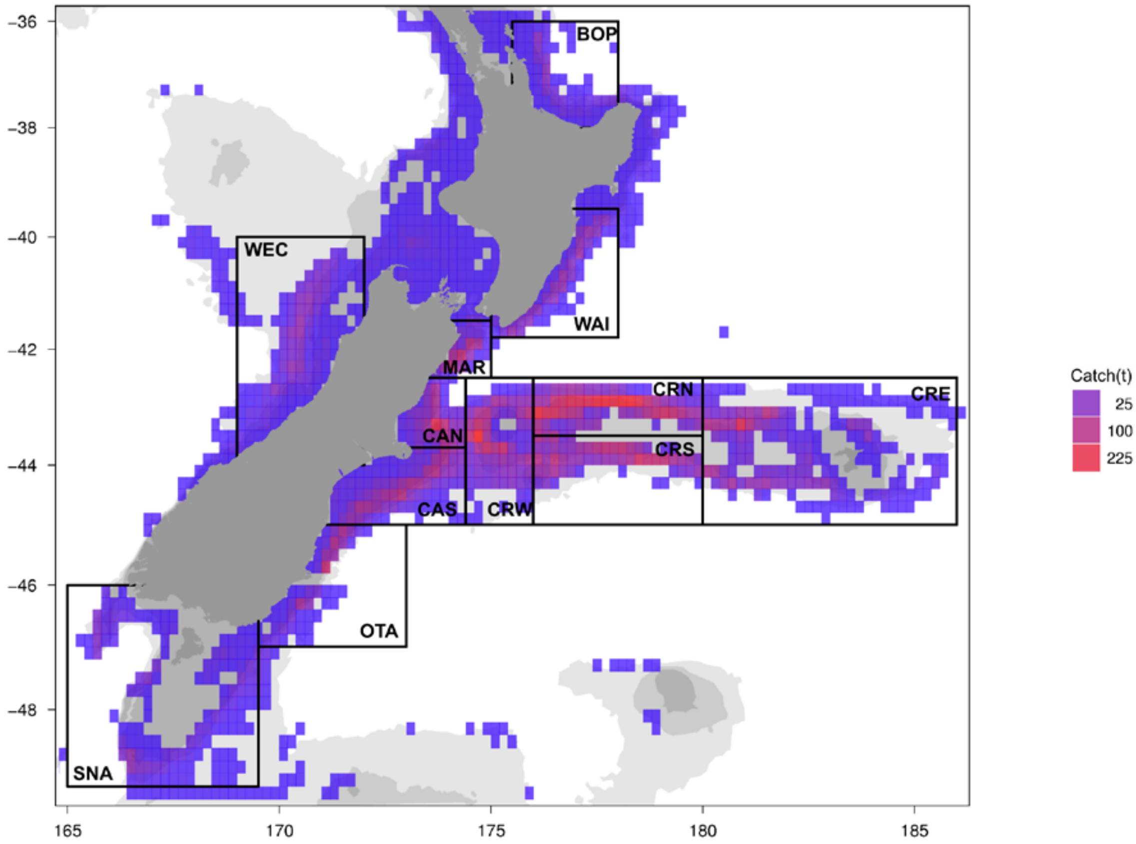


Figure 6: Areas defined for analyses of catch per unit effort: Bay of Plenty (BOP), Wairarapa (WAI), Marlborough (MAR), Canterbury North (CAN), Canterbury South (CAS), Chatham Rise West (CRW), Chatham Rise North (CRN), Chatham Rise South (CRS), Chatham Rise East (CRE), Otago (OTA), Snares (SNA) and West Coast (WEC). The total catch across all years is also shown.

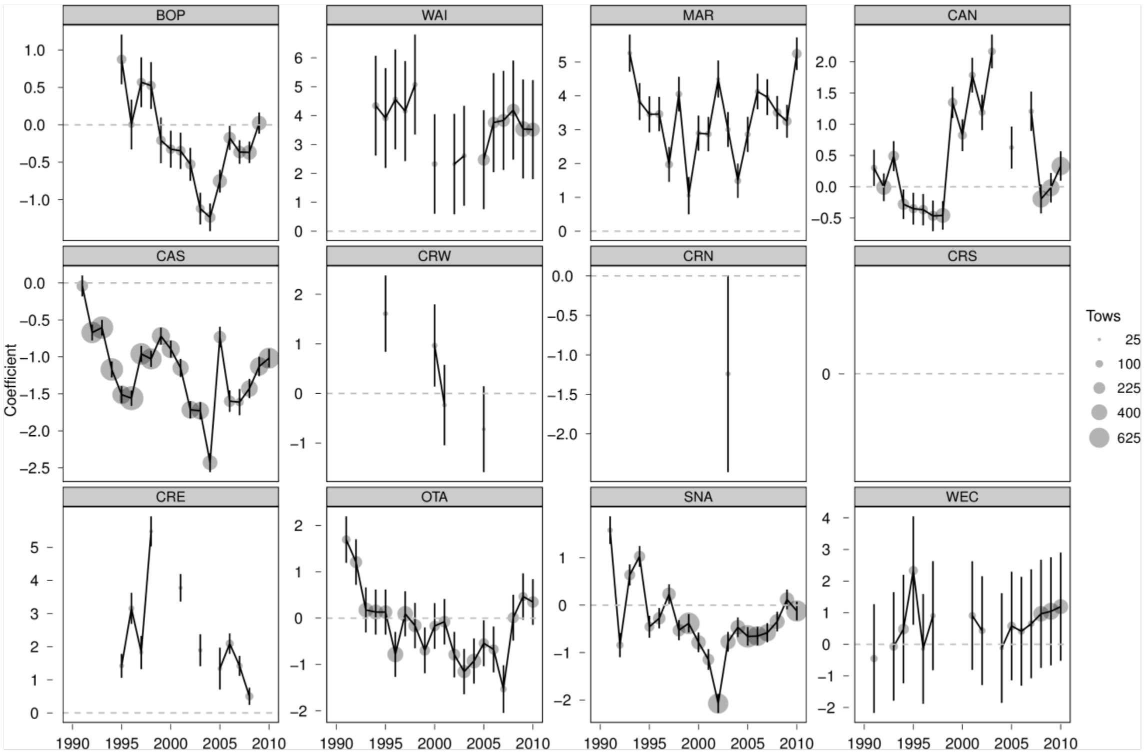


Figure 7: Estimated year coefficients for sea perch in depths less than or equal to 250 m for each area. Coefficients are from exploratory GLM model with a fishing year x area interaction estimated and are in log space. The size of circles indicates the number of tows that each coefficient is estimated from. Fishing years are labelled according to the latter calendar year e.g. 1990 = the 1989–90 fishing year.

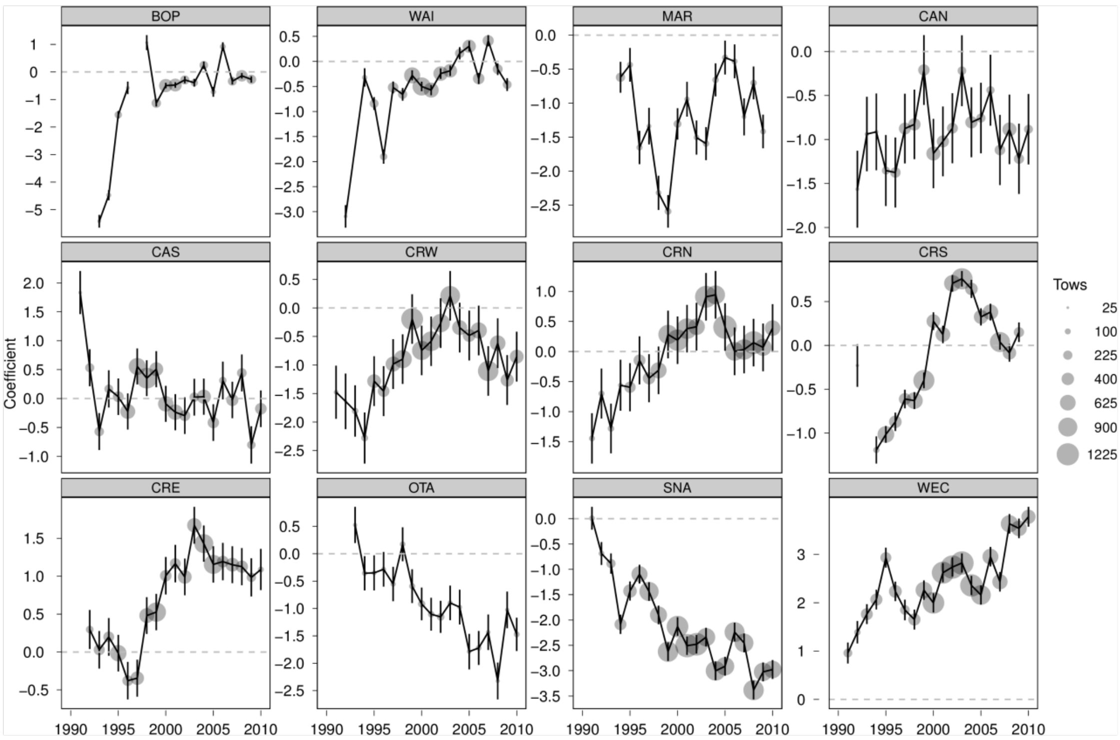


Figure 8: Estimated year coefficients for sea perch in depths greater than 250 m for each area. See Figure 7 caption for further details.

6.2 Canterbury Coast

From 2005–2006 to 2009–10, catches of sea perch off the Canterbury coast (areas 020, 022, 024) ranged from 235 to 323 t. During the early 2000s catches in this region reached over 450 t. A large proportion of sea perch caught off the Canterbury Coast is from bottom trawling targeting red cod in areas 020 and 022 and hoki in area 020 (Figure C8). Barracouta, tarakihi and sea perch are other important target species. There is a small proportion of sea perch caught using bottom longline in 020. There are no substantial differences in the spatial distribution of catch across months (Figure C12). Over time, there has been a gradual increase in the proportion of sea perch taken from area 020 (Figure C10). Historically, most sea perch was caught in autumn to early winter but in the most recent years a greater proportion has been taken in late winter and spring (Figure C11).

6.3 Chatham Rise

Catches of sea perch on the Chatham Rise reached over 1800 t in 2002–03 but have since declined to 393 t in 2009–10. A large proportion of sea perch caught on the Chatham Rise is from bottom trawling targeting hoki although hake, ling, scampi and sea perch are also important target species (Figure C13). A small proportion of sea perch is caught using bottom longline targeting ling. Over time areas 401 and 402 on the northern Chatham Rise have remained the most important areas although sea perch catches are widely distributed through the region (Figure C15). Sea perch is caught throughout the year although spring and early summer appear to be the most important (Figure C16).

6.4 West Coast South Island

Off the west coast of the South Island (036,035,034,033) annual catches of sea perch have been less than 100 t in all years since 1989–90. In 2009–10, they were 73 t. The vast majority of the sea perch catch is taken by bottom or midwater trawling targeting hoki or hake from June to September during the spawning season in areas 034 and 035 (Figure C17). There are some catches from bottom trawling targeting inshore species such as barracouta and tarakihi but these are relatively minor. Catches from deeper waters in the vicinity of the Hokitika Canyon dominate during June to September but smaller catches from shallower inshore waters occur year round (Figure C21). According to our species hypothesis catches from deeper water are *H. barathri* and those from shallow water are *H. percoides*. The spatial and seasonal distribution of sea perch catch has remained relatively constant (Figures C19-C20).

6.5 Kaikoura

Sea perch is caught off Kaikoura (statistical area 018) by bottom trawling targeting a variety of species (Figure C22). Targeting of sea perch was once important but this fishery has since ceased (Starr et al. 2008). In 1999–2000, catches peaked at 302 t and have fallen to less than 100 t in all years since 2005–06. Most of the catch is now taken by bottom trawling targeting hoki, red cod, barracouta, flatfish and tarakihi. Traditionally most of the catch was taken during the winter and early spring but recently summer and autumn are more important seasons (Figure C24).

6.6 Other areas

The catch of sea perch in all other areas combined has been between 100 t and 200 t since 1999–2000. In these areas it is taken mainly by bottom trawling targeting hoki, scampi, squid, silver warehou and tarakihi although bottom longlining for ling and other species has taken a significant proportion as well (Figure C25). The proportion of catches from the south of the South Island (areas 026–028) have declined and the proportion from the Wairarapa coast (areas 014–015) and Bay of Plenty (008–009) have increased (Figure C27).

7. CPUE ANALYSES

Catch-per-unit-effort analyses were done for the two key areas for sea perch catches: the east coast South Island (ECSI) and the Chatham Rise (CR). As far as possible, data was subdivided so that each analysis represents the primary species, according to our species hypothesis, in each of these areas i.e. *H. percoides* off ECSI and *H. sp. A* on the Chatham Rise. For each of these areas we conducted two CPUE analyses of bottom trawl catches using alternative data sets.

A CPUE analysis was also attempted for sea perch bycatch from bottom longline targeting ling (mostly occurring in SPE 4). However, the data included few vessels (less than 20 in most years) and less than 150 t in all years. Although a CPUE standardisation model could be fitted, the sparse nature of the data meant we had little confidence in the resultant index. Those analyses are not presented.

A CPUE analysis was also attempted for sea perch bycatch from the west coast South Island hoki fishery. According to our species hypothesis, this bycatch represents *H. barathri*, the third species occurring in New Zealand waters. A standardisation model could be fitted to this data. However, although the proportion of trips landing sea perch is relatively high (more than 80 % in all years since the 2000–01 fishing year), the total catches were small (less than 50 t in most years) and as such there was little confidence in the resulting CPUE index. Those analyses are not presented.

7.1 East Coast South Island *H. percoides* using aggregated data

Details for this CPUE analysis are provided in Appendix D.

7.1.1 Data subset and core vessel selection

This analysis used catch and effort data from bottom trawling targeting sea perch, tarakihi, barracouta, red cod or flatfish in statistical areas 018, 020, 022, 024 or 026. These target species and areas were chosen so that, as far as possible, the dataset represented fishing effort which was likely to catch *H. percoides*. It intentionally excludes data from non-coastal statistical areas of SPE 3 such as areas 021 and 023, which are likely to catch *H. sp. A* in the hoki target fishery. Only data from TCEPR, CELR and TCER forms were used. Data were aggregated to strata representing a unique combination of vessel, date, area, method and target. This is the intended level of reporting detail for effort on CELR forms.

Alternative core vessels selection criteria were investigated by considering the reduction in the number of vessels against the reduction in the percentage of catch represented (Figure D1). A criterion of vessels that had fished caught sea perch on at least five trips in each of at least five years was chosen which resulted in a core fleet size of 58 vessels which took 84% of the total catch. Most of the core vessel had more than 12 years history in the data and there was good overlap across years (Figure D2, Figure D3). The proportion of strata with positive catches and unstandardised CPUE were similar between the core vessels and all vessels (Figure D4–D5). The sudden drop in the proportion of positive catches in the 2007–08 fishing year is likely to be due to the change from CELR to TCER forms which resulted in better reporting of target species at the stratum level and therefore less roll-up of catches into the aggregation strata.

7.1.2 Selection of error distribution and model terms

A generalised linear model (GLM) was developed for the catch from tows with positive catches. 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 + target*. On this basis the lognormal distribution was selected (Figure D6).

An initial lognormal model with term for fishing year was fitted followed by forward stepwise selection of the following terms: *month*, *area*, *vessel*, *poly(log(duration), 3),* and *poly(log(num), 3).* The final model included the terms *vessel*, *target*, *poly(log(num), 3)*, *month* and *area* and had a pseudo-coefficient of determination of 29.3% (Table D4).

7.1.3 Influence of model terms on standardisation

The standardised CPUE index is similar to the unstandardised index with the most substantial difference being a greater upturn since 2007–08 for the standardised index (Figure D7). This is due to the change in forms from CELR to TCER which reduces the number of tows per stratum which in turn depresses the catch per stratum as represented by the unstandardised index. As a result of this effect, the number of tows is the most influential term followed by vessel and target (Table D4). Note that the standardisation effects of vessel and target somewhat counteract each other and there is probably some degree of confounding between these variables (Figure D8). The standardisation suggests that there has been a shift in the fleet composition towards vessels that have a lower catch rate of sea perch (Figure D9) but that this is counteracted by increased targeting of tarakihi which has higher catch rates for sea perch (Figure D10). Note that there are quite large differences in standardisation coefficients among months and areas but because the distribution of effort across these variables has changed little they have had little influence on the standardisation (Figures D12–D13).

Analysis of model residuals shows that there are similar annual patterns across target species and areas (Figures D15–16) and seasonal patterns across areas (Figure D17) and do not suggest that interaction terms are required. Residuals were also summarised by the mean depth of tows with a vessel-date-target-area stratum (for those strata reported on TCEPR or TCER forms where depth was available). This shows increased catch rates with depth up to a maximum near 125 m and then declining again. This pattern is consistent across target species and month (Figures D18–19) although there is evidence that the depth of peak catch rates differs among areas (Figure D20).

7.1.4 CPUE index

Final standardised CPUE indices for *H. percoides* from the Canterbury coast inshore fishery are provided in Figure 9 and Table D6.

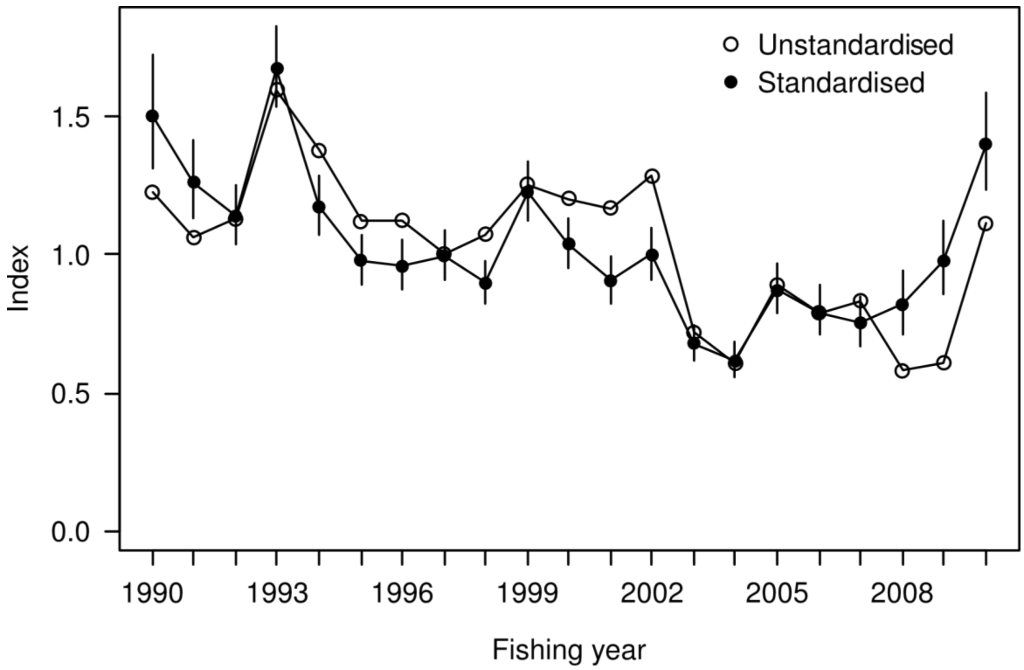


Figure 9: Standardised and unstandardised CPUE indices for sea perch from the Canterbury coast inshore fishery. Fishing years are labelled according the latter calendar year e.g. 1990 = the 1989–90 fishing year. The standardised index is from the base-case GLM (see text for details). The unstandardised index is based on the geometric mean of the catch per stratum and thus is not standardised for changes in fishing effort.

7.2 East Coast South Island *H. percoides* using shallow tow data

An additional CPUE analysis for the east coast South Island was done using data from individual tows recorded on TCEPR or TECR forms in water less than 250 m. Although this CPUE analysis allows for more detailed data on individual tows, such as latitude/longitude, to be used, it excludes a large proportion of the catch that was recorded on CELR forms prior to the 2007–08 fishing year. Thus, it is provided principally as a supplement to the previous CPUE analysis for the ECSI that used aggregated data and included CELR forms. Details for this CPUE analysis are provided in Appendix E.

7.2.1 Data subset and core vessel selection

This analysis used catch and effort data from bottom trawling targeting hoki, barracouta, tarakihi, red cod, flatfishes, sea perch, ling, squid, hake, scampi, or silver warehou in areas MAR, CAN, CAS or OTA (see Section 6 for definitions of these areas) and reported on TCPER or TCER forms. In addition, so that, as far as possible, the dataset represented catch of *H. percoides* only tows where both the depth of tow and bottom depth was between 20 and 250 m were used. Some other restrictions were placed on the height, width, speed and duration of tows to remove likely reporting errors. The resulting dataset involves a relatively small number of vessels (a maximum of 24 in the 1999–00 fishing year) and low volume of catches (a maximum of 196 t in the 1992–93 fishing year) (Table E1).

Alternative core vessels selection criteria were investigated by considering the reduction in the number of vessels against the reduction in the percentage of catch represented (Figure E1). The criterion that vessels had to have caught sea perch on at least three trips in each of at least three years was chosen. This resulted in a core fleet size of 49 vessels which took 88% of the catch in the dataset over all years. Most of the core vessels only had three years history in the data, corresponding to the last three years when TCER forms replaced CELR forms for trawling. There was adequate, albeit limited, overlap of vessels across years (Figure E2, Figure E3). The proportion of tows with positive catches and the unstandardised CPUE were similar between the core vessels and all vessels (Figures E4–E5). There was reasonable overlap in vessel activity across the CAN, CAS and OTA areas while the vessels which fished in MAR had limited, or no, effort recorded in the other areas. This was likely to result in confounding between the coefficients for MAR and the coefficients for the vessels that fished in that area.

7.2.2 Selection of error distribution and model terms

A generalised linear model (GLM) was developed for the catch from tows with positive catches. 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 + target*. On this basis the lognormal distribution was selected (Figure E7).

An initial lognormal model with term for fishing year was fitted followed by forward stepwise selection of the following terms: *month, area, target, vessel, poly(log(duration), 3), poly(log(num), 3), poly(log(speed), 3), poly(log(depth), 3), poly(time, 3), poly(moon, 3)*. The final model included the terms *poly(log(depth), 3), vessel, area, target, month and poly(log(speed), 3)*. Other model terms were statistically significant according to the AIC criterion but were not included because they only increased the coefficient of determination (R^2) slightly. The final model had a pseudo-coefficient of determination of 35.4% (Table E3).

7.2.3 Influence of model terms on standardisation

The standardised CPUE index is similar to the unstandardised index with the most substantial difference being prior to the 1993–94 fishing year (Figure E8). Nonetheless, depth, vessel, area and target are all estimated to have had relatively large influence on standardised CPUE (Table E4). However, the influence of these terms is mainly related to the change from CELR to TCEPR forms, is restricted to the last three years of data, and to a large extent, counteract each other. There is a strong influence of depth with peak catch rates at around 125 m being approximately 4 times the catch rates at either 50 m or 200 m (Figure E10). The smaller inshore vessels which entered the dataset with the introduction of TCER forms in the 2007–08 fishing year generally had lower catch rates of sea perch (Figure E11). The changes in these two variables decreased unstandardised CPUE since the 2007–08 fishing year. However, this was counteracted by (a) a greater proportion of effort occurring in the CAN area which has a higher catch rate (Figure E12) and (b) a greater proportion of effort being targeted at tarakihi than other inshore species which have higher catch rates of sea perch (Figure E13).

Analysis of model residuals shows that there are similar annual patterns across target species (Figure E17). There is some suggestion from summaries of residuals that the annual and monthly patterns of catch rates may differ slightly for the MAR area (Figures E18-19). Residuals were also summarised by the depth of tow (Figures E21–23). There is evidence that the depth profile of catch rates differs by region with MAR being most different (Figure E23). Given these apparent differences, as well as the aforementioned lack of overlap in vessel activity, it is recommended that future CPUE analyses of this dataset do not include the MAR area.

7.2.4 CPUE index

Final standardised CPUE indices for *H. percoides* from the ECSI inshore fishery are provided in Figure 9 and Table E5.

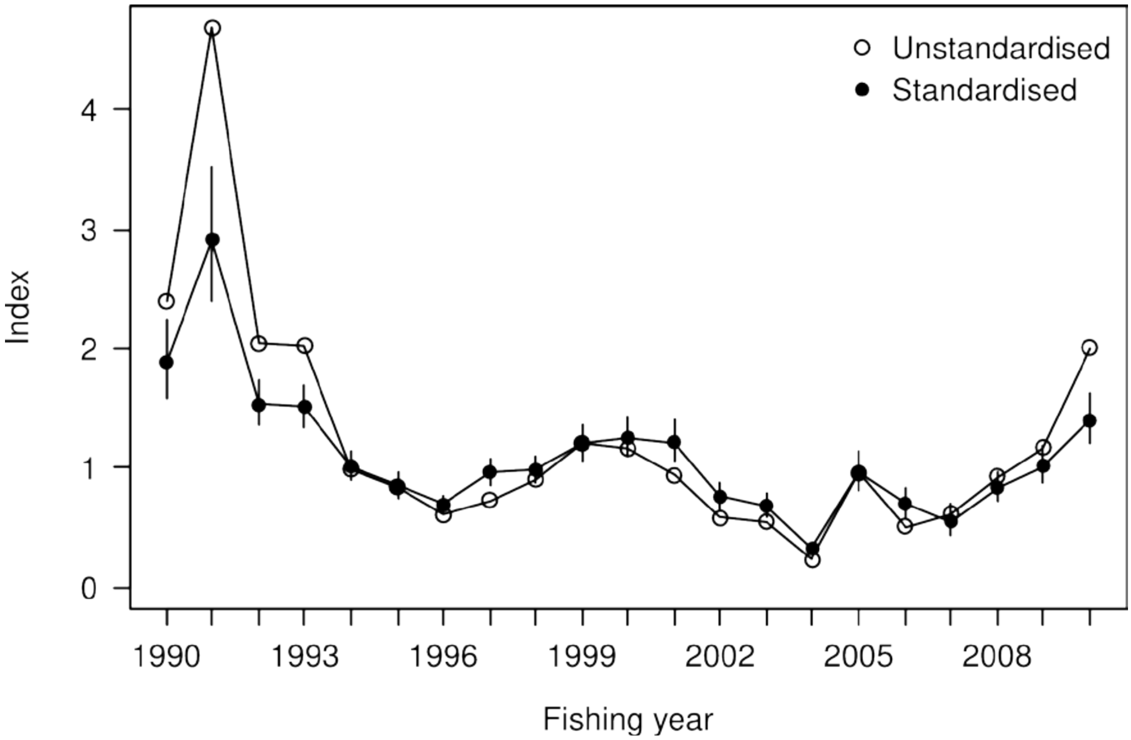


Figure 9: Standardised and unstandardised CPUE indices for sea perch from the ECSI inshore fishery. Fishing years are labelled according the latter calendar year e.g. 1990 = 1989–90. The standardised index is from the base-case GLM (see text for details). The unstandardised index is based on the geometric mean of the catch per tow and thus is not standardised for changes in fishing effort.

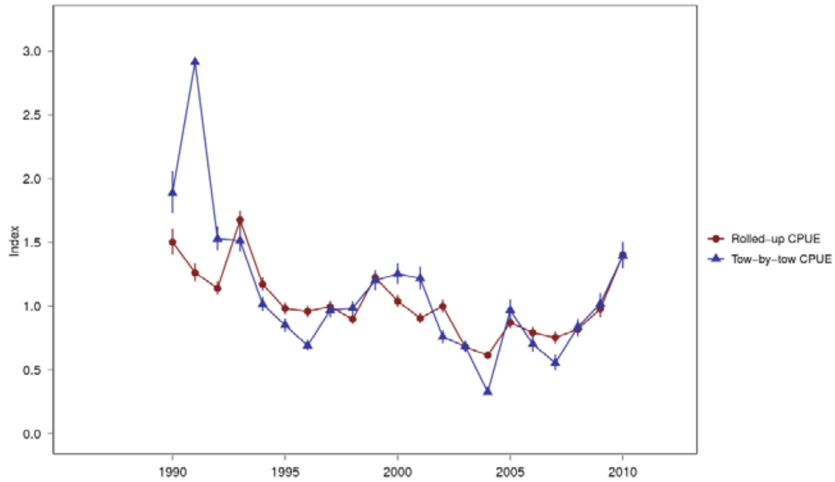
7.3 East Coast South Island *H. percoides* indices compared

There is reasonable correspondence between the two CPUE indices estimated using data from shallow depth off the East Coast of the South Island and assumed to represent *H. percoides* (Figure 10A). There is a high correspondence between these indices in the period since the 2007–08 fishing year because during that period these two indices are based on the same set of data (although they treat it differently). Both indices exhibit a fall in CPUE during the mid-1990s, a levelling until the early-2000s, followed by a drop to a nadir in the 2003–04 fishing year and a subsequent recovery. In 2009–10 both indices were at their highest level since the 1992–93 fishing year. Of these two indices, the one based on aggregated data is preferred because it includes more sea perch catch and does not suffer from a sudden change in fleet composition associated with a change in form types (see Section 8.2 for discussion on this).

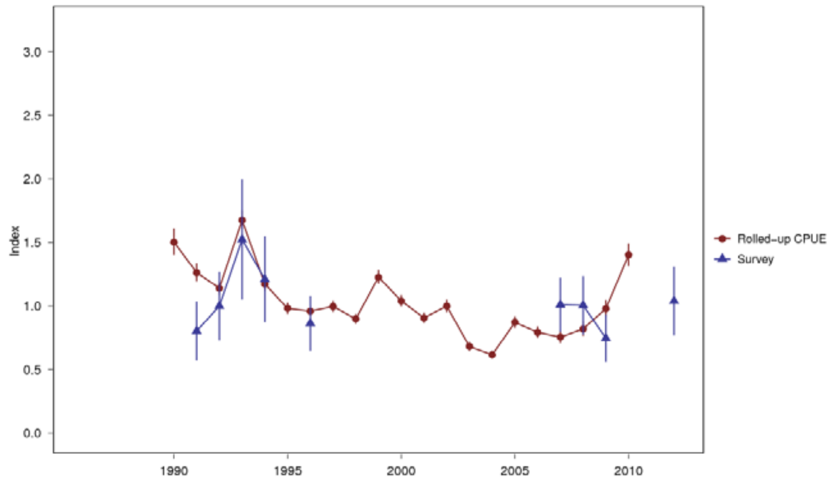
There is consistency between the aggregated ECSI CPUE index and the biomass index from the ESCI *Kaharoa* trawl survey (Figure 10). Both indices have a peak in 1992–93 and have a value near 1.0 during the late 2000s. It will be of interest to see if this correspondence is continued when these series are both updated.

A CPUE index for *H. percoides* is available from shallow water off the east coast of Australia (Malcolm Haddon, CSIRO, pers. comm.). This index is from a GLM using catch and effort data from bottom trawl in 0–200 m off the east coast of Victoria and New South Wales. The index shows similarities to the ECSI index with both series having a peak in 1992–93, a nadir in the mid-2000s and a subsequent recovery to levels close to the long term average (Figure 10).

A



B



C

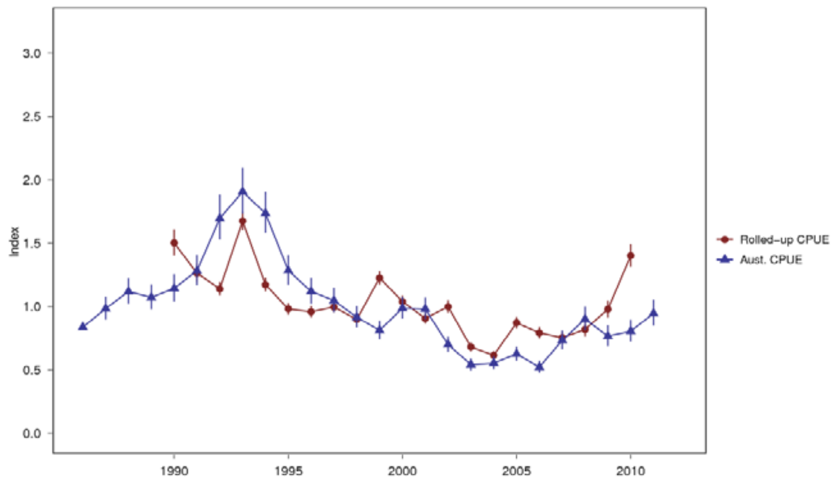


Figure 10: Comparison of the Canterbury coast aggregated CPUE index ("rolled-up") with other indices of biomass. A: versus the CPUE index based on tow data; B: versus the biomass index from the *Kaharoa* survey; C: versus the CPUE index for inshore ocean perch from the east coast of Australia. Each index has been standardised to have a geometric mean of 1.0 across all years.

7.4 Chatham Rise *H. sp. A* using tows targeting various species

A CPUE analysis was done for the Chatham Rise using data from bottom trawl tows in depths of 250–1000 m to attempt to obtain an index of relative abundance for *H. sp. A*.

7.4.1 Data subset and core vessel selection

This analysis used catch and effort data from bottom trawling targeting hoki, hake or scampi (for consistency with other analyses, data for some other target species were included but these are minor compared to these three main target species) in areas CRW, CRN, CRS or CRE (see Section 6 for definitions of these areas). So that the CPUE index represented *H. sp. A* as far as possible, only tows in 250–1000 m depth were used. Some other restrictions were placed on the height, width, speed and duration of tows to remove likely reporting errors. The resulting dataset involves a reasonable number of vessels (a maximum of 64 in the 1996–97 fishing year) and over 1000 t of catch in some years (Table F1).

Alternative core vessels selection criteria were investigated by considering the reduction in the number of vessels against the reduction in the percentage of catch represented (Figure F1). The criterion that vessels had to have caught sea perch on at least three trips in each of at least five years was used. This resulted in a core fleet size of 36 vessels which took 80% of the catch in the dataset over all years. Most of the core vessels had more than ten years of history in the data and there was good overlap of vessels across years (Figures F2–F3). The proportion of tows with positive catches and the unstandardised CPUE were similar between the core vessels and all vessels (Figure F4–F5). There was good overlap in vessel activity across the CRE, CRS, CRN and CRW areas.

7.4.2 Selection of error distribution and model terms

A generalised linear model (GLM) was developed for the catch from tows with positive catches. 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 + target*. On this basis the log-logistic distribution was selected (Figure F7).

An initial lognormal model with a term for fishing year was fitted followed by forward stepwise selection of the following terms: *month, area, target, vessel, poly(log(duration), 3), poly(log(height), 3), poly(log(width), 3), poly(log(speed), 3), poly(log(depth), 3), poly(time, 3), poly(moon, 3).* The final model included the terms *vessel, area, poly(log(depth), 3), poly(log(duration), 3), target, month and poly(log(height), 3).* Other model terms were statistically significant according to the AIC criterion but were not included because they only increased the coefficient of determination (R^2) slightly. The final model had a pseudo-coefficient of determination of 49.3% (Table F3).

7.4.3 Influence of model terms on standardisation

Overall, the standardised CPUE index is similar to the unstandardised index with the most substantial difference being in the first year of data (1989–90 fishing year) and in the period of the 2005–06 to 2006–07 fishing years (Figure F8). Note that the absolute differences between the indices are actually quite large but that these differences are swamped by the large changes in the index from around 0.5 in the 1990s to over 2 in the early 2000s. Vessel had the largest influence in the model and is estimated to have affected the CPUE index by an average of 28% across years (Table F4). The influence of vessel was particularly strong prior to the 1993–94 fishing year when there were relatively few vessels in the data set. In comparison, the influence of the other standardising variables is minor and several do not exhibit any clear trends in their distribution. Tow duration shifted upwards and had increasingly positive influence (Figure F13). There was a shift towards trawls with lower headline height in 2004–05 which had a positive influence (Figure F16) but this was counteracted by a shift towards greater targeting of scampi which has lower catch rates of sea perch (Figure F14). Note that tows targeting hoki have a higher than average catch rate of sea perch and also represent the majority of the data (Figure F14).

Analysis of model residuals shows that there are similar annual patterns across areas (Figure F19). It is difficult to conclude whether there are differences in annual patterns across target species because the data from target species other than hoki tends to be sporadic (Figure F18). There is some suggestion that monthly patterns in catch rates differ. On the western Chatham Rise (CRW) catch rates tend to be highest in spring and lowest in summer (Figure F20). In contrast, catch rates on the eastern Chatham Rise are highest in autumn and lowest in winter. The other areas in this analysis show different seasonal patterns again.

The standardisation model estimated that sea perch catch rates were highest at around 375 m depth (Figure F12). There is no strong evidence that this depth profile differs across target species or month. (Figures F22–23). However, there is evidence that the depth profile of catch rates differs by area, with residuals suggesting a stronger peak in catches rates around 375 m on the western Chatham Rise (CRW) and higher catch rates at greater depths on the eastern Chatham Rise (CRE; Figure F24).

7.4.4 Sensitivity test

The sensitivity of the CPUE index to the assumed error distribution (log-logistic) was tested by fitting the final model using a lognormal error distribution. There was very little difference between the two resulting indices (Figure F26).

7.4.5 CPUE index

Final standardised CPUE indices for *H. sp. A* on the Chatham Rise are provided in Figure 11 and Table F5.

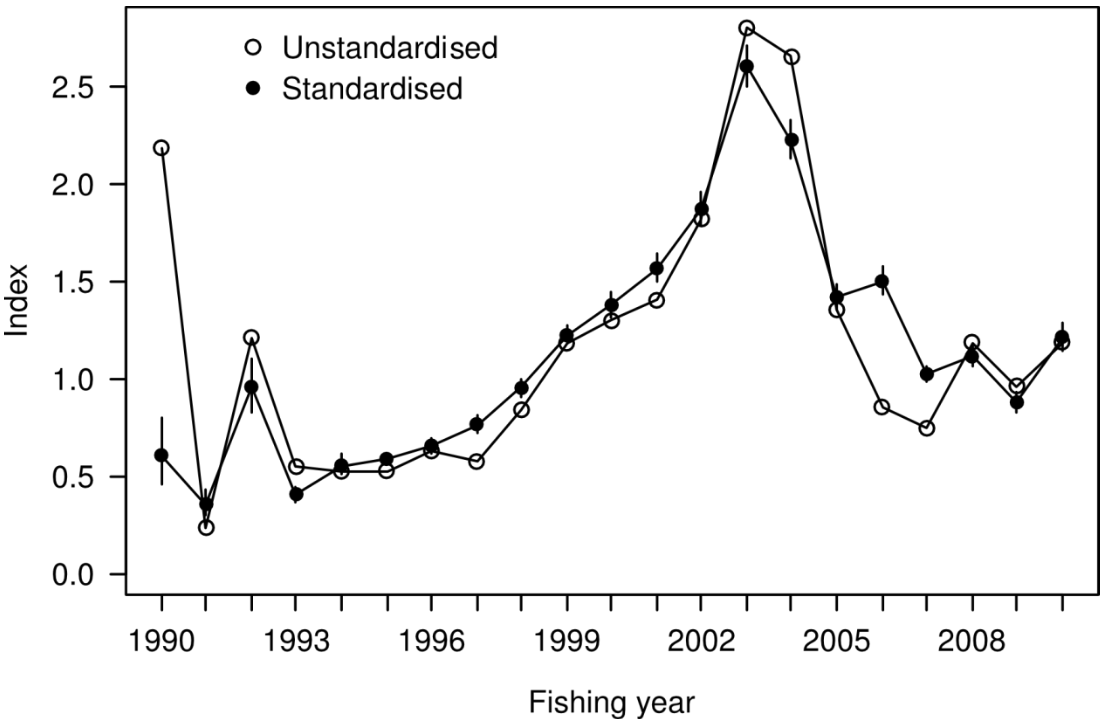


Figure 11: Standardised and unstandardised CPUE indices for sea perch from the ECSI inshore fishery. Fishing years are labelled according the latter calendar year e.g. 1990 = 1989–90. The standardised index is from the base-case GLM (see text for details). The unstandardised index is based on the geometric mean of the catch per tow and thus is not standardised for changes in fishing effort.

7.5 Chatham Rise *H. sp. A* using tows targeting hoki

A second CPUE analysis was done for the Chatham Rise using only tows targeting hoki. This analysis was done because tows targeting hoki catch the majority of sea perch on the Chatham Rise and change in targeting patterns for scampi and hake may have confounded the previous analysis while not adding a significant deal of sea perch catch data.

7.5.1 Data subset and core vessel selection

This analysis used catch and effort data from bottom trawls targeting hoki in 250–800 m in areas CRW, CRN, CRS or CRE (see Section 6 for definitions of these areas). Some other restrictions were placed on the height, width, speed and duration of tows to remove likely reporting errors. There were very few vessels that reported catching sea perch from hoki target tows prior to the 1994–95 fishing year so the dataset was truncated to start in that year. The resulting dataset includes a smaller number of vessels (a maximum of 52 in the 1997–98 fishing year) but still includes over 1000 t of catch in one year (Table G1).

Alternative core vessels selection criteria were investigated by considering the reduction in the number of vessels against the reduction in the percentage of catch represented (Figure G1). The criterion that vessels had to have caught sea perch on at least three trips in each of at least three years was used. This resulted in a core fleet size of 29 vessels which took 91% of the catch in the dataset over all years. Most of the core vessels had more than nine years history in the data and there was good overlap of vessels across years (Figures G2–G3). The proportion of tows with positive catches and the unstandardised CPUE were similar between the core vessels and all vessels (Figure G4–G5). There was good overlap in vessel activity across the CRE, CRS, CRN and CRW areas.

7.5.2 Selection of error distribution and model terms

A generalised linear model (GLM) was developed for the catch from tows with positive catches. 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*. On this basis the log-logistic distribution was selected (Figure G7).

An initial lognormal model with a term for fishing year was fitted followed by forward stepwise selection of the following terms: *month, area, vessel, poly(log(duration), 3), poly(log(height), 3), poly(log(width), 3), poly(log(speed), 3), poly(log(depth), 3), poly(time, 3), poly(moon, 3).* The final model included the terms *area, vessel, poly(log(depth), 3), poly(log(duration), 3),* and *month*. Other model terms were statistically significant according to the AIC criterion but were not included because they only increased the coefficient of determination (R^2) slightly. The final model had a pseudo-coefficient of determination of 53.4% (Table G3).

7.5.3 Influence of model terms on standardisation

Overall, the standardised CPUE index is similar to the unstandardised index with the most substantial difference being in the period from the 2002–03 to 2007–08 fishing years (Figure G8). Area had the largest influence in the model and is estimated to have affected the CPUE index by an average of 13% across years (Table G4, Figure G9). In 2005–06 there was a sudden shift in the proportion of records towards the western Chatham Rise (CRW) which has much lower catch rates of sea perch than the other areas (Figure G10). Because the standardisation model accounts for this shift the standardised index is generally higher than the unstandardised index in later years (Figure G8).

Depth was estimated to have a strong influence with catch rates peaking around 350 m at approximately double the catch rates at 250 m and 500 m. Note that tows targeting hoki on the Chatham Rise are concentrated around 500 m and do not coincide with the depth of maximum sea perch catch rates (Figure G12). There is no evidence that the depth profile of sea perch catch rates differs across area or month (Figures G19–20).

Analysis of model residuals suggests that there are differences in annual trends across areas with the eastern Chatham Rise not showing the same magnitude of decline since the mid-2000s (Figure G16). There is some suggestion that the seasonality of sea perch catch rates also differs in the CRE area with a more pronounced drop in May to July (Figure G17).

7.5.4 Sensitivity test

The CPUE index is robust to the assumption regarding the distribution of errors. There was little difference between the indices obtained from the base model (which used a log-logistic distribution) and those obtained from a model assuming lognormal errors (Figure G22).

7.5.5 CPUE index

Final standardised CPUE indices for *H. sp. A* on the Chatham Rise are provided in Figure 12 and Table G5.

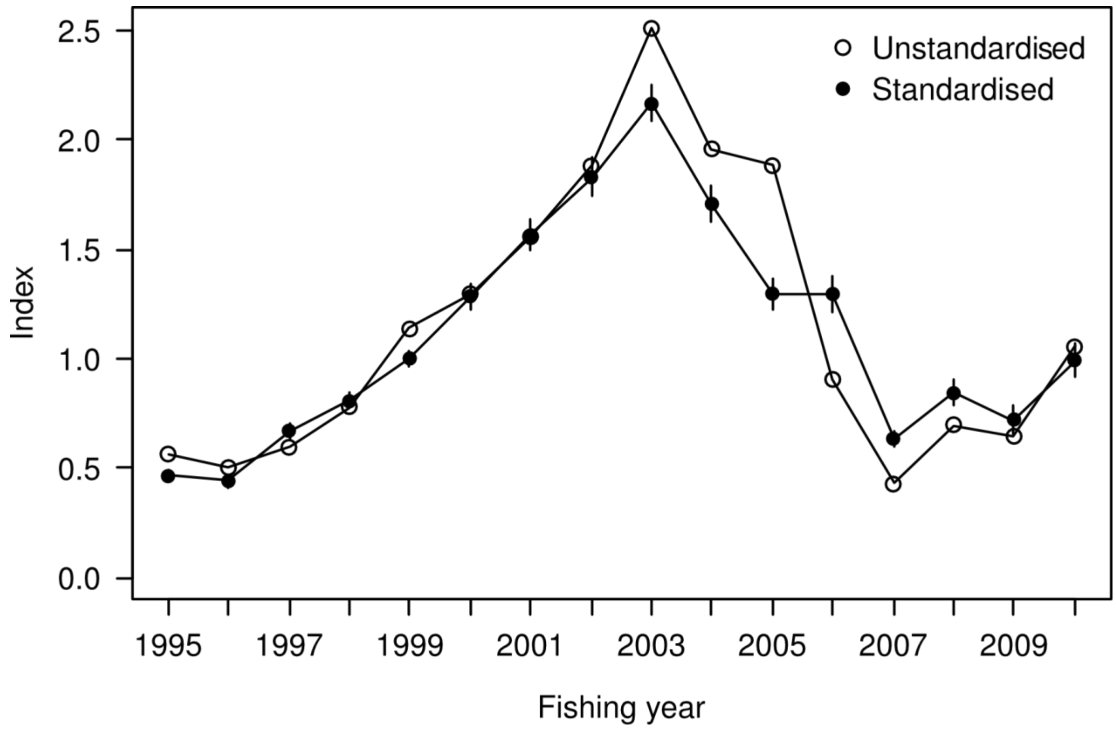


Figure 12: Standardised and unstandardised CPUE indices for sea perch on the Chatham Rise from tows targeting hoki in 250–800 m. Fishing years are labelled according the latter calendar year e.g. 1990 = 1989–90. The standardised index is from the base-case GLM (see text for details). The unstandardised index is based on the geometric mean of the catch per tow and thus is not standardised for changes in fishing effort.

7.6 Chatham Rise *H. sp. A* indices compared

There is good correspondence between the two CPUE indices derived for the Chatham Rise and assumed to represent *H.sp. A* (Figure 13A). Both indices exhibit a substantial increase during the late-1990s and early-2000s, peak in 2002–03, and then decline to close to the long term average. The index derived from tows targeting hoki is preferred, despite being shorter, because it is not susceptible to the changes in fishing methods associated with changes in relative targeting of alternative species.

There is also strong consistency between the CPUE index based on hoki-targeted tows and the biomass index from the Chatham Rise *Tangaroa* trawl survey (Figure 13B). Both indices exhibit a strong peak of similar magnitude during the early-2000s, although the survey peaks one year prior to the CPUE. This difference in timing may be related to differences in size selectivity of the commercial and survey trawls.

A

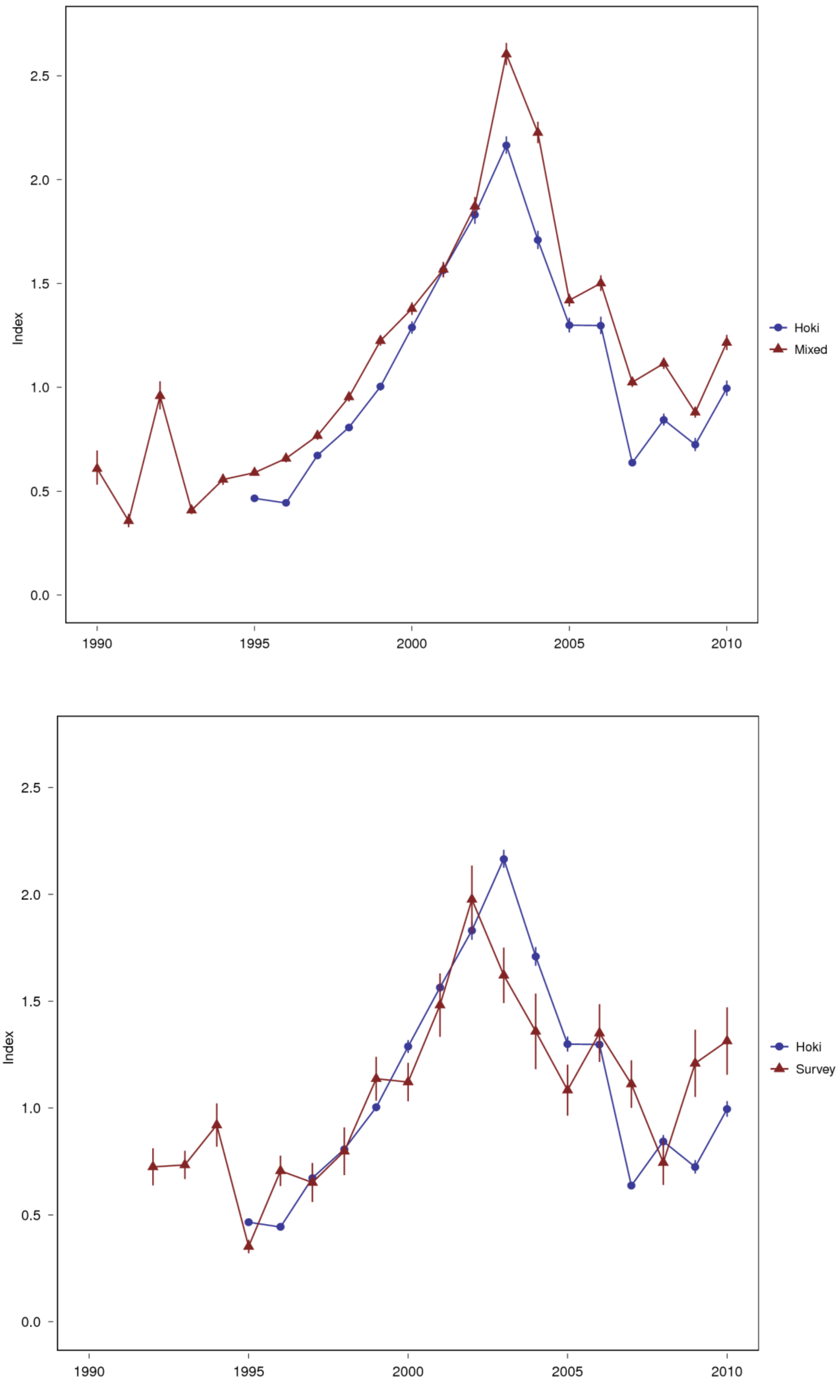


Figure 13: Comparison of indices of biomass for the Chatham Rise sea perch *H. sp. A*.: Comparison of CPUE indices derived from tows targeting various species ("Mixed") and tows targeting hoki only; B: Comparison of the CPUE index derived from tows targeting hoki and the relative biomass index from the *Tangaroa* trawl survey. Each index has been standardised to have a geometric mean of 1.0 across all years.

8. SUMMARY AND RECOMENDATIONS

8.1 Biology

Recent research has improved understanding of sea perch speciation, stock relationships, natural mortality and growth rates. Further research to clarify speciation and formally describe potentially undescribed species would be useful. to determine whether morphological and/or colour traits can be used to discriminate amongst species.

If species discrimination is possible based on easily identified external features it would make surveys to understand the distribution and habitat preferences of each species easier and cheaper. Such surveys could be done over a range of depths at several locations around New Zealand to quantify the extent of species overlap. Similarly, the species composition of commercial and recreational catches in different parts of New Zealand could be quantified.

Although there is evidence that three species of *Helicolenus* are caught in New Zealand this does not necessarily cause substantial issues for the existing quota management of sea perch which combines all species. If the species hypothesis presented here is correct then the existing quota management areas mostly encompass the principal areas inhabited by each species: *H. percoides* in SPE 3, *H. sp. A* in SPE 1, 2, and 4, and *H. barathri* in SPE 7. Although there is evidence that suggests that *H. percoides* also occurs in the shallow waters of all QMAs it is currently caught in small quantities compared to the other species in those areas. The most significant overlap between QMAs and species distributions is probably the part of the western Chatham Rise that occurs in SPE 3 but where mostly *H. sp. A* is caught.

8.2 Biomass indices

Biomass indices for sea perch obtained from the winter east coast South Island *Kaharoa* and summer Chatham Rise *Tangaroa* surveys will continue to be important tools for monitoring sea perch in SPE 3 and SPE 4 respectively. The catch-per-unit-effort (CPUE) indices developed in this study appear to be relatively robust. There was close consistency between the CPUE and survey indices for the Chatham Rise. More east coast South Island surveys will be required to see if a similar consistency occurs there.

8.3 Stock assessment

There are several reasons to think that stock assessments for SPE 3 and SPE 4 may be viable. First, a validated ageing method has provided estimates of natural mortality rates and growth parameters for both areas. Second, this study has suggested that biomass indices from both CPUE and surveys are satisfactory for both areas and, at least for the SPE 4, exhibit substantial contrast. Third, length frequency data from trawl surveys appear to be useful for tracking strong year classes and, at least for SPE 4, are consistent with biomass indices. Stock assessments need not wait until species identification is resolved since the evidence suggests that, even if sea perch in these two QMAs are not different species, they are most likely at least different stocks.

9. ACKNOWLEDGEMENTS

This research was funded by the New Zealand Ministry for Primary Industries. Thanks to Alistair Dunn, Rosie Hurst and other members of the Middle Depths Fisheries Assessment Working Group for helpful discussions about the project. We are grateful to Malcolm Haddon, CSIRO for providing CPUE indices for the Australia fisheries and to Kevin Sullivan for useful suggestions on an earlier draft.

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11. APPENDIX A: SUMMARIES OF TRAWL SURVEY DATA

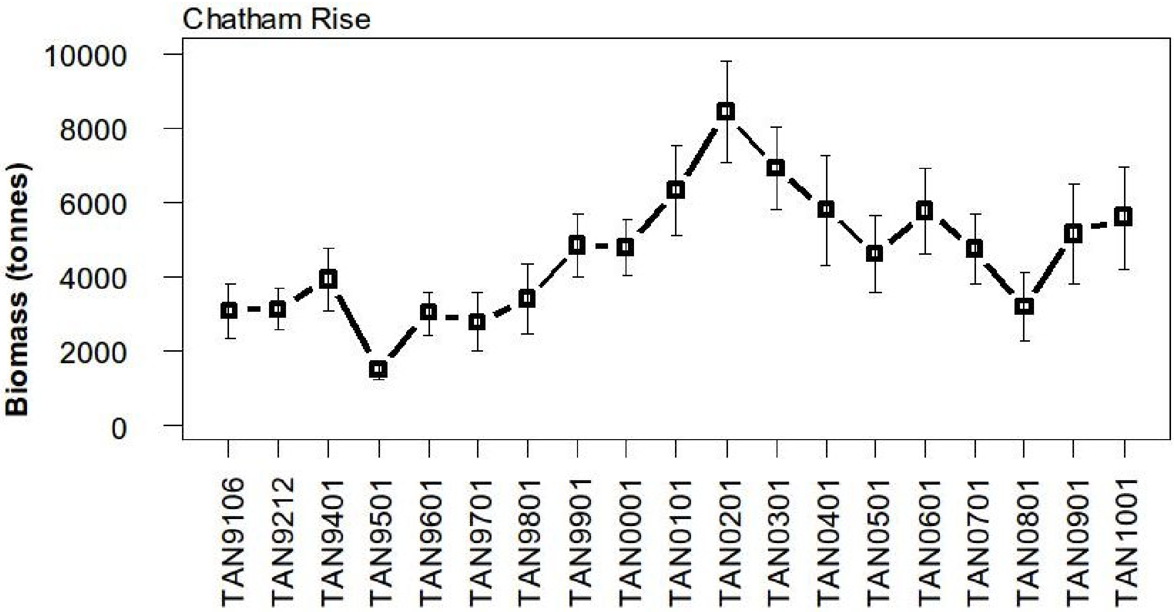

Figure A1: Doorspread biomass estimates of total sea perch from the Chatham Rise, from *Tangaroa* surveys from 1991 to 2010.

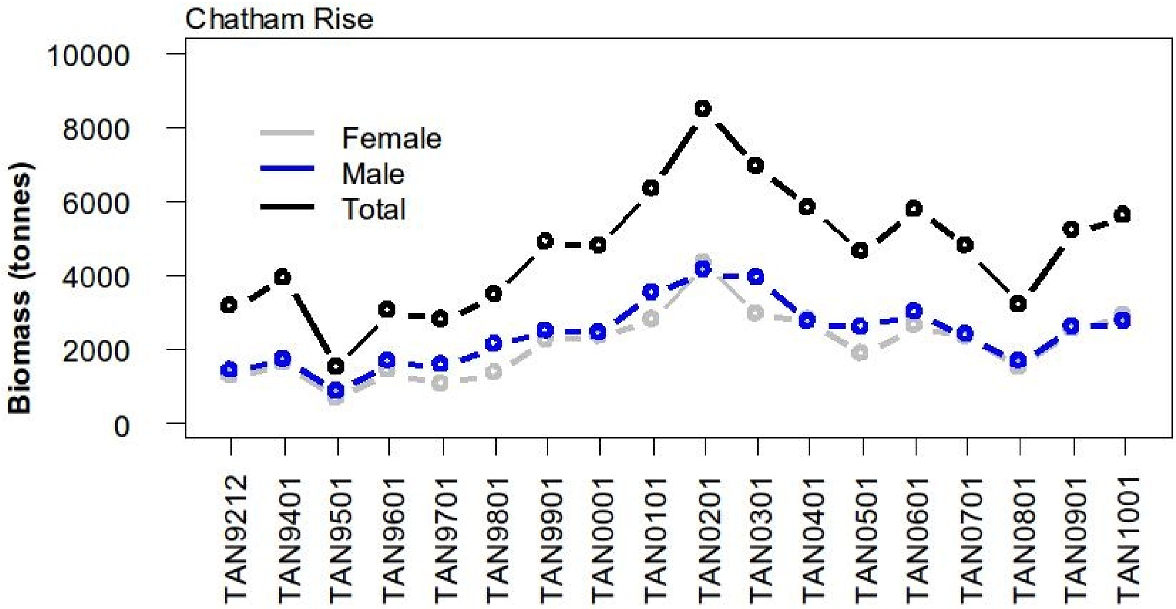

Figure A2: Doorspread biomass estimates of sea perch by sex from the Chatham Rise, from *Tangaroa* surveys from 1992 to 2010. NB: biomass by sex not available for 1991.

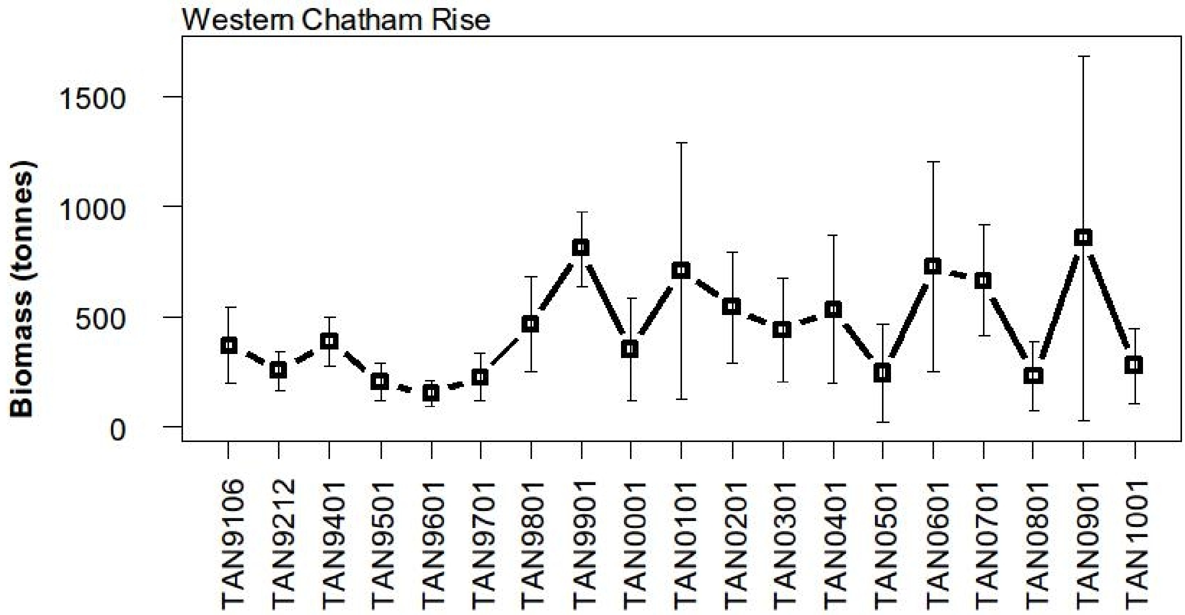

Figure A3: Doorspread biomass estimates of total sea perch from the Western Chatham Rise, from *Tangaroa* surveys from 1991 to 2010.

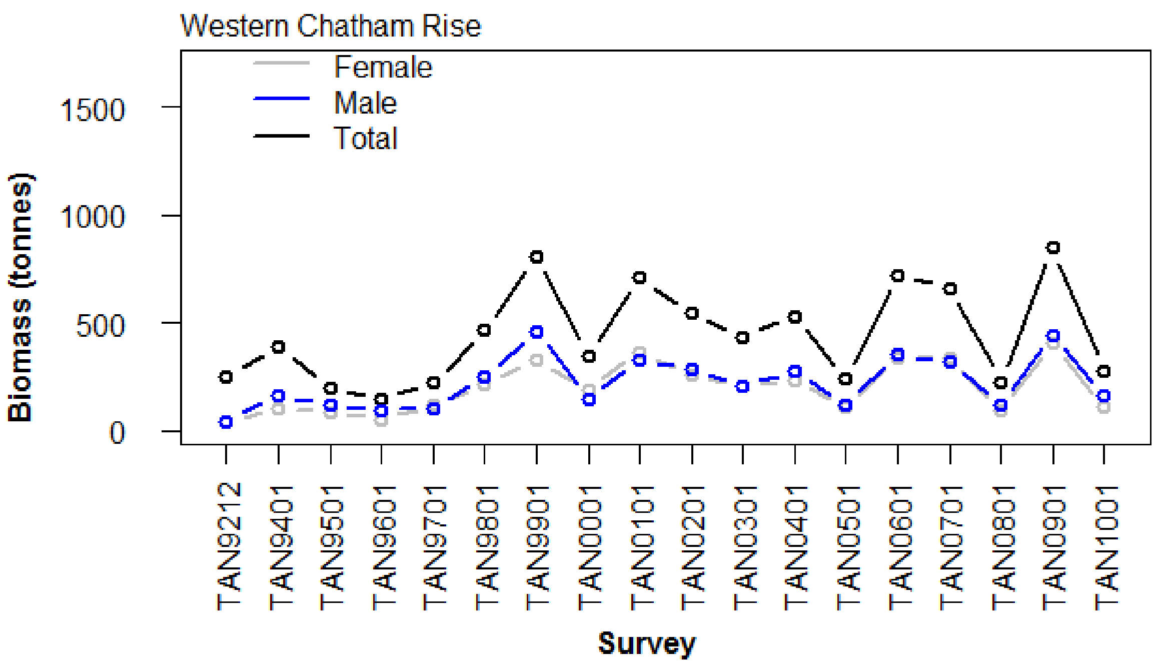

Figure A4: Doorspread biomass estimates of sea perch by sex from the Western Chatham Rise, from *Tangaroa* surveys from 1992 to 2010. NB: biomass by sex not available for 1991.

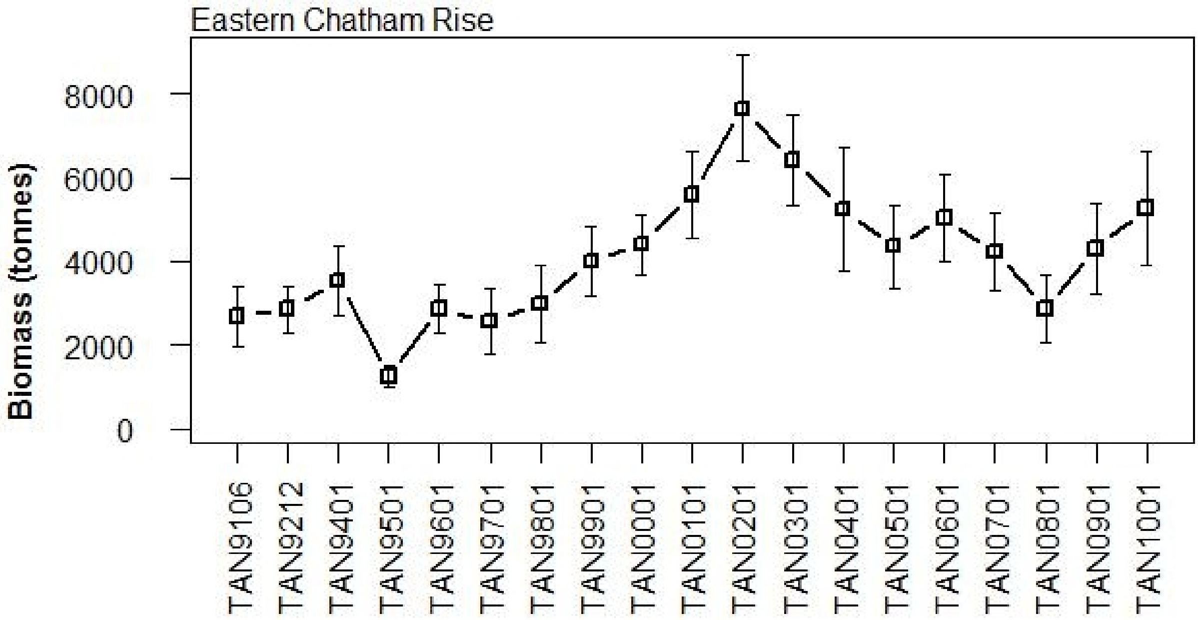

Figure A5: Doorspread biomass estimates of total sea perch from the Eastern Chatham Rise, from *Tangaroa* surveys from 1991 to 2010.

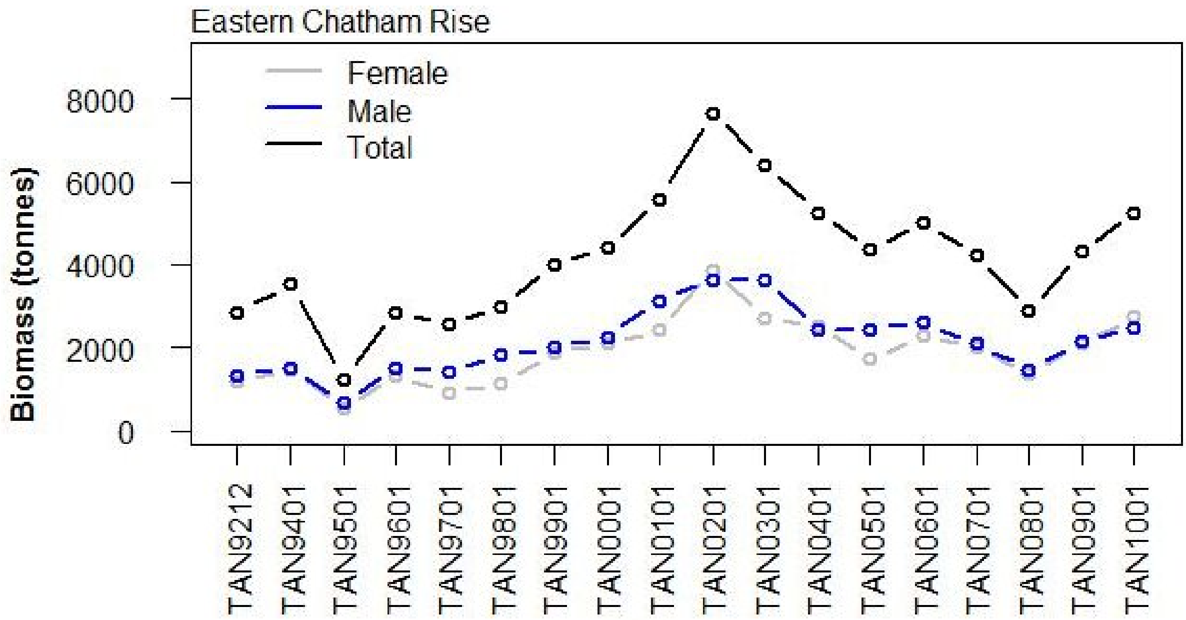

Figure A6: Doorspread biomass estimates of sea perch by sex from the Eastern Chatham Rise, from *Tangaroa* surveys from 1992 to 2010. NB: biomass by sex not available for 1991.

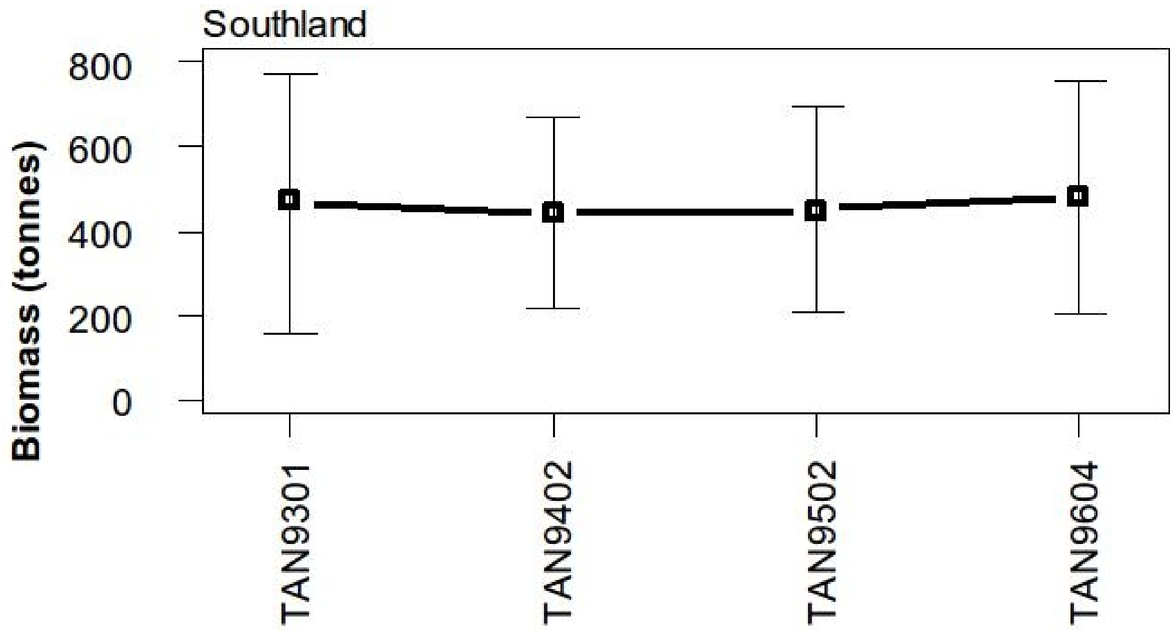

Figure A7: Doorspread biomass estimates of total sea perch from the Southland time series, from *Tangaroa* surveys from 1993 to 1996.

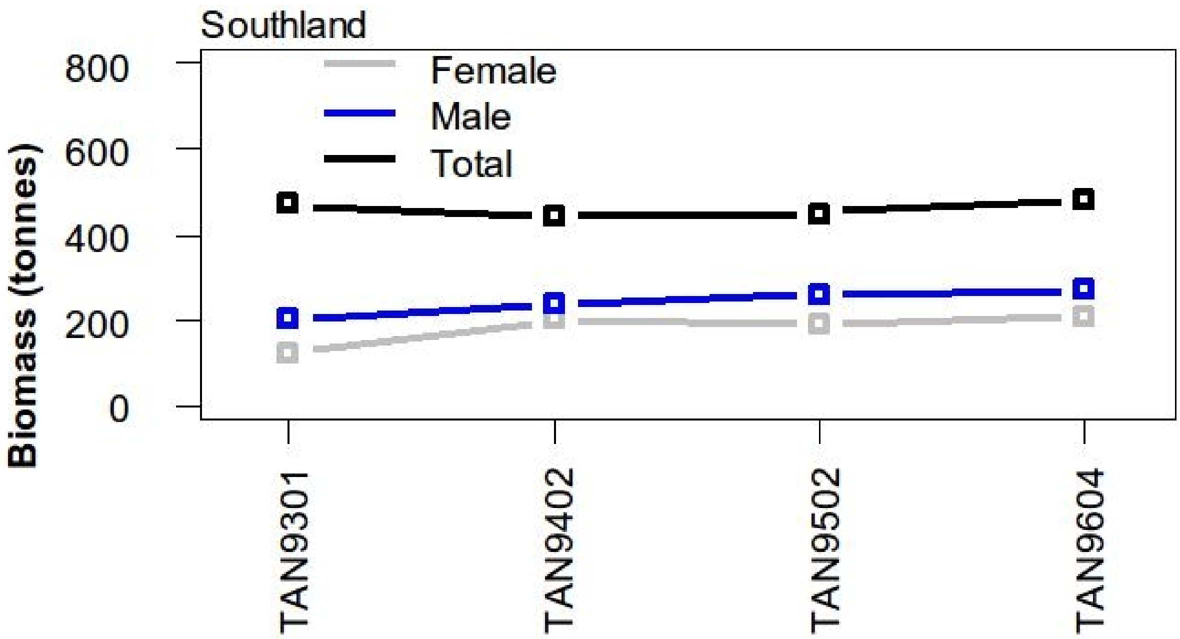

Figure A8: Doorspread biomass estimates of sea perch by sex from the Southland time series, from *Tangaroa* surveys from 1993 to 1996.

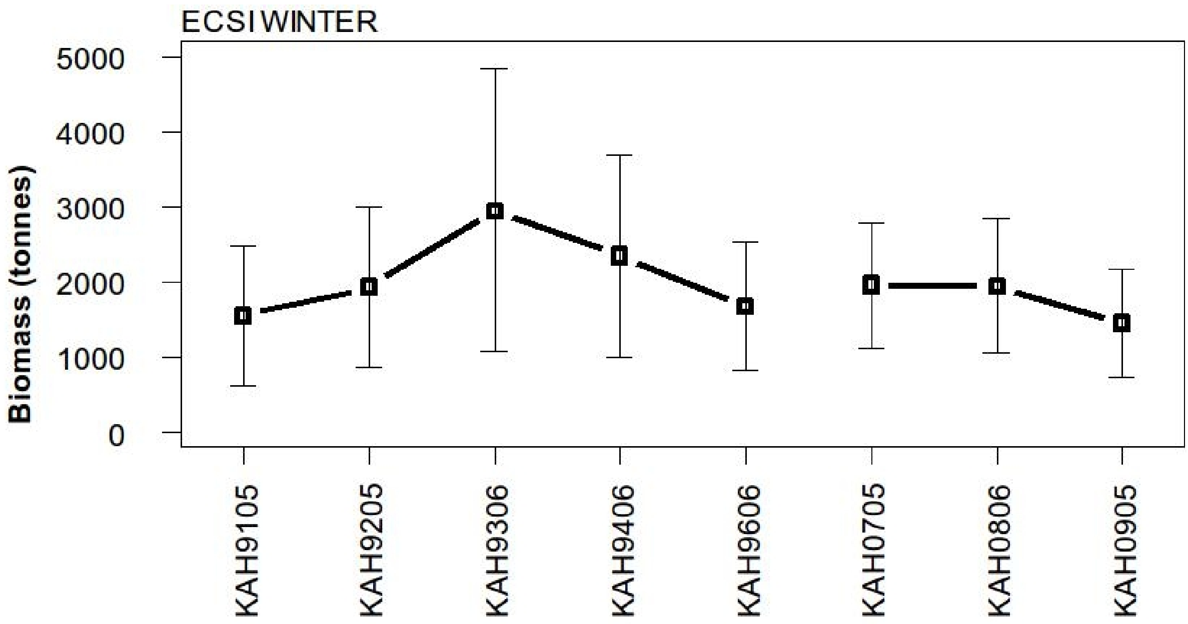

Figure A9: Doorspread biomass estimates of total sea perch from the winter east coast South Island time series, from *Kaharoa* surveys from 1991 to 2009.

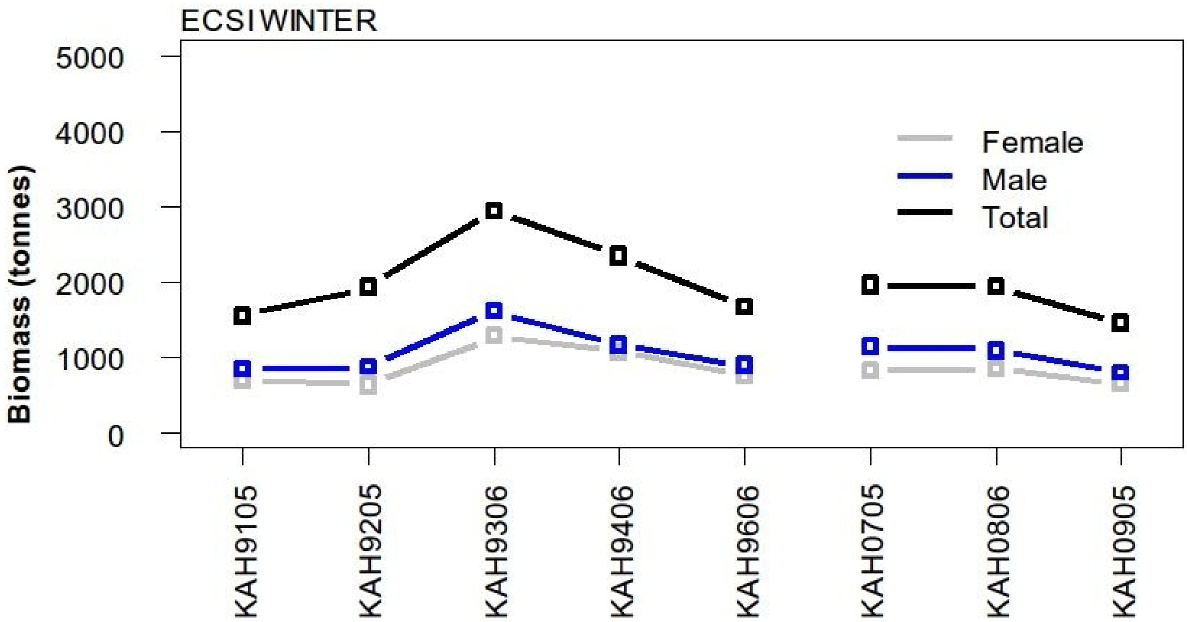

Figure A10: Doorspread biomass estimates of sea perch by sex from the winter east coast South Island time series, from *Kaharoa* surveys from 1991 to 2009.

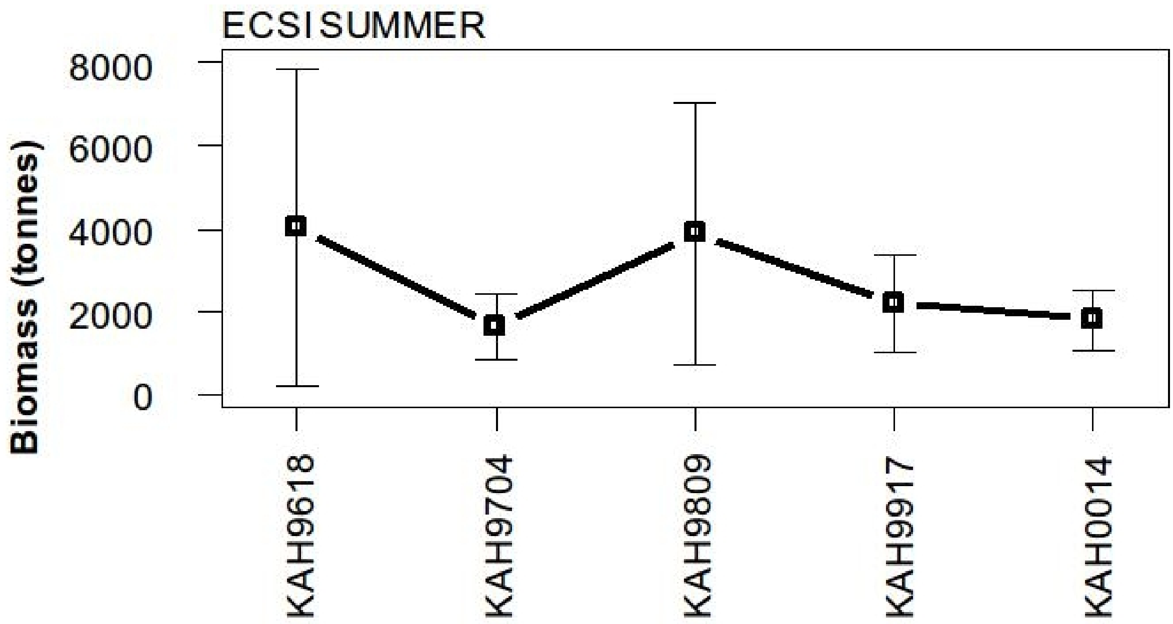

Figure A11: Doorspread biomass estimates of total sea perch from the summer east coast South Island time series, from *Kaharoa* surveys from 1996 to 2000.

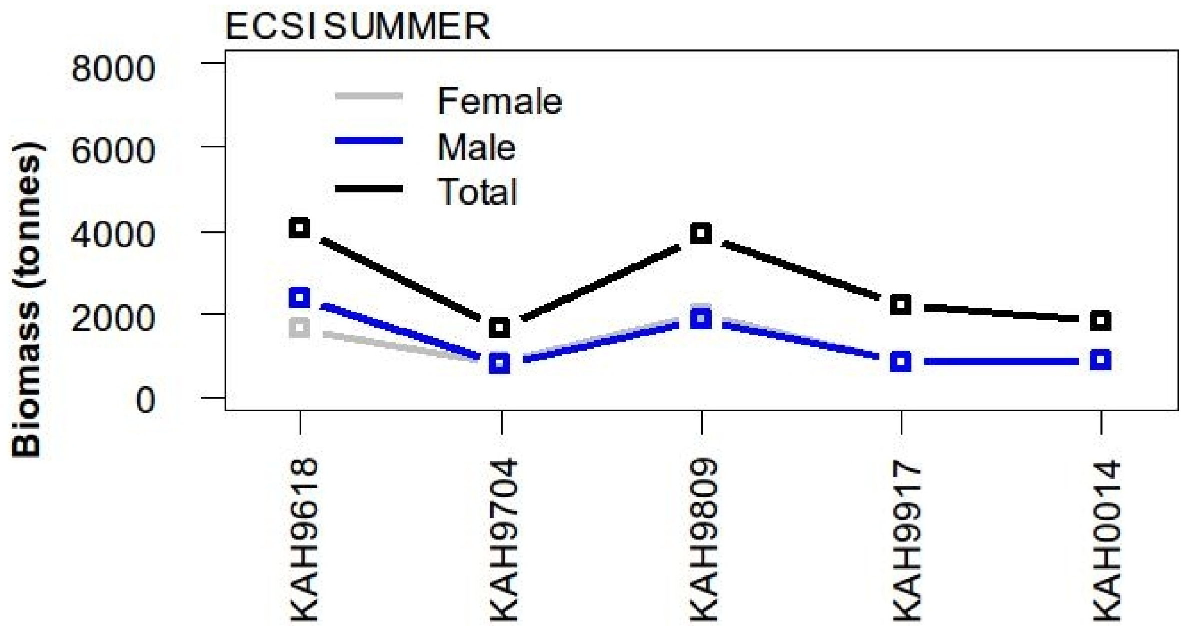

Figure A12: Doorspread biomass estimates of sea perch by sex from the summer east coast South Island time series, from *Kaharoa* surveys from 1996 to 2000.

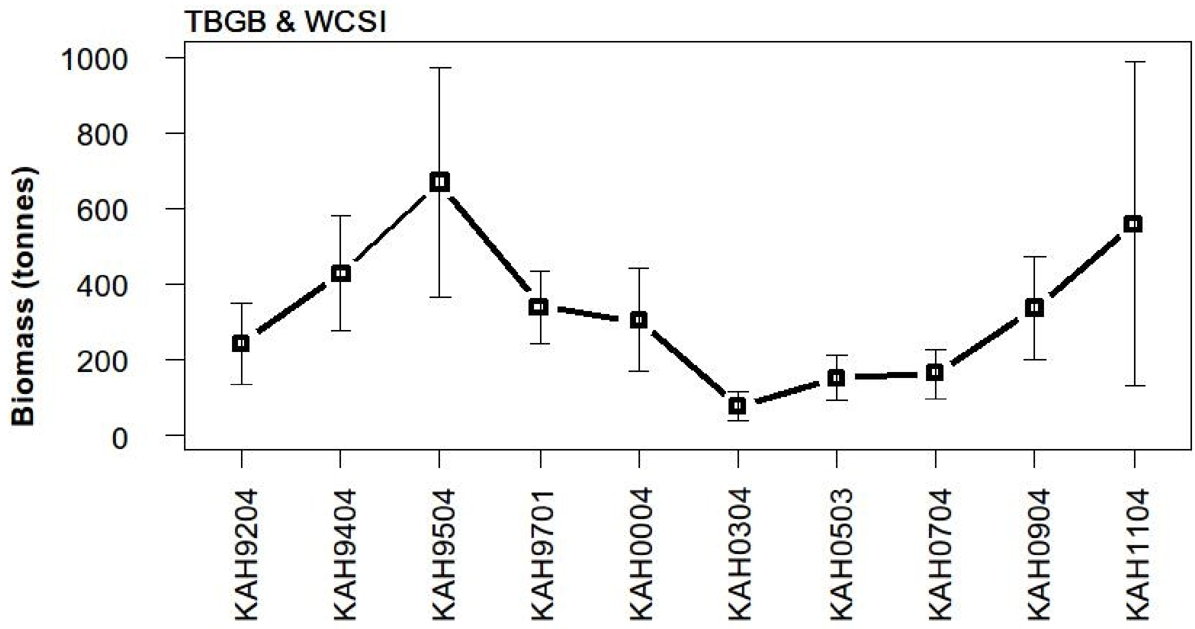

Figure A13: Doorspread biomass estimates of total sea perch from the west coast South Island time series, from *Kaharoa* surveys from 1992 to 2011.

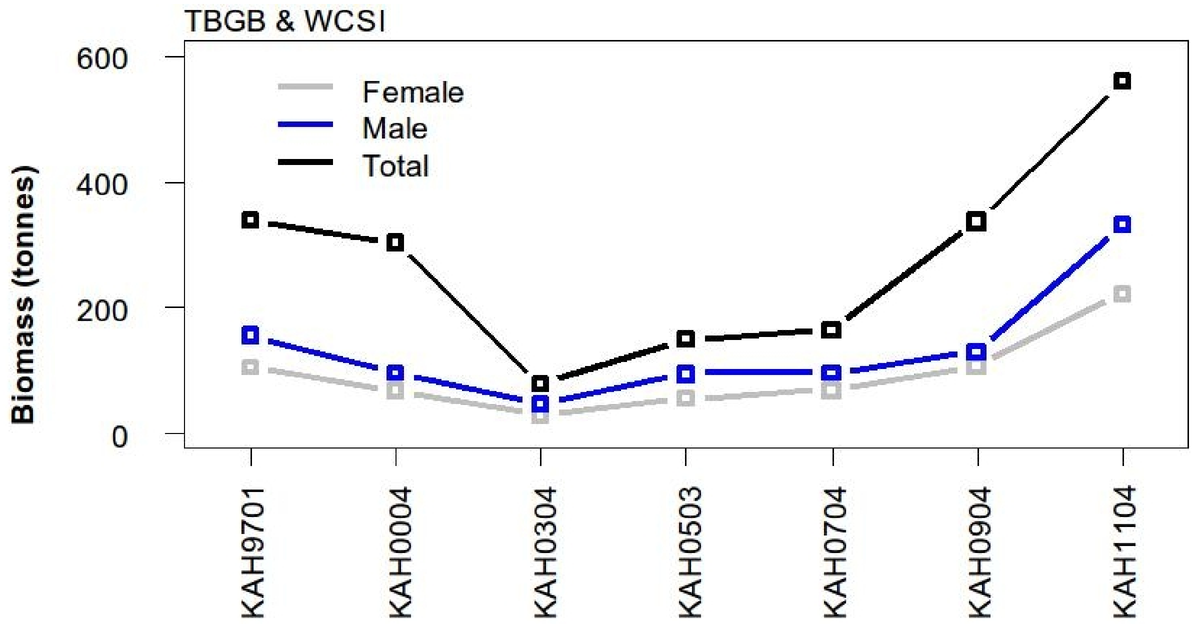

Figure A14: Doorspread biomass estimates of sea perch by sex from the west coast South Island time series, from *Kaharoa* surveys from 1997 to 2011. NB: Biomass estimates by sex were not available before 1997.

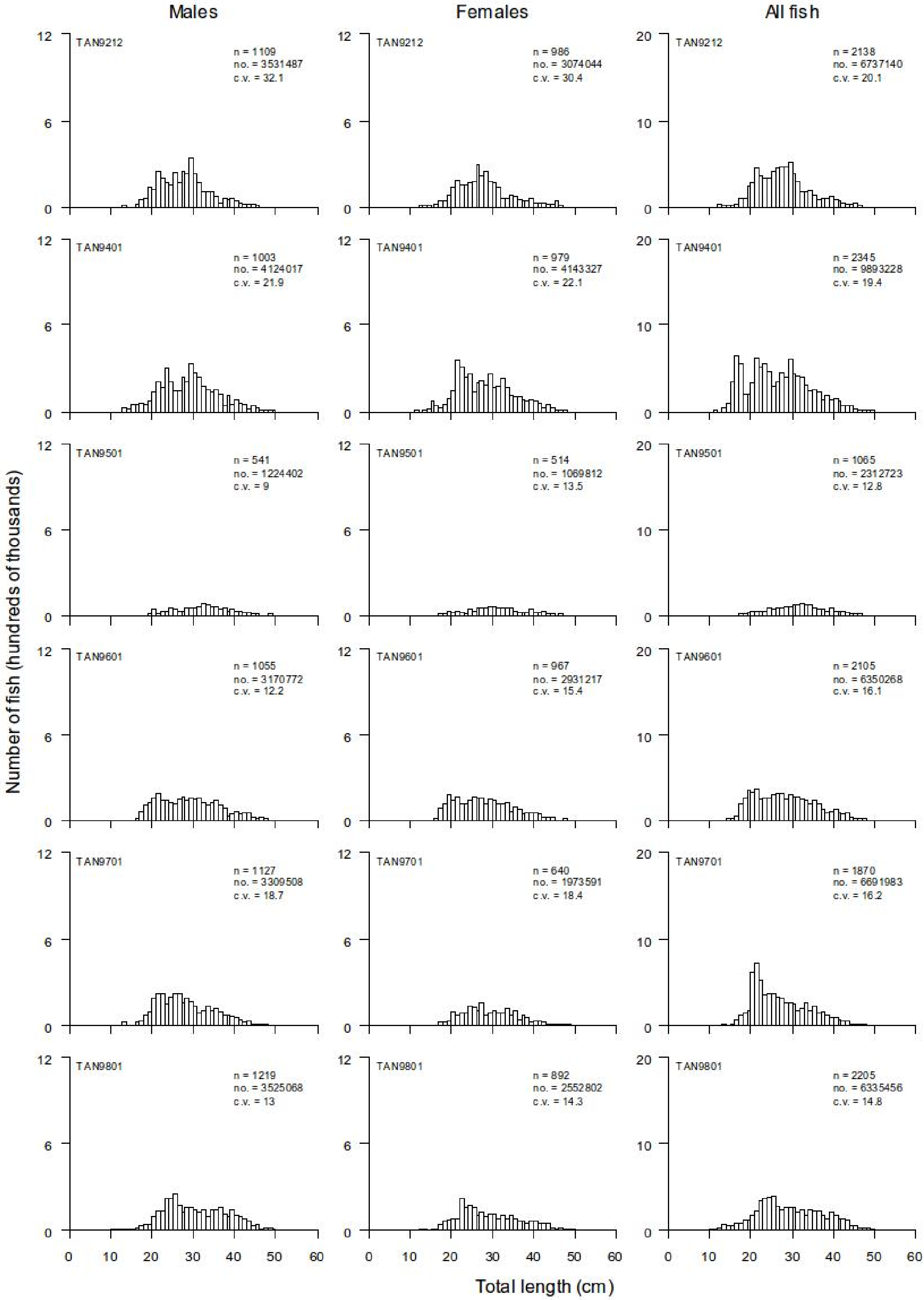

Figure A15: Scaled population length frequencies by sex of sea perch from the Chatham Rise from *Tangaroa* surveys from 1991 to 1998.

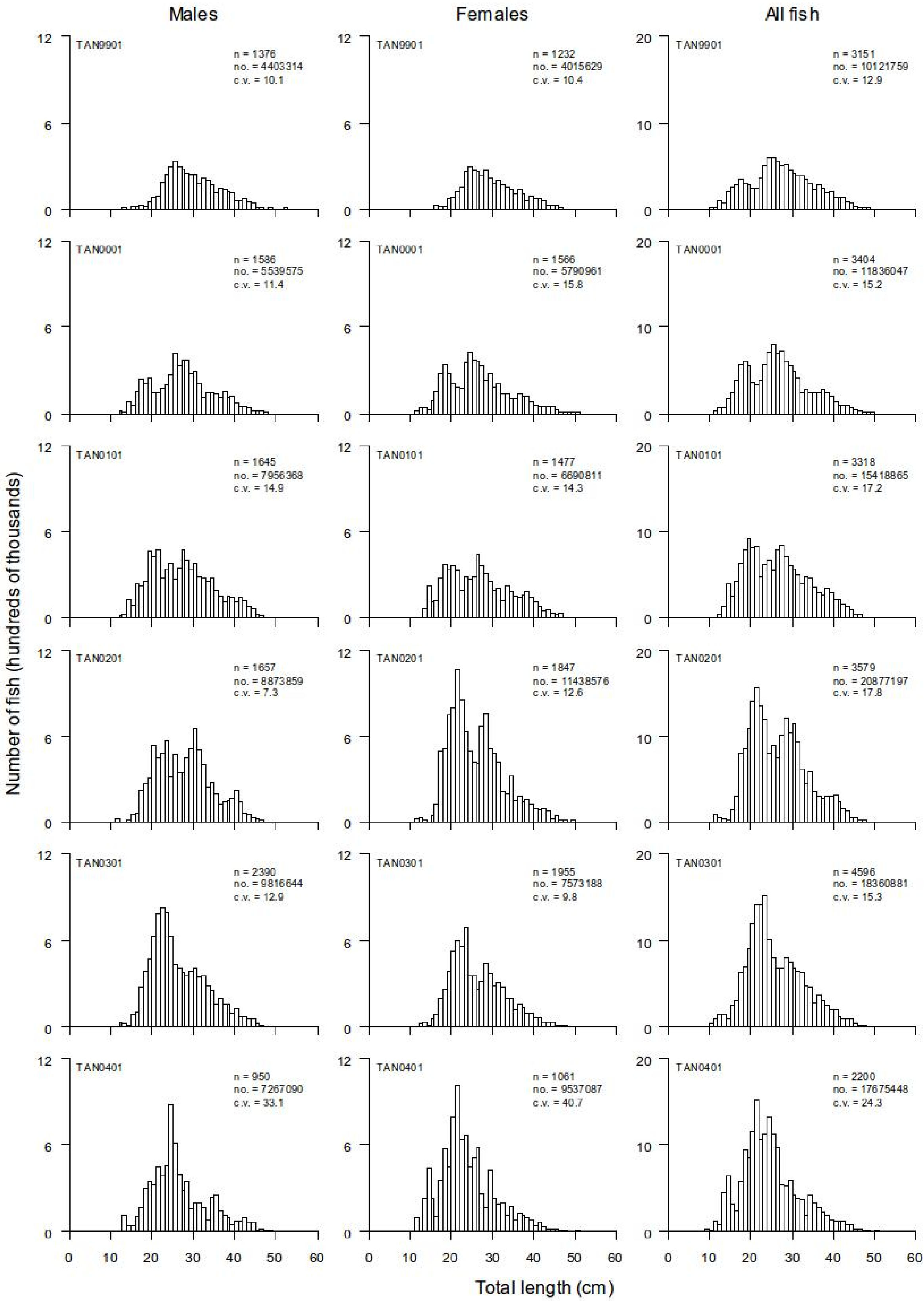

Figure A16: Scaled population length frequencies by sex of sea perch from the Chatham Rise from *Tangaroa* surveys from 1999 to 2004.

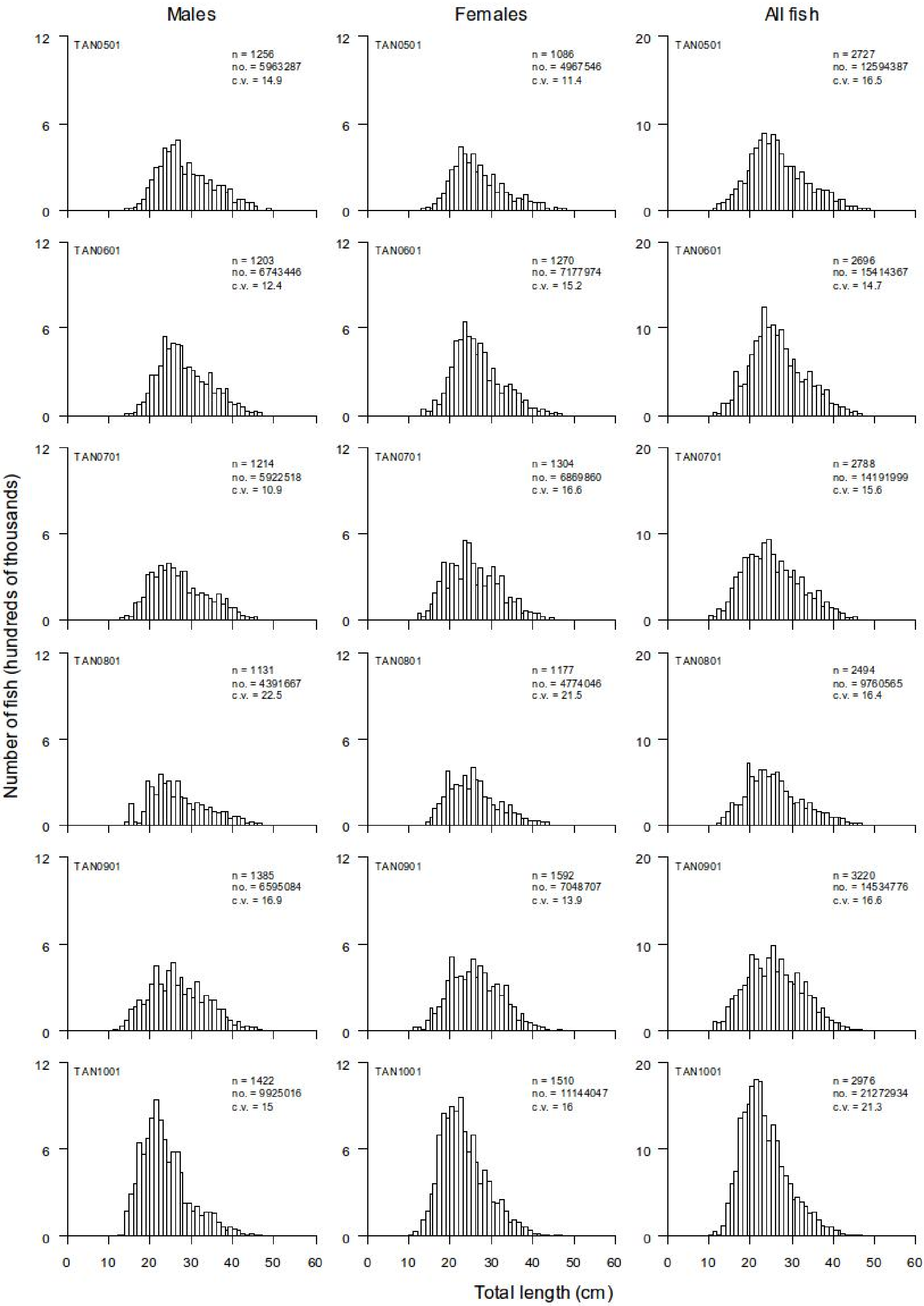

Figure A17: Scaled population length frequencies by sex of sea perch from the Chatham Rise from *Tangaroa* surveys from 2005 to 2010.

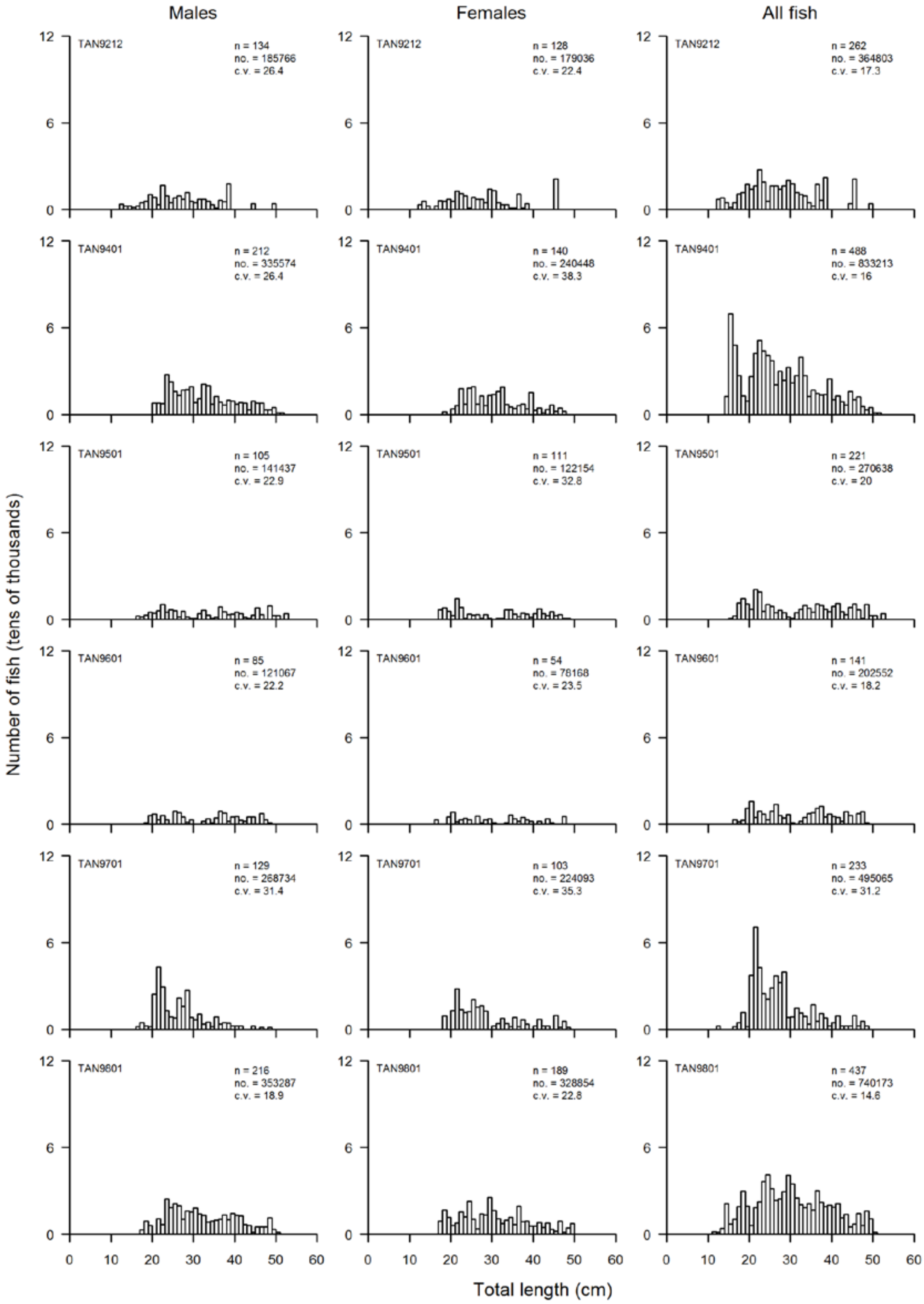

Figure A18: Scaled population length frequencies by sex of sea perch from the Western Chatham Rise from *Tangaroa* surveys from 1992 to 1998.

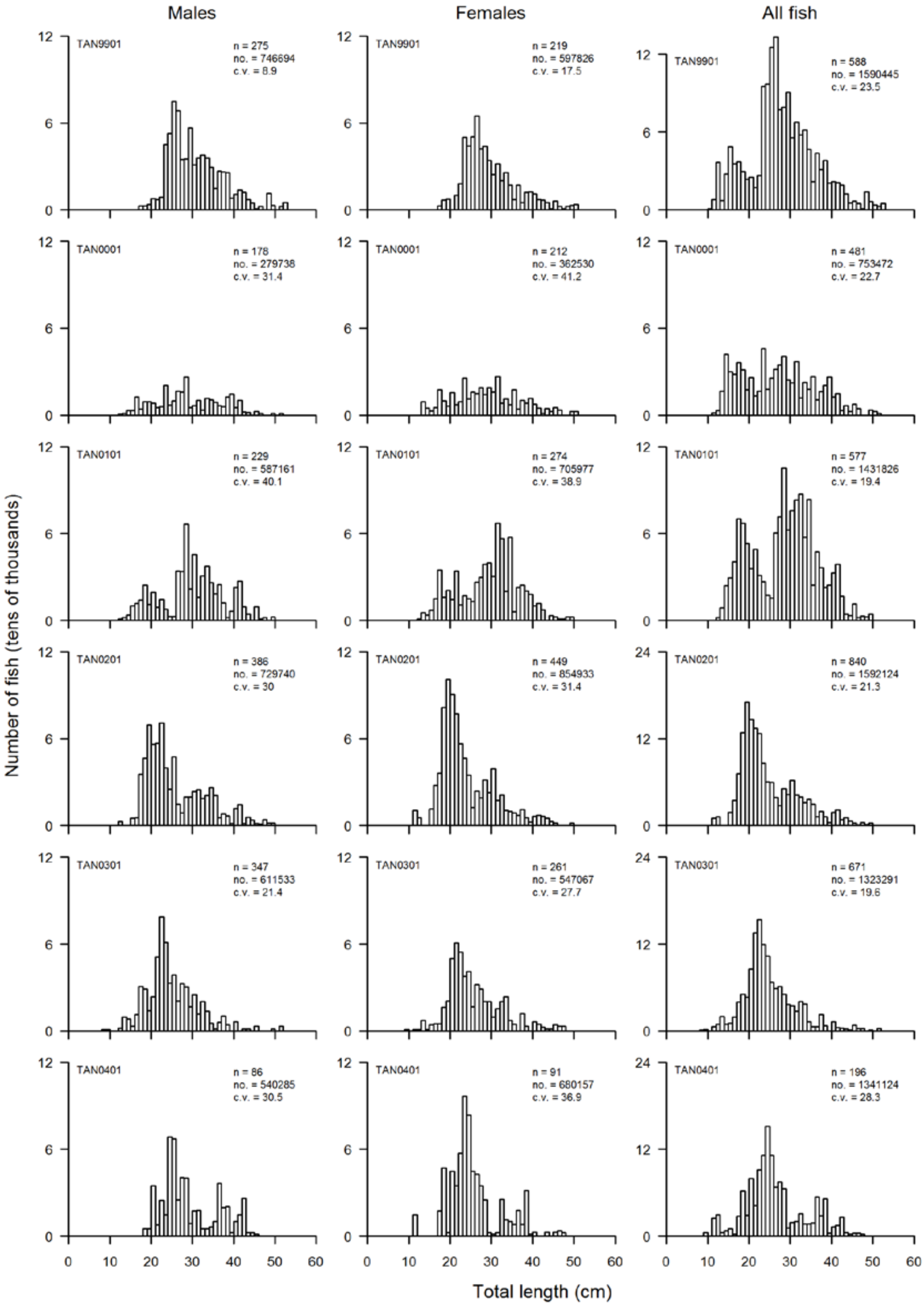

Figure A19: Scaled population length frequencies by sex of sea perch from the Western Chatham Rise from *Tangaroa* surveys from 1999 to 2004.

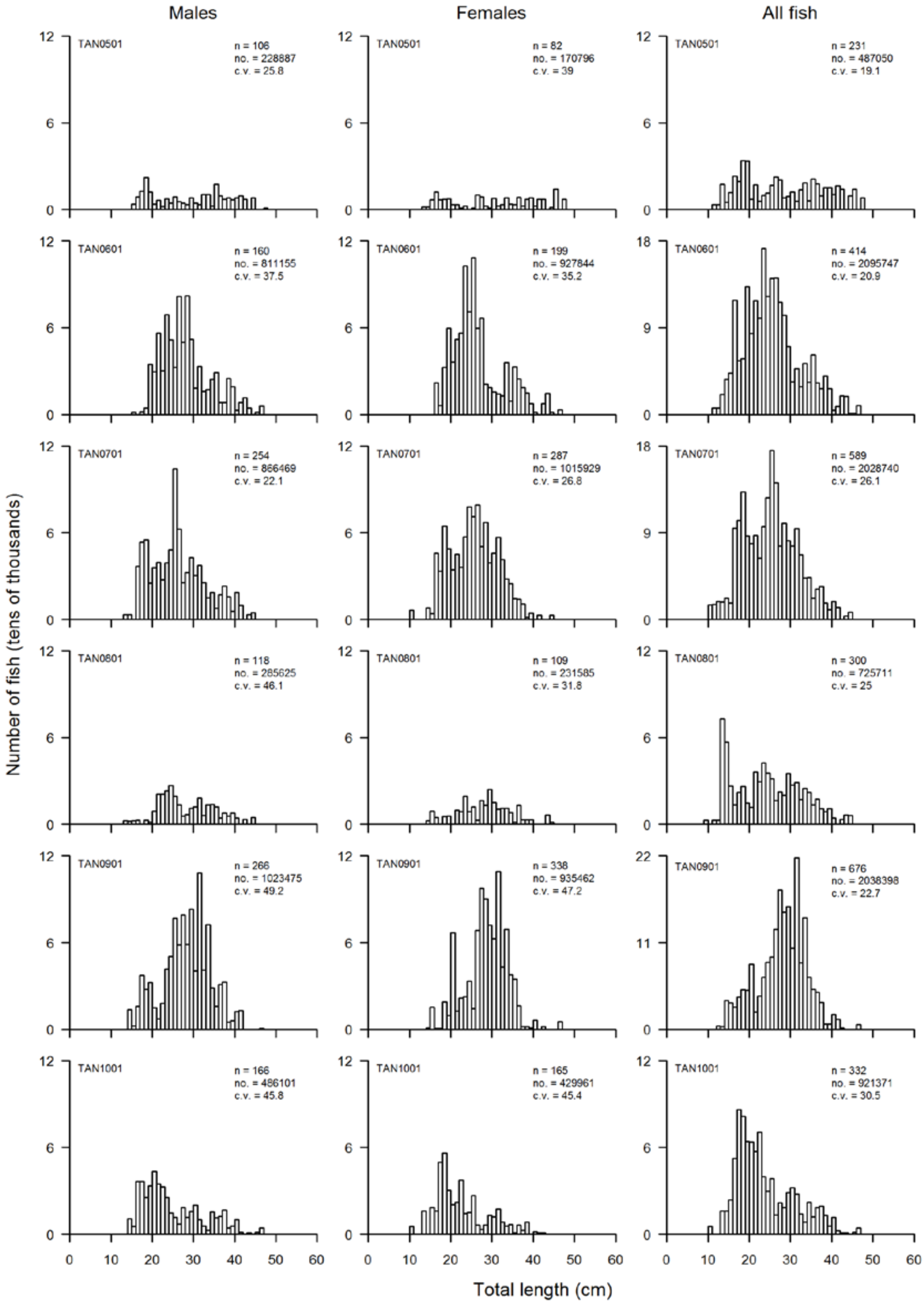

Figure A20: Scaled population length frequencies by sex of sea perch from the Western Chatham Rise from *Tangaroa* surveys from 2005 to 2010.

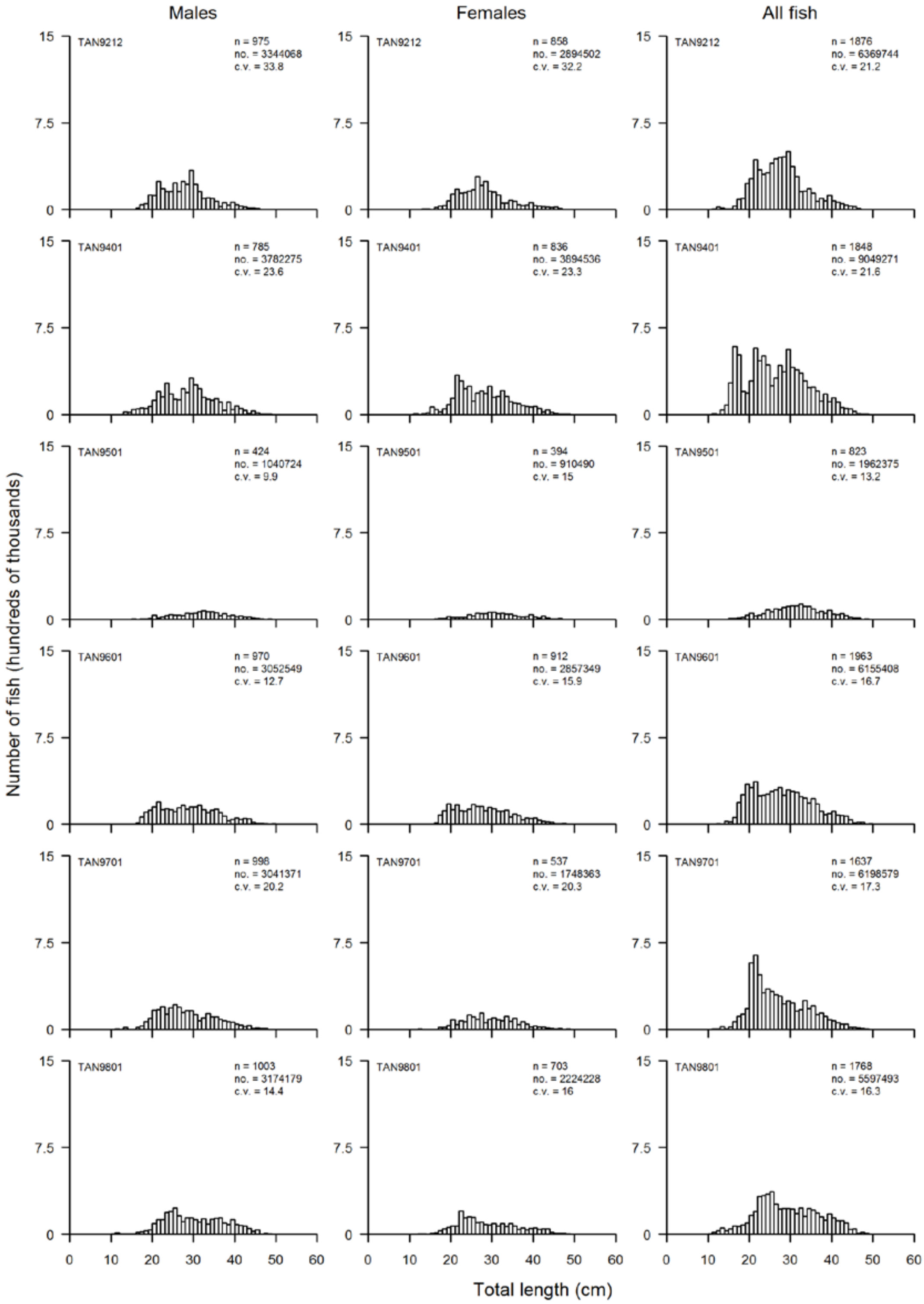

Figure A21: Scaled population length frequencies by sex of sea perch from the Eastern Chatham Rise from *Tangaroa* surveys from 1992 to 1998.

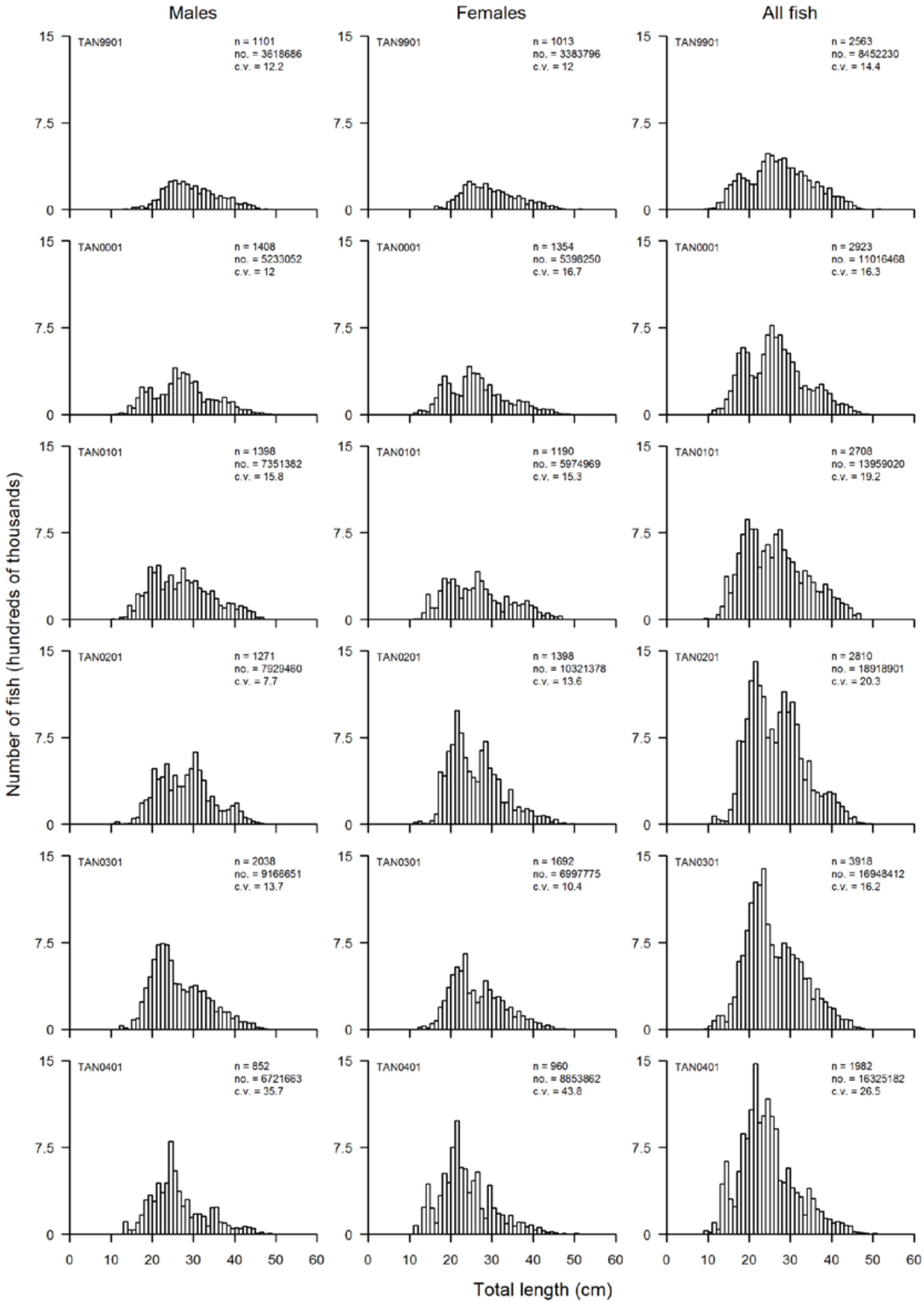

Figure A22: Scaled population length frequencies by sex of sea perch from the Eastern Chatham Rise from *Tangaroa* surveys from 1999 to 2004.

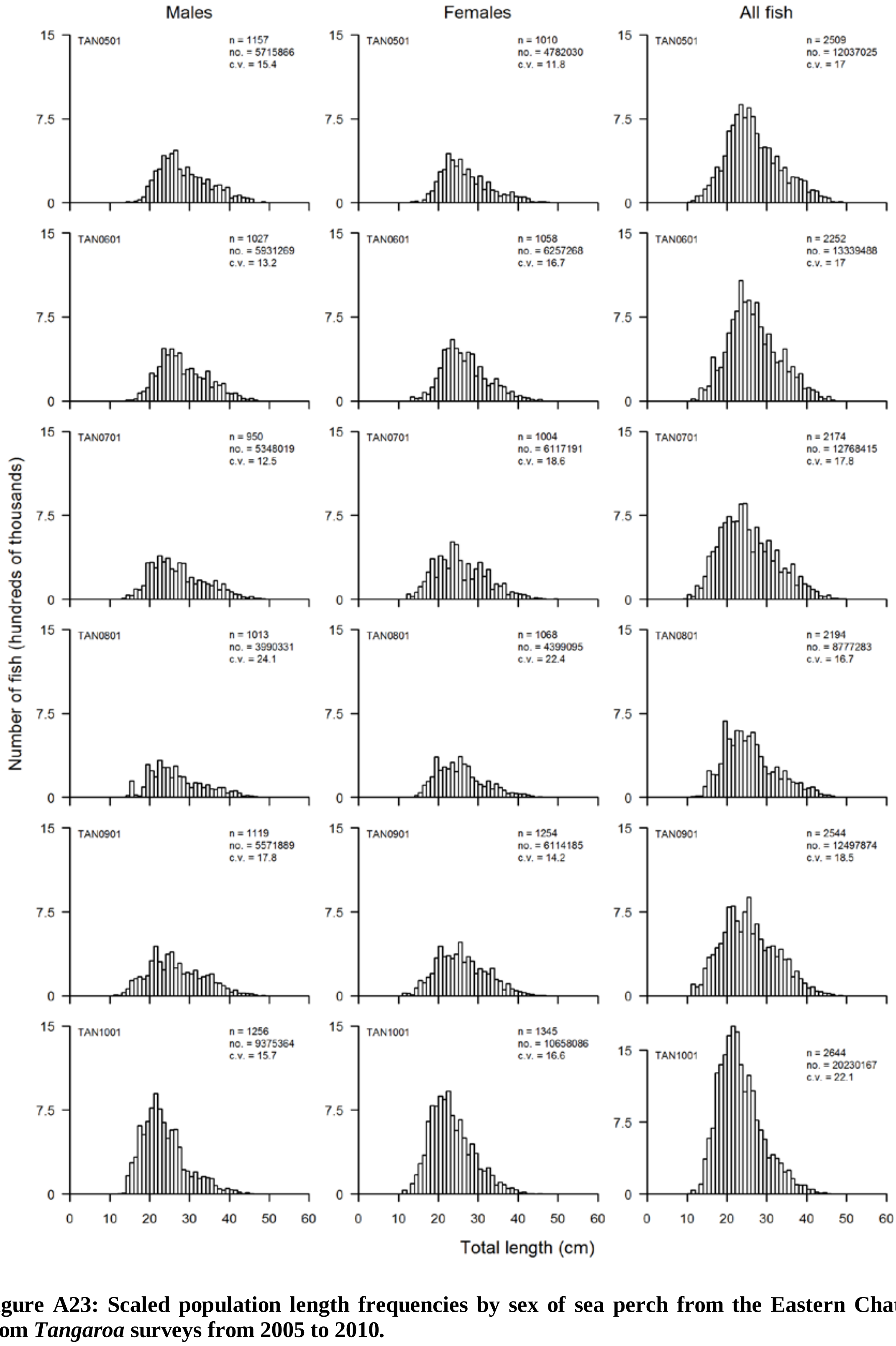

Figure A23: Scaled population length frequencies by sex of sea perch from the Eastern Chatham Rise from *Tangaroa* surveys from 2005 to 2010.

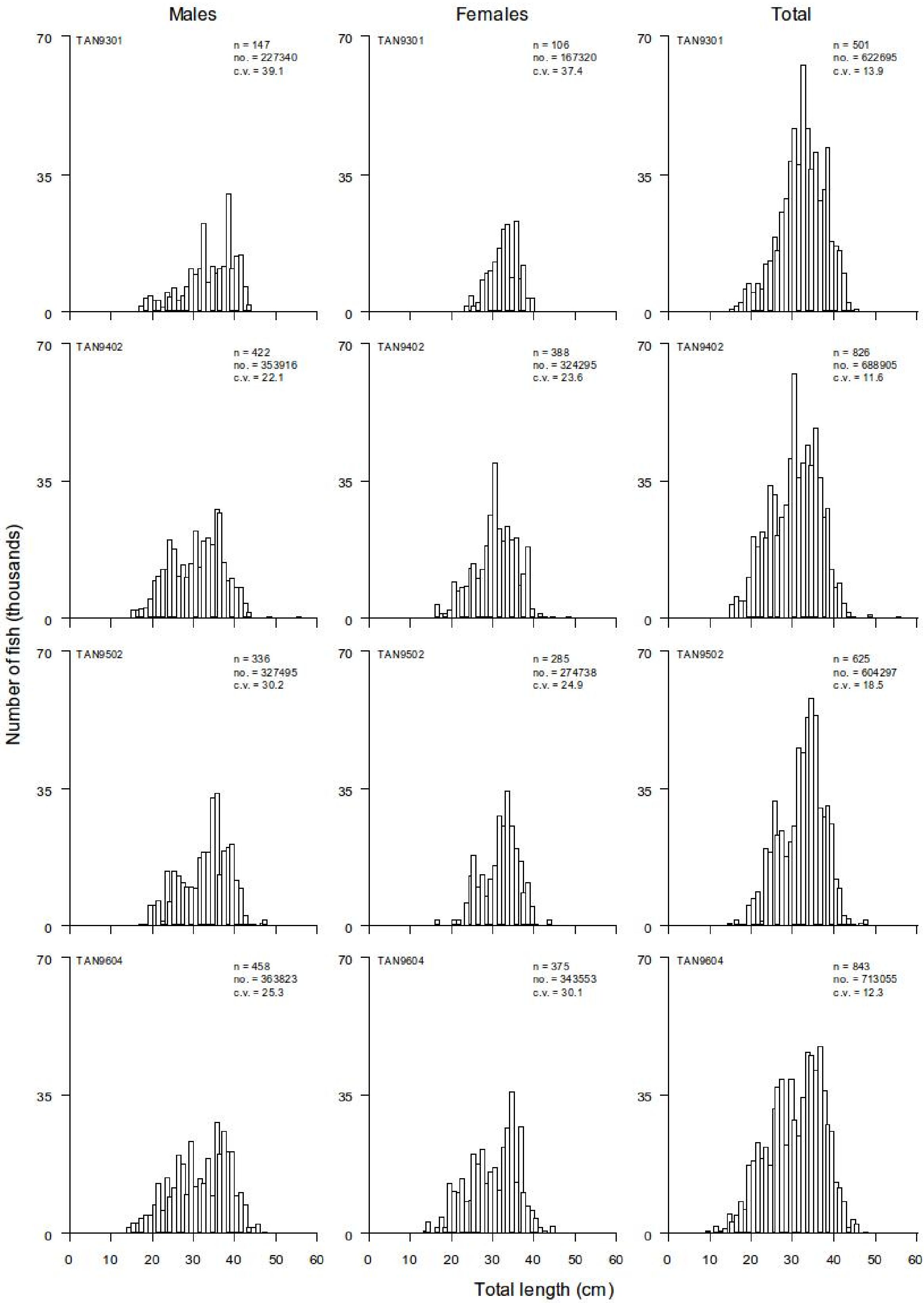

Figure A24: Scaled population length frequencies by sex of sea perch from the Southland time series from *Tangaroa* surveys from 1993 to 1996.

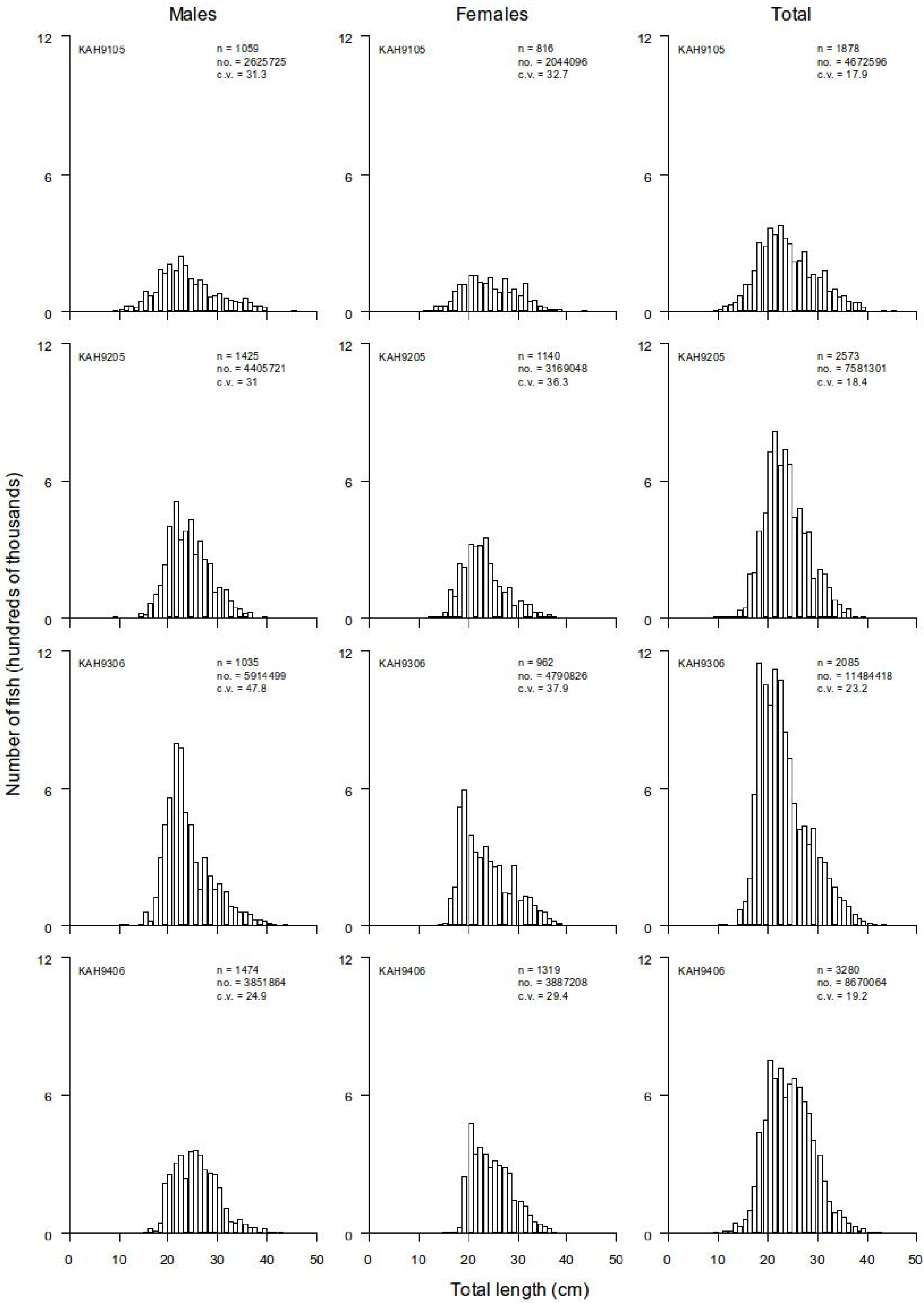

Figure A25: Scaled population length frequencies by sex of sea perch from the winter east coast South Island from *Kaharoa* surveys from 1991 to 1994.

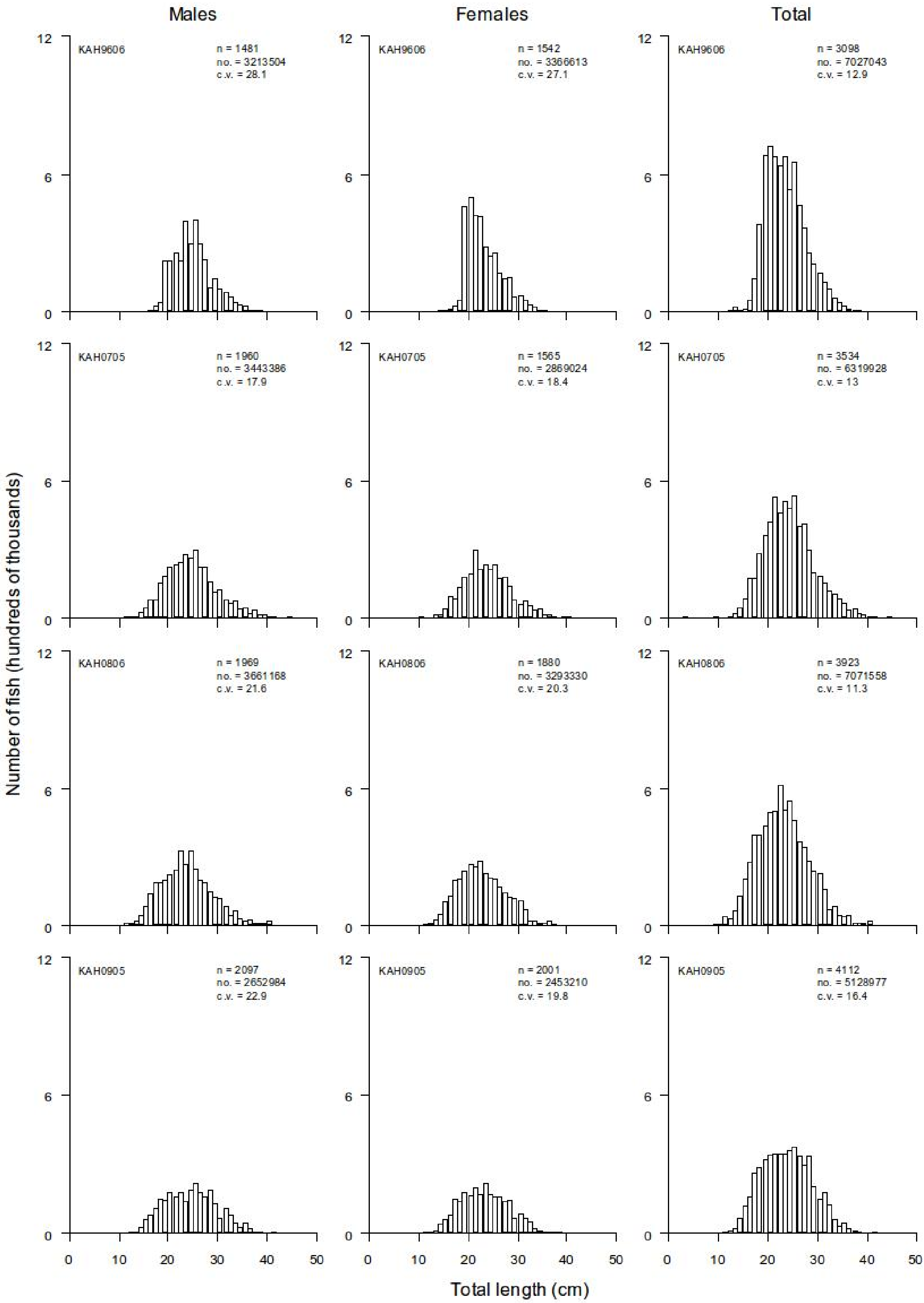

Figure A26: Scaled population length frequencies by sex of sea perch from the winter east coast South Island from *Kaharoa* surveys from 1996 to 2009.

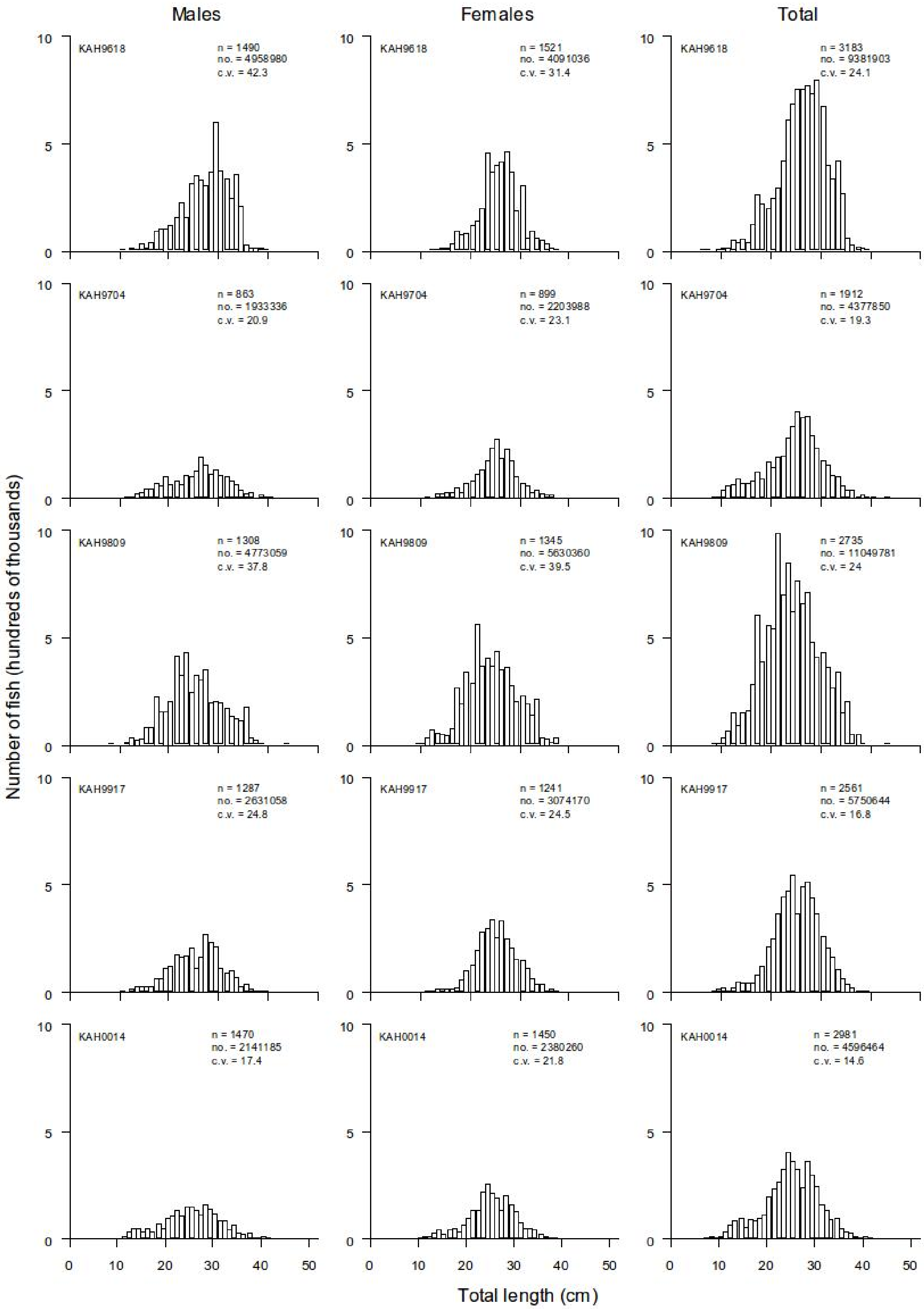

Figure A27: Scaled population length frequencies by sex of sea perch from the summer east coast South Island from *Kaharoa* surveys from 1996 to 2000.

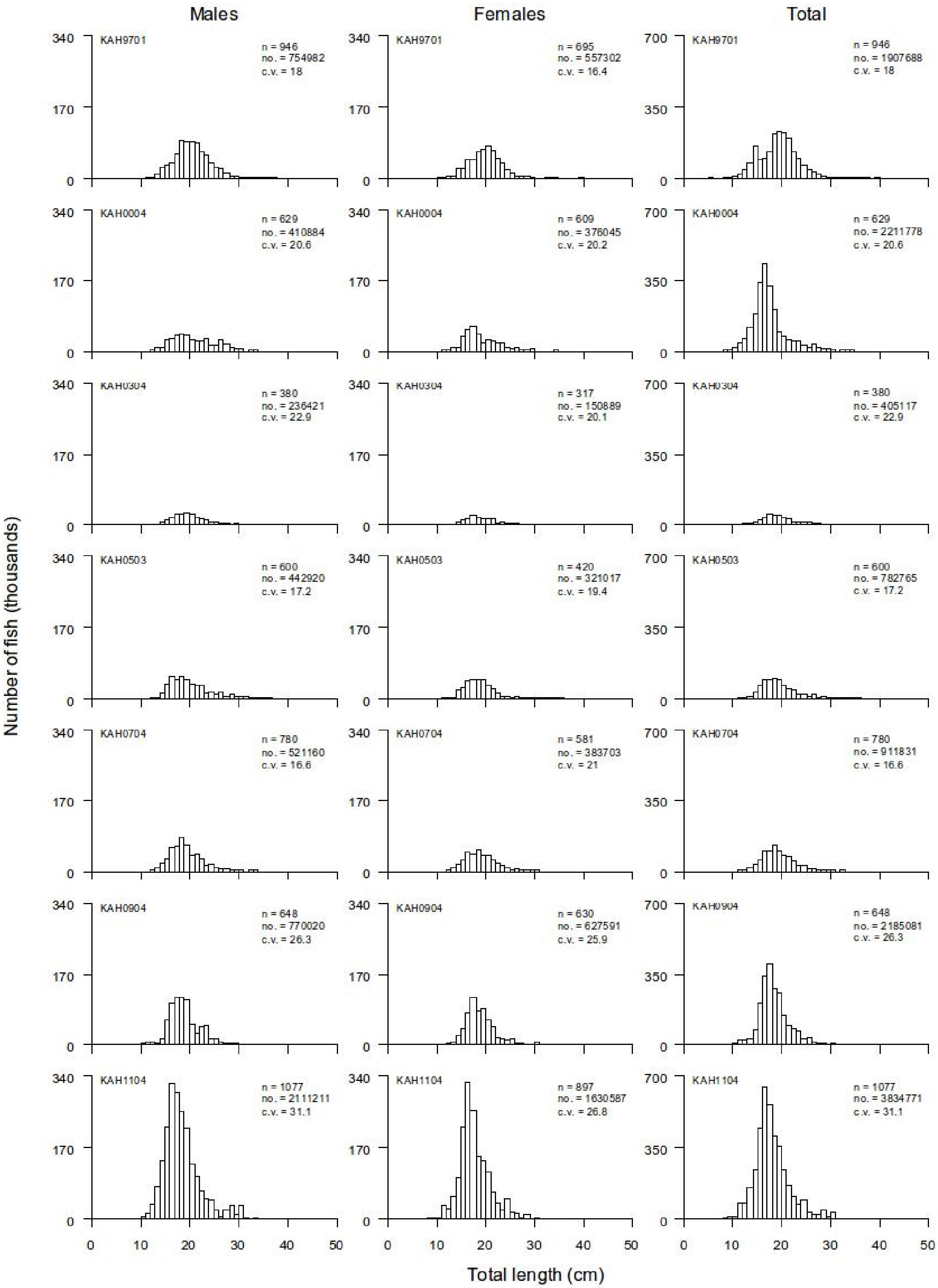

Figure A28: Scaled population length frequencies by sex of sea perch from the west coast South Island from *Kaharoa* surveys from 1997 to 2011.

12. APPENDIX B: SUMMARIES OF OBSERVER PROGRAMME DATA

Table B1: Total number of tows by fishing year sampled for sea perch length from each area overall by the observer programme for all available fishing years between 1990 and 2010. CANT = Canterbury; CREA = eastern Chatham Rise; CRNO = northern Chatham Rise; CRSO = southern Chatham Rise; CRWE = western Chatham Rise; ECNI = east coast North Island; SOUTH = Southland; WCSI = west coast South Island; Other = all other areas combined.

Fishing Year	CANT	CREA	CRNO	CRSO	CRWE	ECNI	OTHER	SOUTH	WCSI	Total
1995–96	–	–	–	–	1	–	–	–	–	1
1997–98	11	–	–	–	5	–	–	3	–	19
1998–99	3	–	2	–	–	–	–	–	–	5
1999–00	1	–	–	–	1	–	3	1	–	6
2000–01	23	15	6	13	28	2	2	3	1	93
2001–02	6	–	4	10	26	4	1	2	3	56
2002–03	29	4	30	6	17	–	9	14	8	117
2003–04	19	13	34	7	12	–	6	11	3	105
2004–05	16	–	36	30	12	4	2	7	–	107
2005–06	12	2	23	13	8	–	4	10	5	77
2006–07	14	15	24	17	7	3	4	2	12	98
2007–08	6	3	21	6	5	3	14	1	7	66
2008–09	–	–	10	–	–	–	1	2	1	14
2009–10	24	–	15	1	8	1	14	–	1	64
Total	164	52	205	103	130	17	60	56	41	828

Table B2: Total number of tows by fishing year sampled for sea perch length by month for all areas combined by the observer programme for all available fishing years between 1990 and 2010.

Fishing year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1995–96	–	–	–	–	–	–	–	1	–	–	–	–	1
1997–98	–	–	–	–	–	3	13	–	–	–	–	3	19
1998–99	–	–	–	–	2	–	–	3	–	–	–	–	5
1999–00	–	1	1	–	–	–	2	2	–	–	–	–	6
2000–01	6	21	21	7	22	3	5	2	3	2	–	1	93
2001–02	2	–	1	9	3	–	13	20	–	2	6	–	56
2002–03	30	15	13	3	3	7	8	8	4	6	5	15	117
2003–04	32	9	8	1	3	6	20	4	–	3	12	7	105
2004–05	3	20	15	6	27	19	–	5	11	1	–	–	107
2005–06	20	1	2	8	3	3	6	–	6	15	11	2	77
2006–07	–	18	13	1	9	6	6	30	3	11	–	1	98
2007–08	–	21	2	2	3	10	6	13	–	2	4	3	66
2008–09	–	1	–	–	1	–	–	1	–	–	5	6	14
2009–10	8	4	14	7	1	9	1	13	3	–	–	4	64
Total	101	111	90	44	77	66	80	102	30	42	43	42	828

Table B3: Total number of tows by fishing year sampled for sea perch length by month for Canterbury by the observer programme for all available fishing years between 1990 and 2010.

Fishing year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1997–98	–	–	–	–	–	2	6	–	–	–	–	3	11
1998–99	–	–	–	–	–	–	–	3	–	–	–	–	3
1999–00	–	–	–	–	–	–	–	1	–	–	–	–	1
2000–01	2	3	8	1	3	–	2	1	1	1	–	1	23
2001–02	–	–	–	1	1	–	2	2	–	–	–	–	6
2002–03	2	2	5	2	–	–	2	3	2	–	–	11	29
2003–04	–	–	2	–	–	–	–	–	–	1	10	6	19
2004–05	–	1	1	–	2	4	–	4	4	–	–	–	16
2005–06	2	–	–	–	3	–	–	–	2	–	3	2	12
2006–07	–	5	4	–	–	–	2	2	1	–	–	–	14
2007–08	–	4	–	–	–	–	–	2	–	–	–	–	6
2009–10	4	–	3	6	1	9	–	1	–	–	–	–	24
Total	10	15	23	10	10	15	14	19	10	2	13	23	164

Table B4: Total number of tows by fishing year sampled for sea perch length by month for the eastern Chatham Rise by the observer programme for all available fishing years between 1990 and 2010.

Fishing year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
2000–01	2	9	–	–	3	–	1	–	–	–	–	–	15
2002–03	1	2	–	–	–	–	–	–	–	–	–	1	4
2003–04	1	5	–	–	–	–	7	–	–	–	–	–	13
2005–06	–	–	–	–	–	–	–	–	–	2	–	–	2
2006–07	–	2	–	1	7	5	–	–	–	–	–	–	15
2007–08	–	2	–	–	–	–	–	–	–	–	1	–	3
Total	4	20	–	1	10	5	8	–	–	2	1	1	52

Table B5: Total number of tows by fishing year sampled for sea perch length by month for the northern Chatham Rise by the observer programme for all available fishing years between 1990 and 2010.

Fishing year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1998–99	–	–	–	–	2	–	–	–	–	–	–	–	2
2000–01	1	–	–	–	5	–	–	–	–	–	–	–	6
2001–02	1	–	–	–	–	–	–	3	–	–	–	–	4
2002–03	21	6	1	–	–	–	–	–	–	–	–	2	30
2003–04	21	4	–	–	–	2	4	2	–	1	–	–	34
2004–05	3	14	9	1	5	2	–	–	2	–	–	–	36
2005–06	5	–	–	–	–	–	4	–	–	11	3	–	23
2006–07	–	1	1	–	1	1	–	20	–	–	–	–	24
2007–08	–	8	1	1	3	–	–	8	–	–	–	–	21
2008–09	–	–	–	–	–	–	–	–	–	–	4	6	10
2009–10	1	3	–	–	–	–	–	7	–	–	–	4	15
Total	53	36	12	2	16	5	8	40	2	12	7	12	205

Table B6: Total number of tows by fishing year sampled for sea perch length by month for the southern Chatham Rise by the observer programme for all available fishing years between 1990 and 2010.

Fishing year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
2000–01	–	4	2	4	–	1	2	–	–	–	–	–	13
2001–02	–	–	1	–	–	–	3	6	–	–	–	–	10
2002–03	–	2	1	–	–	–	–	3	–	–	–	–	6
2003–04	–	–	–	–	–	–	5	2	–	–	–	–	7
2004–05	–	3	1	4	9	12	–	–	1	–	–	–	30
2005–06	7	–	2	2	–	–	–	–	1	1	–	–	13
2006–07	–	8	7	–	–	–	1	1	–	–	–	–	17
2007–08	–	3	–	–	–	–	1	2	–	–	–	–	6
2009–10	1	–	–	–	–	–	–	–	–	–	–	–	1
Total	8	20	14	10	9	13	12	14	2	1	–	–	103

Table B7: Total number of tows by fishing year sampled for sea perch length by month for the western Chatham Rise by the observer programme for all available fishing years between 1990 and 2010.

Fishing year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1995–96	–	–	–	–	–	–	–	1	–	–	–	–	1
1997–98	–	–	–	–	–	1	4	–	–	–	–	–	5
1999–00	–	–	1	–	–	–	–	–	–	–	–	–	1
2000–01	–	5	10	2	8	1	–	–	2	–	–	–	28
2001–02	1	–	–	8	2	–	6	9	–	–	–	–	26
2002–03	6	1	6	–	–	–	–	2	1	–	–	1	17
2003–04	8	–	2	1	–	–	–	–	–	–	1	–	12
2004–05	–	1	–	1	4	1	–	1	4	–	–	–	12
2005–06	4	1	–	–	–	–	1	–	1	1	–	–	8
2006–07	–	2	1	–	–	–	1	3	–	–	–	–	7
2007–08	–	3	1	–	–	–	–	1	–	–	–	–	5
2009–10	1	–	4	1	–	–	–	2	–	–	–	–	8
Total	20	13	25	13	14	3	12	19	8	1	1	1	130

Table B8: Total number of tows by fishing year sampled for sea perch length by month for Southland by the observer programme for all available fishing years between 1990 and 2010.

Fishing year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1997–98	–	–	–	–	–	–	3	–	–	–	–	–	3
1999–00	–	–	–	–	–	–	1	–	–	–	–	–	1
2000–01	–	–	–	–	2	1	–	–	–	–	–	–	3
2001–02	–	–	–	–	–	–	2	–	–	–	–	–	2
2002–03	–	1	–	1	1	7	4	–	–	–	–	–	14
2003–04	–	–	4	–	3	4	–	–	–	–	–	–	11
2004–05	–	–	–	–	7	–	–	–	–	–	–	–	7
2005–06	–	–	–	6	–	3	1	–	–	–	–	–	10
2006–07	–	–	–	–	1	–	1	–	–	–	–	–	2
2007–08	–	–	–	1	–	–	–	–	–	–	–	–	1
2008–09	–	–	–	–	1	–	–	1	–	–	–	–	2
Total	–	1	4	8	15	15	12	1	–	–	–	–	56

Table B9: Total number of tows by fishing year sampled for sea perch length by month for the west Coast South Island by the observer programme for all available fishing years between 1990 and 2010.

Fishing year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
2000–01	–	–	–	–	–	–	–	–	–	1	–	–	1
2001–02	–	–	–	–	–	–	–	–	–	2	1	–	3
2002–03	–	–	–	–	–	–	–	–	1	5	2	–	8
2003–04	–	–	–	–	–	–	–	–	–	1	1	1	3
2005–06	–	–	–	–	–	–	–	–	2	–	3	–	5
2006–07	–	–	–	–	–	–	–	–	2	10	–	–	12
2007–08	–	–	–	–	–	–	–	–	–	1	3	3	7
2008–09	–	–	–	–	–	–	–	–	–	–	1	–	1
2009–10	1	–	–	–	–	–	–	–	–	–	–	–	1
Total	1	–	–	–	–	–	–	–	5	20	11	4	41

Table B10: Total number of tows by fishing year sampled for sea perch length by month for the east coast North Island by the observer programme for all available fishing years between 1990 and 2010.

Fishing year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
2000–01	1	–	1	–	–	–	–	–	–	–	–	–	2
2001–02	–	–	–	–	–	–	–	–	–	–	4	–	4
2004–05	–	–	4	–	–	–	–	–	–	–	–	–	4
2006–07	–	–	–	–	–	–	–	3	–	–	–	–	3
2007–08	–	1	–	–	–	–	2	–	–	–	–	–	3
2009–10	–	1	–	–	–	–	–	–	–	–	–	–	1
Total	1	2	5	–	–	–	2	3	–	–	4	–	17

Table B11: Total number of tows by fishing year sampled for sea perch length by month for all other areas combined by the observer programme for all available fishing years between 1990 and 2010.

Fishing year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1999–00	–	1	–	–	–	–	1	1	–	–	–	–	3
2000–01	–	–	–	–	1	–	–	1	–	–	–	–	2
2001–02	–	–	–	–	–	–	–	–	–	–	1	–	1
2002–03	–	1	–	–	2	–	2	–	–	1	3	–	9
2003–04	2	–	–	–	–	–	4	–	–	–	–	–	6
2004–05	–	1	–	–	–	–	–	–	–	1	–	–	2
2005–06	2	–	–	–	–	–	–	–	–	–	2	–	4
2006–07	–	–	–	–	–	–	1	1	–	1	–	1	4
2007–08	–	–	–	–	–	10	3	–	–	1	–	–	14
2008–09	–	1	–	–	–	–	–	–	–	–	–	–	1
2009–10	–	–	7	–	–	–	1	3	3	–	–	–	14
Total	4	4	7	–	3	10	12	6	3	4	6	1	60

Table B12: Number of sea perch otoliths collected by fishing year and QMA by the observer programme.

Fishing year	SPE 1	SPE 2	SPE 3	SPE 4	SPE 5 & 6	SPE 7	SPE 9	Total
1996	–	–	2	–	–	–	–	2
1998	–	–	49	–	8	–	–	57
2000	–	–	58	–	–	1	–	59
2001	–	6	179	141	12	–	–	338
2002	–	54	87	56	9	5	–	211
2003	12	–	230	161	50	18	13	484
2004	15	–	165	306	40	7	10	543
2005	–	21	93	263	34	–	–	411
2006	7	–	56	152	27	22	–	264
2007	–	15	64	284	1	60	3	427
2008	26	20	28	146	5	15	–	240
2009	–	2	28	–	5	–	–	35
2010	60	–	129	74	–	5	–	268
Total	120	118	1168	1583	191	133	26	3339

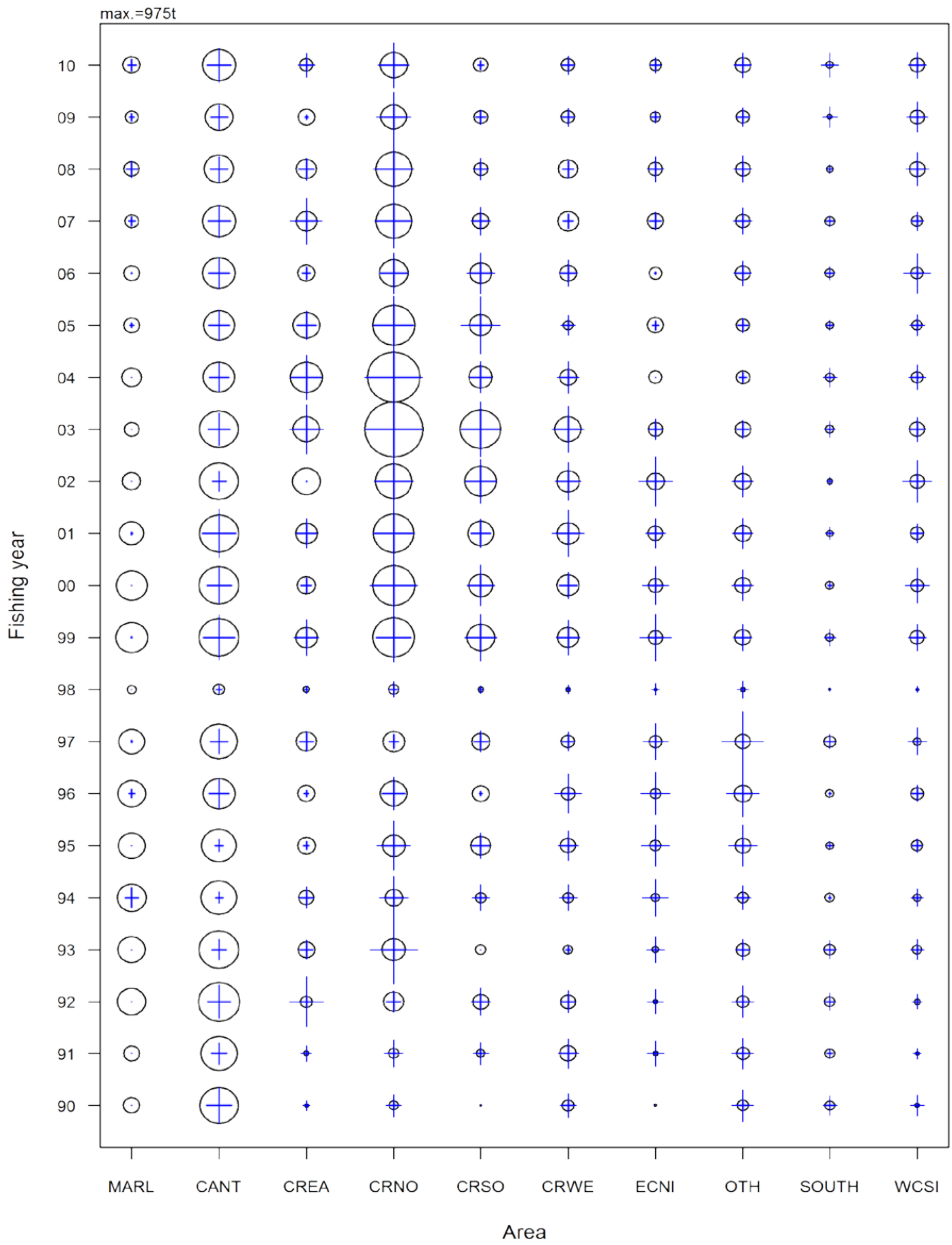

Figure B1: Representativeness of observer sampling of sea perch catch by fishing year and area for fishing years 1990–2010. Circles show the proportion of sea perch catch by area within a fishing year; crosses show the proportion of observed sea perch catch for the same cells. Representation is demonstrated by how closely the cross matches the circle diameter. CANT = Canterbury; CREA = eastern Chatham Rise; CRNO = northern Chatham Rise; CRSO = southern Chatham Rise; CRWE = western Chatham Rise; ECNI = east coast North Island; SOUTH = Southland; WCSI = west coast South Island; Other = all other areas combined.

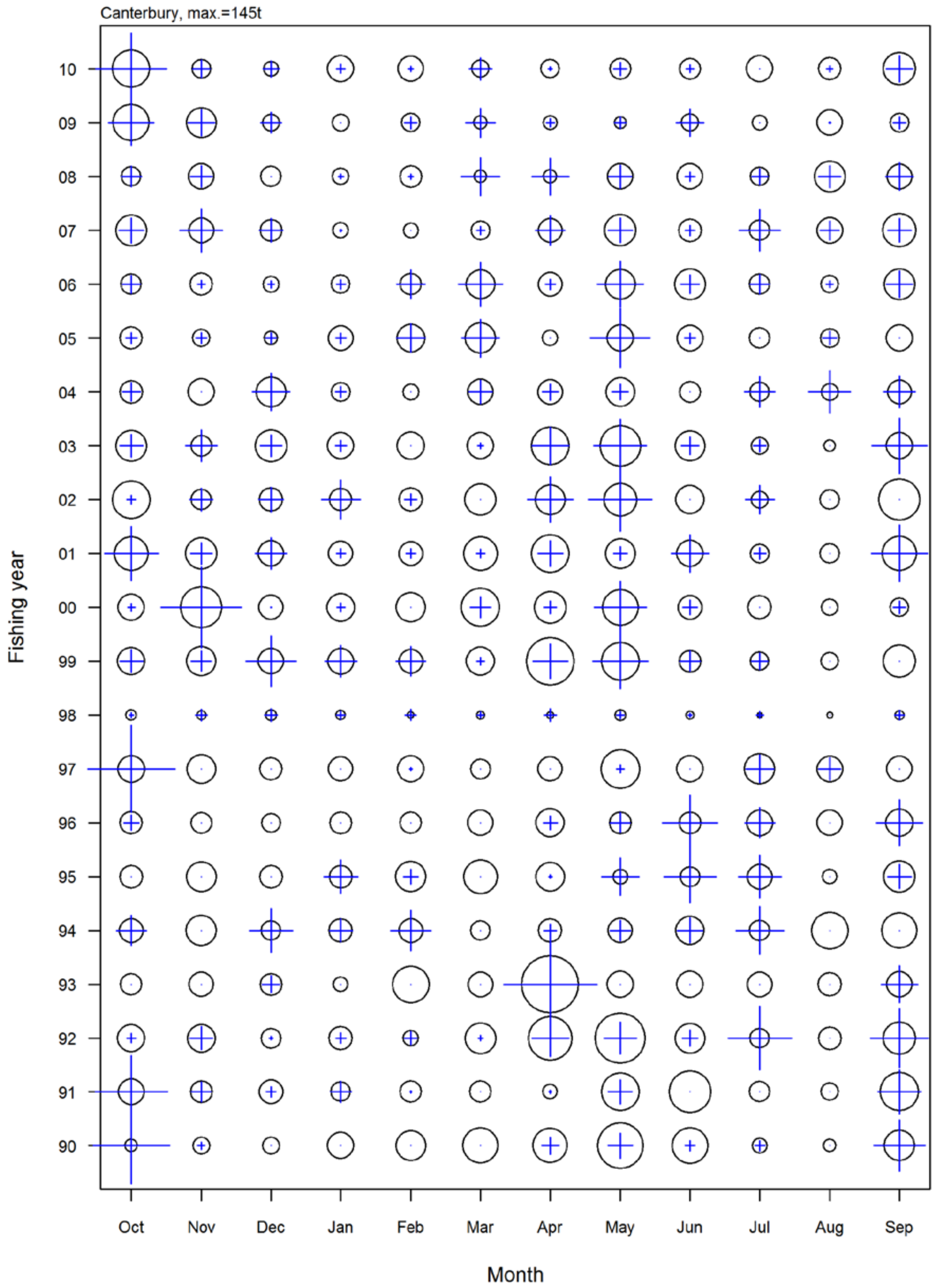

Figure B2: Representativeness of observer sampling of sea perch catch by fishing year and month for Canterbury for fishing years 1990–2010. Circles show the proportion of sea perch catch by month within a fishing year; crosses show the proportion of observed sea perch catch for the same cells. Representation is demonstrated by how closely the cross matches the circle diameter.

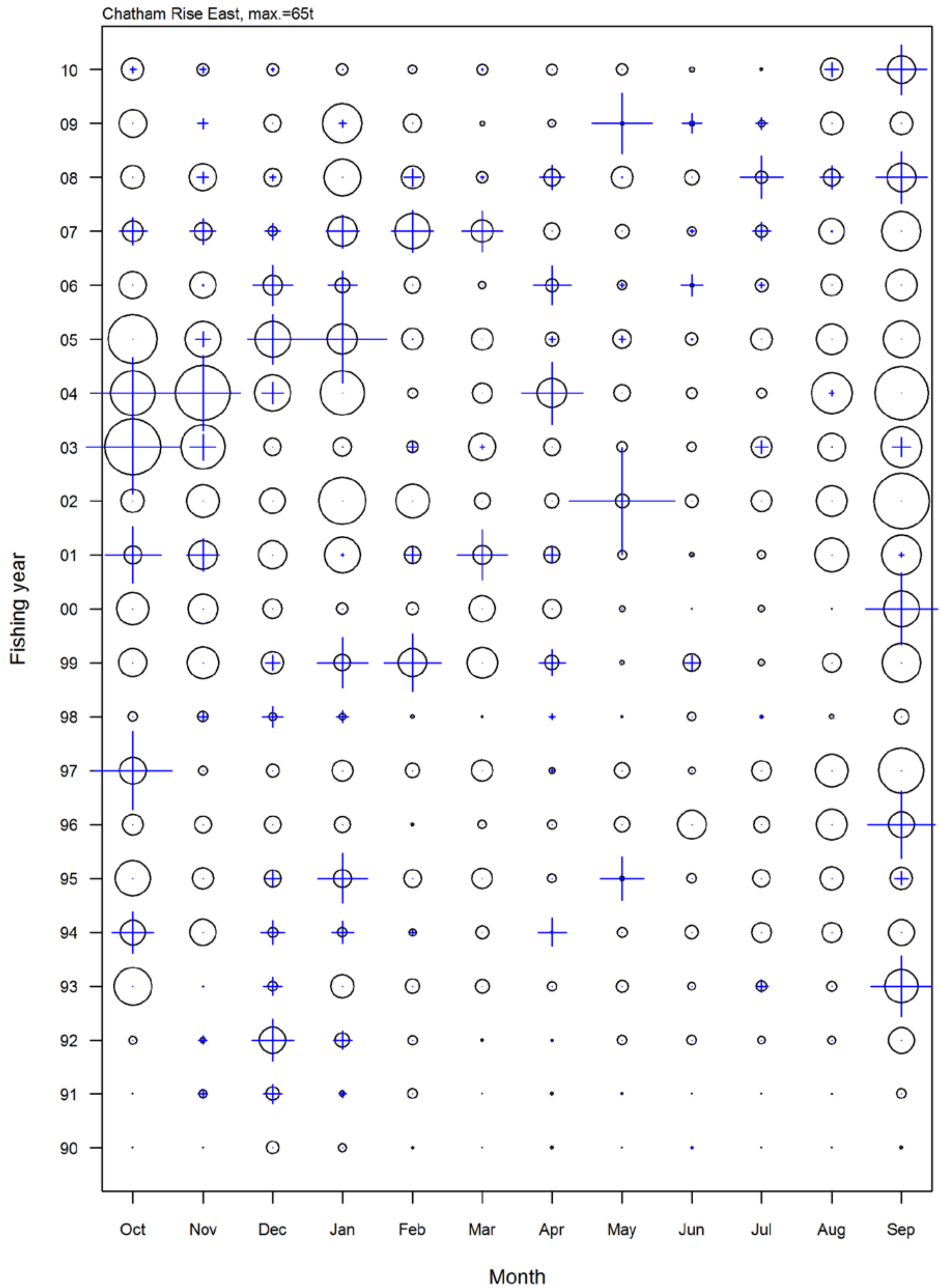

Figure B3: Representativeness of observer sampling of sea perch catch by fishing year and month for the eastern Chatham Rise for fishing years 1990–2010. Circles show the proportion of sea perch catch by month within a fishing year; crosses show the proportion of observed sea perch catch for the same cells. Representation is demonstrated by how closely the cross matches the circle diameter.

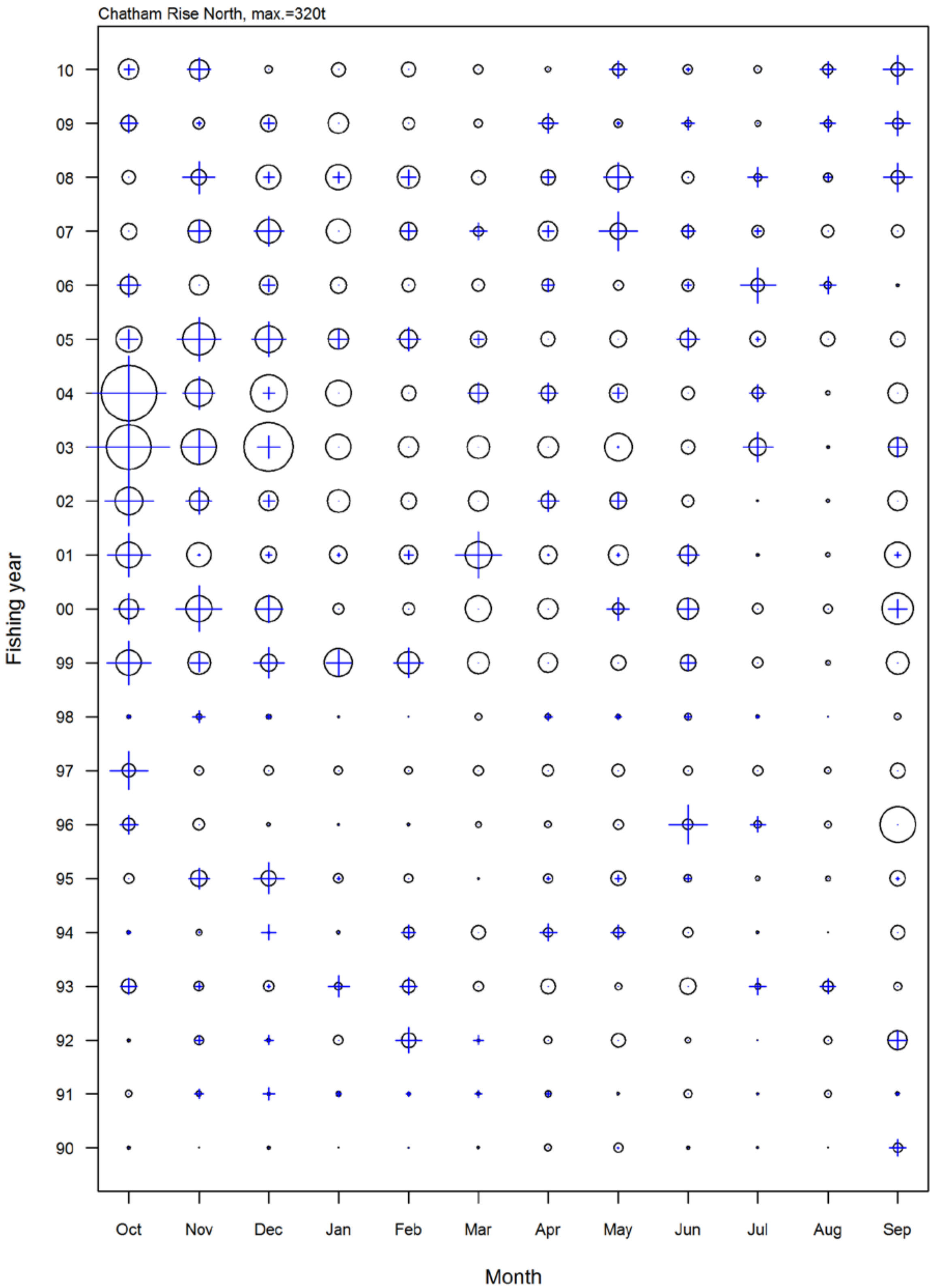

Figure B4: Representativeness of observer sampling of sea perch catch by fishing year and month for the northern Chatham Rise for fishing years 1990–2010. Circles show the proportion of sea perch catch by month within a fishing year; crosses show the proportion of observed sea perch catch for the same cells. Representation is demonstrated by how closely the cross matches the circle diameter.

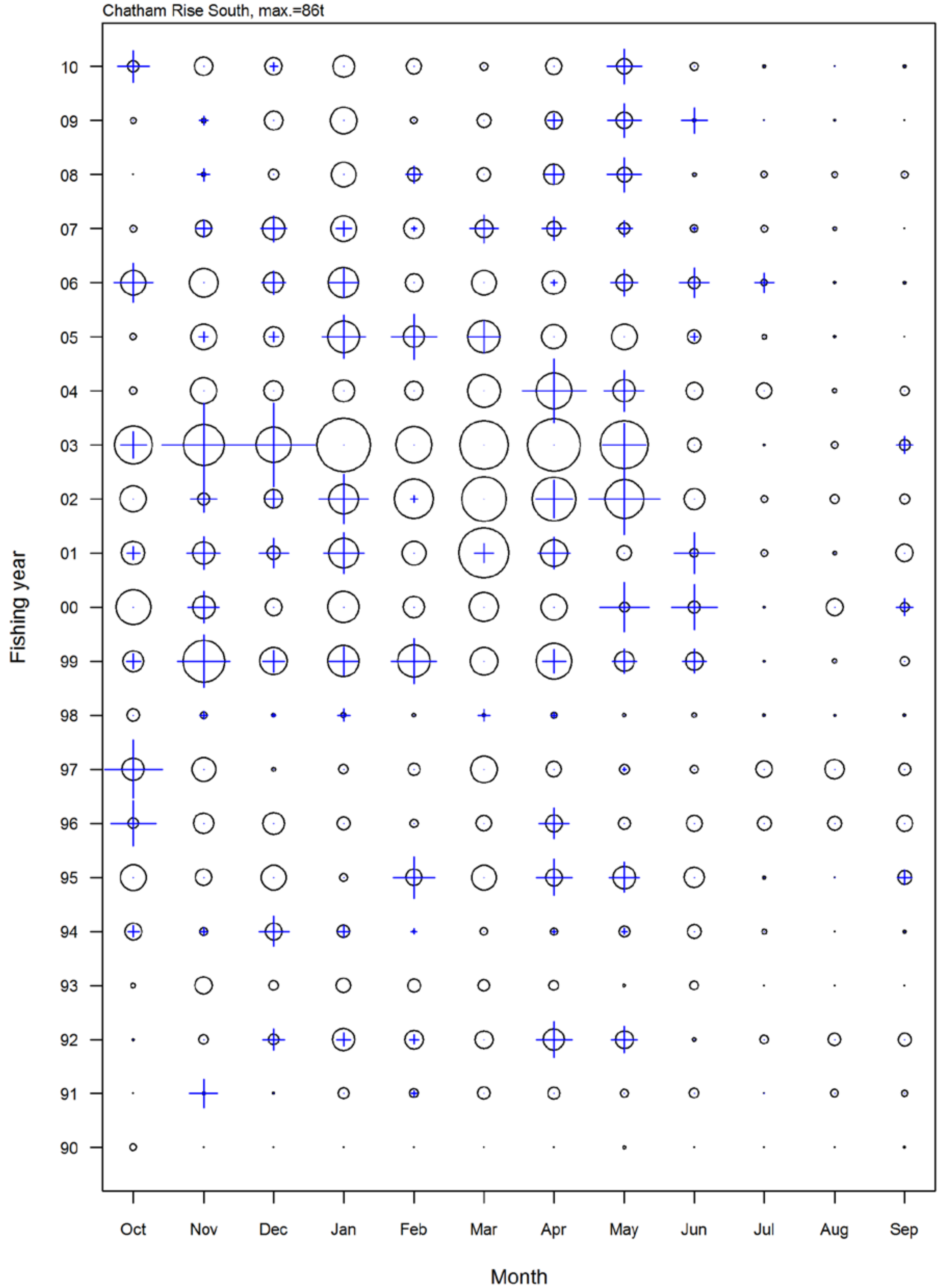

Figure B5: Representativeness of observer sampling of sea perch catch by fishing year and month for the southern Chatham Rise for fishing years 1990–2010. Circles show the proportion of sea perch catch by month within a fishing year; crosses show the proportion of observed sea perch catch for the same cells. Representation is demonstrated by how closely the cross matches the circle diameter.

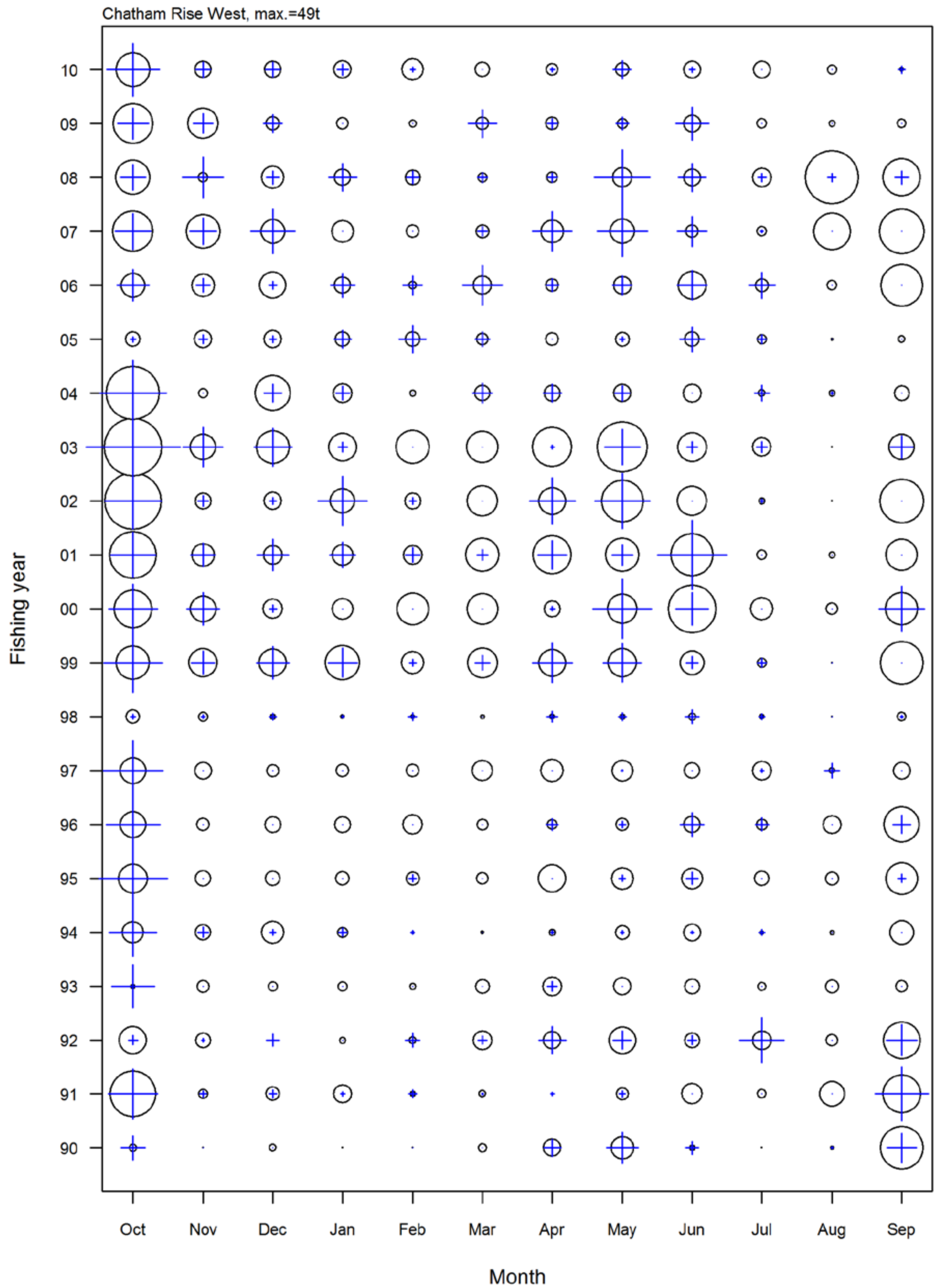

Figure B6: Representativeness of observer sampling of sea perch catch by fishing year and month for the western Chatham Rise for fishing years 1990–2010. Circles show the proportion of sea perch catch by month within a fishing year; crosses show the proportion of observed sea perch catch for the same cells. Representation is demonstrated by how closely the cross matches the circle diameter.

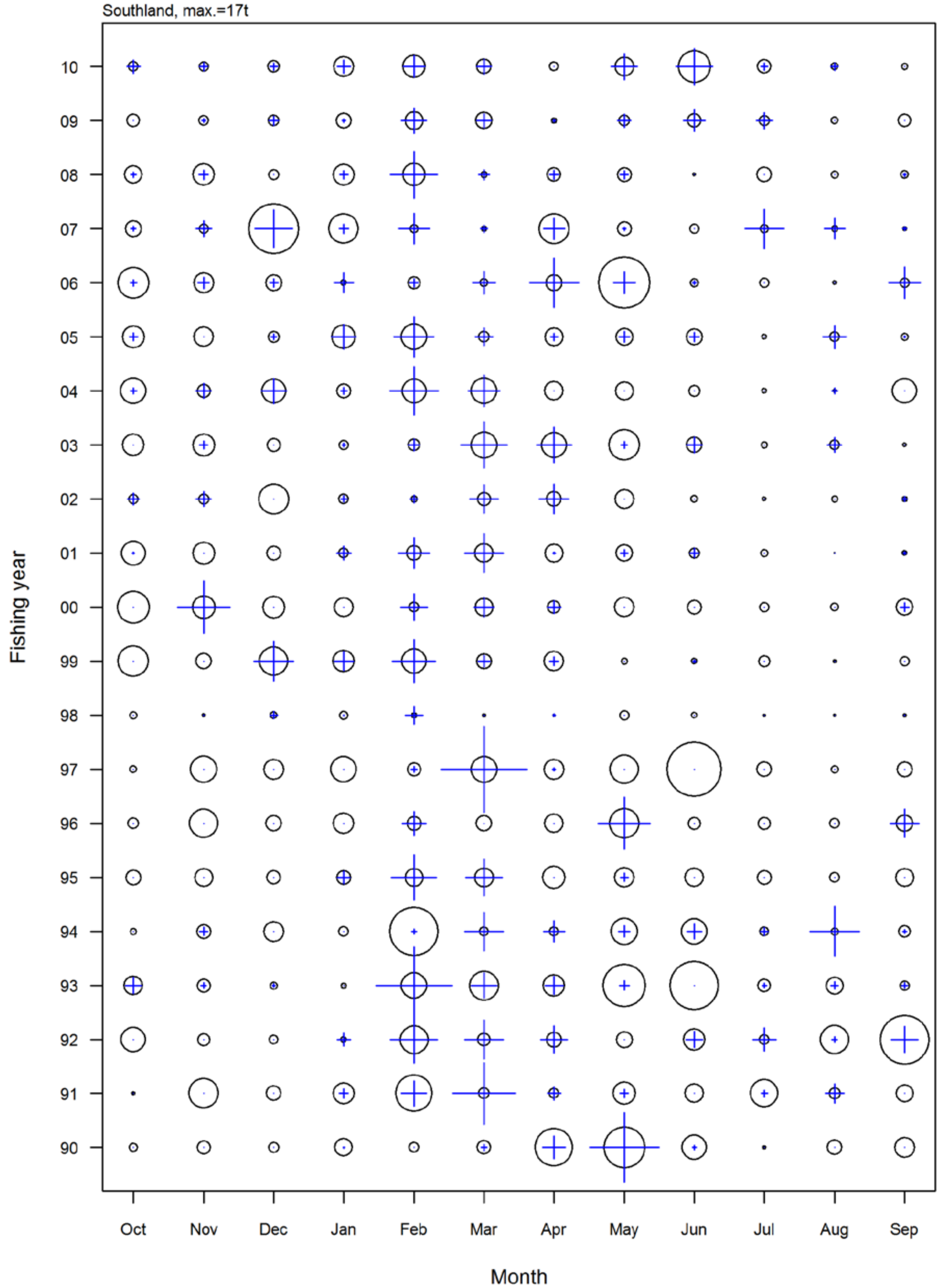

Figure B7: Representativeness of observer sampling of sea perch catch by fishing year and month for Southland for fishing years 1990–2010. Circles show the proportion of sea perch catch by month within a fishing year; crosses show the proportion of observed sea perch catch for the same cells. Representation is demonstrated by how closely the cross matches the circle diameter.

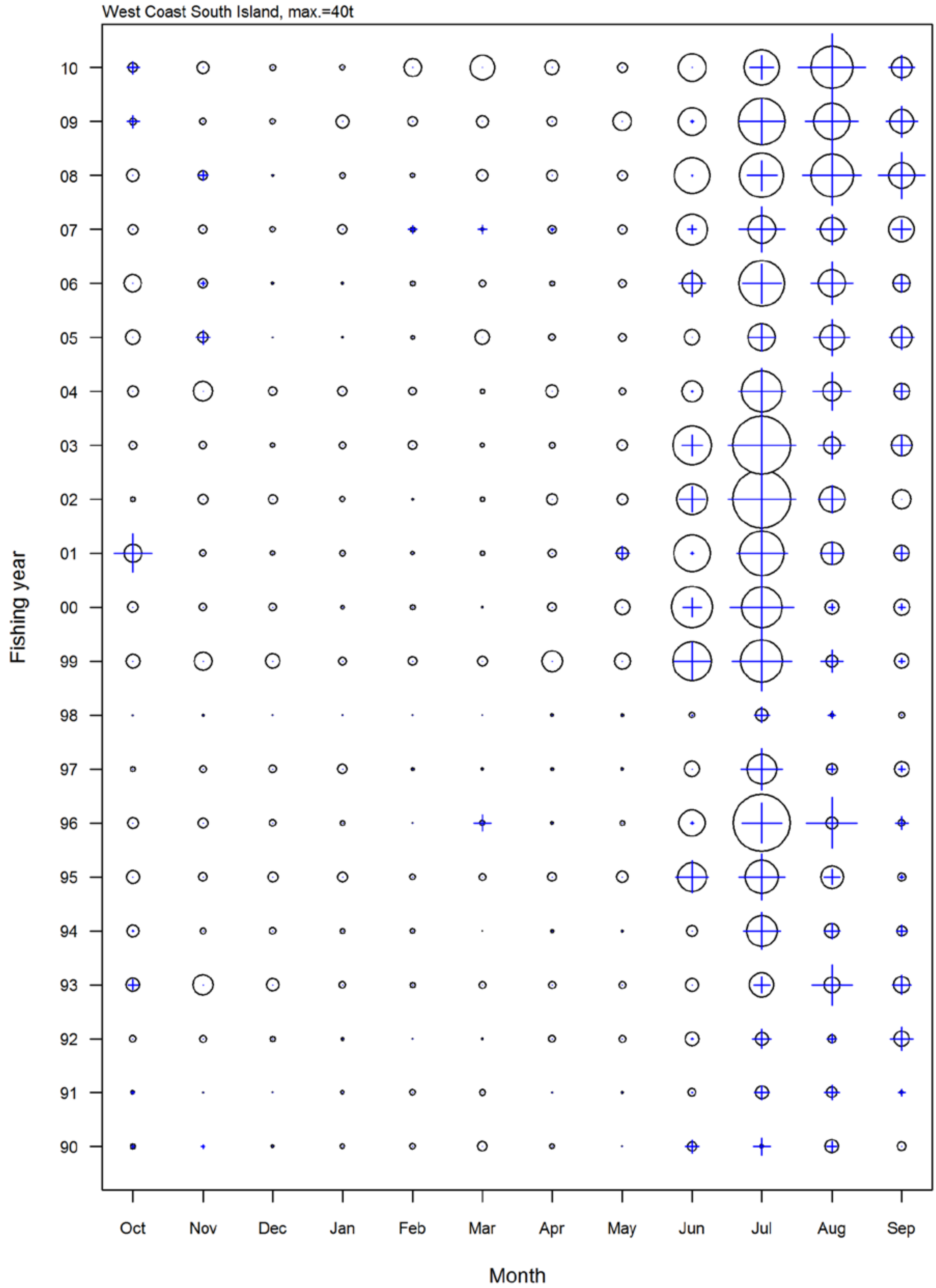

Figure B8: Representativeness of observer sampling of sea perch catch by fishing year and month for west coast South Island for fishing years 1990–2010. Circles show the proportion of sea perch catch by month within a fishing year; crosses show the proportion of observed sea perch catch for the same cells. Representation is demonstrated by how closely the cross matches the circle diameter.

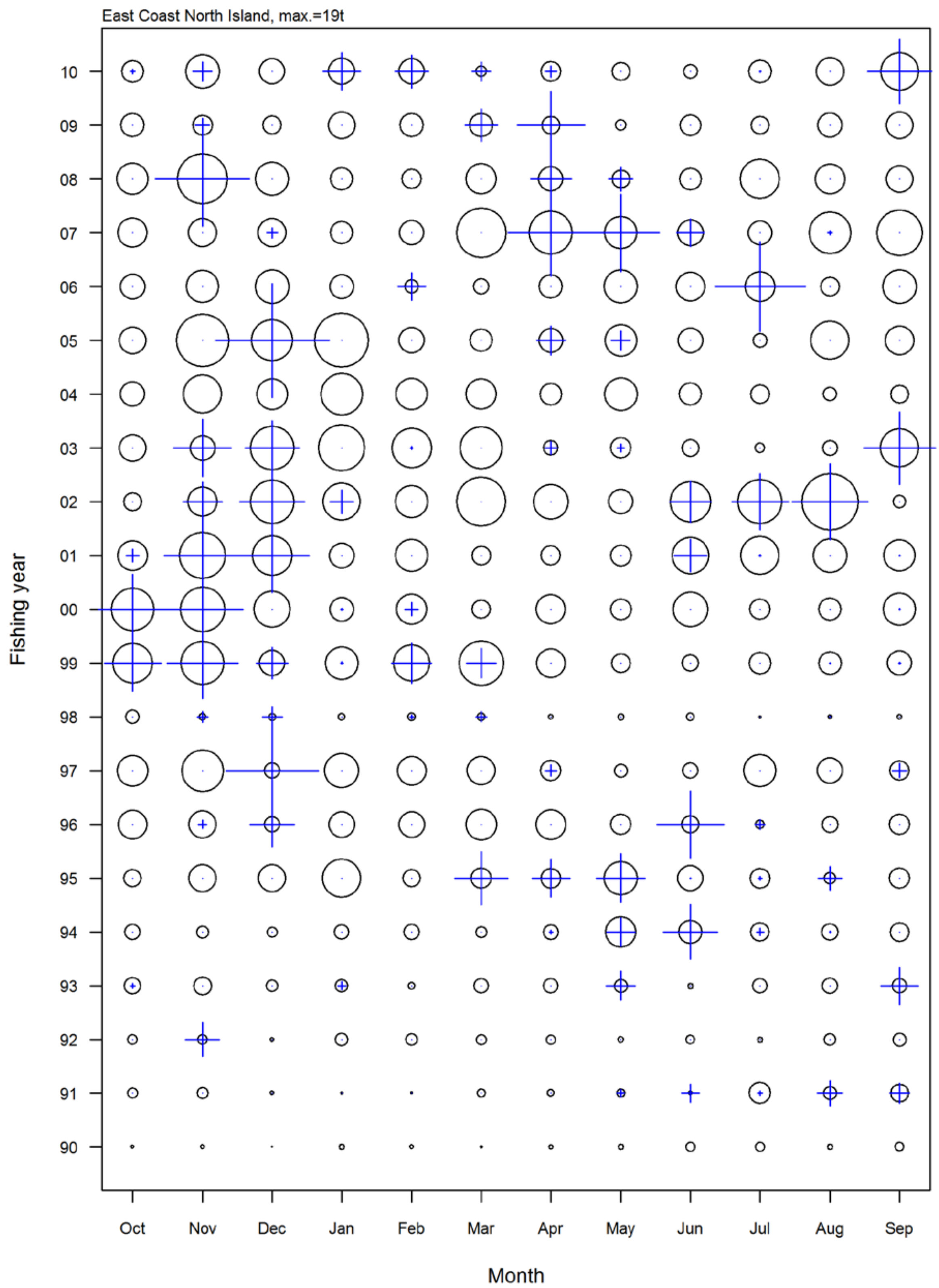

Figure B9: Representativeness of observer sampling of sea perch catch by fishing year and month for east coast North Island for fishing years 1990–2010. Circles show the proportion of sea perch catch by month within a fishing year; crosses show the proportion of observed sea perch catch for the same cells. Representation is demonstrated by how closely the cross matches the circle diameter.

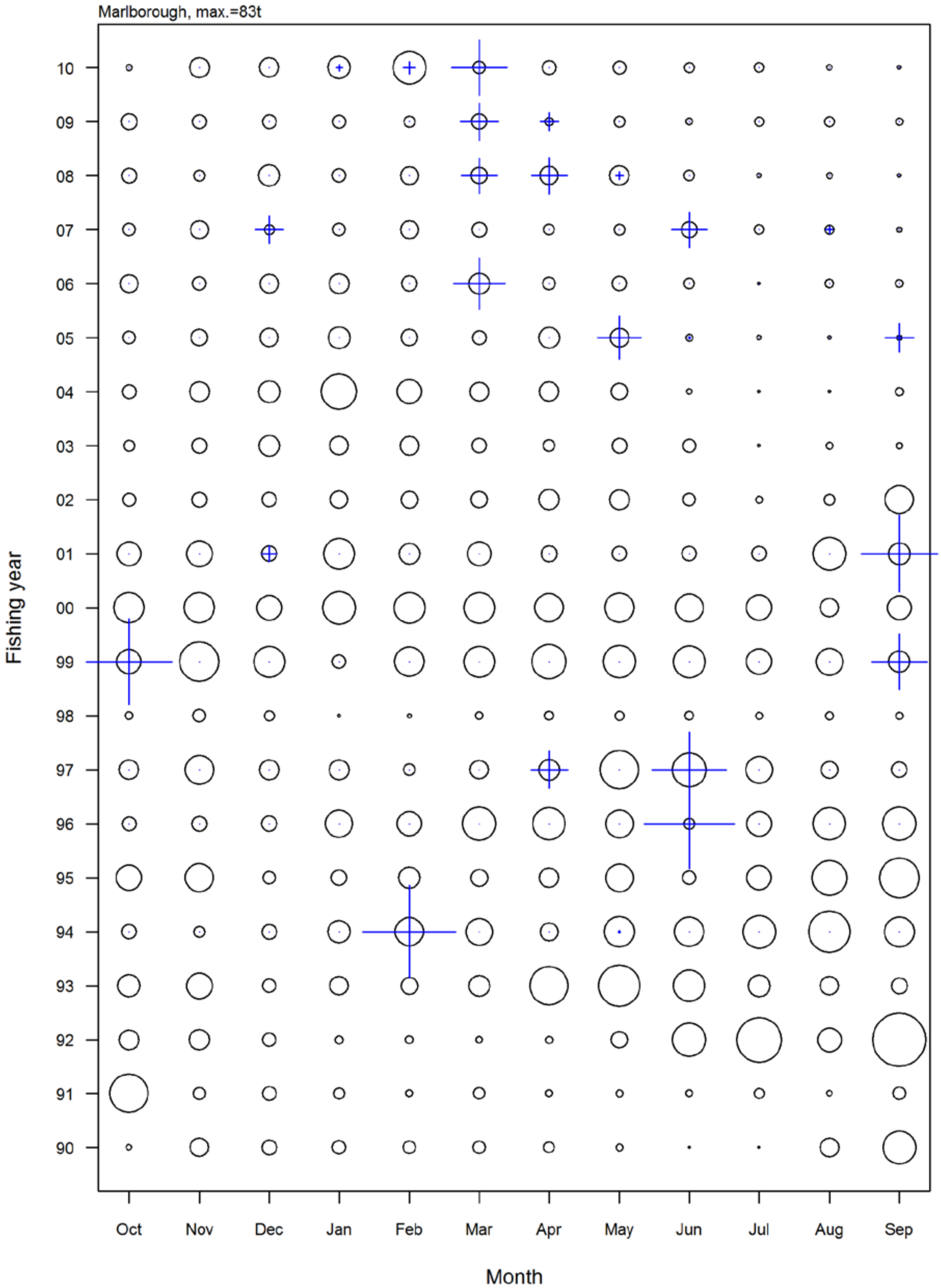

Figure B10: Representativeness of observer sampling of sea perch catch by fishing year and month for Marlborough for fishing years 1990–2010. Circles show the proportion of sea perch catch by month within a fishing year; crosses show the proportion of observed sea perch catch for the same cells. Representation is demonstrated by how closely the cross matches the circle diameter.

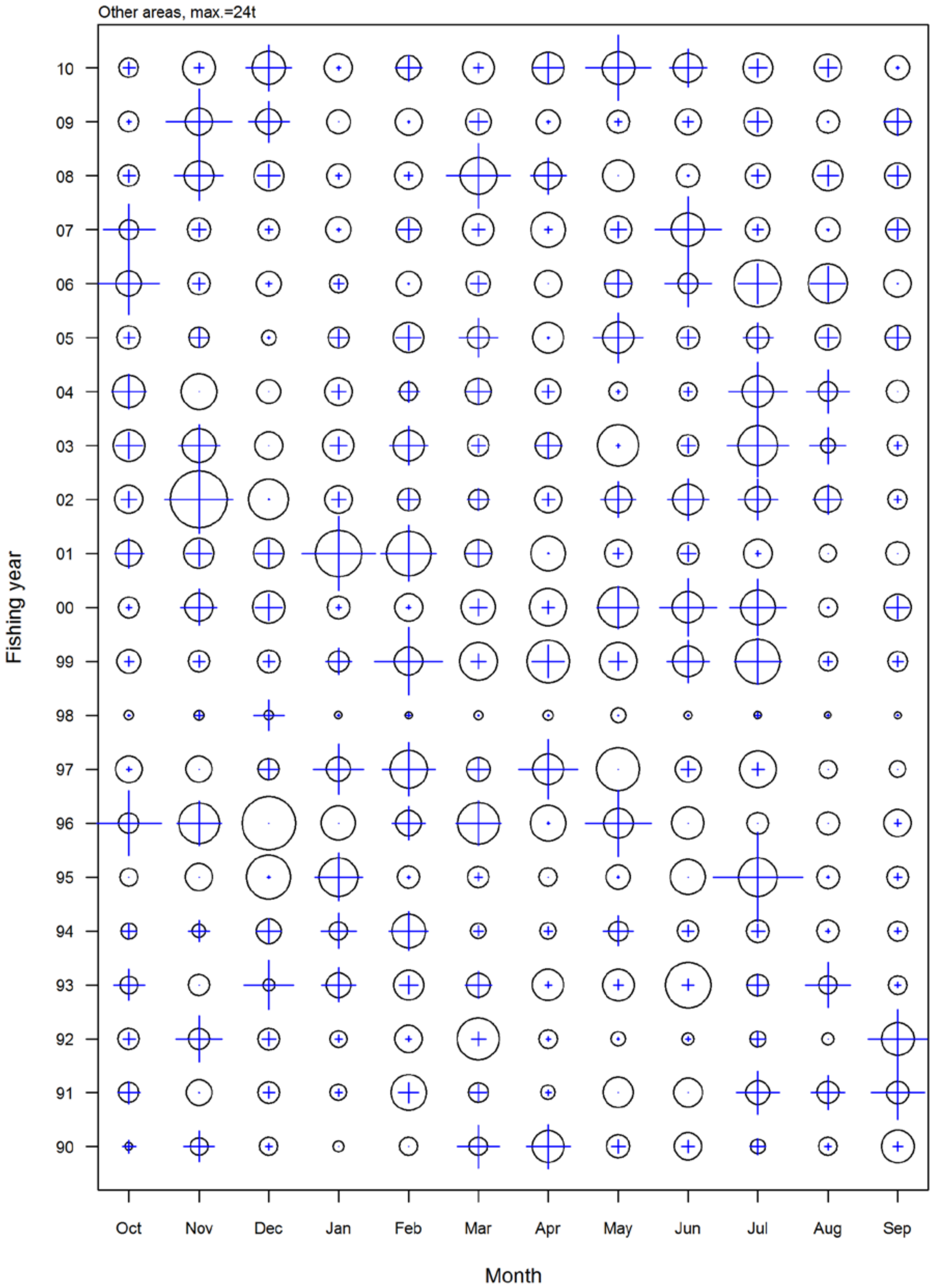

Figure B11: Representativeness of observer sampling of sea perch catch by fishing year and month for all other areas combined for fishing years 1990–2010. Circles show the proportion of sea perch catch by month within a fishing year; crosses show the proportion of observed sea perch catch for the same cells. Representation is demonstrated by how closely the cross matches the circle diameter.

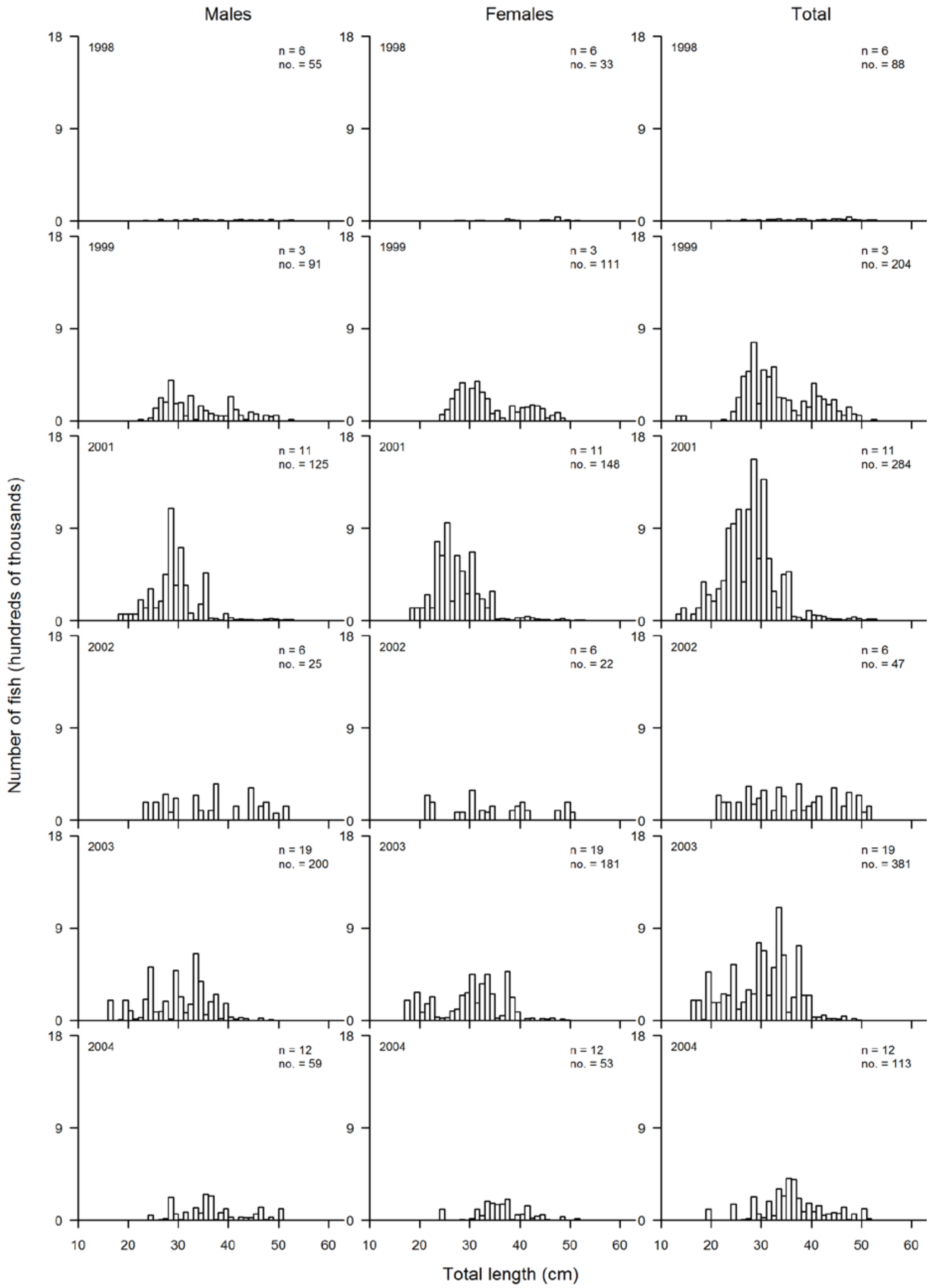

Figure B12: Scaled length frequency of sea perch taken in commercial catches from the Canterbury fishery by fishing year sampled by the Observer Programme, for fishing years 1998–2004. n, number of tows sampled; no., number of fish sampled.

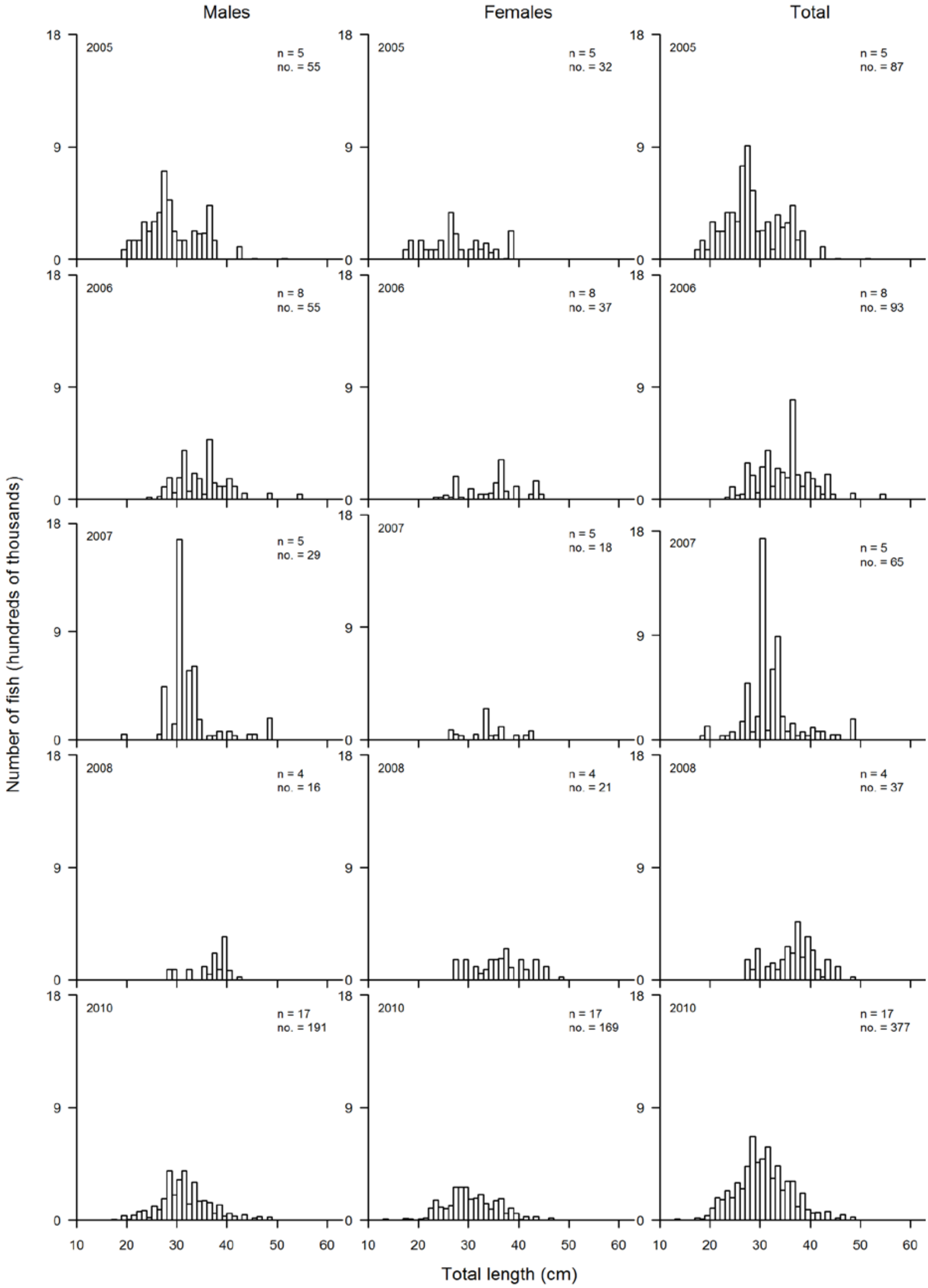

Figure B13: Scaled length frequency of sea perch taken in commercial catches from the Canterbury fishery by fishing year sampled by the Observer Programme, for fishing years 2005–2010. n, number of tows sampled; no., number of fish sampled.

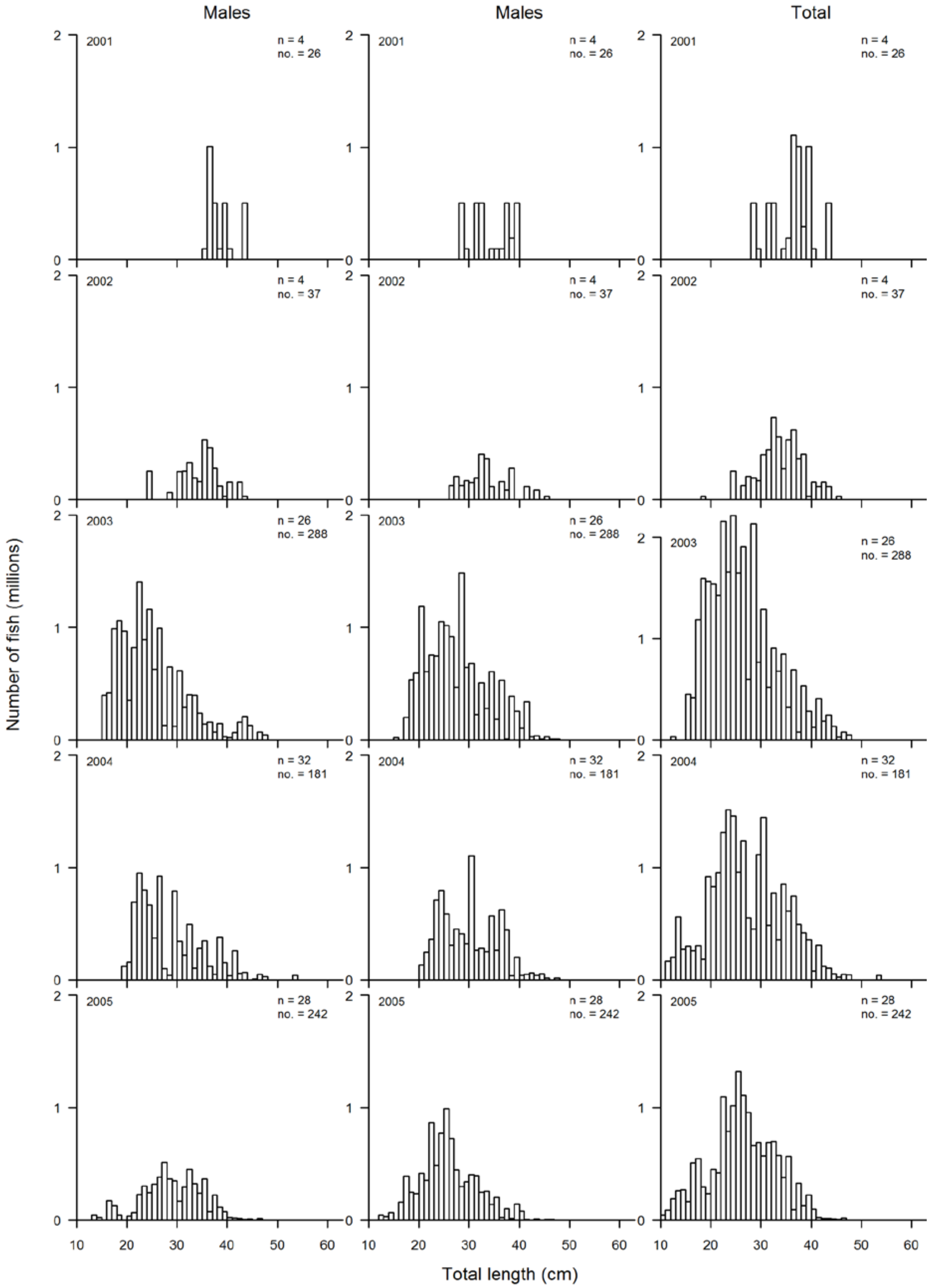

Figure B14: Scaled length frequency of sea perch taken in commercial catches from the northern Chatham Rise fishery by fishing year sampled by the Observer Programme, for fishing years 2001–2005. n, number of tows sampled; no., number of fish sampled.

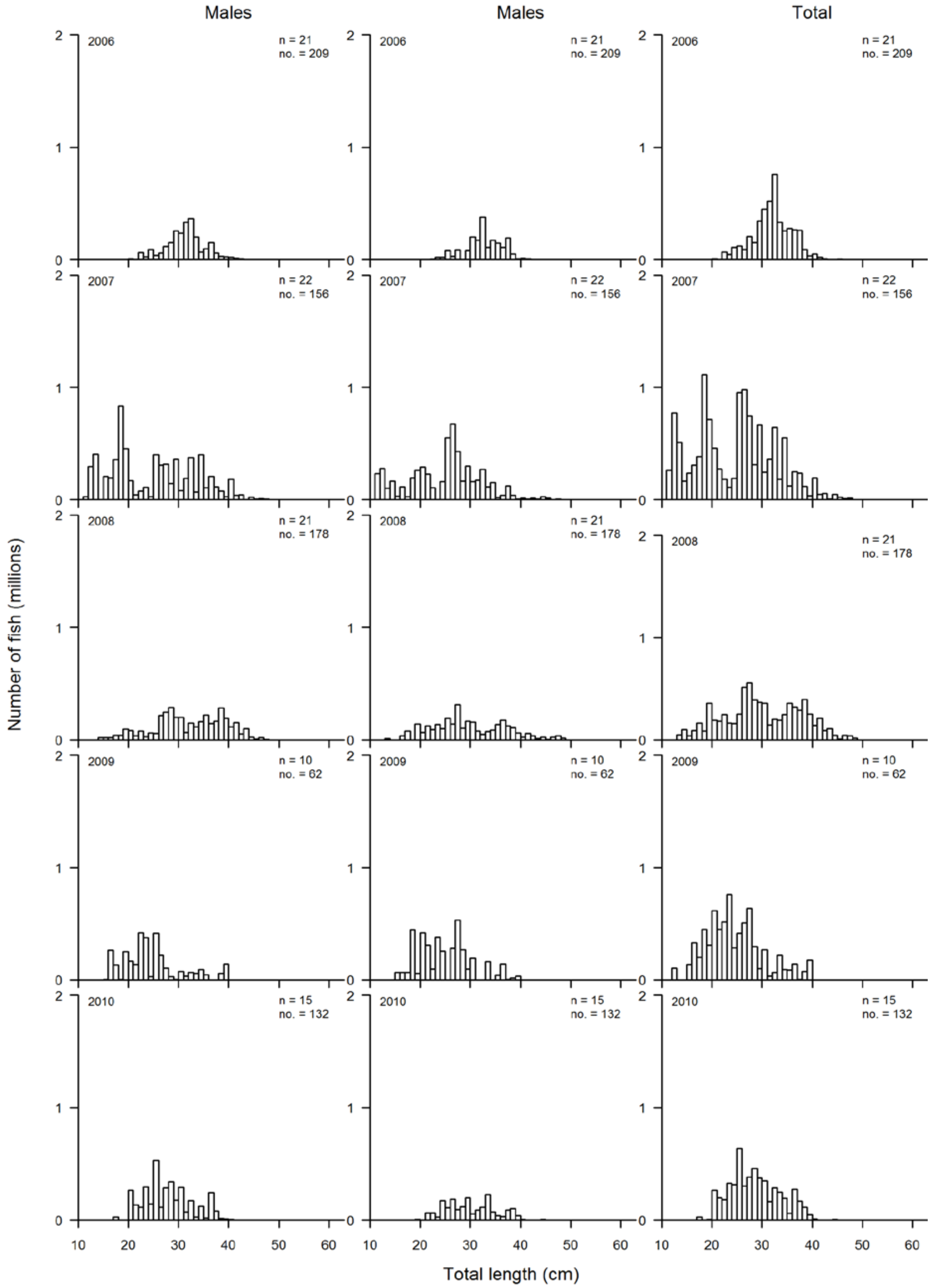

Figure B15: Scaled length frequency of sea perch taken in commercial catches from the northern Chatham Rise fishery by fishing year sampled by the Observer Programme, for fishing years 2006–2010. n, number of tows sampled; no., number of fish sampled.

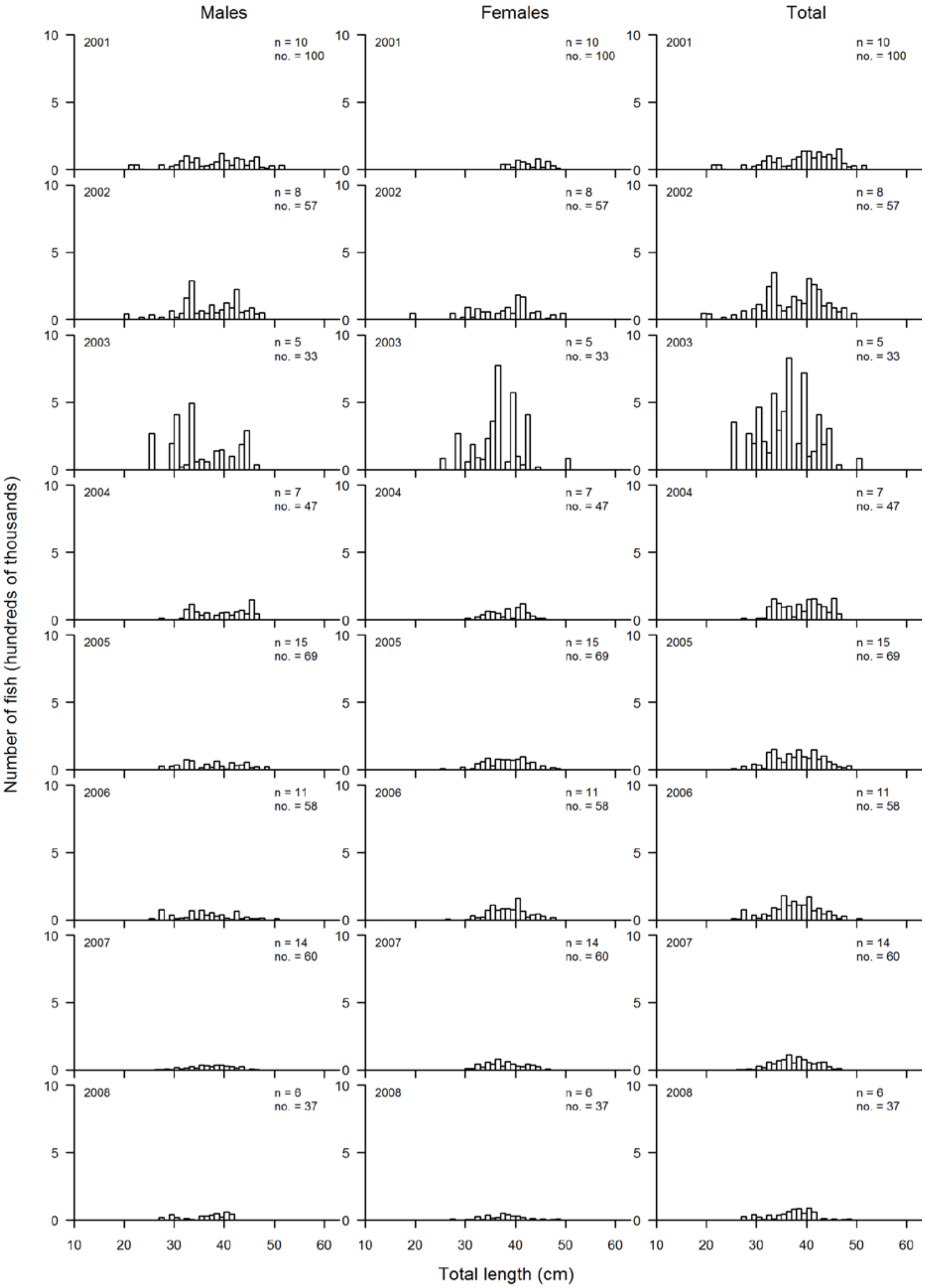

Figure B16: Scaled length frequency of sea perch taken in commercial catches from the southern Chatham Rise fishery by fishing year sampled by the Observer Programme, for fishing years 2001–2008. n, number of tows sampled; no., number of fish sampled.

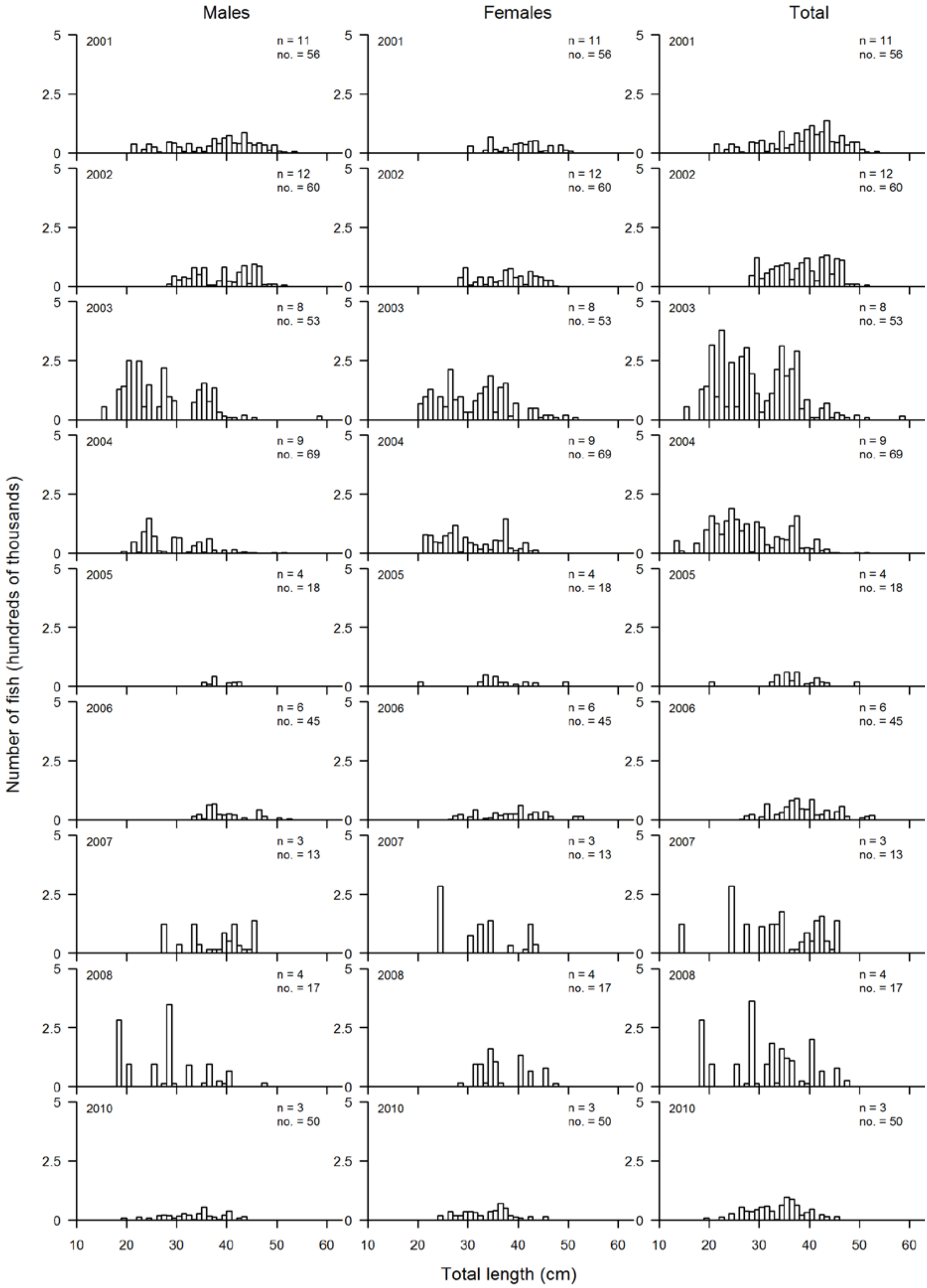

Figure B17: Scaled length frequency of sea perch taken in commercial catches from the western Chatham Rise fishery by fishing year sampled by the Observer Programme, for fishing years 2001–2010. n, number of tows sampled; no., number of fish sampled.

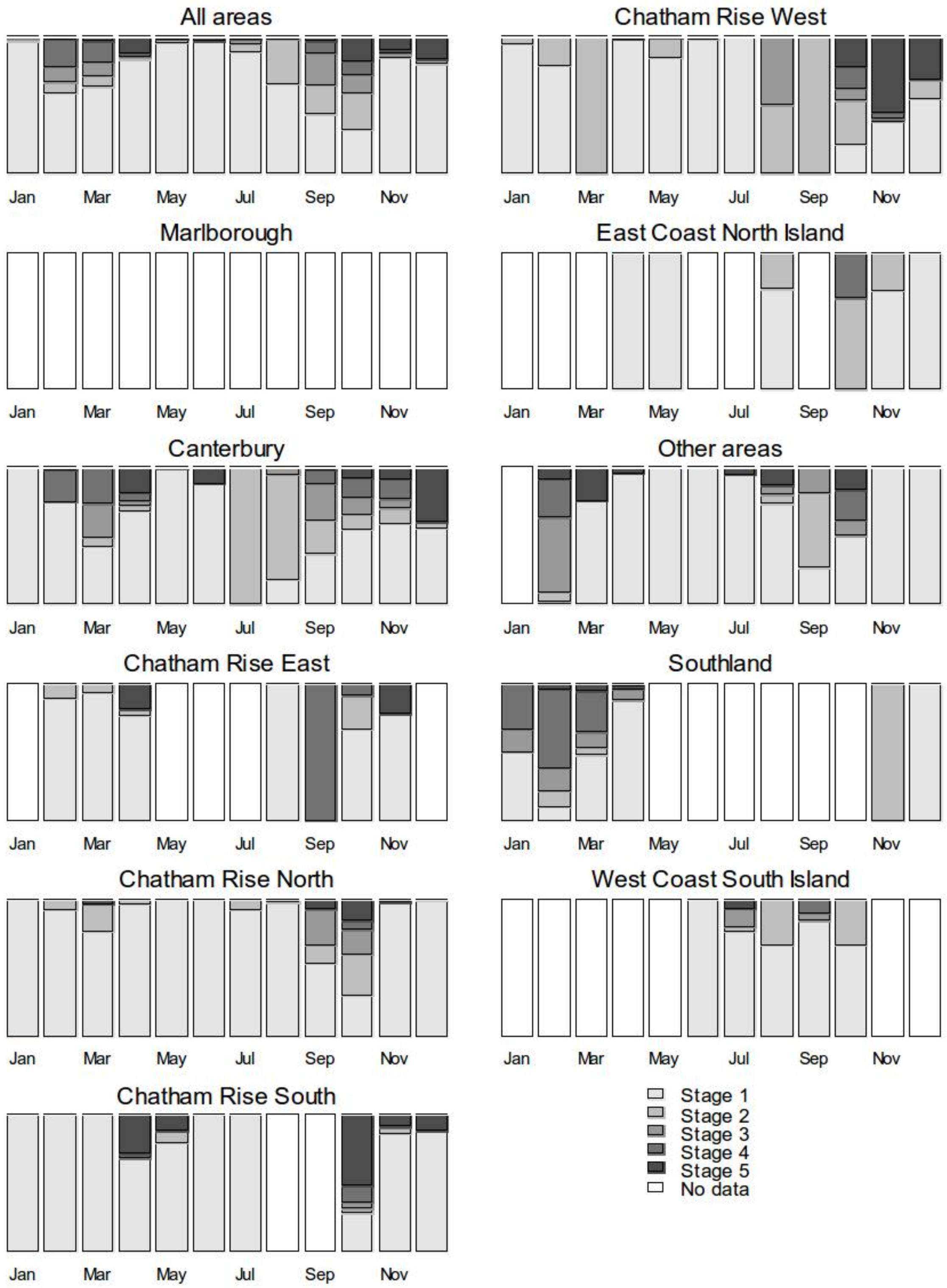

Figure B18: Gonad stages of female sea perch taken in commercial catches, by month and area, sampled by the Observer Programme, for all available fishing years between 1990–2010. Stages are: 1, resting/immature; 2, maturing; 3, ripe; 4, running ripe; 5, spent. The numbers of observations for each area are given in Table B4.

13. APPENDIX C: SUMMARIES OF CATCH AND EFFORT DATA

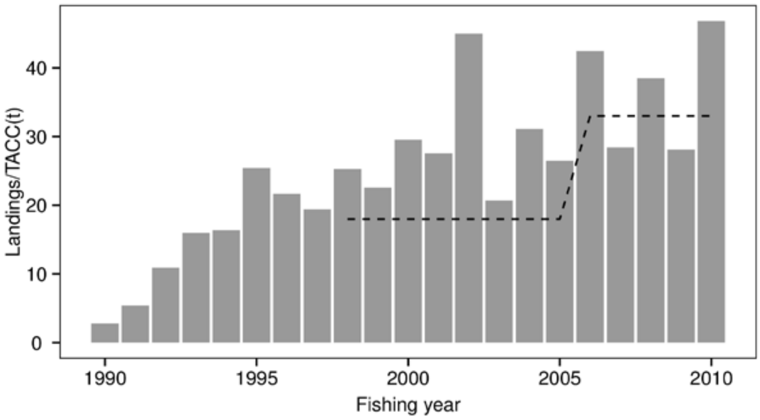

Figure C1: Landings and TACC for SPE 1 by fishing year, 1989–90 to 2009–10.

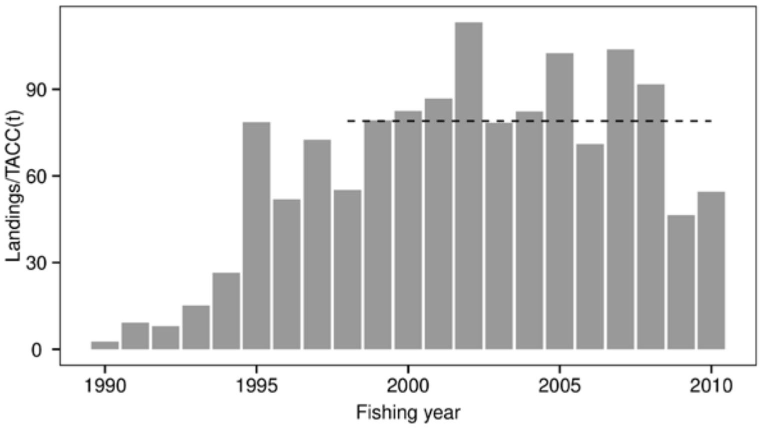

Figure C2: Landings and TACC for SPE 2 by fishing year, 1989–90 to 2009–10.

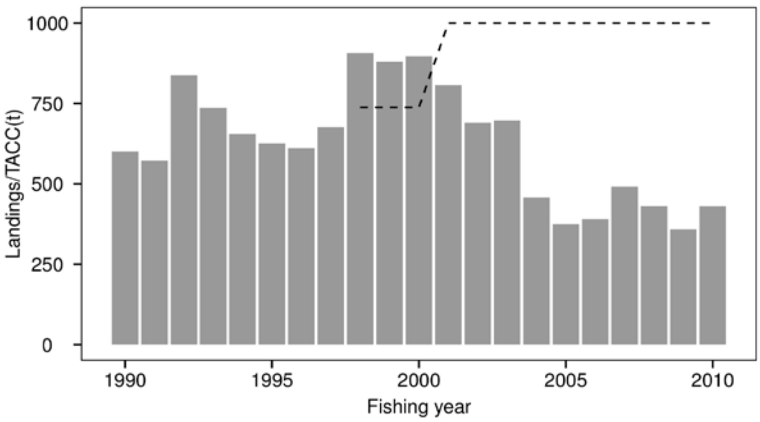

Figure C3: Landings and TACC for SPE 3 by fishing year, 1989–90 to 2009–10.

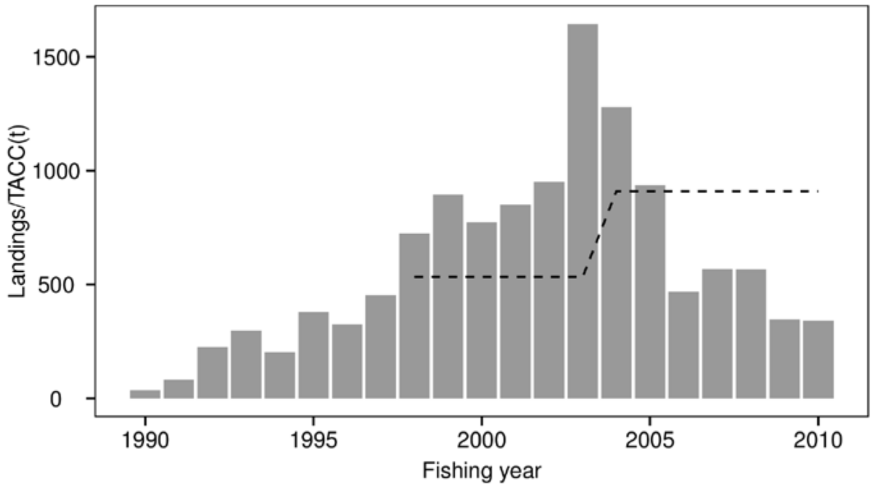

Figure C4: Landings and TACC for SPE 4 by fishing year, 1989–90 to 2009–10.

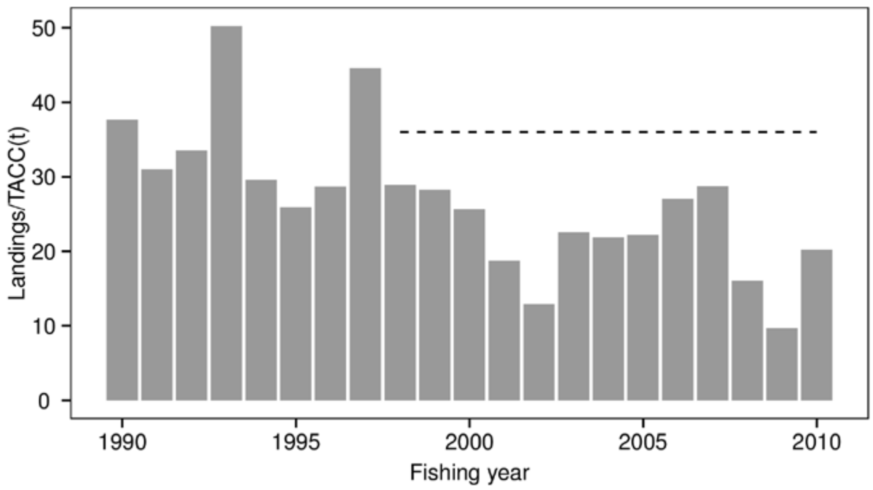

Figure C5: Landings and TACC for SPE 5 by fishing year, 1989–90 to 2009–10.

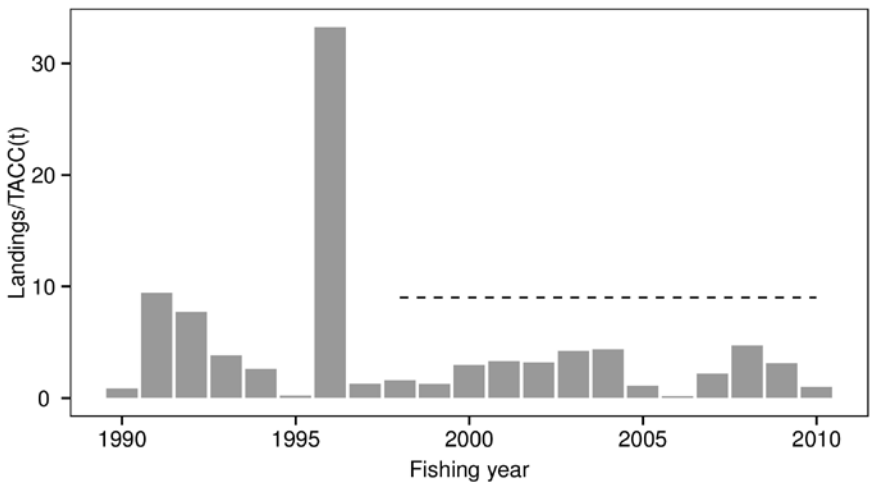

Figure C6: Landings and TACC for SPE 6 by fishing year, 1989–90 to 2009–10.

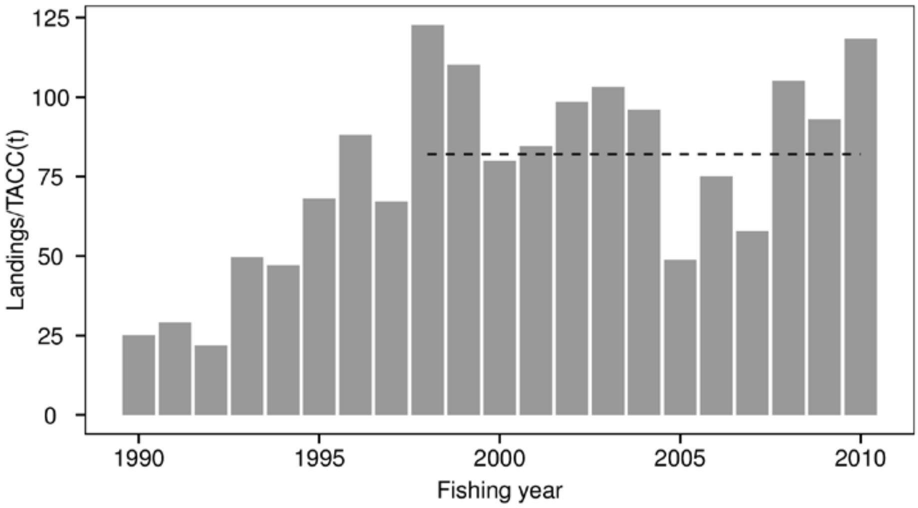

Figure C7: Landings and TACC for SPE 7 by fishing year, 1989–90 to 2009–10.

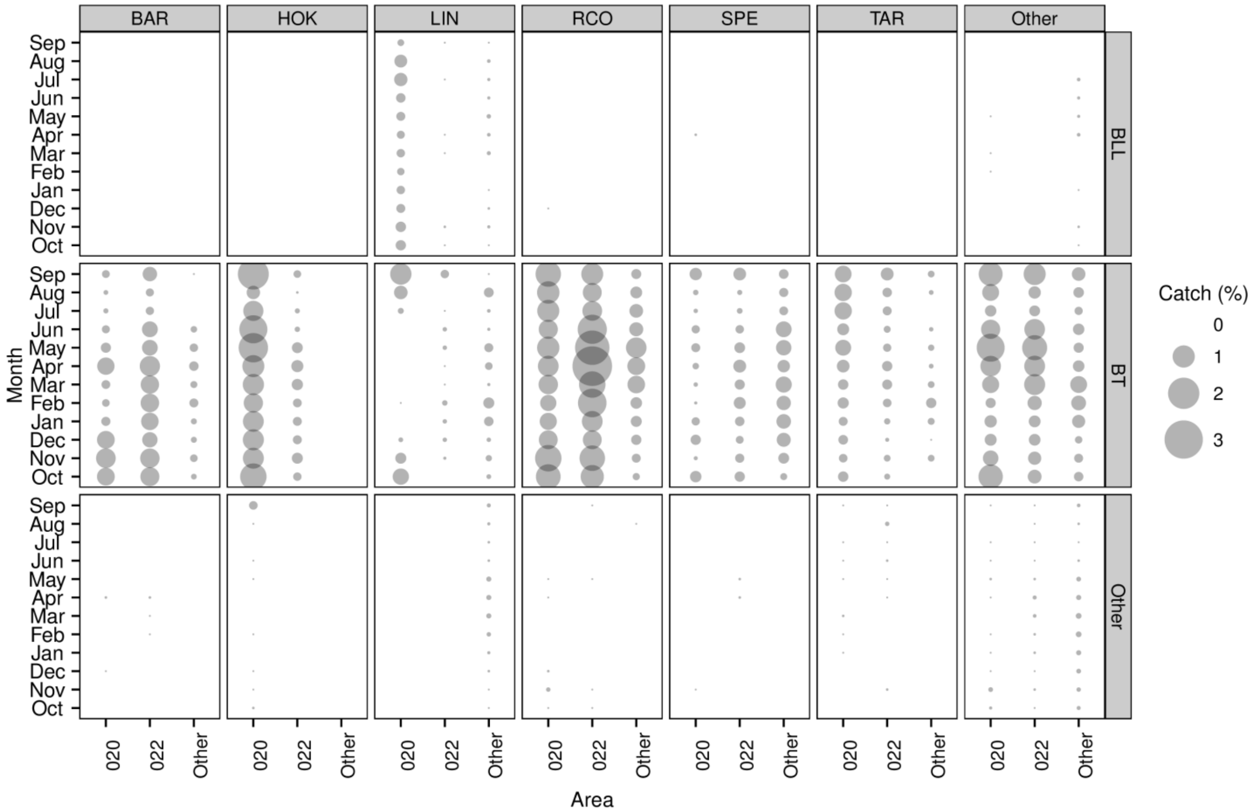

Figure C8: Percentage of catch by method, target species, month and statistical area in the Canterbury Coast region over all fishing years, 1989–90 to 2009–10.

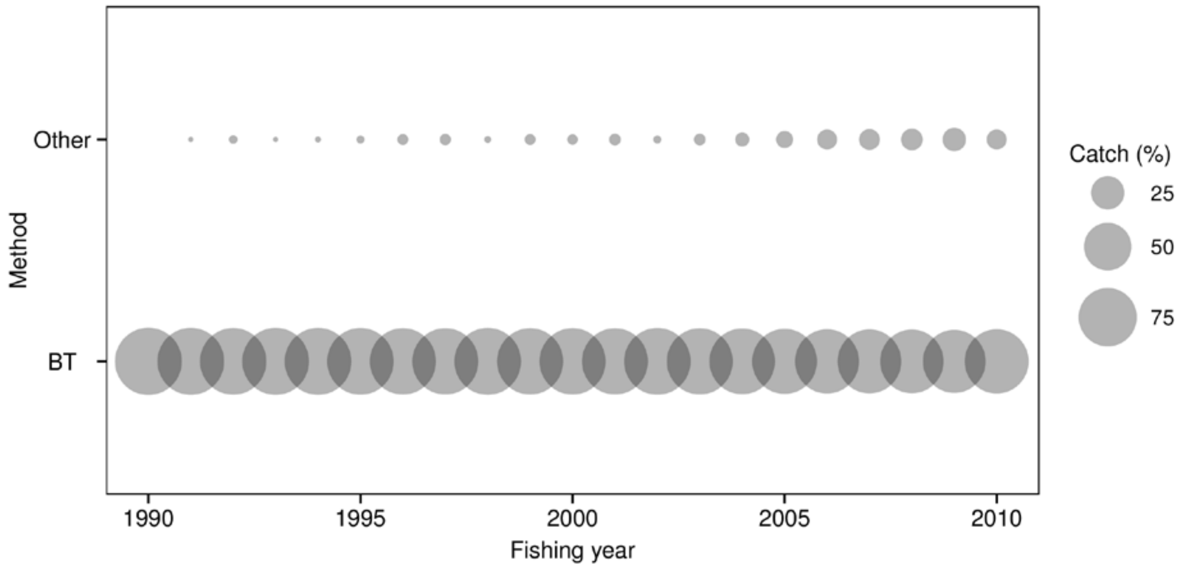

Figure C9: Percentage of catch by method for each fishing year for the Canterbury Coast region.

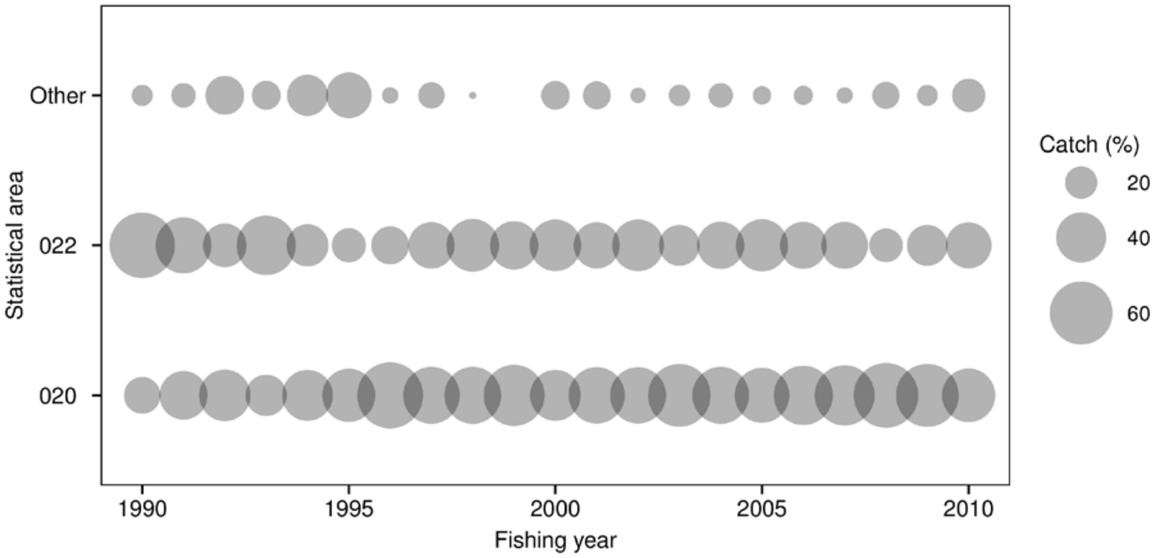

Figure C10: Percentage of catch by statistical area for each fishing year for the Canterbury Coast region.

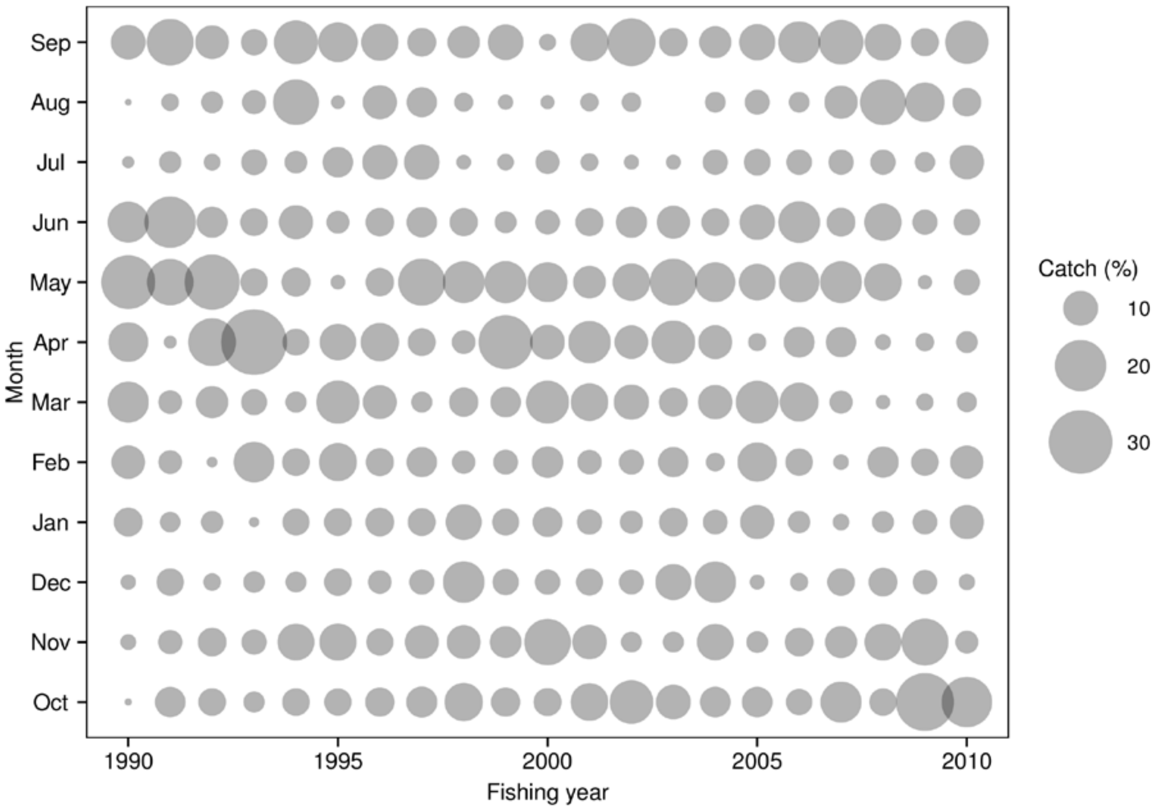

Figure C11: Percentage of catch by month for each fishing year for the Canterbury Coast region.

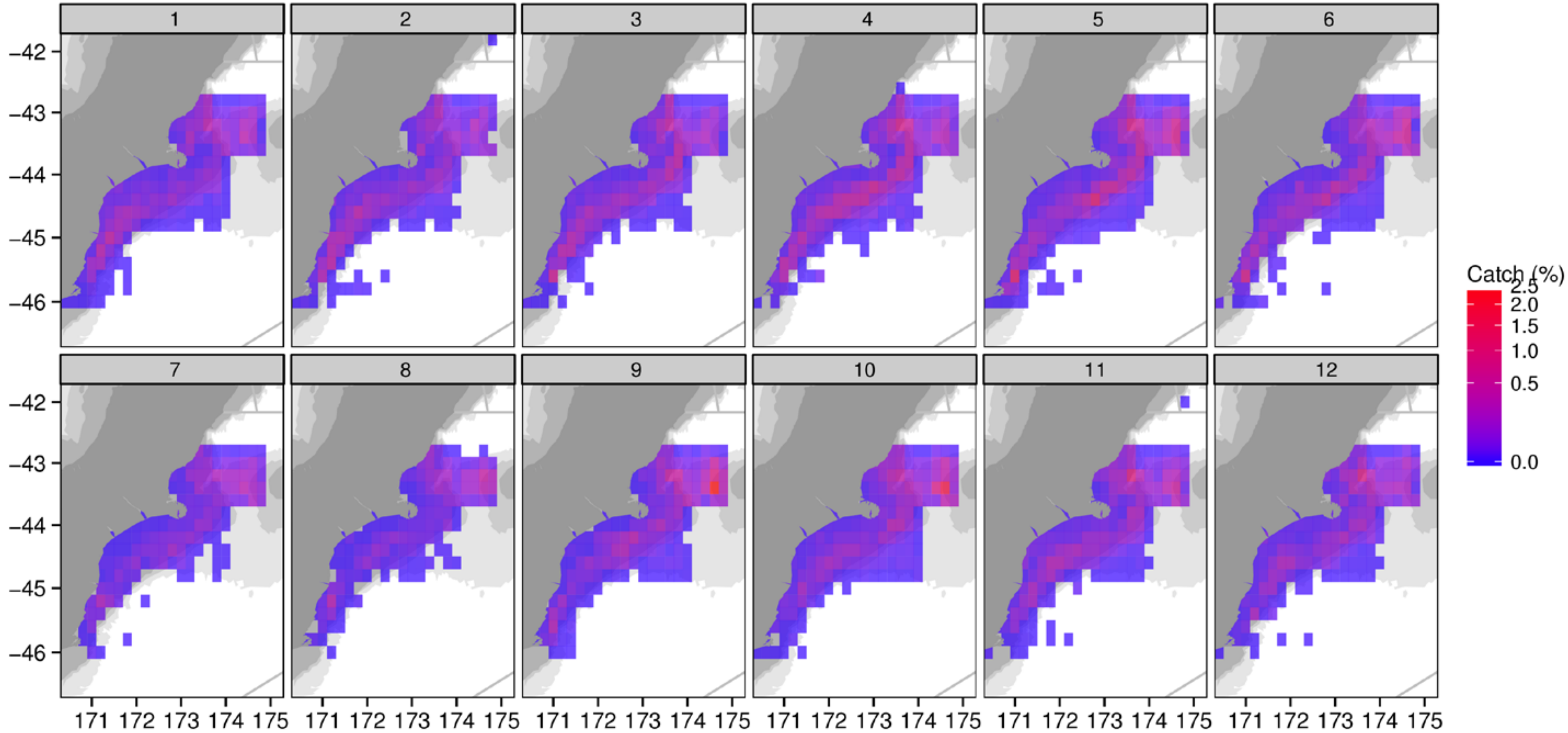

Figure C12: Percentage of SPE catch by 0.2 degree cell and month in the Canterbury Coast region over all fishing years, 1989–90 to 2009–10.

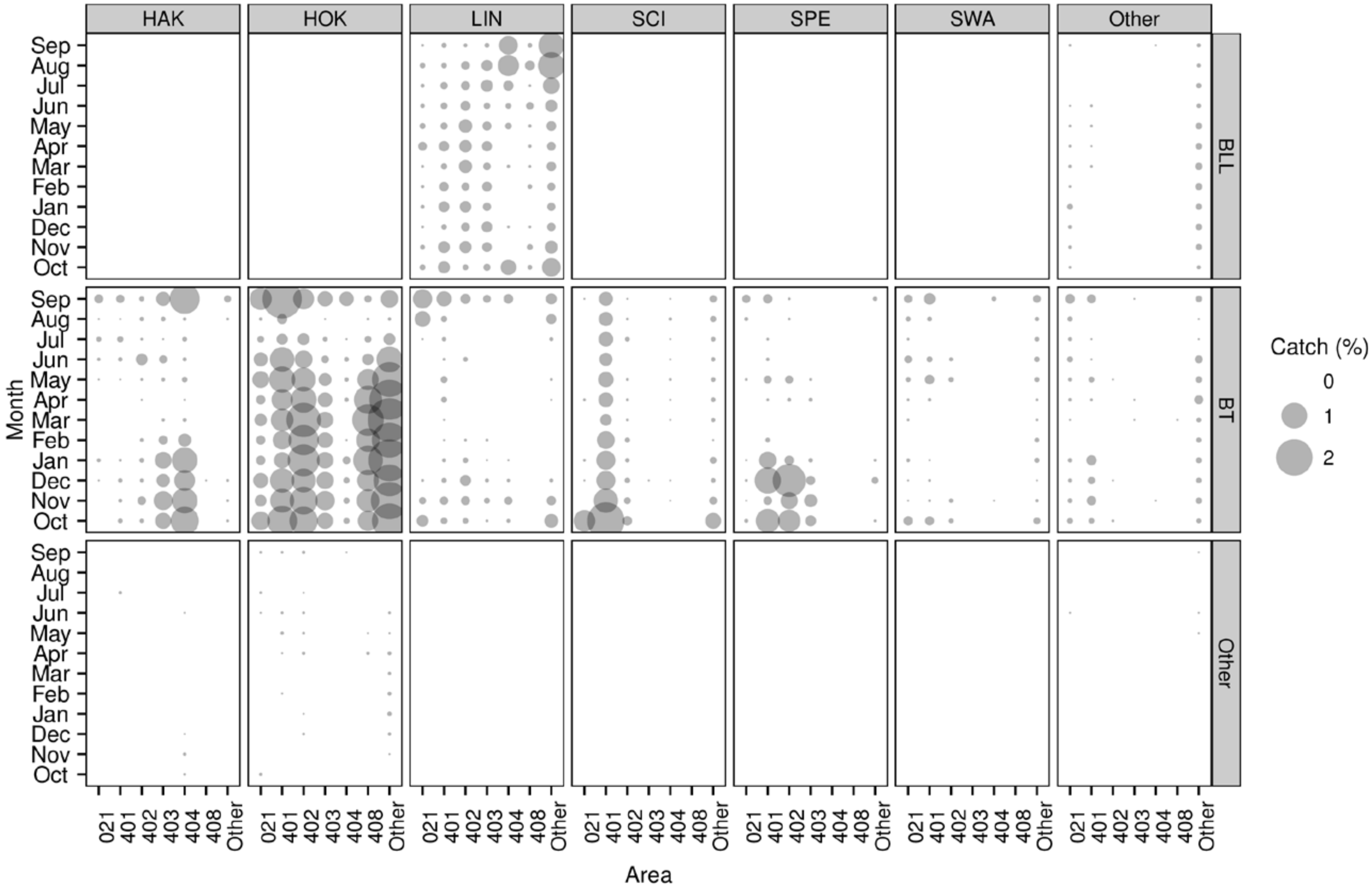

Figure C13: Percentage of catch by method, target species, month and statistical area in the Chatham Rise region over all fishing years, 1989-90 to 2009–10.

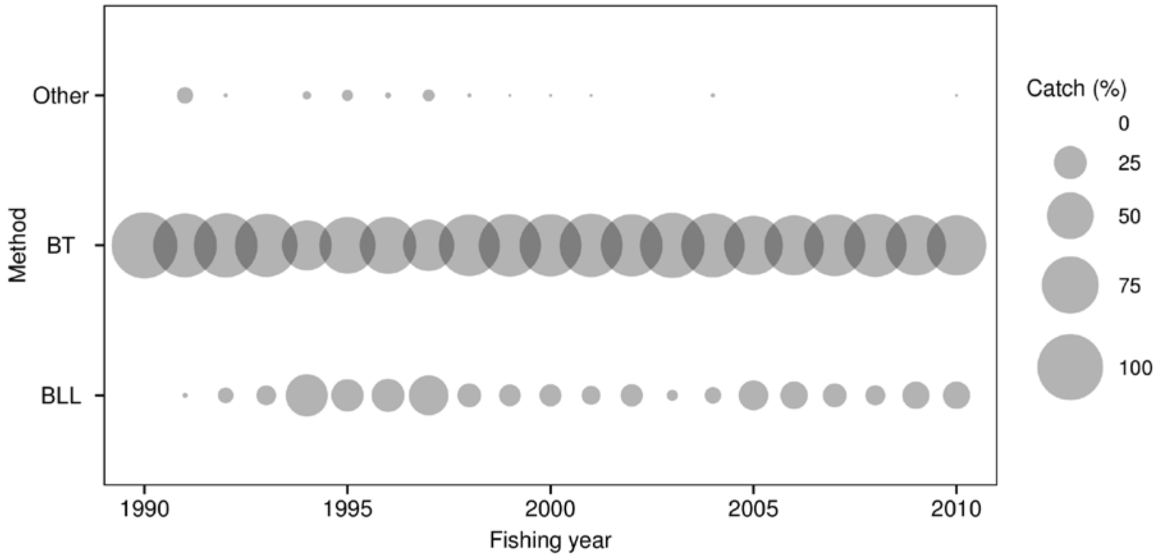

Figure C14: Percentage of catch by method for each fishing year for the Chatham Rise region.

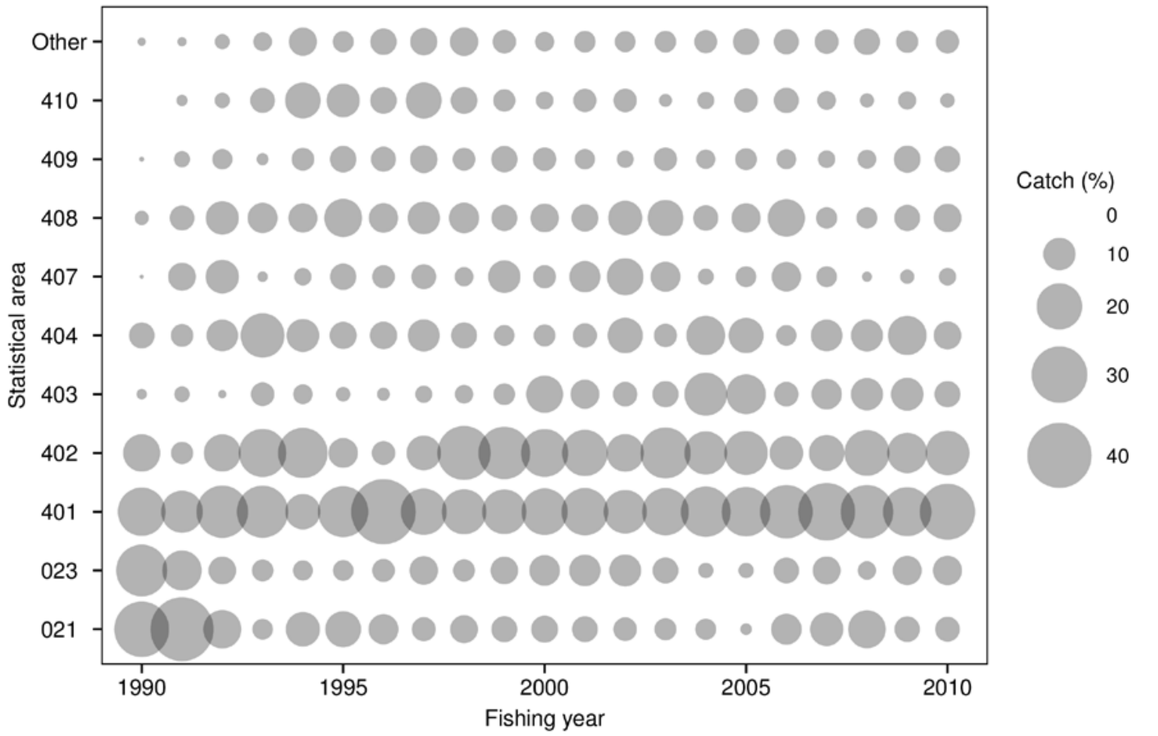

Figure C15: Percentage of catch by statistical area for each fishing year for the Chatham Rise region.

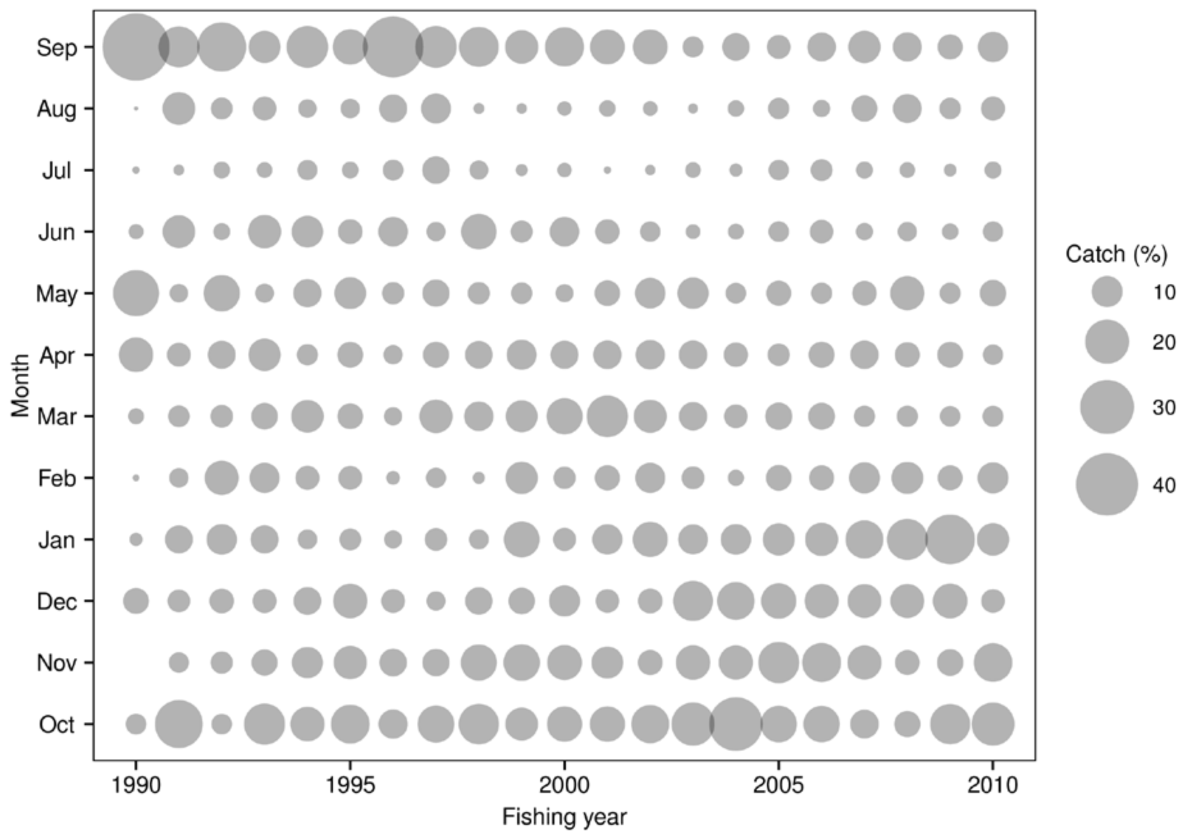

Figure C16: Percentage of catch by month for each fishing year for the Chatham Rise region.

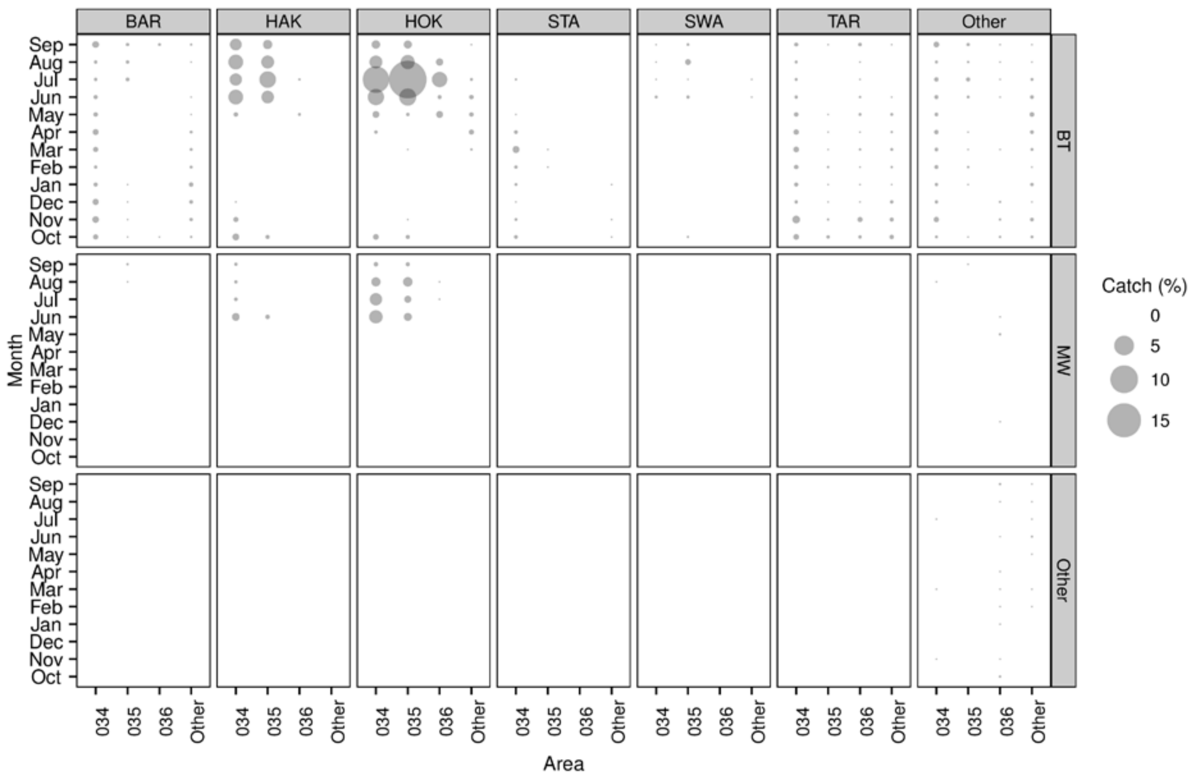

Figure C17: Percentage of catch by method, target species, month and statistical area in the West Coast South Island region over all fishing years, 1989–90 to 2009–10.

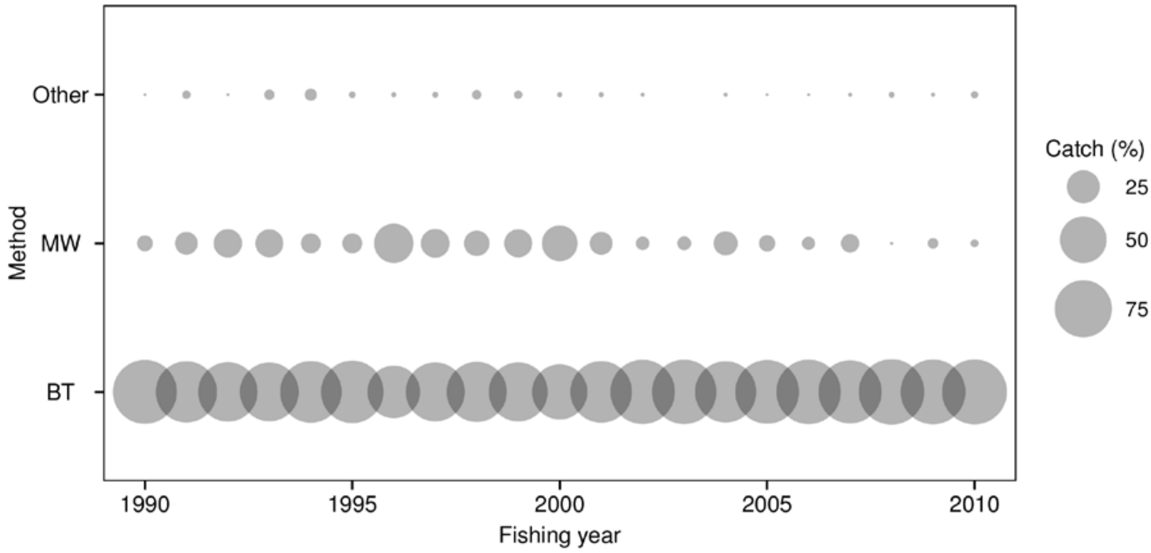

Figure C18: Percentage of catch by method for each fishing year for the West Coast South Island region.

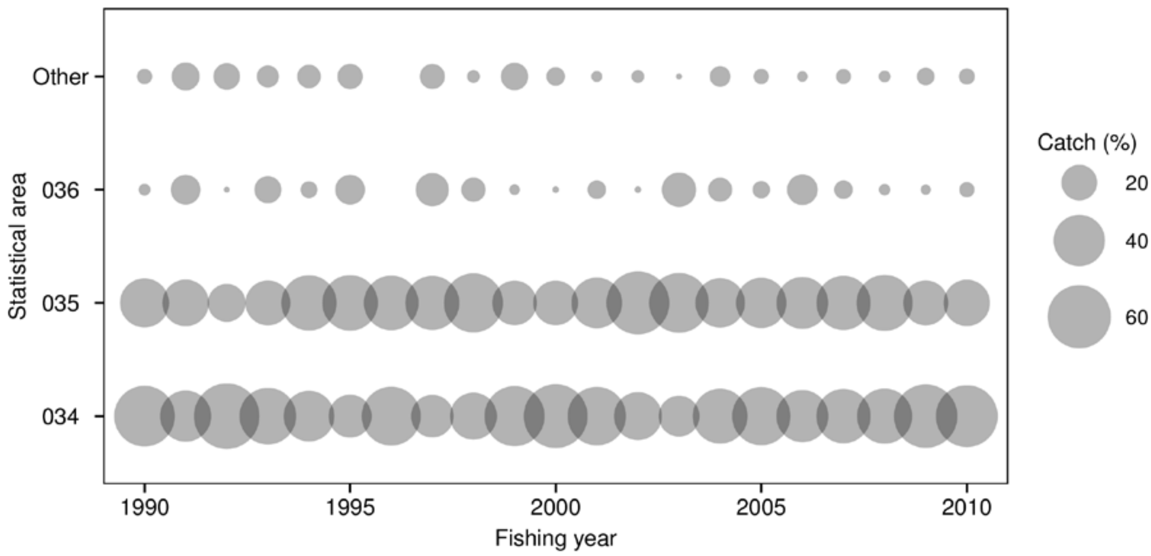

Figure C19: Percentage of catch by statistical area for each fishing year for the West Coast South Island region.

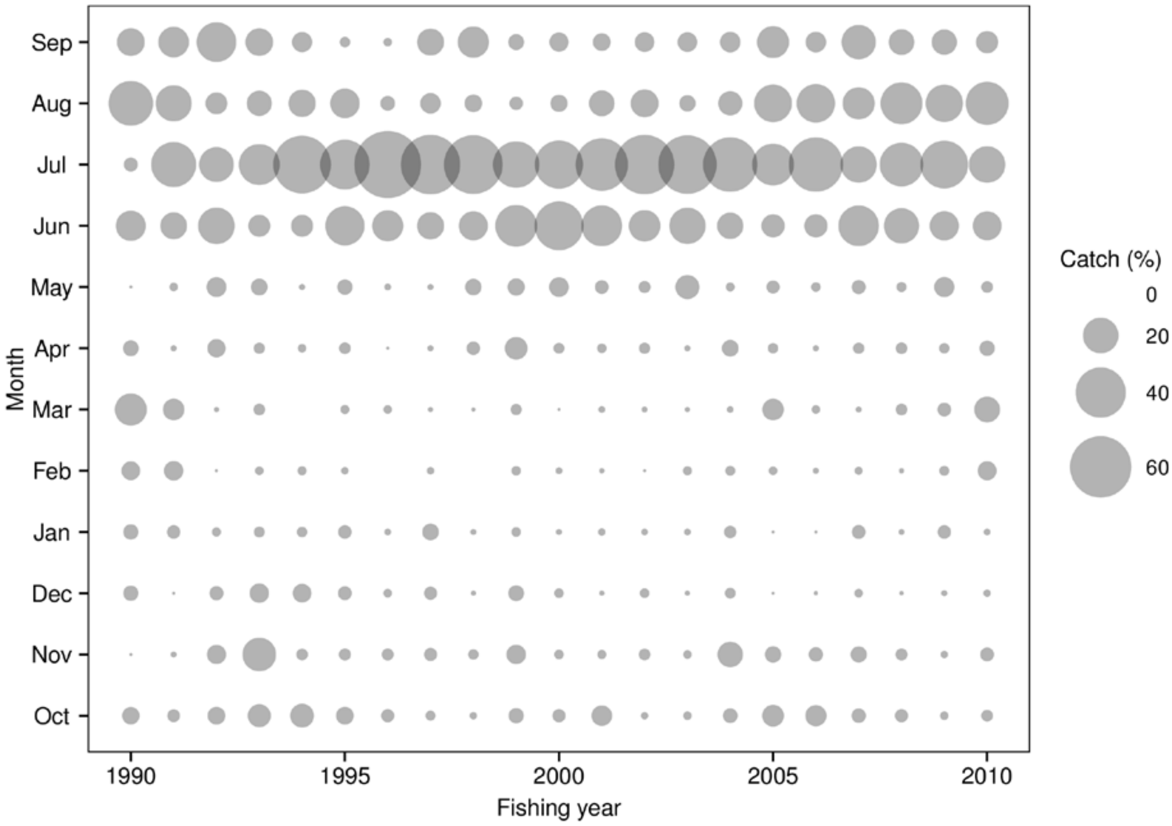

Figure C20: Percentage of catch by month for each fishing year for the West Coast South Island region.

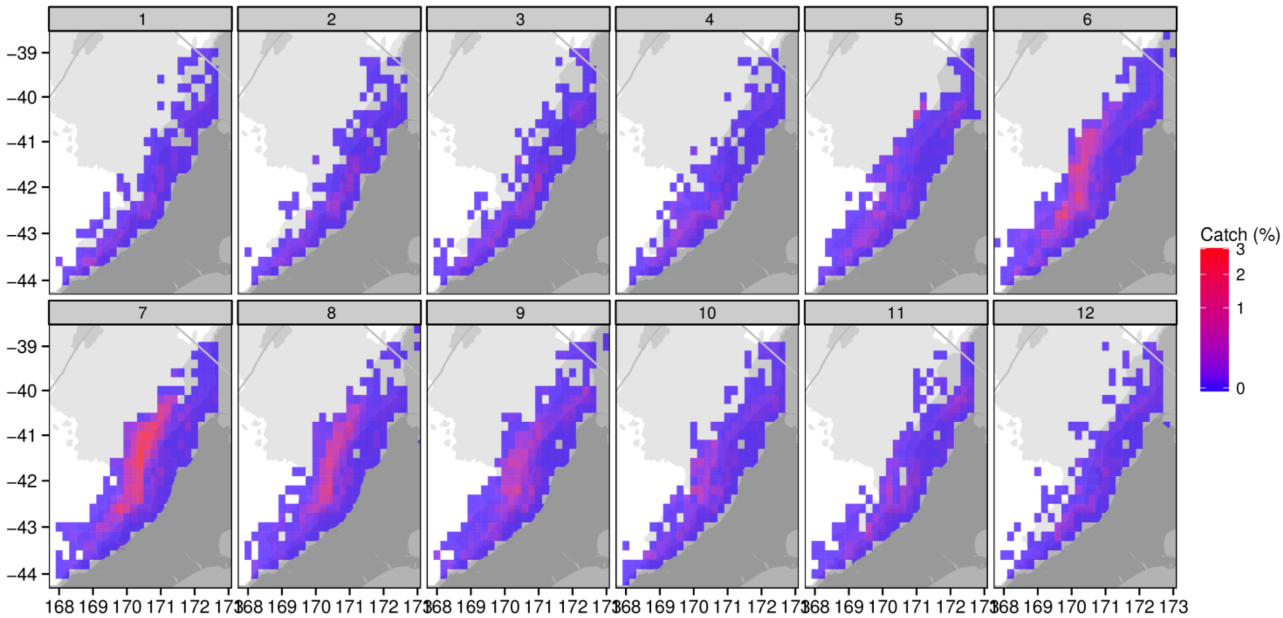

Figure C21: Percentage of SPE catch by 0.2 degree cell and month for the West Coast South Island region over all fishing years, 1989–90 to 2009–10.

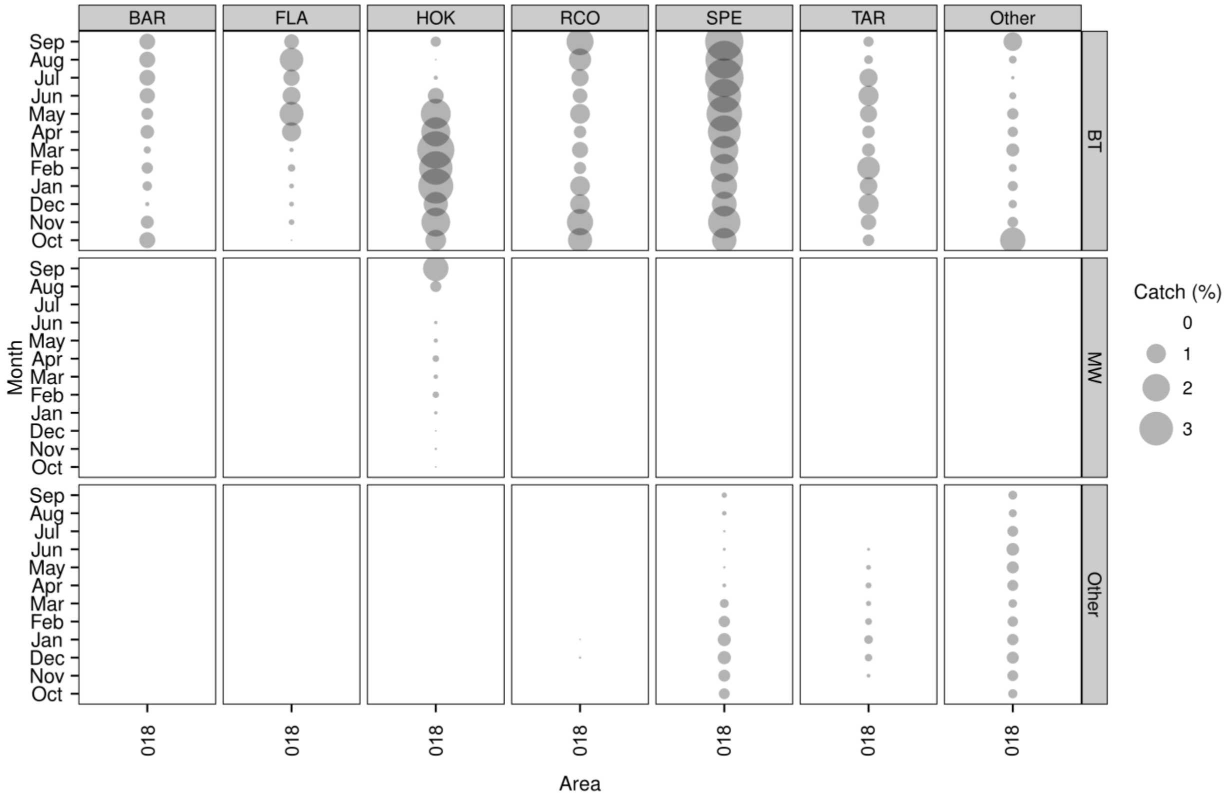

Figure C22: Percentage of catch by method, target species, month and statistical area in the Kaikoura region over all fishing years, 1989–90 to 2009–10.

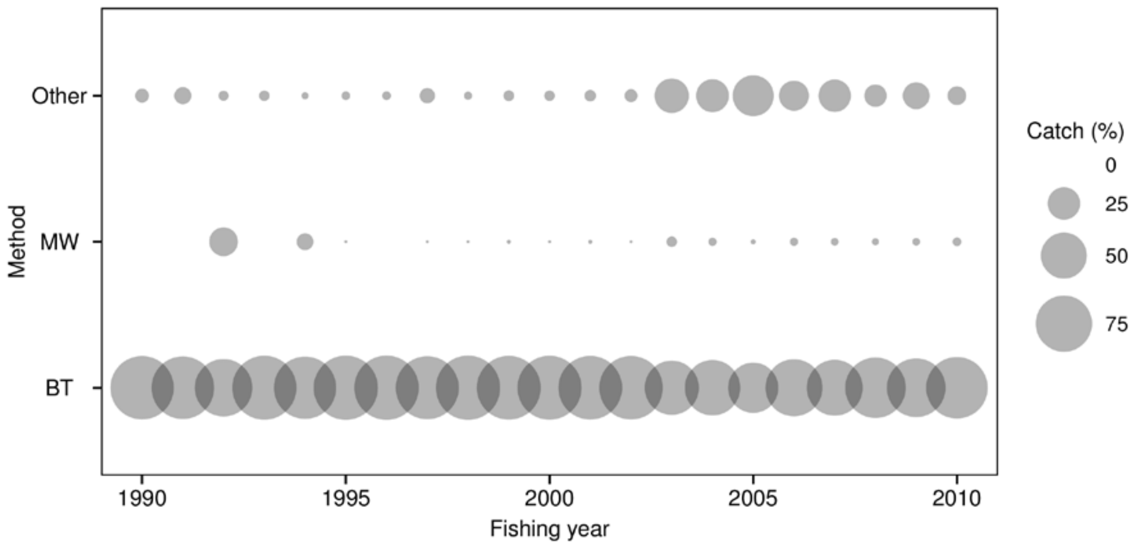

Figure C23: Percentage of catch by method for each fishing year for the Kaikoura region.

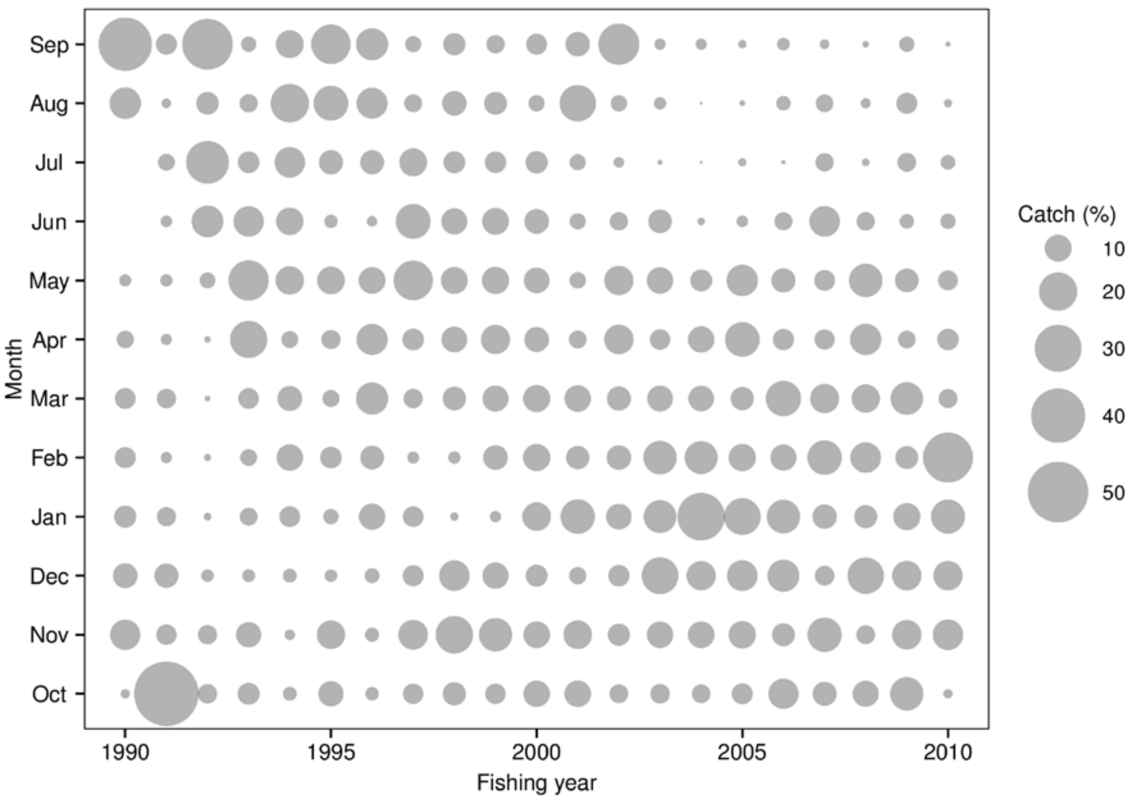

Figure C24: Percentage of catch by month for each fishing year for the Kaikoura region.

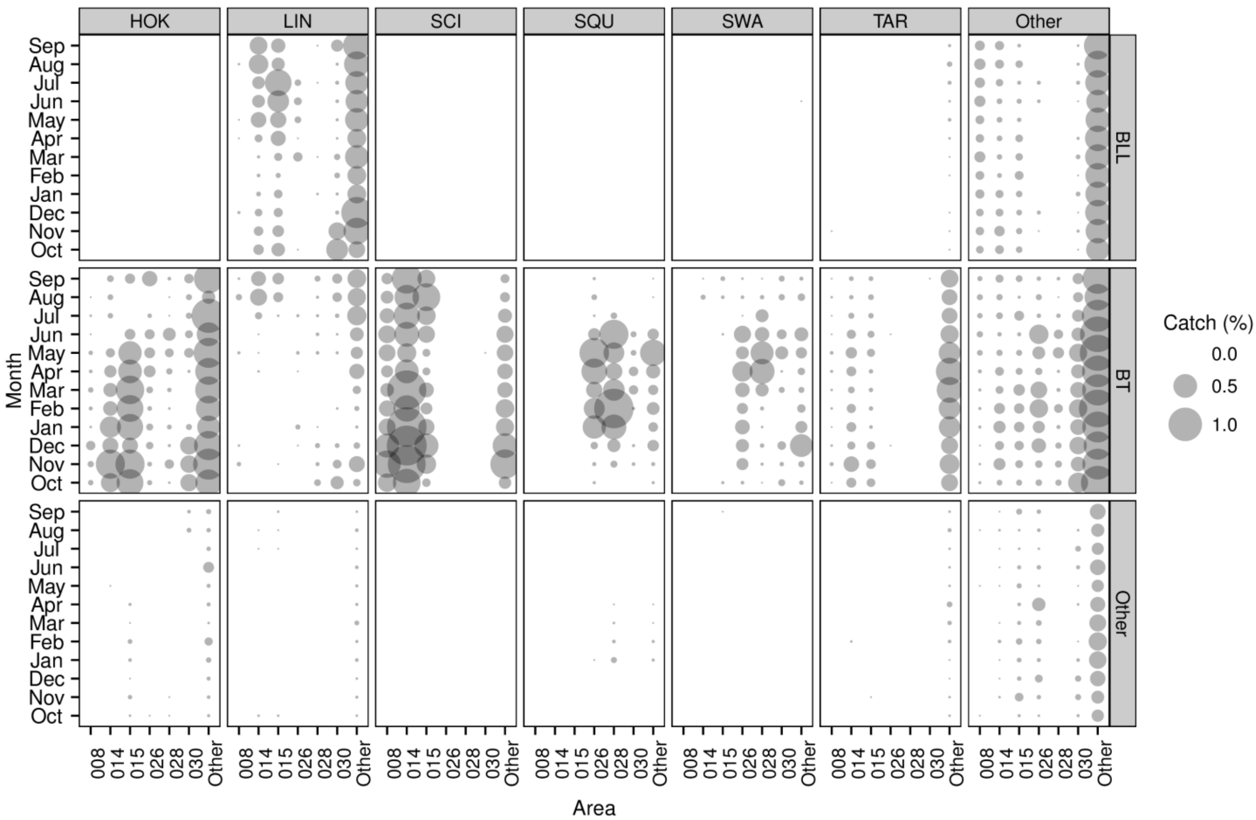

Figure C25: Percentage of catch by method, target species, month and statistical area in other regions over all fishing years, 1989–90 to 2009–10.

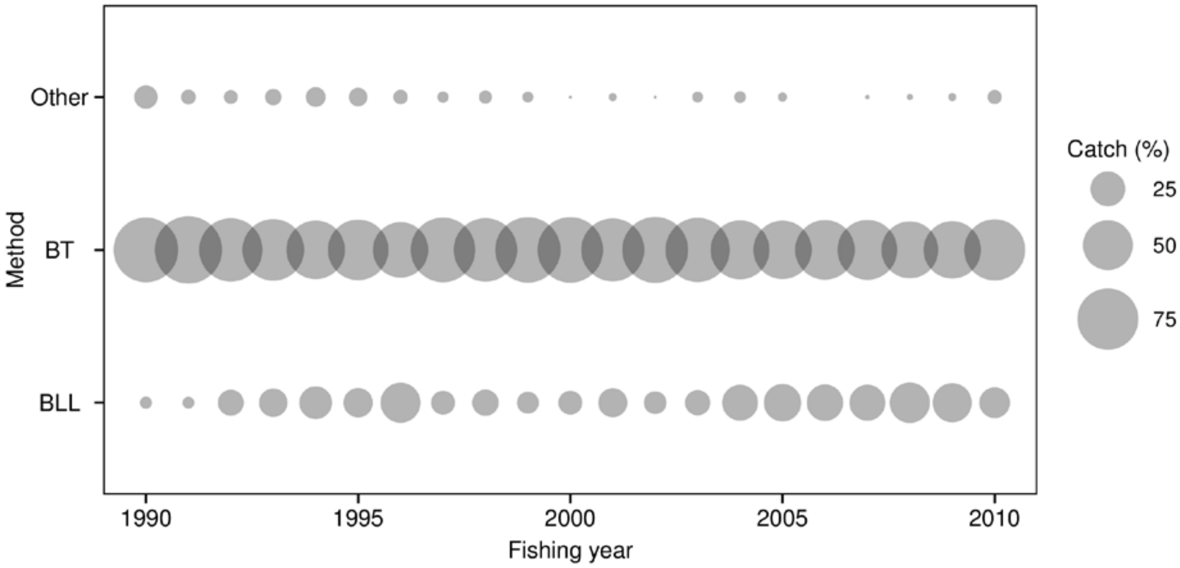

Figure C26: Percentage of catch by method for each fishing year for other regions.

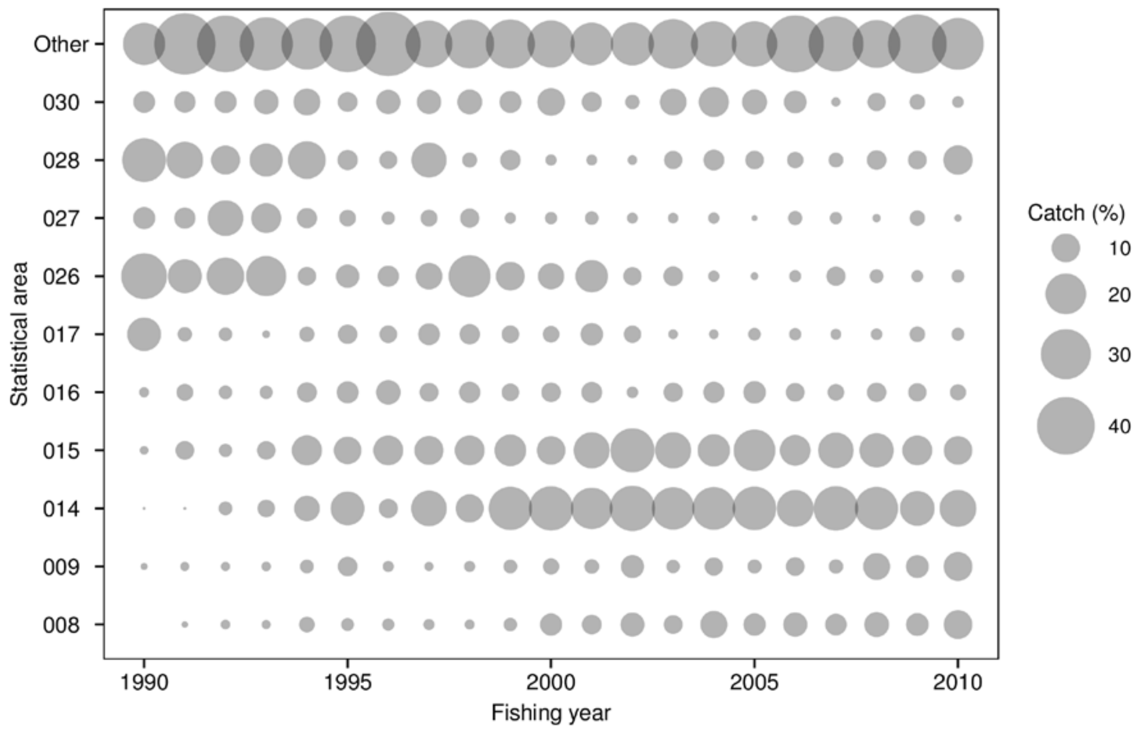

Figure C27: Percentage of catch by statistical area for each fishing year for other regions.

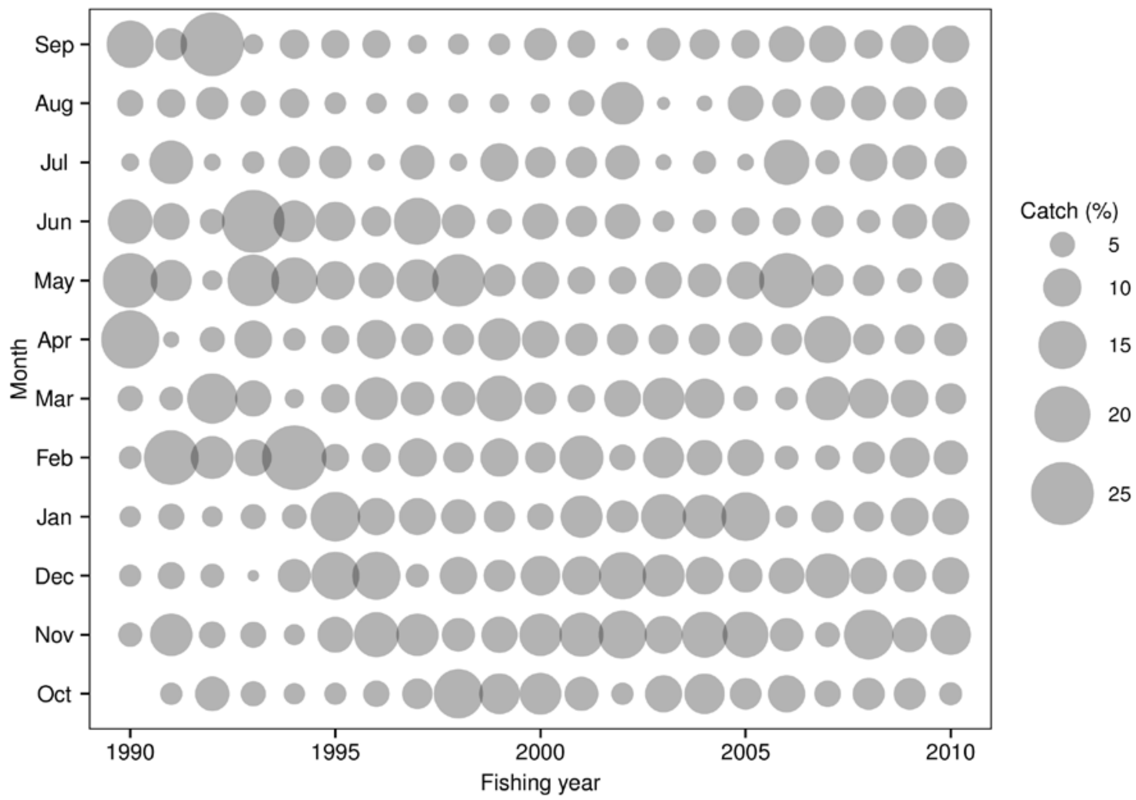

Figure C28: Percentage of catch by month for each fishing year for other regions.

14. APPENDIX D: CPUE FOR ECSI USING AGGREGATED DATA

14.1 Data subset and processing

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

- form type was TCP, CEL, or TCE
- method was BT
- target was one of TAR, SPE, BAR, RCO, FLA
- area was one of 018, 020, 022, 024, 026

Table D1 summarises the number of fishing events, vessels, trips, effort and catch in the resultant dataset. The minimum number of vessels was 52 in 2007. The percentage of positive catches ranged from 44% to 73%.

Table D1: Summary by fishing year of the data subset used for this analysis.

Fishing year	Vessels	Trips	Events	Effort (num)	Effort (hrs)	Catch (t)	Events with catch (landed,%)
1990	92	1 080	3 387	6 210	20 355	315.63	52.55
1991	104	1 201	3 628	6 945	23 671	259.57	53.53
1992	98	1 485	4 300	8 028	28 812	481.49	63.05
1993	98	1 644	4 701	8 692	30 615	600.92	61.35
1994	96	1 501	3 313	7 167	23 407	471.87	72.86
1995	89	1 522	3 317	6 999	22 516	420.10	69.04
1996	95	1 440	4 083	7 605	23 779	359.79	58.95
1997	98	1 515	4 021	8 071	25 072	383.27	64.46
1998	90	1 720	4 485	9 387	27 639	582.76	65.33
1999	78	1 664	3 833	8 516	25 045	520.07	59.54
2000	76	1 523	3 580	8 234	25 041	531.37	65.06
2001	76	1 430	3 210	8 117	25 943	405.64	64.08
2002	71	1 280	3 166	7 680	23 769	374.52	60.68
2003	66	1 106	3 042	7 094	24 149	257.35	60.22
2004	74	958	2 852	5 813	19 446	186.56	56.31
2005	72	1 037	2 471	6 056	20 998	162.33	64.31
2006	60	840	2 071	4 992	18 397	144.64	62.24
2007	52	718	1 812	4 429	16 891	158.03	64.29
2008	57	585	2 898	2 901	11 095	131.19	45.31
2009	55	687	3 636	3 684	14 273	89.84	43.56
2010	58	813	4 299	4 317	16 438	210.18	48.13

Data were aggregated into strata where each strata was defined as a unique combination of vessel, trip, date, area, method, target species. Table D2 summarise the extent of "roll–up" (the number of original events associated with each stratum) and the number, proportion and effort from strata that had positive catches.

Table D2: Summary of aggregated data by fishing year.

Fishing year	Vessels	Trips	Strata	Events	Events per stratum	Effort (num)	Effort (hrs)	Catch (t)	Trips with catch (%)	Strata with catch (%)
1990	92	1 079	2 374	3 381	1.424	6 204	20 330	315.63	78.78	59.10
1991	104	1 200	2 617	3 623	1.384	6 940	23 655	259.57	79.17	59.80
1992	98	1 484	3 240	4 288	1.323	8 016	28 774	481.49	86.59	67.78
1993	97	1 642	3 464	4 686	1.353	8 674	30 552	600.92	88.06	69.14
1994	96	1 500	2 591	3 271	1.262	7 122	23 253	471.87	89.47	78.19
1995	89	1 521	2 597	3 310	1.275	6 992	22 486	420.10	84.02	72.47
1996	95	1 439	2 666	4 067	1.526	7 589	23 746	359.79	82.97	68.08
1997	98	1 514	2 720	4 020	1.478	8 070	25 069	383.27	84.48	71.36
1998	89	1 719	3 005	4 480	1.491	9 382	27 628	582.76	87.03	73.98
1999	78	1 663	2 747	3 830	1.394	8 513	25 032	520.07	84.91	70.99
2000	76	1 522	2 635	3 578	1.358	8 232	25 036	531.37	90.28	74.27
2001	76	1 429	2 622	3 205	1.222	8 107	25 897	405.64	88.10	69.98
2002	71	1 280	2 497	3 166	1.268	7 680	23 769	374.52	84.22	66.20
2003	66	1 106	2 399	3 042	1.268	7 094	24 149	257.35	82.19	65.24
2004	74	958	2 131	2 852	1.338	5 813	19 446	186.56	78.71	60.58
2005	72	1 036	2 161	2 465	1.141	6 050	20 981	162.33	81.37	67.52
2006	60	840	1 770	2 071	1.170	4 992	18 397	144.64	80.36	66.10
2007	52	718	1 529	1 812	1.185	4 429	16 891	158.03	84.12	70.24
2008	57	584	1 662	2 883	1.735	2 886	11 021	131.19	74.83	52.53
2009	55	686	2 009	3 621	1.802	3 669	14 194	89.84	74.93	51.57
2010	58	812	2 372	4 273	1.801	4 291	16 347	210.18	79.80	55.90

14.2 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 five trips in each of at least five years. To qualify, trips were required to have recorded at least 1 kg of catch. These criteria resulted in a core fleet size of 58 vessels which took 84% 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).

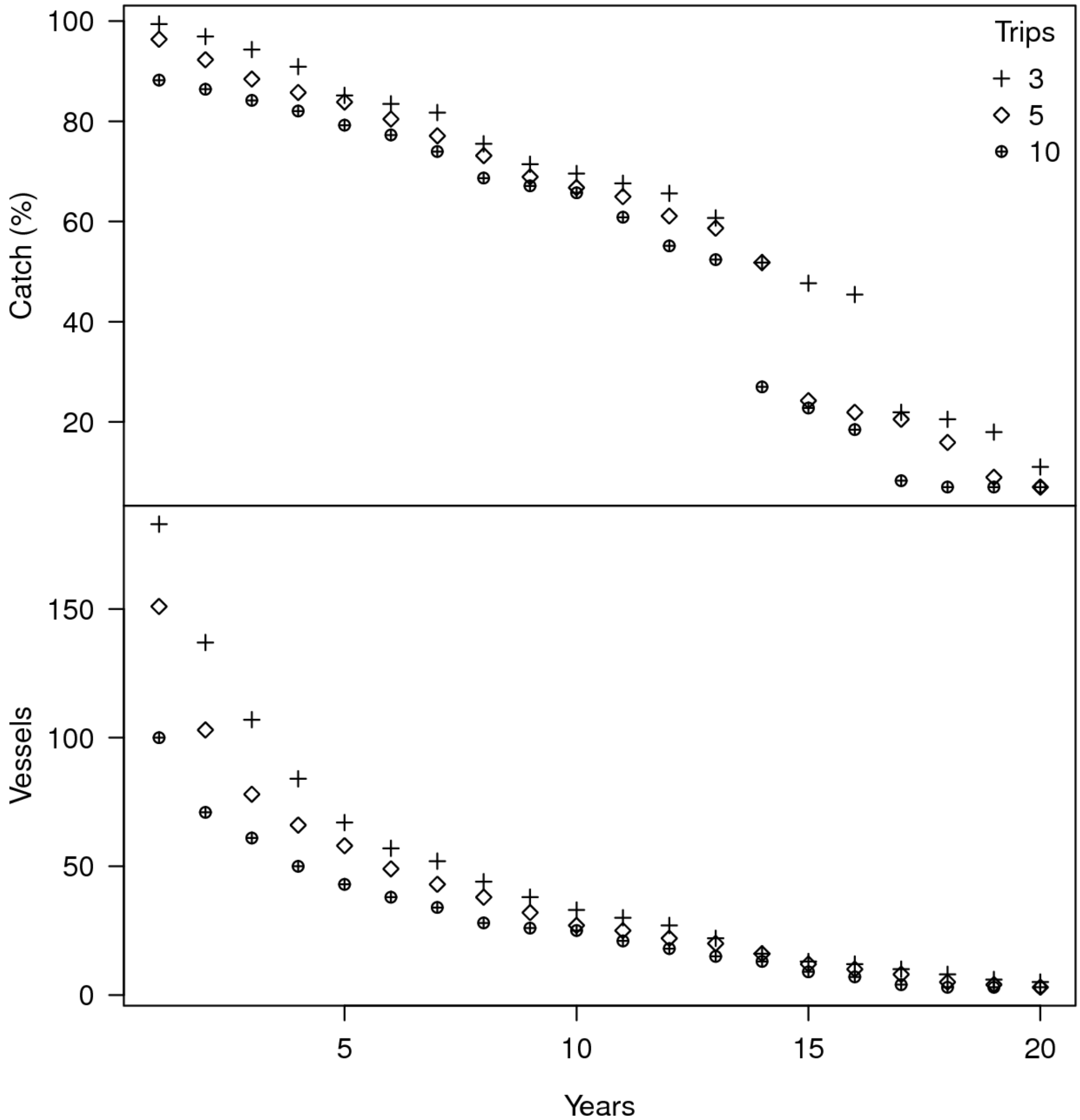

Figure D1: Examination of parameters for defining core vessels.

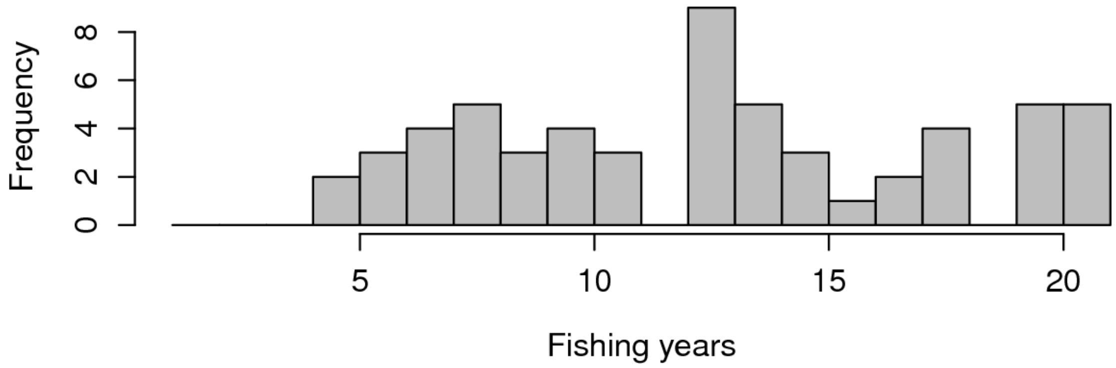

Figure D2: Histogram of the number of years with data for each core vessel.

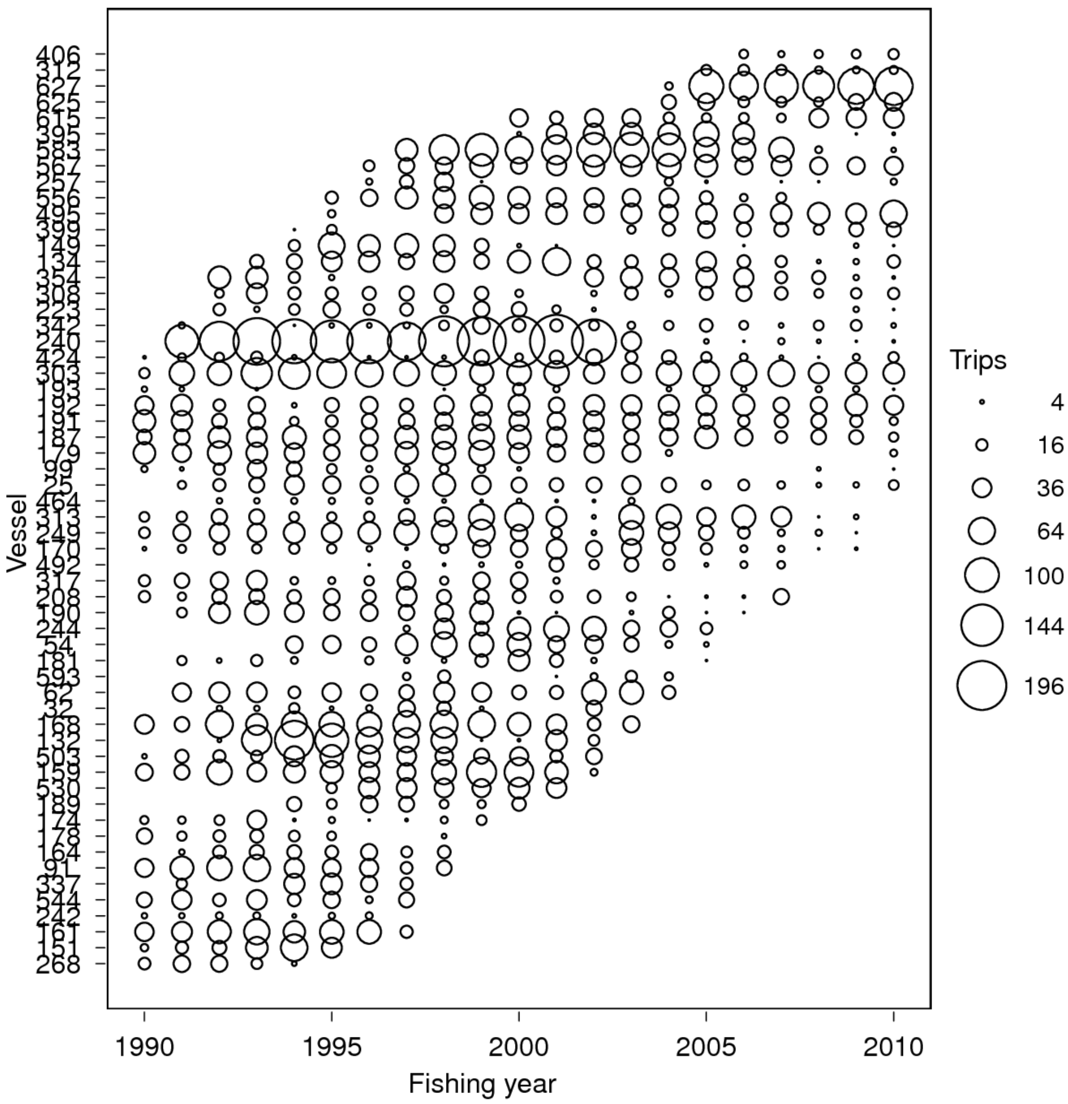

Figure D3: Number of trips by fishing year for core vessels. Area of circles is proportional to the proportion of records over all fishing years and vessels.

Table D3: Summary of core vessel data by fishing year.

Fishing year	Vessels	Trips	Strata	Events	Events per stratum	Effort (num)	Effort (hrs)	Catch (t)	Trips with catch (%)	Strata with catch (%)
1990	26	480	1 060	1 527	1.441	2 864	10 027	134.49	86.67	67.45
1991	33	772	1 551	2 087	1.346	4 270	14 574	147.95	88.08	70.34
1992	37	1 059	2 183	2 925	1.340	5 589	20 367	390.72	91.22	74.03
1993	39	1 337	2 578	3 413	1.324	6 509	23 387	464.19	92.15	75.29
1994	42	1 273	2 152	2 714	1.261	6 006	19 931	433.88	92.07	81.83
1995	42	1 280	2 109	2 711	1.285	5 796	18 847	381.08	88.05	78.76
1996	44	1 197	2 178	3 455	1.586	6 433	20 119	332.70	86.30	71.81
1997	45	1 320	2 279	3 427	1.504	6 927	21 774	355.79	88.11	75.38
1998	44	1 533	2 598	3 905	1.503	8 367	24 500	513.33	90.67	77.83
1999	40	1 501	2 454	3 422	1.394	7 763	22 874	476.48	88.47	74.08
2000	41	1 394	2 419	3 319	1.372	7 682	23 184	507.89	91.97	75.73
2001	38	1 271	2 262	2 797	1.237	7 050	22 356	382.18	90.56	72.63
2002	36	1 093	2 076	2 672	1.287	6 641	20 266	328.90	87.83	67.92
2003	32	985	2 095	2 640	1.260	6 353	21 582	199.31	84.06	67.11
2004	37	861	1 815	2 328	1.283	5 025	16 946	160.37	80.95	65.01
2005	33	850	1 836	2 104	1.146	5 184	18 381	151.15	87.65	70.26
2006	30	682	1 493	1 764	1.182	4 190	15 899	132.54	86.22	69.79
2007	29	610	1 255	1 496	1.192	3 679	14 255	111.37	85.74	71.24
2008	31	454	1 360	2 401	1.765	2 404	9 052	66.53	75.77	52.87
2009	28	504	1 539	2 780	1.806	2 828	10 972	64.12	75.00	50.94
2010	28	546	1 701	3 095	1.820	3 113	11 967	173.42	79.85	54.26

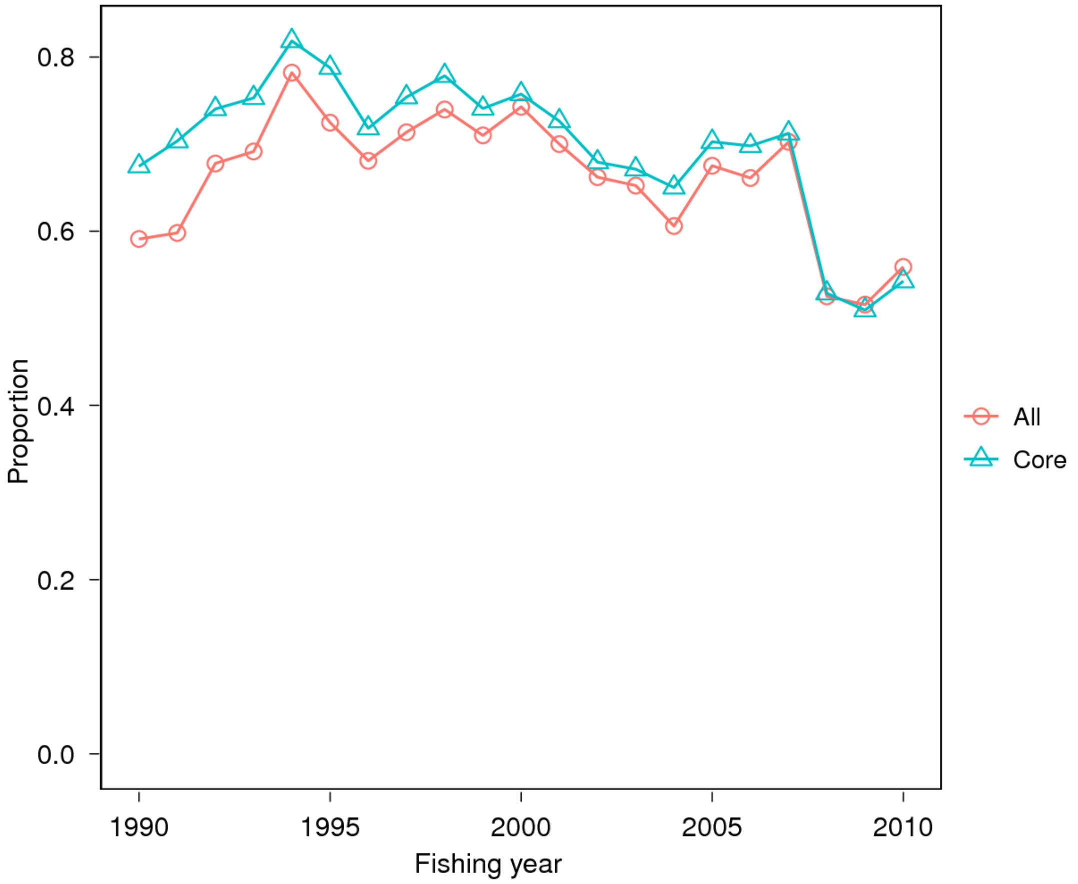

Figure D4: Proportion of positive catches for the entire dataset (All) and core vessels (Core).

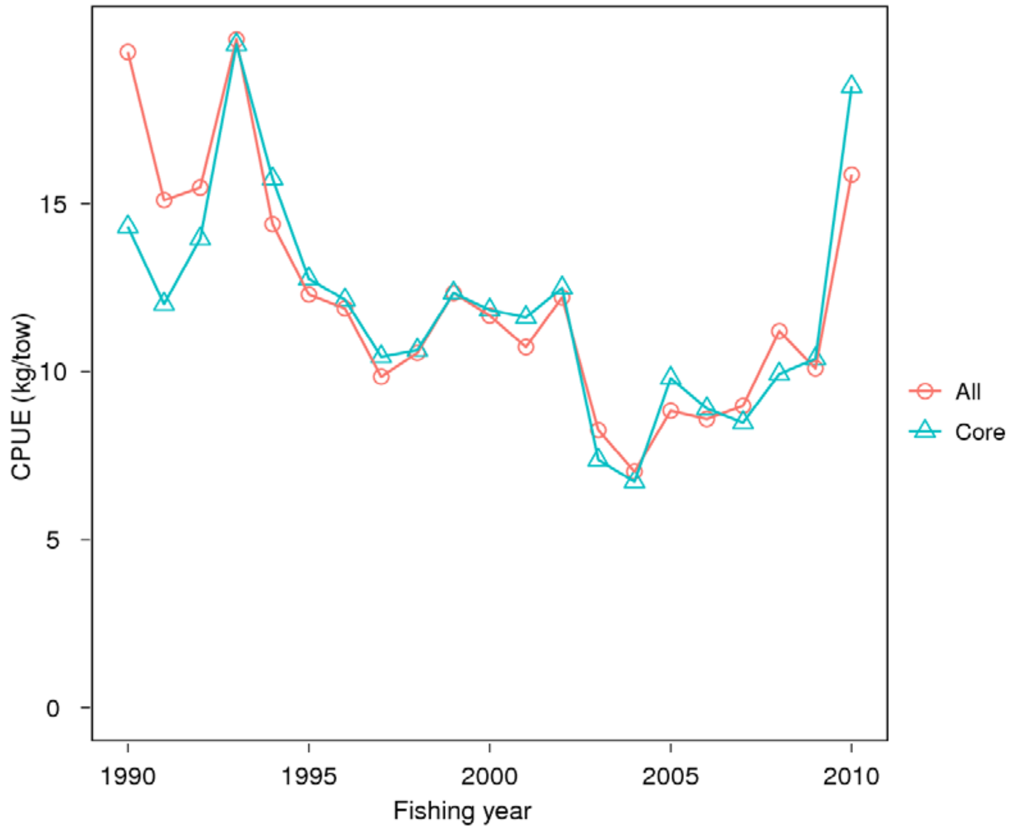

Figure D5: Unstandardised CPUE (geometric mean of positive catches) for the entire dataset (All) and core vessels (Core).

14.3 Selection of appropriate error distribution

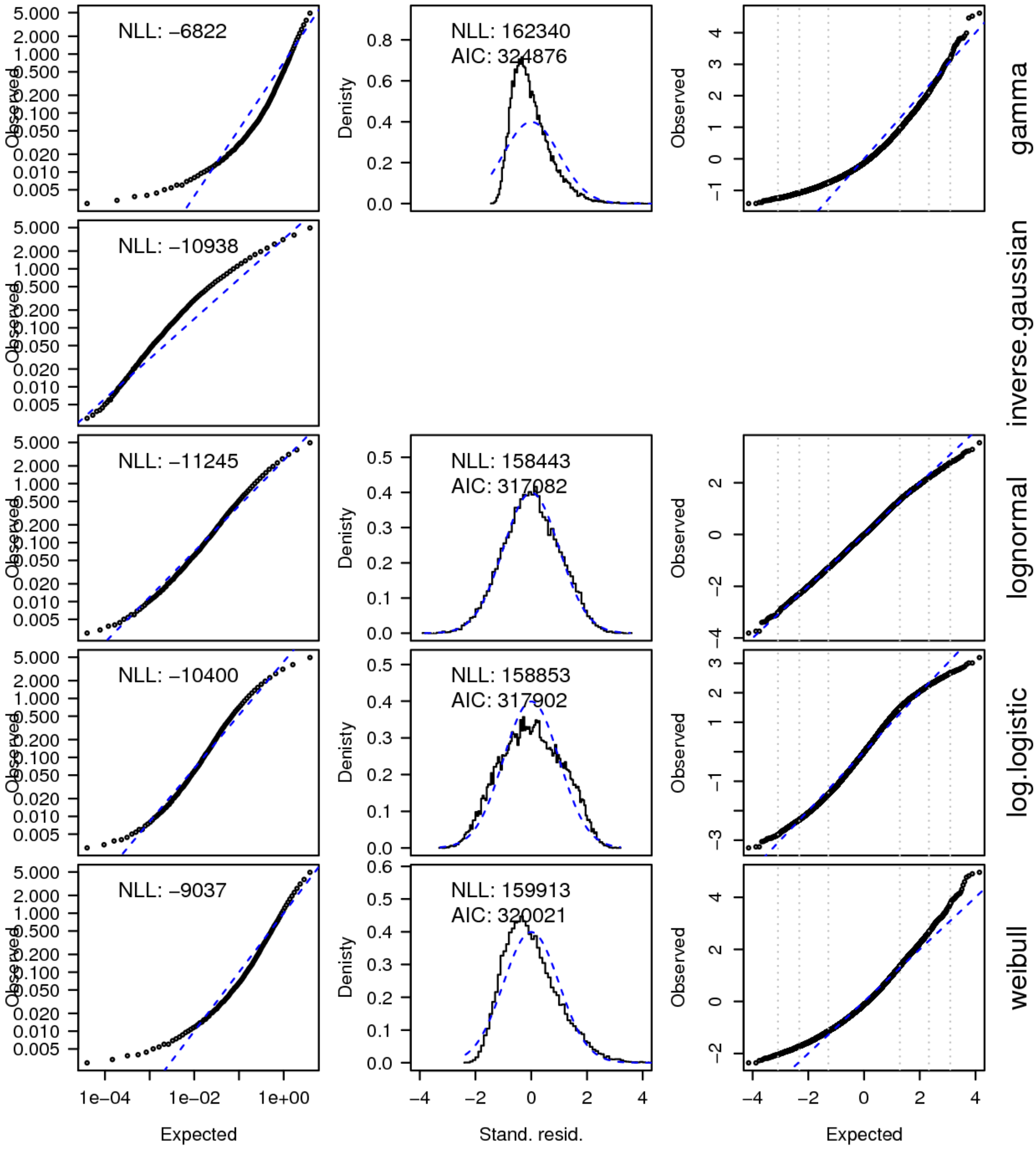

Figure D6: Diagnostics for alternative distributional assumptions for catch. Left: quantile–quantile plot of observed catches (centred (by mean) and scaled (by standard deviation) in log space) versus maximum likelihood fit of distribution (missing panel indicates that the fit failed to converge); Middle: standardised residuals from a generalised linear model fitted using the formula catch ~ fyear + month + area + vessel + target 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.

14.4 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 + target + poly(log(duration), 3) + poly(log(num), 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 D4 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 + target + poly(log(num), 3) + month + area

Table D4: 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	–162 438	324 920	–	1.41	*
vessel	79	–159 634	319 427	–	18.72	*
target	83	–158 785	317 736	–	23.34	*
poly(log(num), 3)	86	–158 043	316 257	–	27.16	*
month	97	–157 768	315 729	–	28.53	*
area	101	–157 605	315 412	–	29.33	*

14.5 Influence of model terms on annual CPUE indices

Table D5: 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	–162 643	325 290	–	–	–	–
fyear	20	–162 438	324 920	1.41	–	1.41	–
vessel	57	–159 634	319 427	17.32	–	17.32	6.65
target	4	–158 785	317 736	4.62	–	4.62	4.81
poly(log(num), 3)	3	–158 043	316 257	3.82	–	3.82	12.19
month	11	–157 768	315 729	1.37	–	1.37	2.03
area	4	–157 605	315 412	0.80	–	0.80	2.98

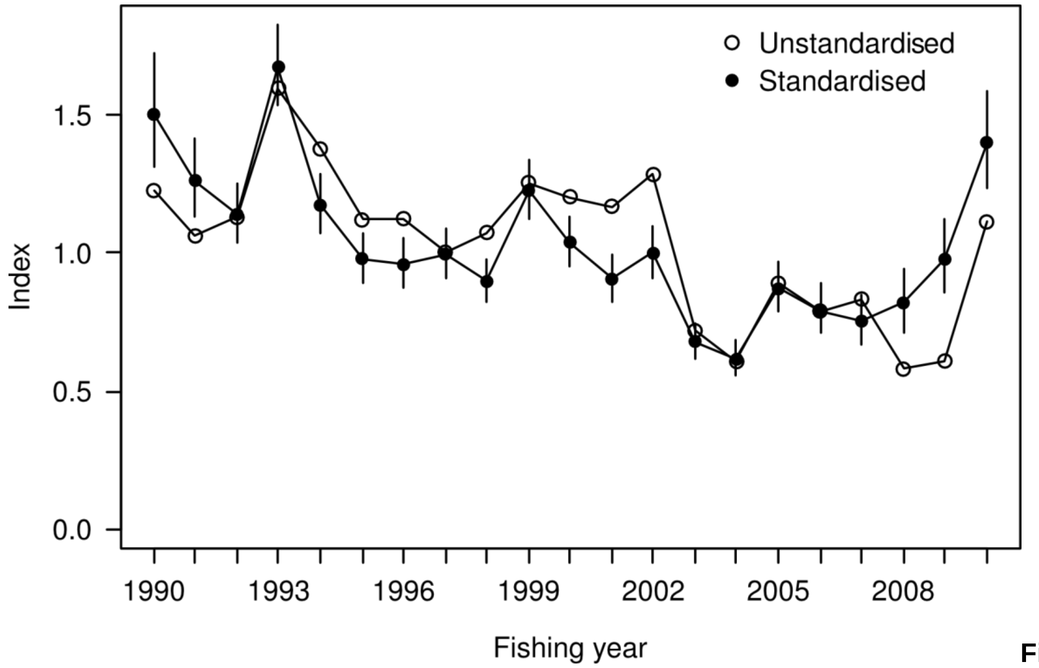

Figure D7: Overall standardisation effect of the model. The unstandardised index is based on the geometric mean of the catch per strata and is not adjusted for effort.

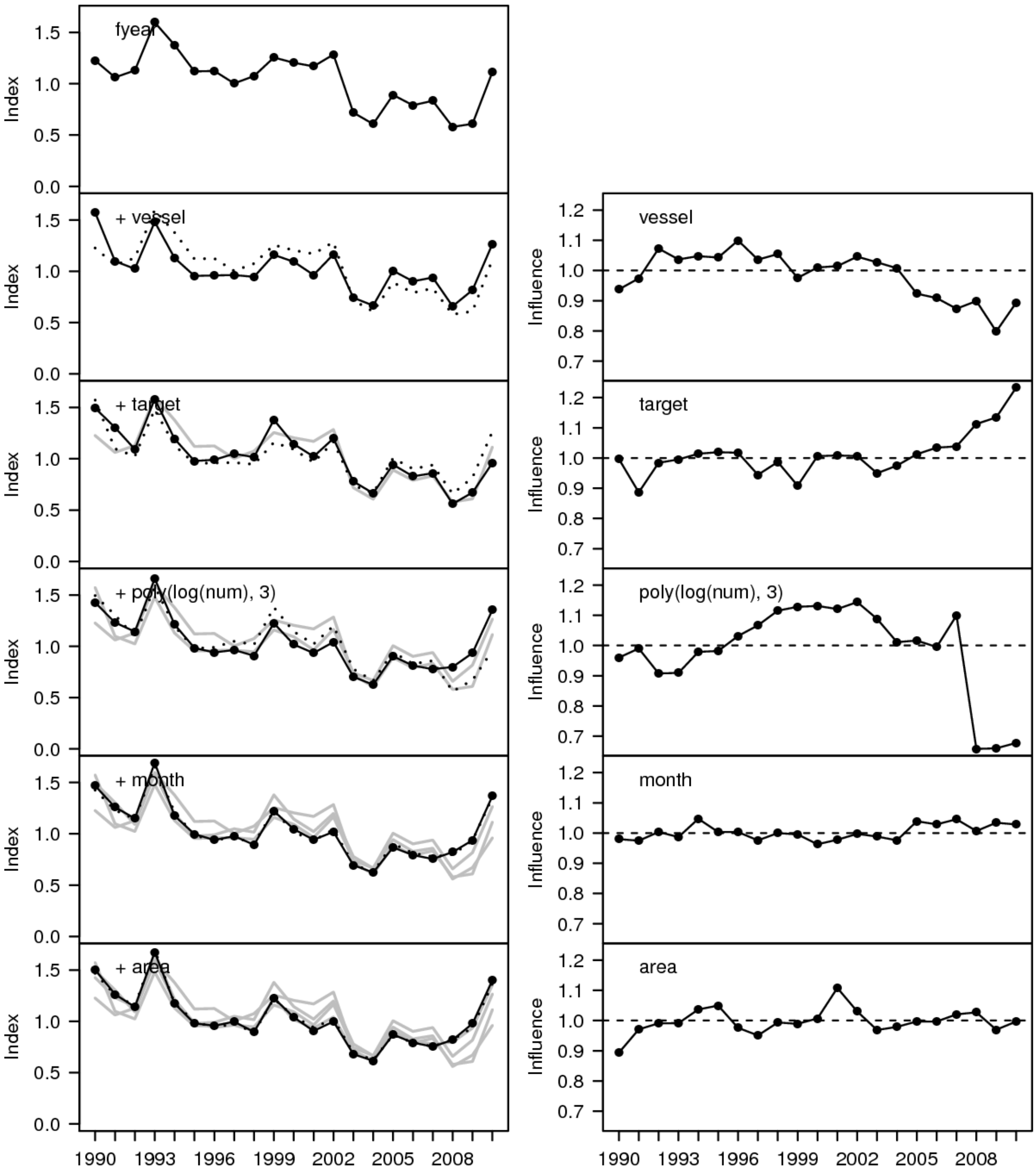

Figure D8: Effect on the standardised index of stepwise addition of model terms (left) and the annual influence of each model term in the final model (right).

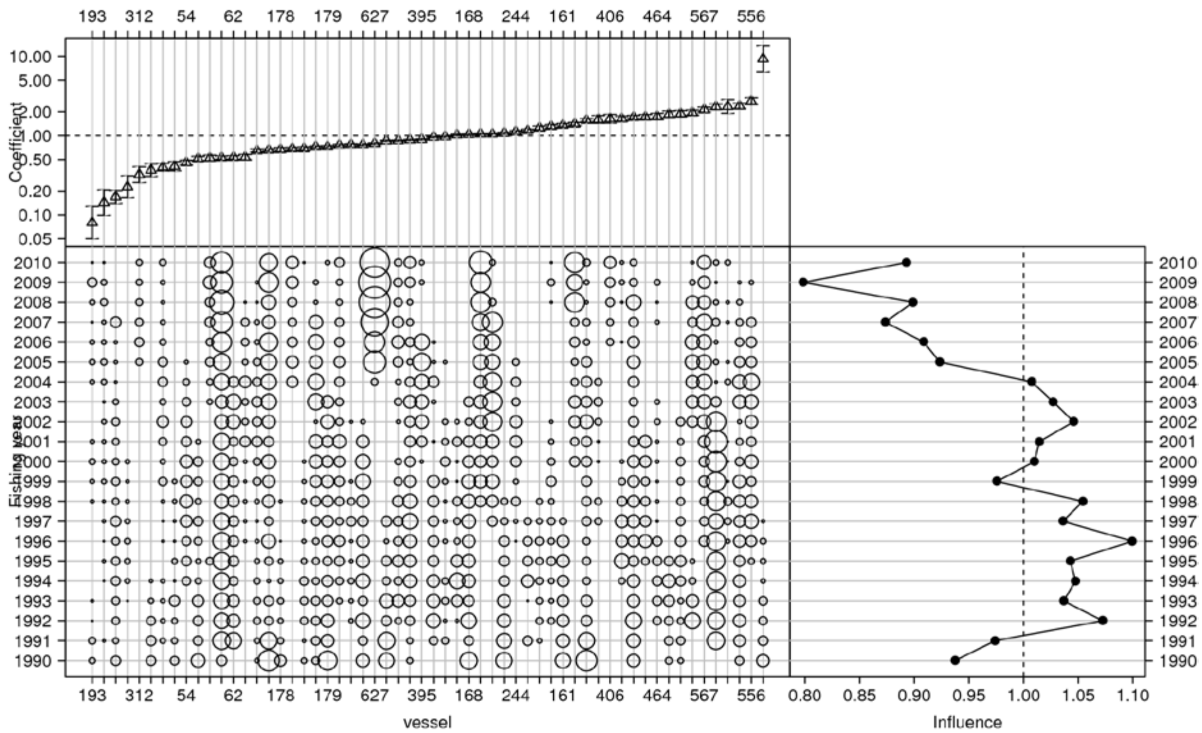

Figure D9: Coefficient–distribution–influence plot for *vessel*.

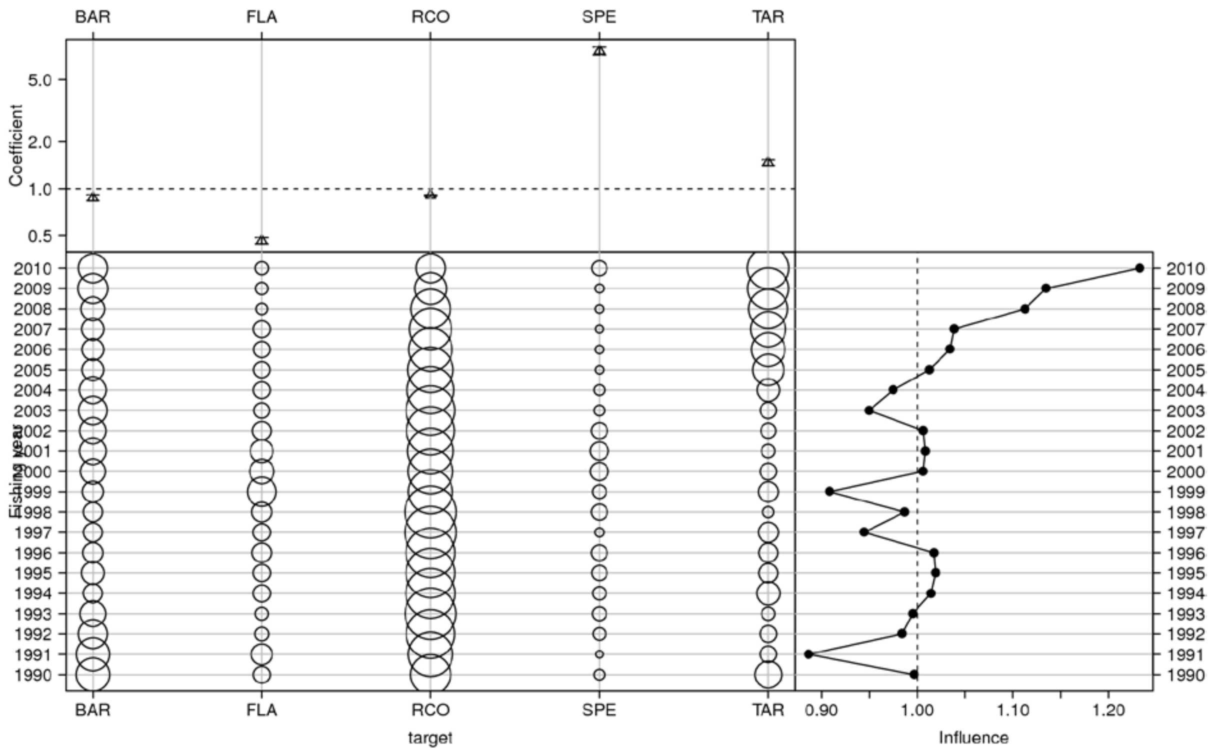

Figure D10: Coefficient–distribution–influence plot for *target*.

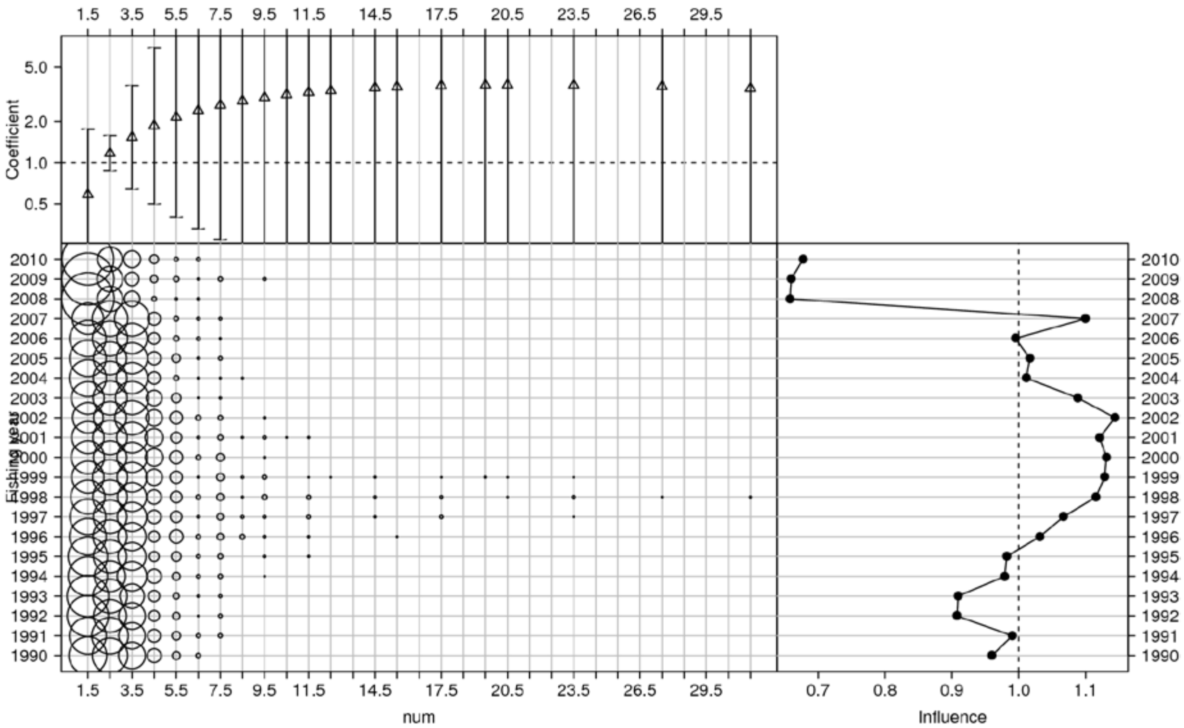

Figure D11: Coefficient–distribution–influence plot for *poly(log(num), 3)*.

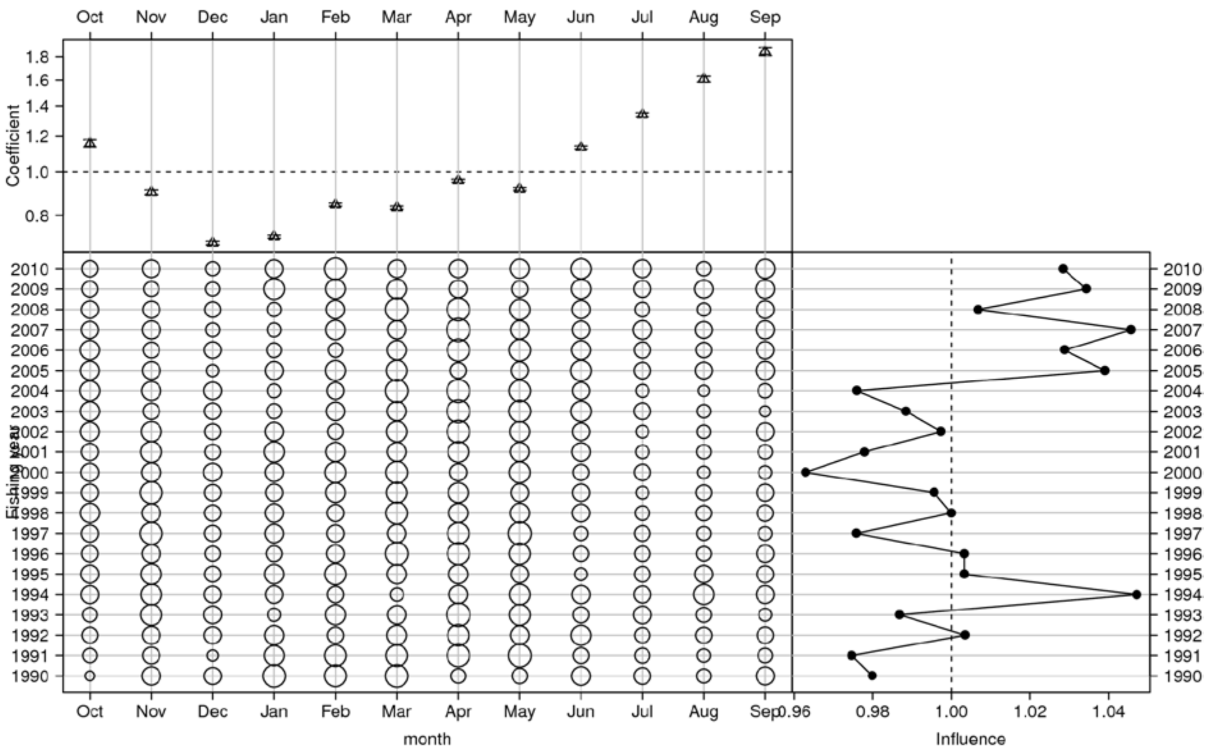

Figure D12: Coefficient–distribution–influence plot for *month*.

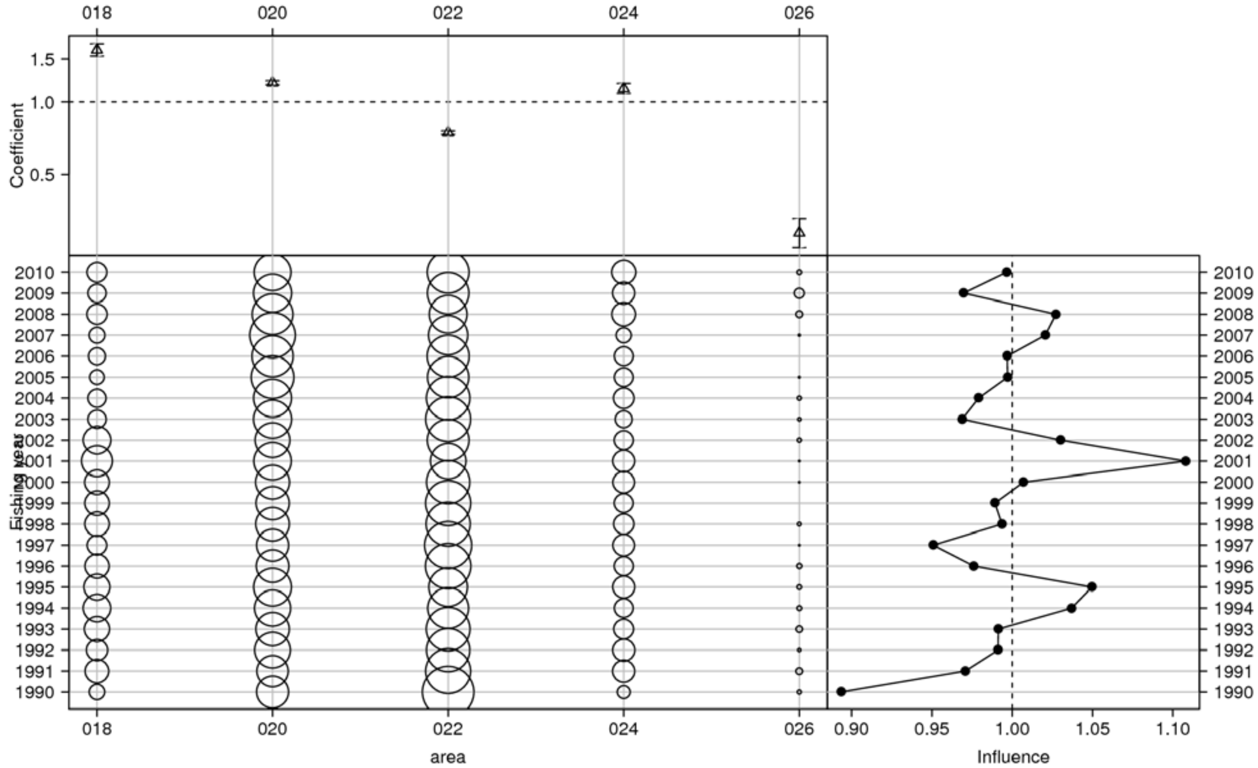

Figure D13: Coefficient–distribution–influence plot for area.

14.6 Residual diagostics

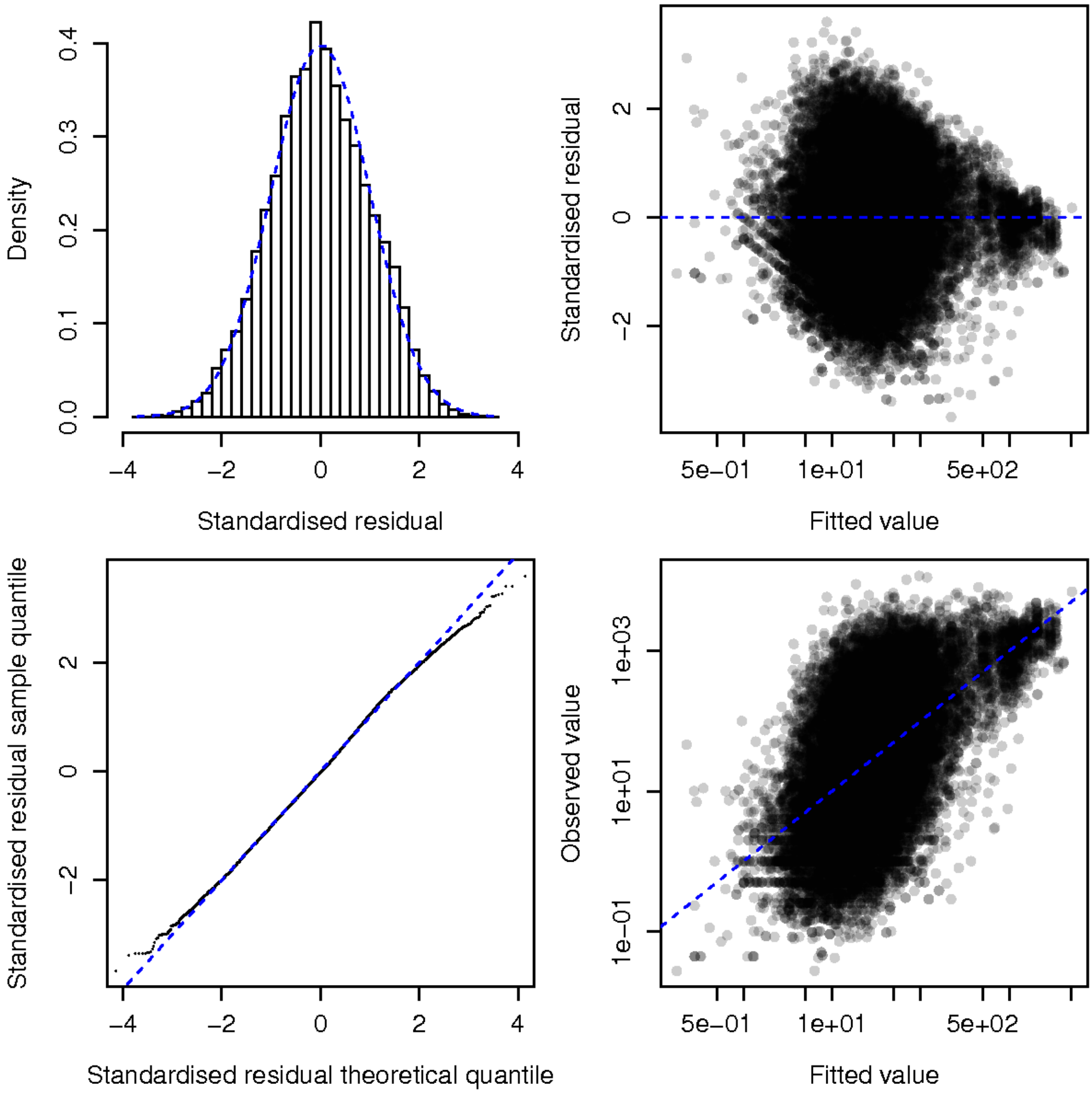

Figure D14: Residual diagnostics. Top left: histogram of standardised residuals compared to standard normal distribution. Bottom left: quantile–quantile plot of standardised residuals. Top right: fitted values versus standardised residuals. Bottom right: observed values versus fitted values.

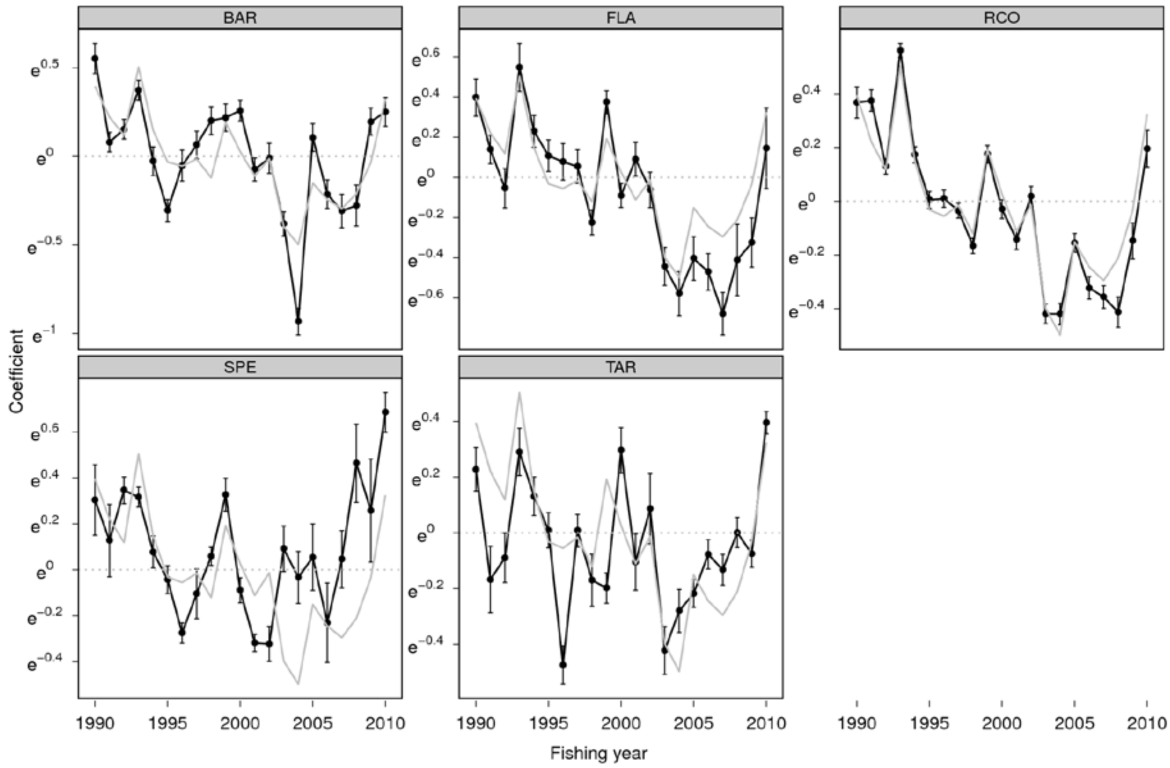

Figure D15: Residual implied coefficients for target × fishing year interactions. Implied coefficients (black points) are calculated as the normalised fishing year coefficient (grey line) plus the mean of the standardised residuals for each target in each fishing year. These values approximate the coefficients obtained when a target × year interaction term is fitted, particularly for those target × year combinations which have a substantial proportion of the records. The error bars indicate one standard error of the standardised residuals.

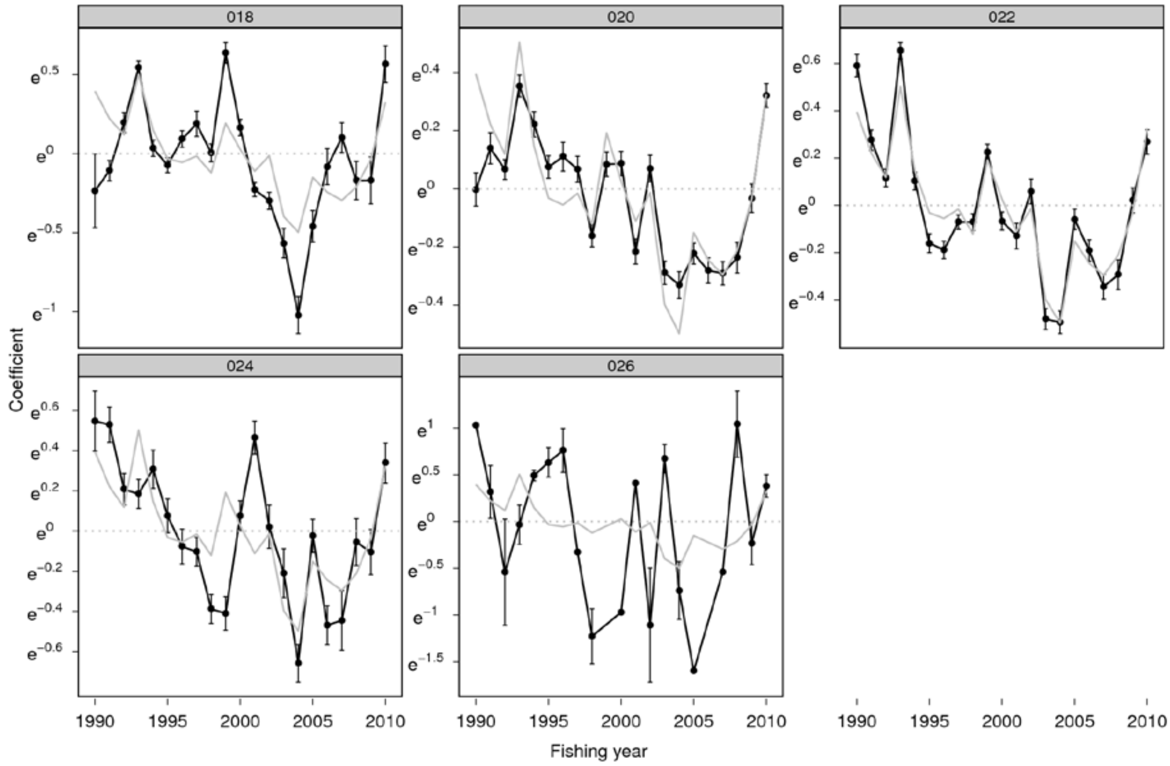

Figure D16: Residual implied coefficients for area × fishing year interactions. Implied coefficients (black points) are calculated as the normalised fishing year coefficient (grey line) plus the mean of the standardised residuals in each fishing year and area.

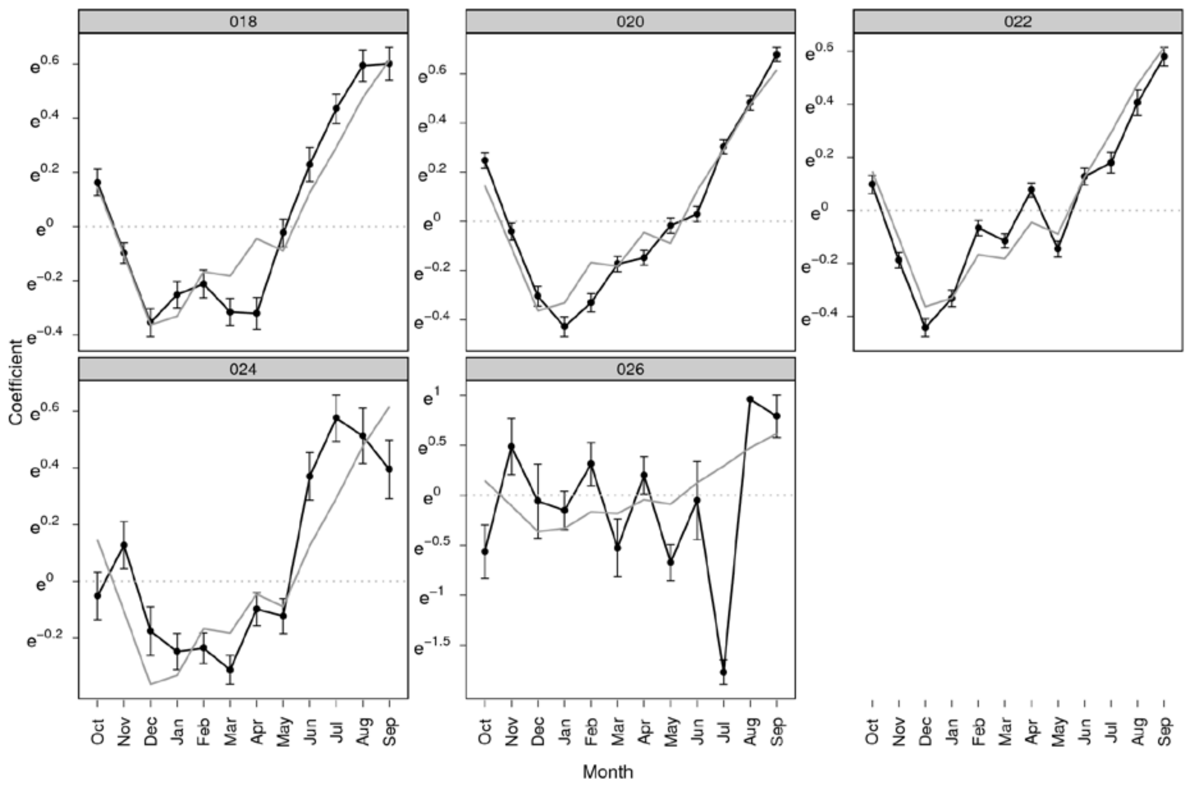

Figure D17: Residual implied coefficients for area × month interactions. Implied coefficients (black points) are calculated as the normalised month coefficients (grey line) plus the mean of the standardised residuals in each month and area.

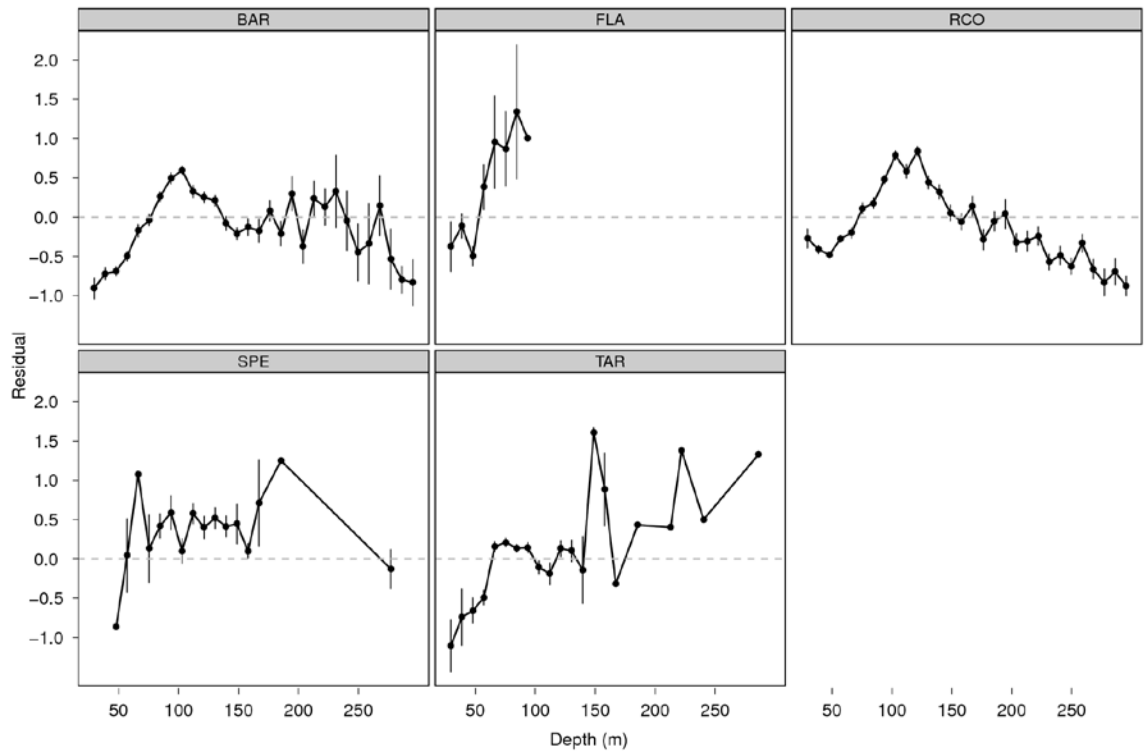

Figure D18: Mean and standard error of residuals by depth and target species.

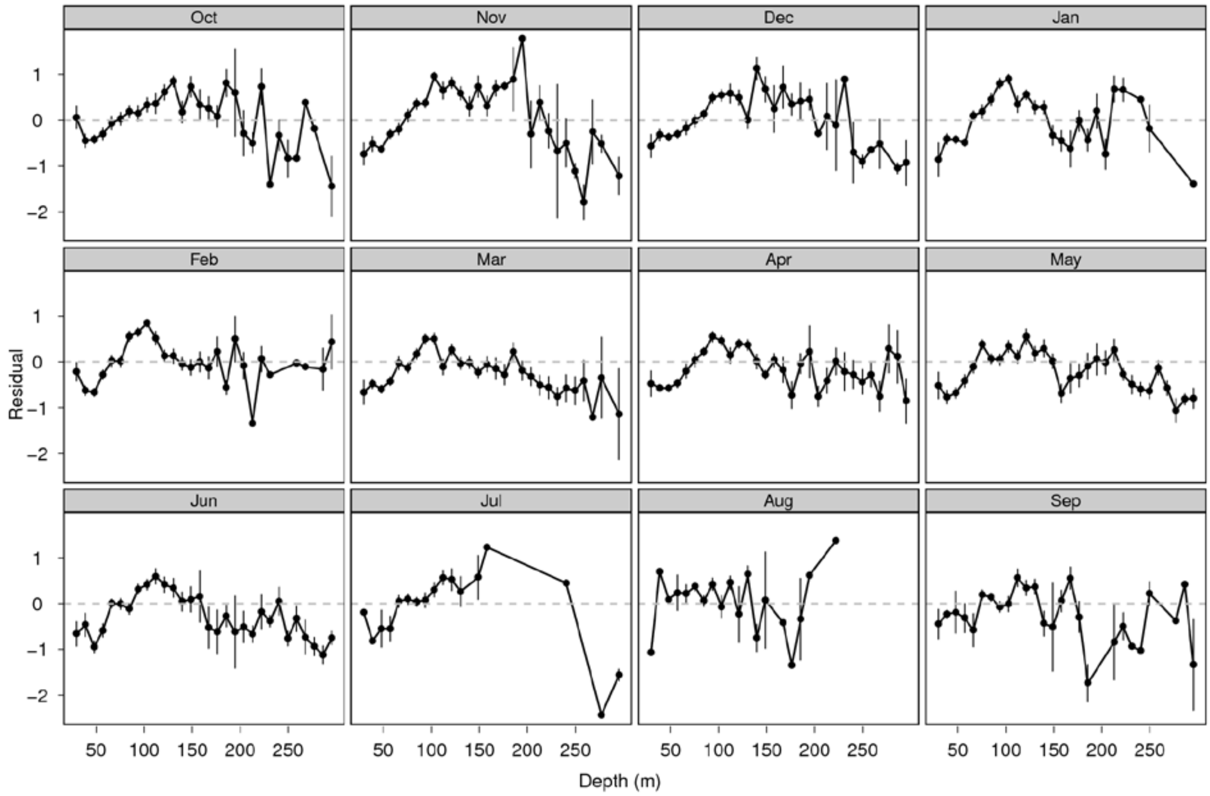

Figure D19: Mean and standard error of residuals by depth and month.

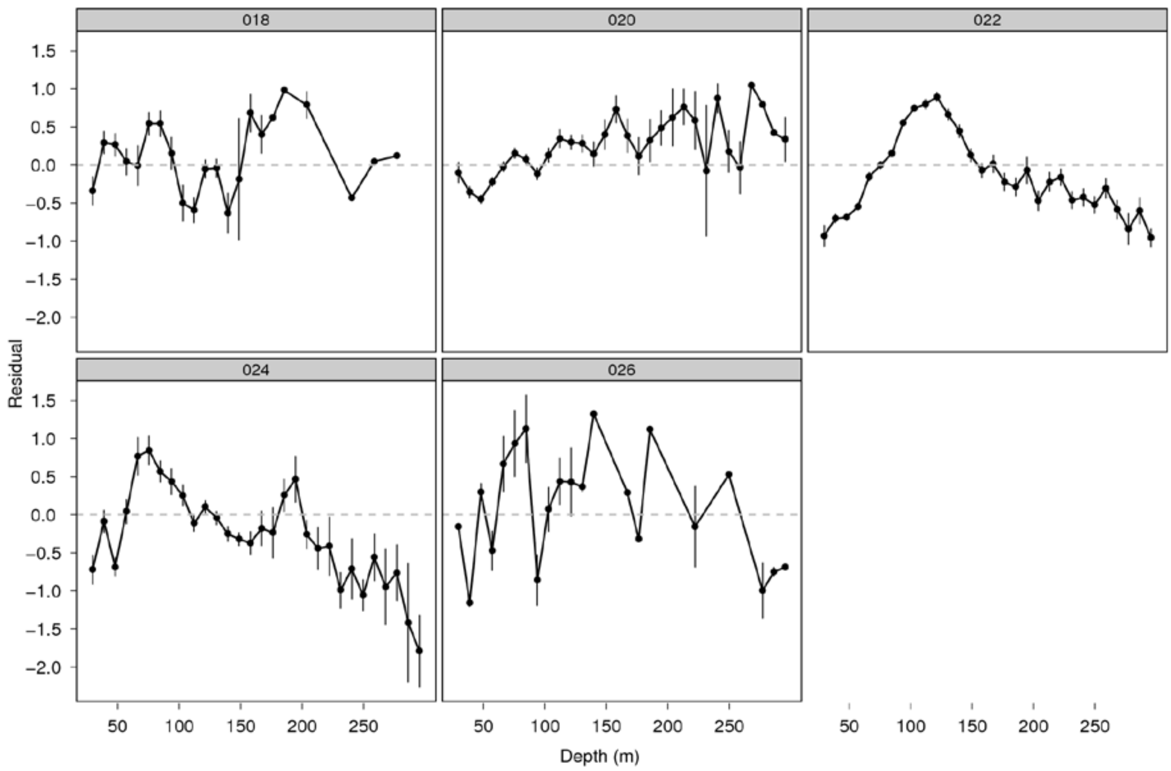

Figure D20: Mean and standard error of residuals by depth and area.

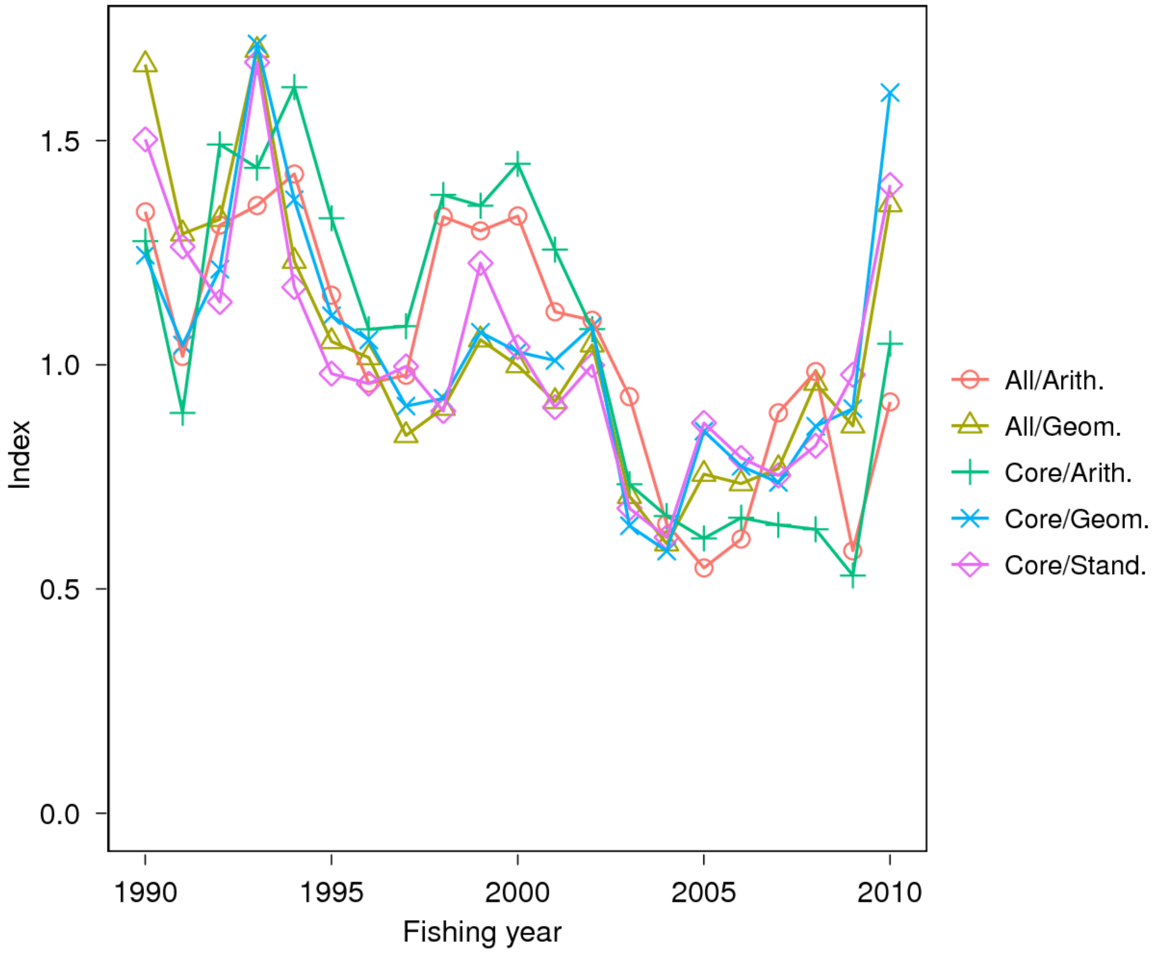

Figure D21: Standardised and unstandardised CPUE indices. All: all vessels, Core: core vessels, Geom.: geometric mean, Arith: arithmetic mean, Stand.: standardised using GLM.

Table D6: 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	1.3409	1.2754	1.6692	1.2441	1.5023	0.06865
1991	1.0185	0.8928	1.2918	1.0439	1.2630	0.05595
1992	1.3111	1.4912	1.3241	1.2130	1.1398	0.04665
1993	1.3547	1.4389	1.7011	1.7151	1.6742	0.04342
1994	1.4254	1.6190	1.2307	1.3679	1.1729	0.04536
1995	1.1548	1.3265	1.0518	1.1091	0.9800	0.04593
1996	0.9587	1.0791	1.0160	1.0551	0.9578	0.04663
1997	0.9767	1.0859	0.8423	0.9078	0.9963	0.04495
1998	1.3298	1.3785	0.9032	0.9249	0.8967	0.04176
1999	1.2983	1.3544	1.0556	1.0723	1.2264	0.04356
2000	1.3314	1.4478	0.9980	1.0286	1.0394	0.04322
2001	1.1180	1.2567	0.9181	1.0095	0.9054	0.04564
2002	1.0990	1.0793	1.0442	1.0856	0.9989	0.04889
2003	0.9290	0.7338	0.7067	0.6410	0.6798	0.04891
2004	0.6455	0.6626	0.6009	0.5847	0.6151	0.05308
2005	0.5471	0.6129	0.7559	0.8521	0.8701	0.05151
2006	0.6114	0.6589	0.7350	0.7737	0.7924	0.05650
2007	0.8931	0.6428	0.7686	0.7374	0.7532	0.06118
2008	0.9848	0.6332	0.9588	0.8629	0.8193	0.06972
2009	0.5854	0.5303	0.8637	0.9021	0.9776	0.06788
2010	0.9170	1.0470	1.3569	1.6066	1.4006	0.06371

15. APPENDIX E: CPUE FOR ECSI USING SHALLOW TOW DATA

15.1 Data subset and processing

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

- form type was either TCP or TCE
- method BT
- target was HOK, BAR, TAR, RCO, FLA, SPE, LIN, SQU, HAK, SCI, or SWA
- area was MAR, CAN, CAS, or OTA
- depth was 20–250 m
- bottom was 20–250 m
- height was 1–100 m
- width was 10–200 m
- speed was 2–7 kts
- duration was <15 hrs

Table E1 summarises the number of fishing events, vessels, trips, effort and catch in the resultant dataset. The minimum number of vessels was 24 in 2000. The percentage of positive catches ranged from 31% to 56%.

Table E1: Summary by fishing year of the data subset used for this analysis.

Fishing year	Vessels	Trips	Events	Effort (num)	Effort (hrs)	Catch (t)	Events with catch (landed,%)
1990	33	224	2 471	2 471	9 250	153.90	30.80
1991	33	214	1 729	1 729	6 833	149.00	33.31
1992	31	380	2 780	2 780	11 317	191.37	49.86
1993	31	369	3 042	3 042	12 132	196.58	46.75
1994	33	365	2 567	2 567	9 142	105.87	56.17
1995	37	332	2 221	2 221	7 886	126.76	47.01
1996	42	446	4 040	4 040	13 211	92.87	42.67
1997	45	438	3 549	3 549	10 895	117.47	41.84
1998	42	402	3 405	3 405	11 477	138.25	44.32
1999	33	369	2 468	2 468	7 950	105.22	35.70
2000	24	305	2 326	2 326	7 662	105.21	38.18
2001	28	241	2 304	2 304	8 845	99.38	38.28
2002	26	257	1 951	1 951	6 321	80.68	44.75
2003	28	265	2 151	2 151	7 327	120.55	45.19
2004	24	248	1 651	1 651	5 637	21.15	49.49
2005	32	200	1 292	1 292	4 381	45.21	45.05
2006	29	175	1 181	1 181	4 385	42.58	43.10
2007	25	157	787	787	2 920	47.37	39.26
2008	65	647	3 319	3 319	12 045	124.95	41.88

2009	60	696	3 494	3 494	13 418	92.56	42.47
2010	61	860	4 286	4 286	15 970	210.61	47.20

15.2 Core vessel selection

Alternative core vessel selection criteria were investigated by considering the reduction in the number of vessels and percentage of catch (Figure E1). 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 1 kg of catch. These criteria resulted in a core fleet size of 49 vessels which took 88% of the catch (Figure E1). A histogram of the number of years in which each core vessel had data in the dataset is provided (Figure E2) as is the overlap of data among core vessels (Figure E3).

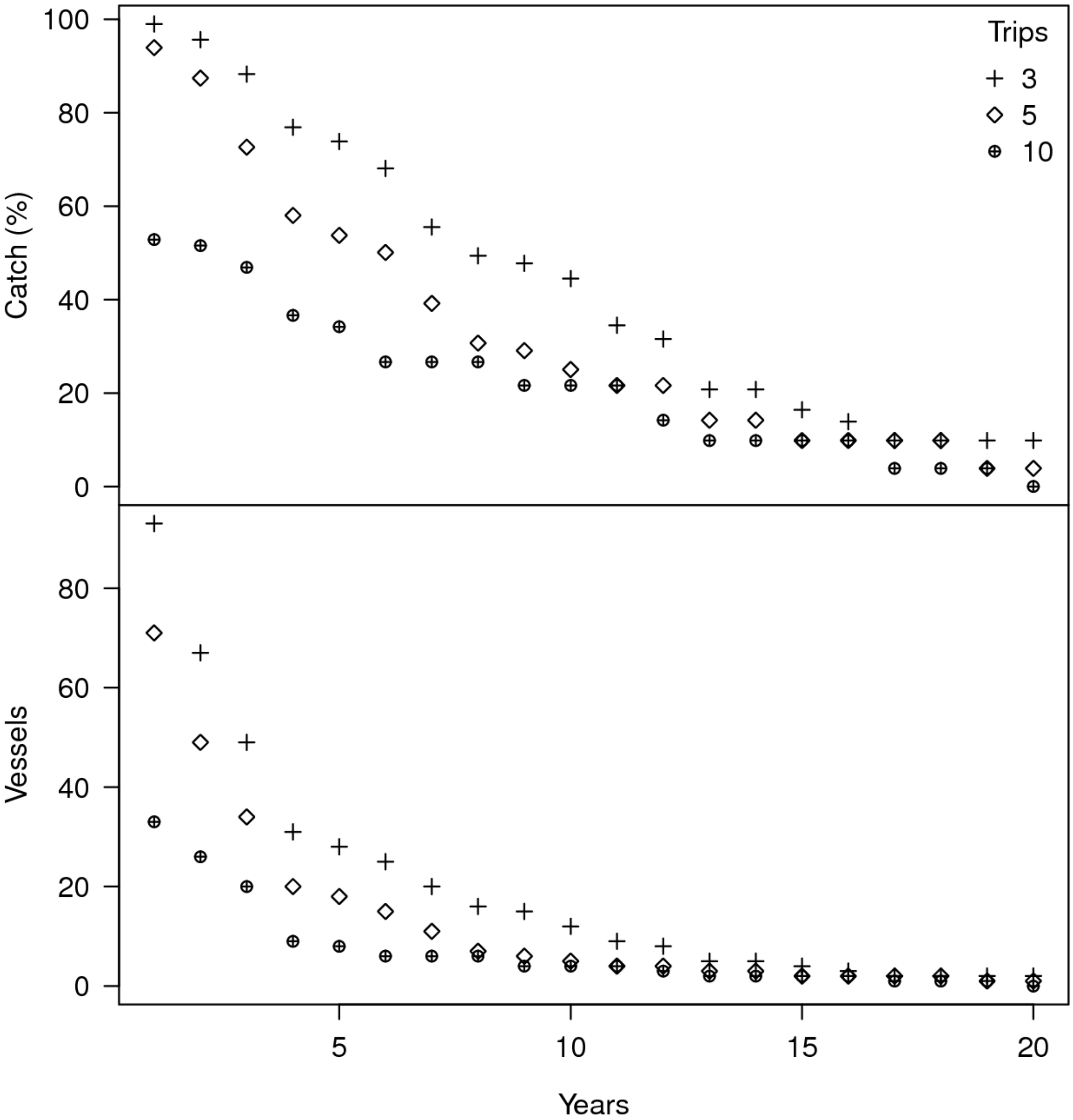

Figure E1: Examination of parameters for defining core vessels.

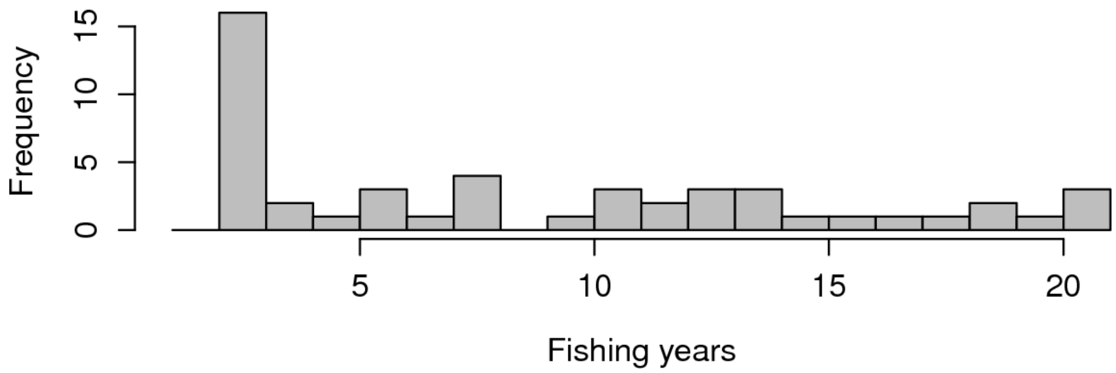

Figure E2: Histogram of the number of years with data for each core vessel.

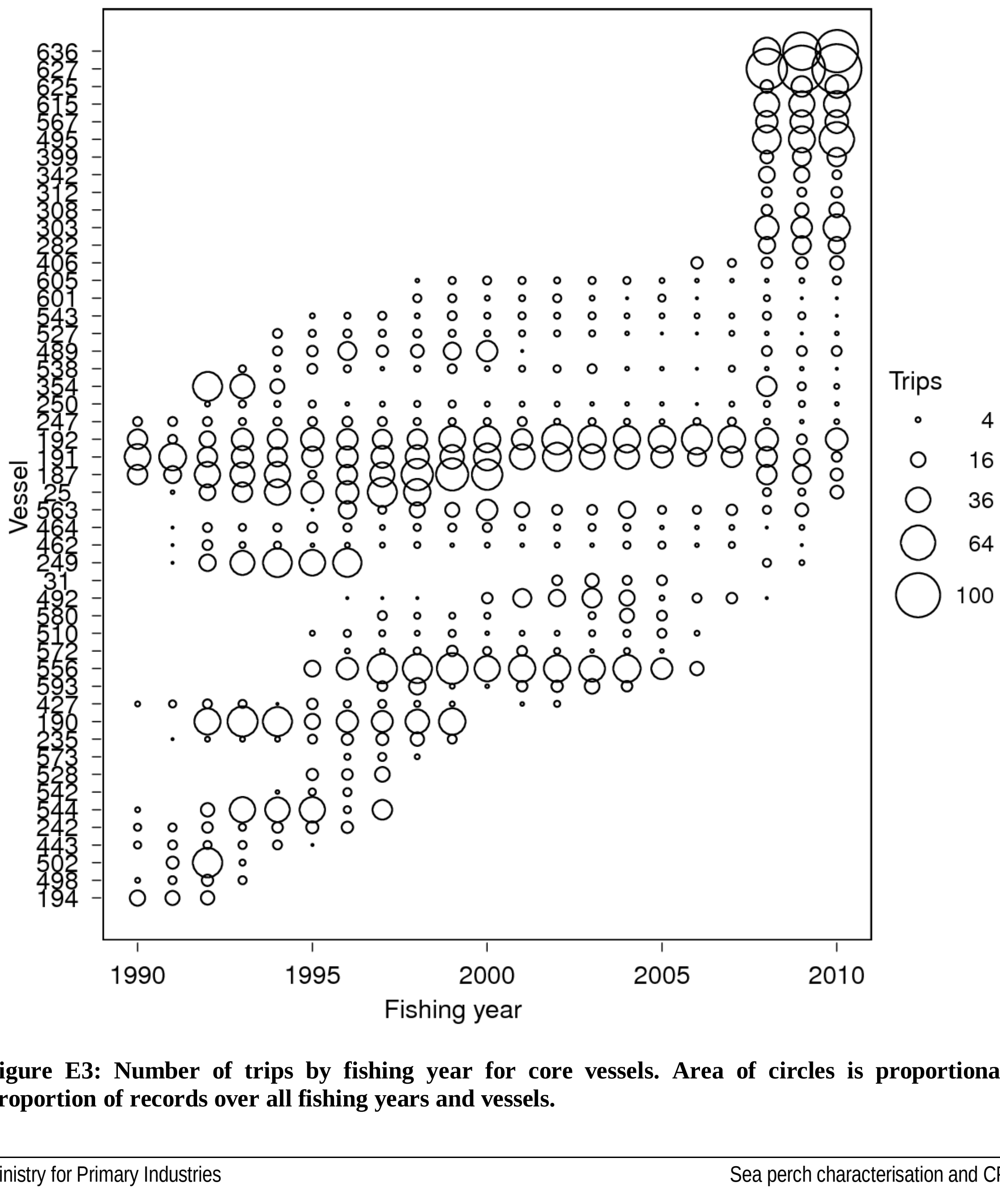

Figure E3: Number of trips by fishing year for core vessels. Area of circles is proportional to the proportion of records over all fishing years and vessels.

Table E2: Summary of core vessel data by fishing year.

Fishing year	Vessels	Trips	Events	Effort (num)	Effort (hrs)	Catch (t)	Trips with catch (%)	Strata with catch (%)
1990	12	139	1 347	1 347	5 178	109.96	79.86	41.80
1991	17	145	1 054	1 054	4 218	102.39	82.76	39.85
1992	19	347	2 558	2 558	10 442	186.97	84.73	51.80
1993	19	340	2 792	2 792	11 468	181.55	88.53	48.71
1994	20	342	2 397	2 397	8 593	103.16	84.80	58.07
1995	25	318	2 163	2 163	7 639	126.26	72.33	48.08
1996	26	365	3 431	3 431	11 520	66.50	74.25	42.44
1997	28	365	2 974	2 974	9 336	96.29	77.53	45.93
1998	25	373	3 122	3 122	10 339	136.49	76.41	45.00
1999	23	354	2 375	2 375	7 578	102.40	68.64	36.17
2000	20	299	2 317	2 317	7 632	104.09	74.25	38.24
2001	20	219	2 167	2 167	8 346	94.32	79.91	37.10
2002	20	247	1 898	1 898	6 165	79.13	75.71	43.99
2003	20	245	1 972	1 972	6 831	119.16	75.10	46.60
2004	19	237	1 505	1 505	5 139	14.08	57.38	52.36
2005	18	173	1 136	1 136	3 824	40.02	75.72	46.21
2006	18	146	918	918	3 395	27.38	70.55	49.78
2007	16	135	711	711	2 585	36.46	54.07	38.54
2008	31	533	2 955	2 955	10 914	100.29	75.42	41.56
2009	31	561	2 836	2 836	11 397	82.88	75.58	43.09
2010	26	613	3 183	3 183	12 378	179.86	80.91	47.13

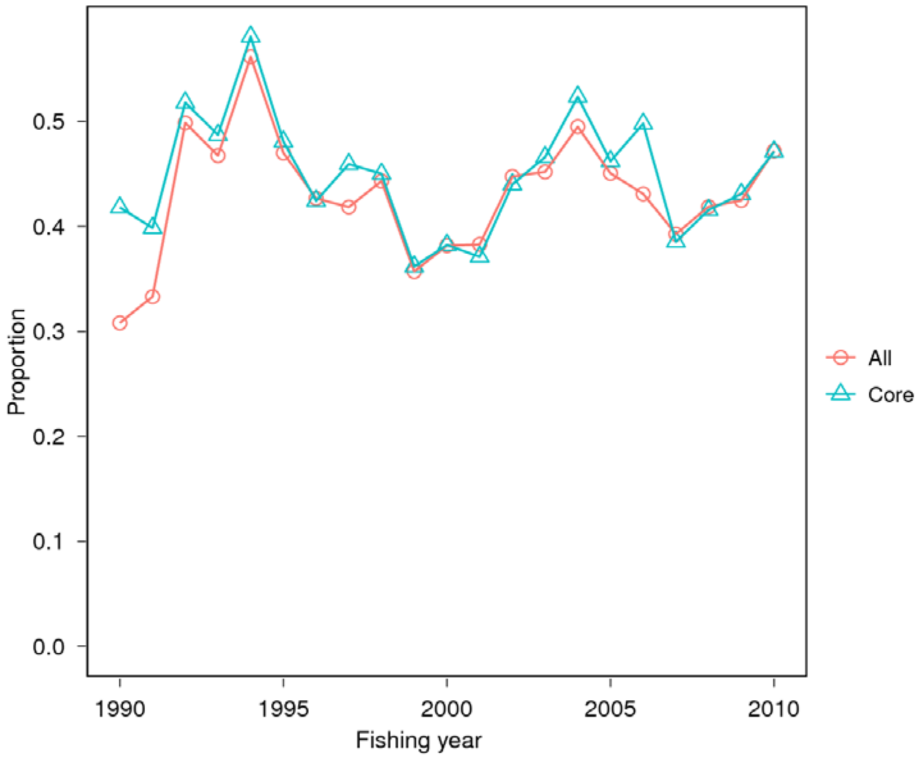

Figure E4: Proportion of positive catches for the entire dataset (All) and core vessels (Core).

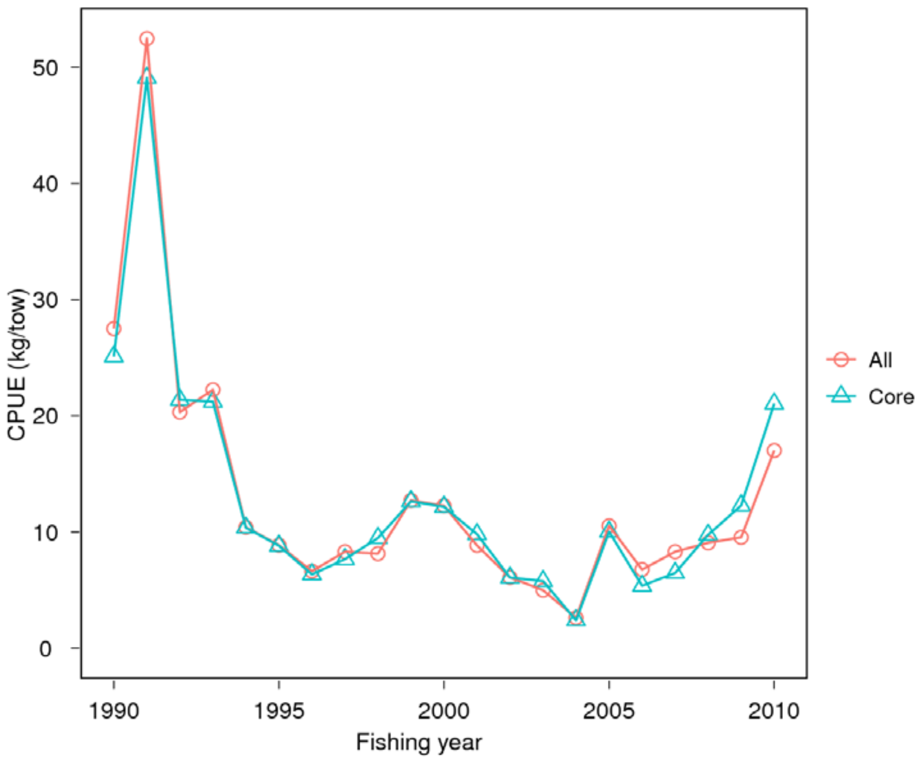

Figure E5: Unstandardised CPUE (geometric mean of positive catches) for the entire dataset (All) and core vessels (Core).

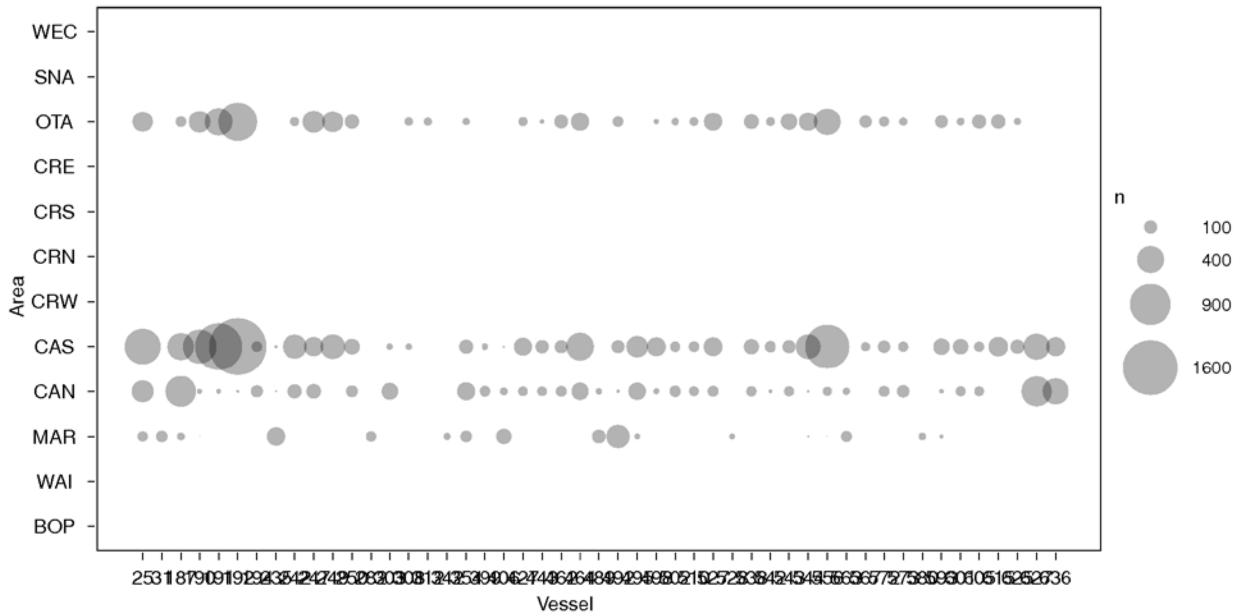

Figure E6: Number of tows by area for each core vessel over all years, 1989–90 to 2009–10.

15.3 Selection of appropriate error distribution

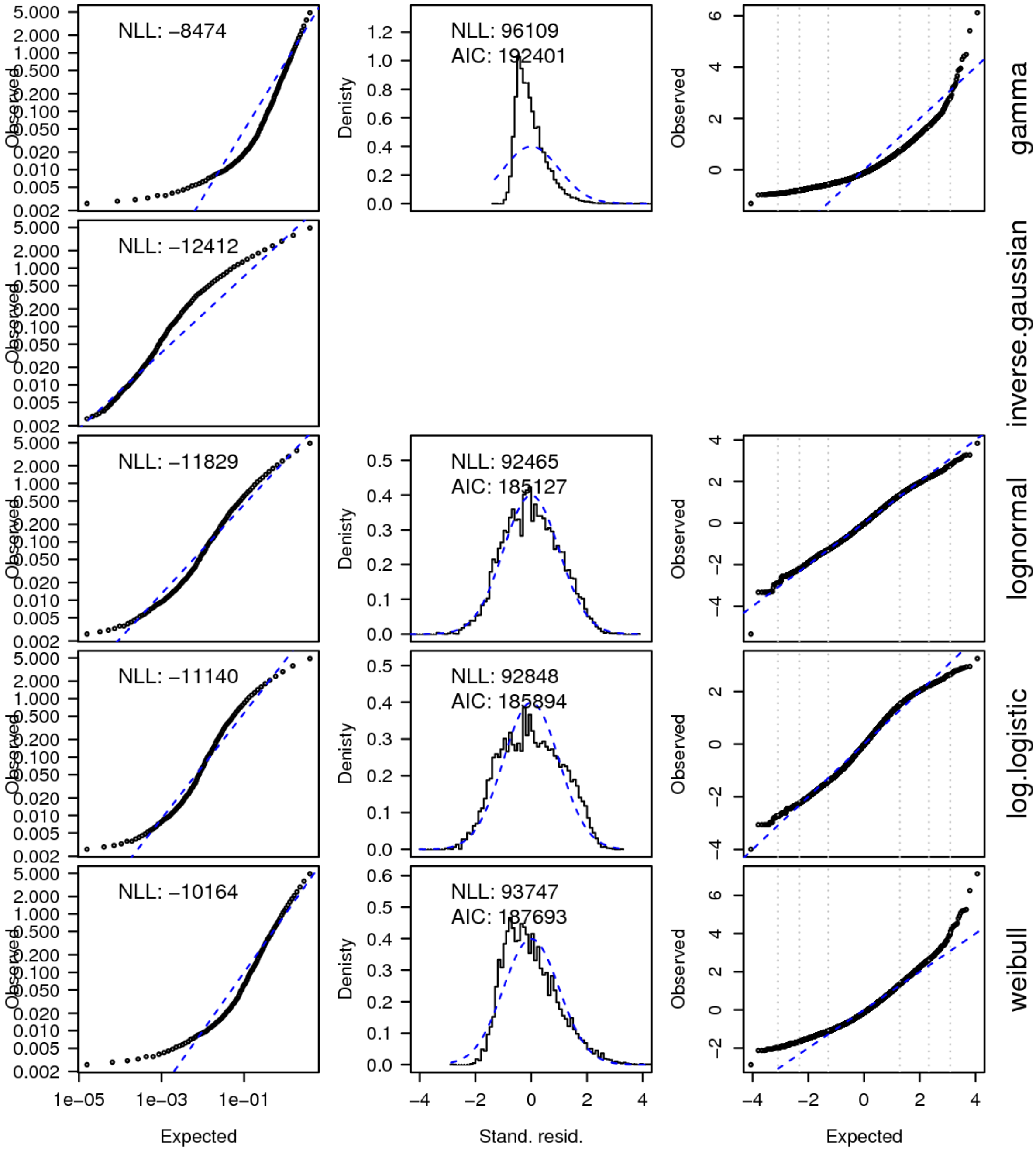

Figure E7: Diagnostics for alternative distributional assumptions for catch. Left: quantile–quantile plot of observed catches (centred (by mean) and scaled (by standard deviation) in log space) versus maximum likelihood fit of distribution (missing panel indicates that the fit failed to converge); Middle: standardised residuals from a generalised linear model fitted using the formula catch ~ fyear + month + area + target + 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.

15.4 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 + target + poly(log(duration), 3) + poly(log(height), 3) + poly(log(width), 3) + poly(log(speed), 3) + poly(log(depth), 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 E3 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 + poly(log(depth), 3) + vessel + area + target + month + poly(log(speed), 3)

Table E3: 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	–94 955	189 953	5.92	*
poly(log(depth), 3)	25	–93 787	187 625	15.99	*
vessel	73	–92 668	185 482	24.63	*
area	84	–91 917	184 003	29.93	*
target	91	–91 344	182 870	33.72	*
month	102	–91 122	182 447	35.13	*
poly(log(speed), 3)	105	–91 080	182 371	35.39	*
poly(moon, 3)	108	–91 067	182 349	35.48	
poly(log(height), 3)	111	–91 053	182 329	35.56	
poly(log(width), 3)	114	–91 045	182 319	35.61	
poly(log(duration), 3)	117	–91 038	182 310	35.65	
poly(time, 3)	120	–91 034	182 307	35.68	

15.5 Influence of model terms on annual CPUE indices

Table E4: 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	–95 584	191 172	–	–	–
fyear	20	–94 955	189 953	5.92	5.92	–
poly(log(depth), 3)	3	–93 787	187 625	10.07	10.07	13.84
vessel	48	–92 668	185 482	8.64	8.64	15.64
area	11	–91 917	184 003	5.29	5.29	12.96
target	7	–91 344	182 870	3.79	3.79	17.20
month	11	–91 122	182 447	1.41	1.41	5.31
poly(log(speed), 3)	3	–91 080	182 371	0.26	0.26	6.53

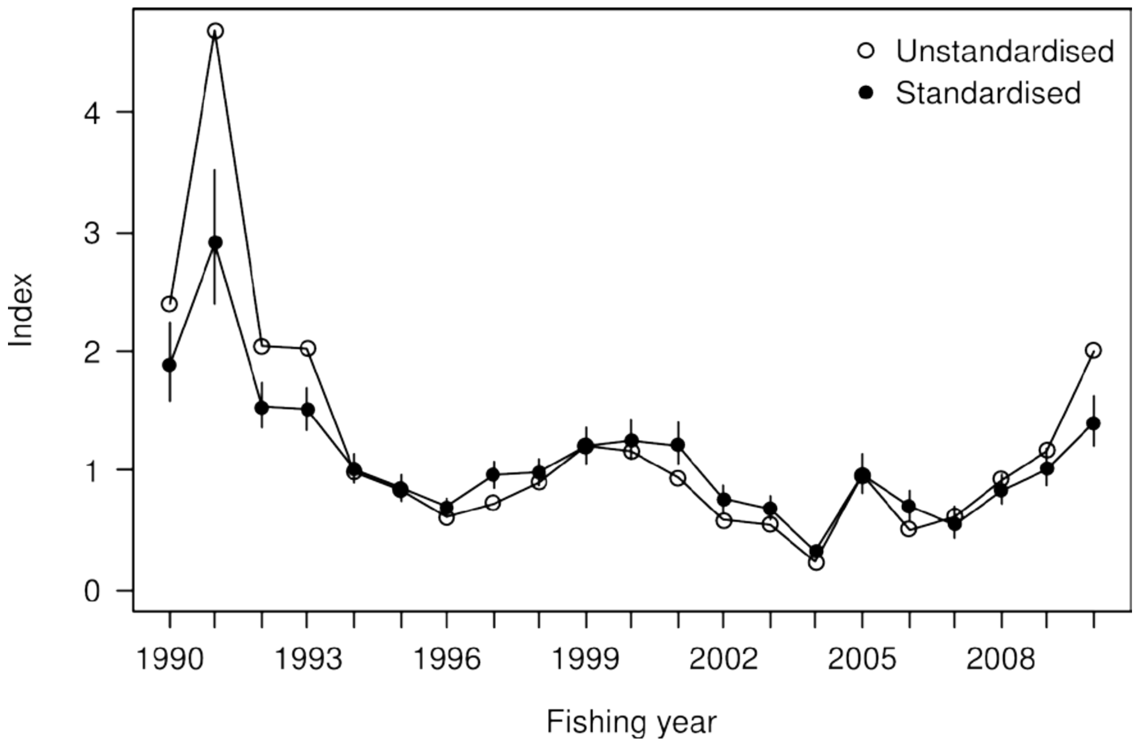

Figure E8: Overall standardisation effect of the model. The unstandardised index is based on the geometric mean of the catch per strata and is not adjusted for effort.

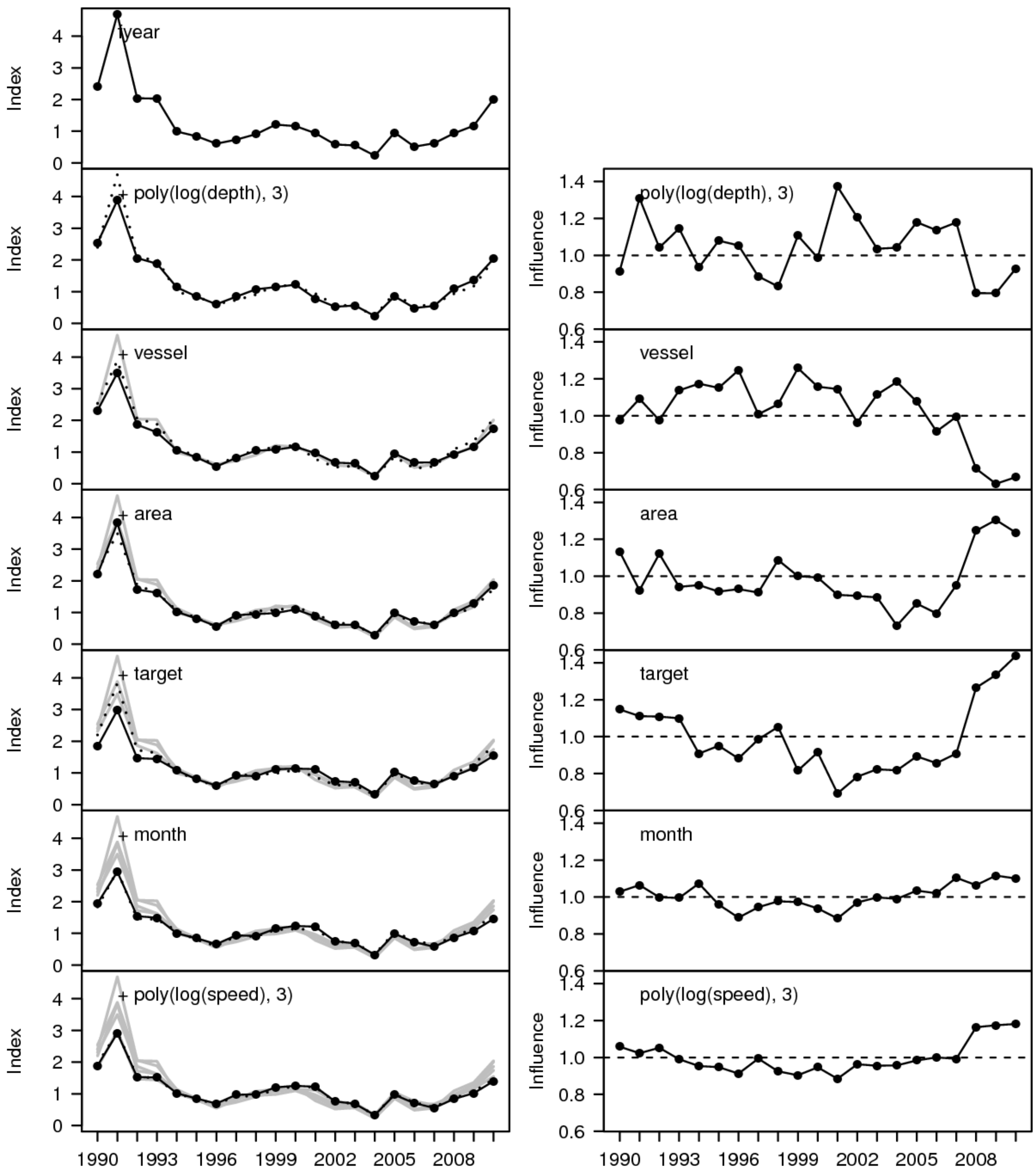

Figure E9: Effect on the standardised index of stepwise addition of model terms (left) and the annual influence of each model term in the final model (right).

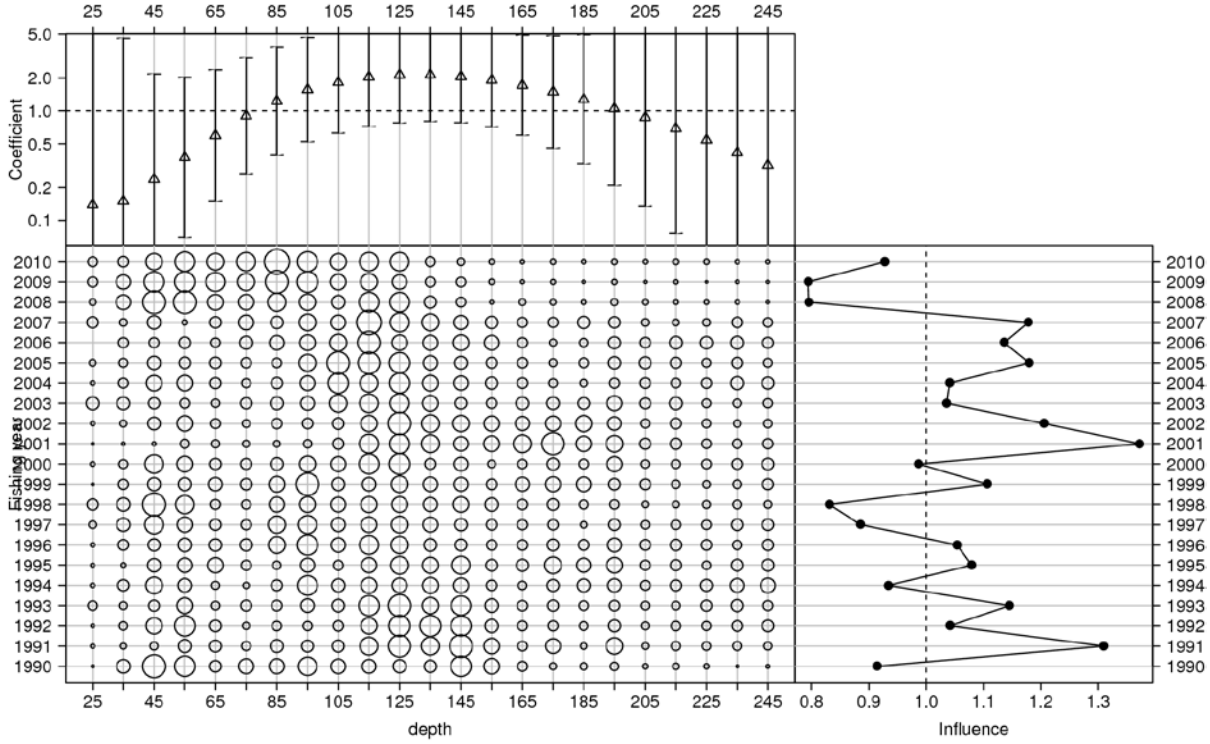

Figure E10: Coefficient–distribution–influence plot for *poly(log(depth), 3)*.

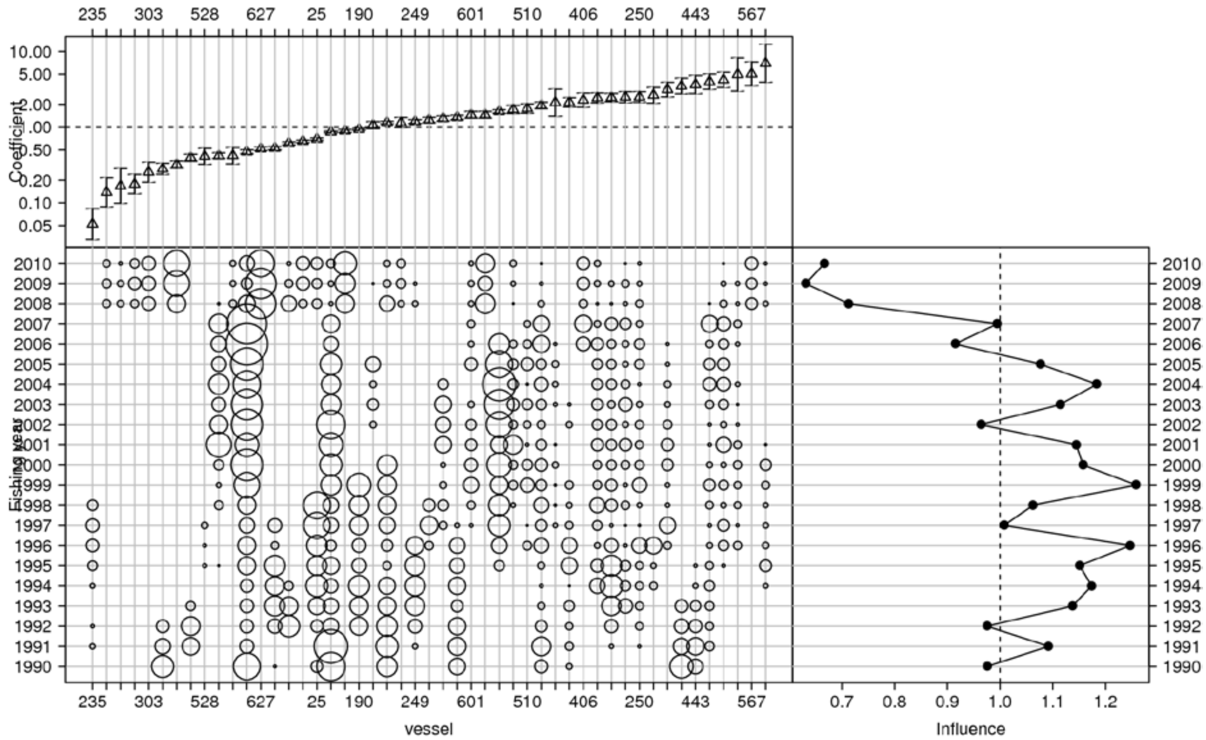

Figure E11: Coefficient–distribution–influence plot for *vessel*.

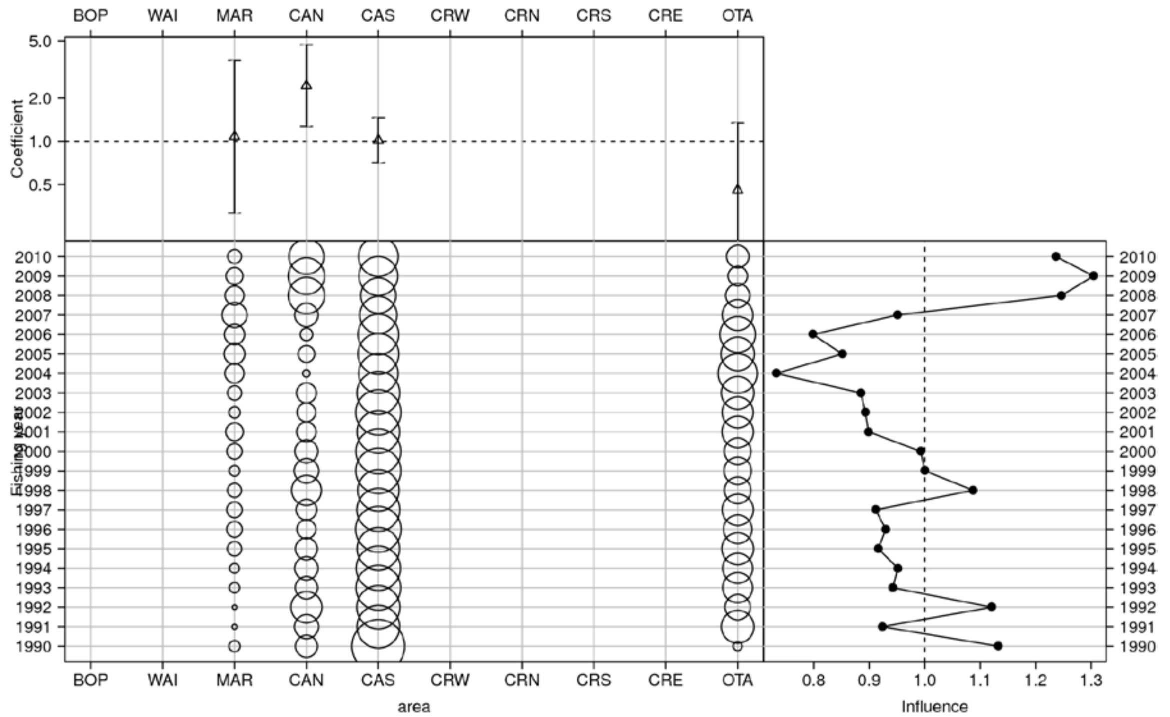

Figure E12: Coefficient–distribution–influence plot for *area*.

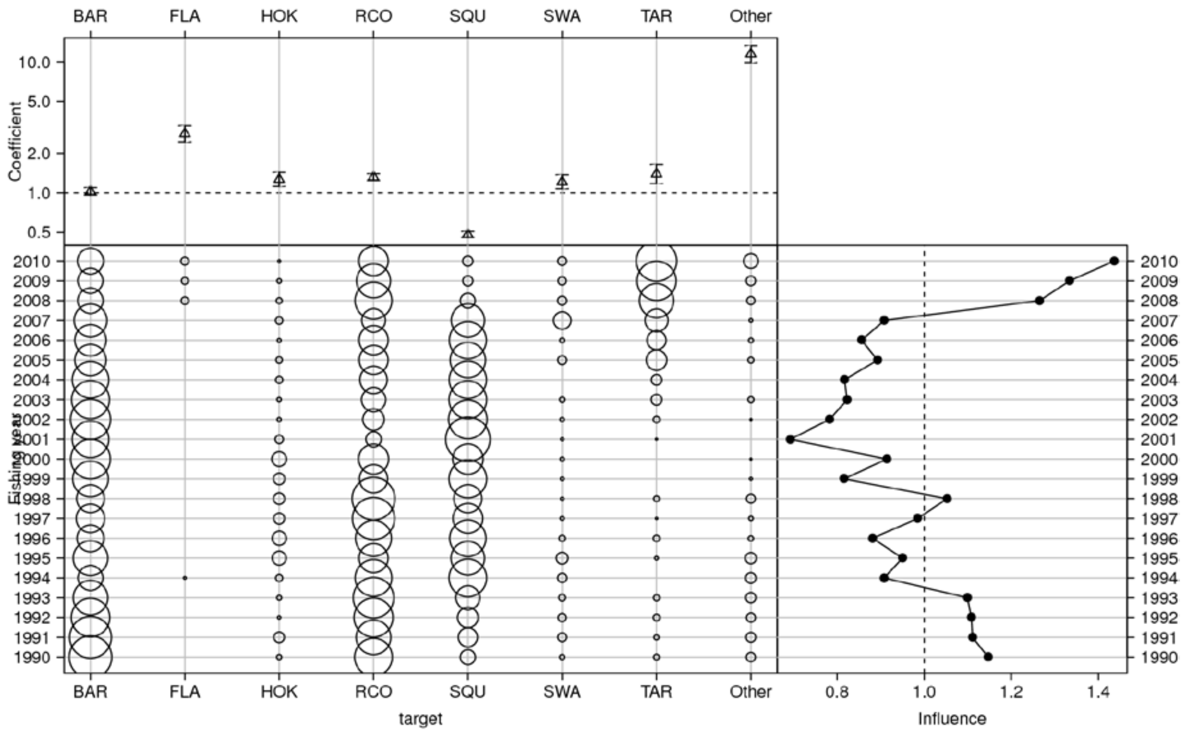

Figure E13: Coefficient–distribution–influence plot for *target*.

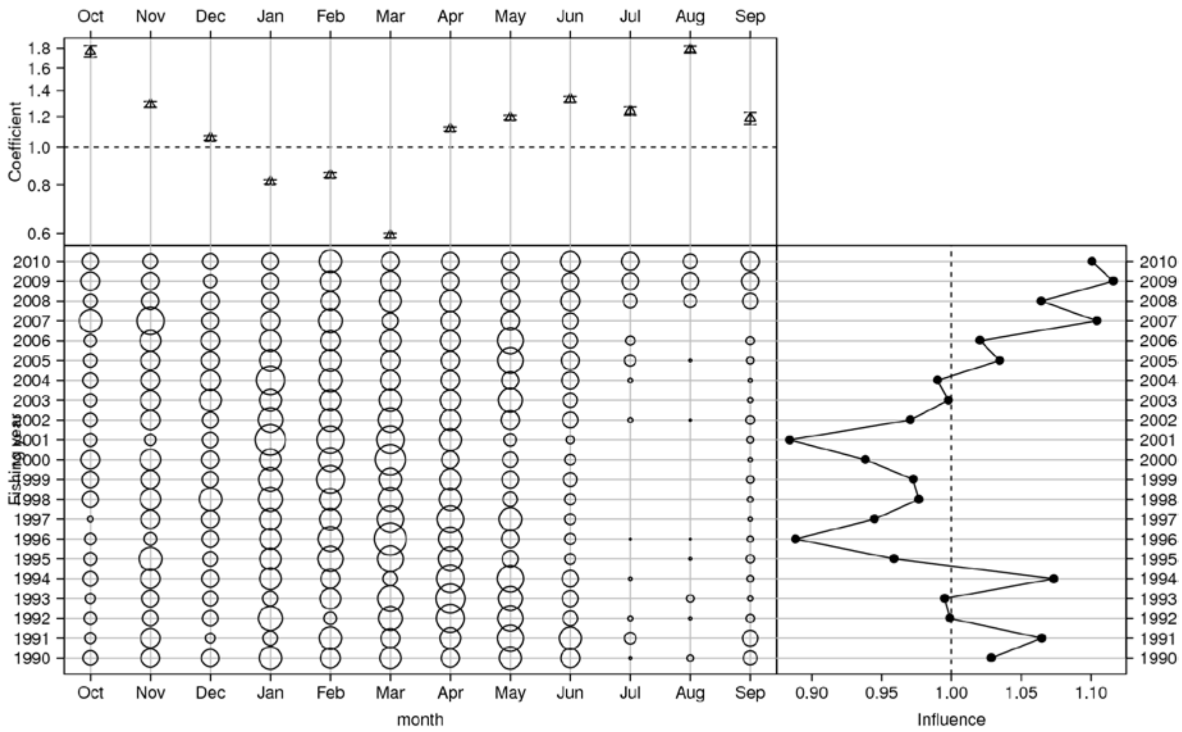

Figure E14: Coefficient–distribution–influence plot for *month*.

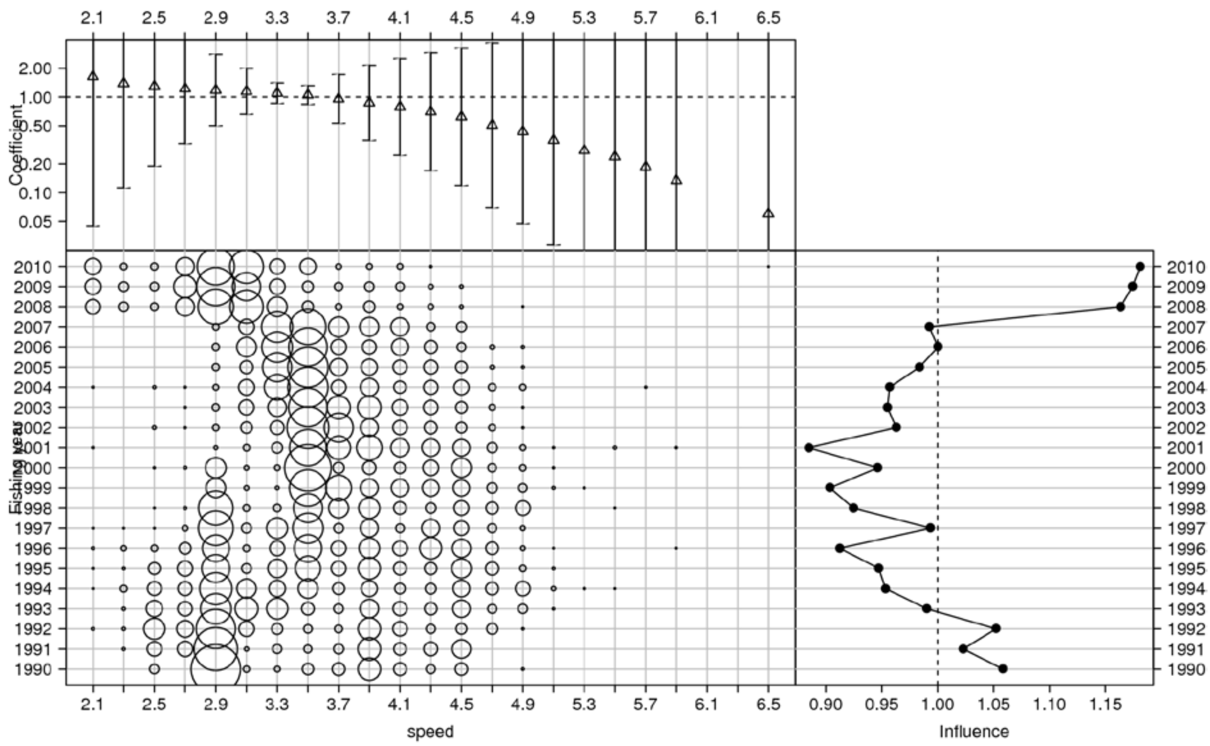

Figure E15: Coefficient–distribution–influence plot for *poly(log(speed), 3)*.

15.6 Residual diagnostics

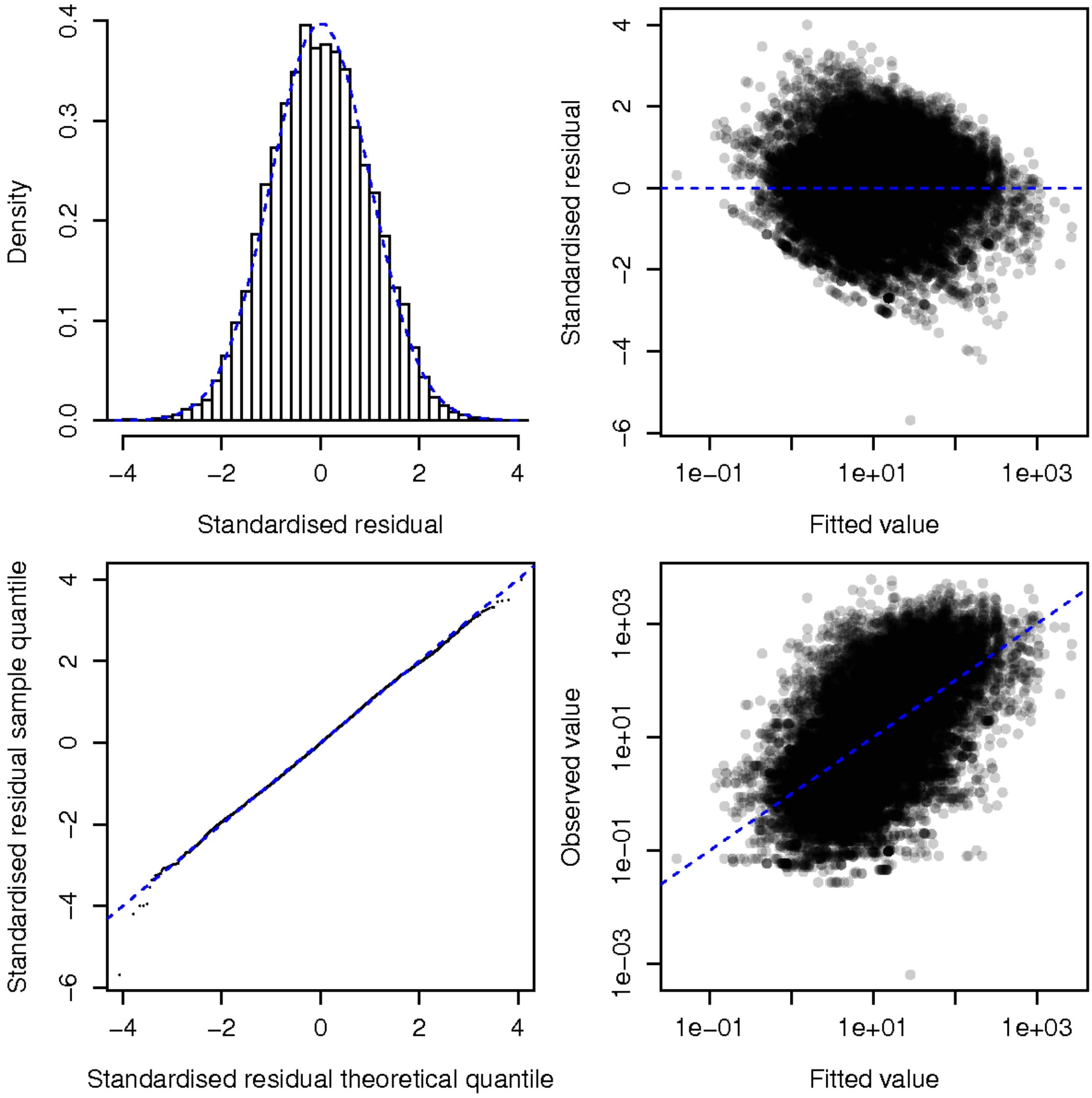

Figure E16: Residual diagnostics. Top left: histogram of standardised residuals compared to standard normal distribution. Bottom left: quantile–quantile plot of standardised residuals. Top right: fitted values versus standardised residuals. Bottom right: observed values versus fitted values.

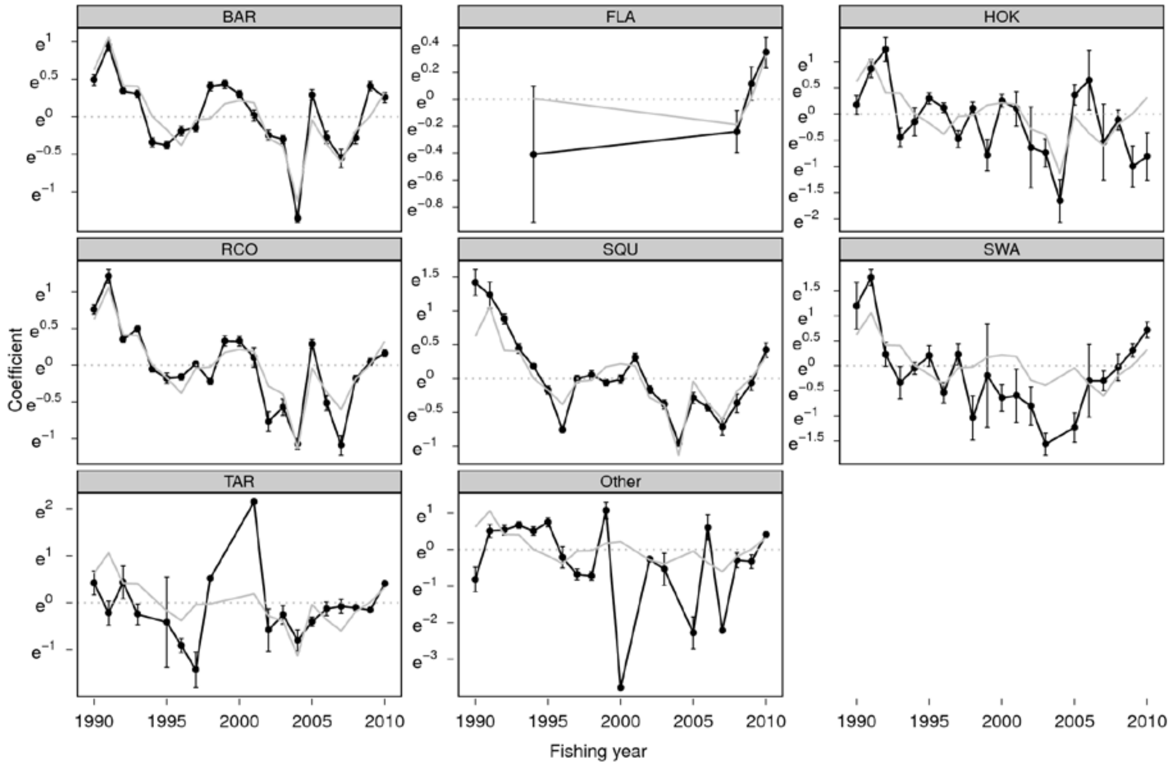

Figure E17: Residual implied coefficients for target × fishing year interactions. Implied coefficients (black points) are calculated as the normalised fishing year coefficient (grey line) plus the mean of the standardised residuals for each target in each fishing year. These values approximate the coefficients obtained when a target × year interaction term is fitted, particularly for those target × year combinations which have a substantial proportion of the records. The error bars indicate one standard error of the standardised residuals.

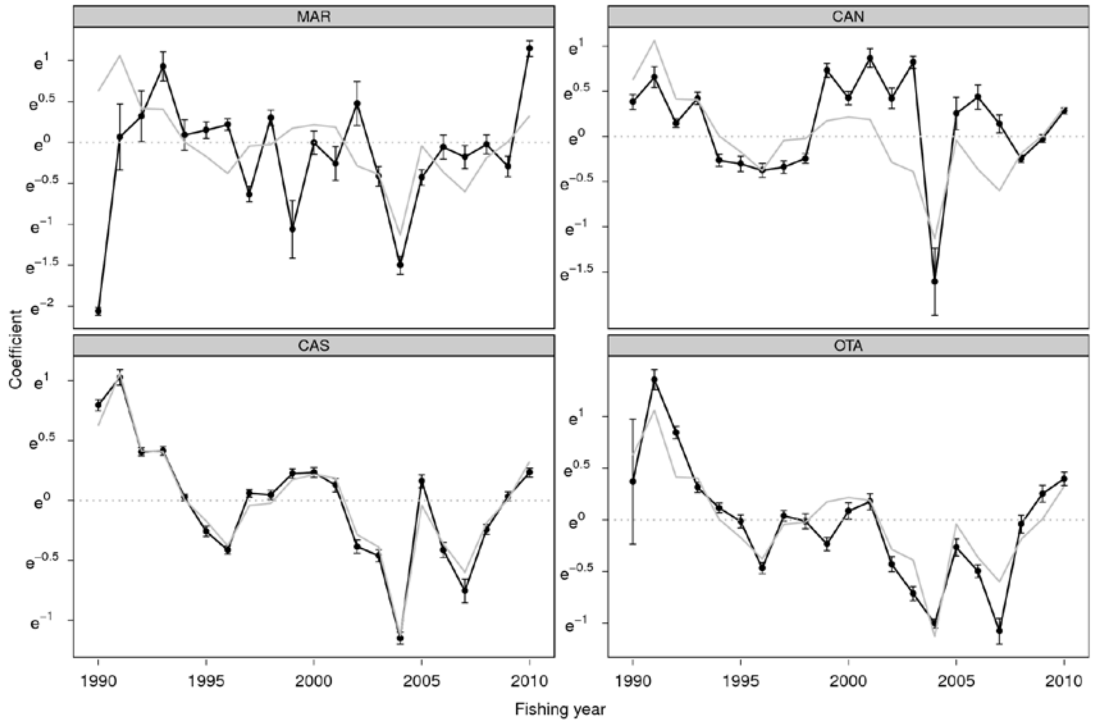

Figure E18: Residual implied coefficients for area × fishing year interactions. Implied coefficients (black points) are calculated as the normalised fishing year coefficient (grey line) plus the mean of the standardised residuals in each fishing year and area.

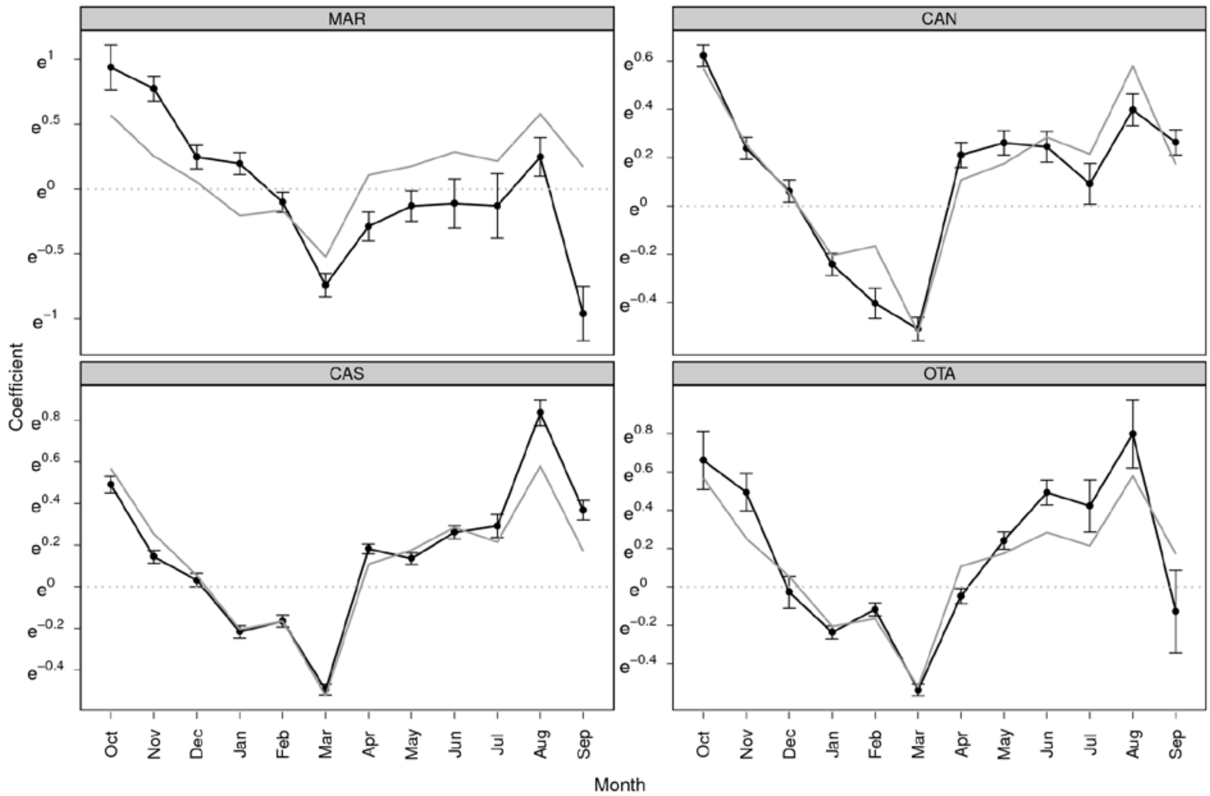

Figure E19: Residual implied coefficients for area × month interactions. Implied coefficients (black points) are calculated as the normalised month coefficients (grey line) plus the mean of the standardised residuals in each month and area.

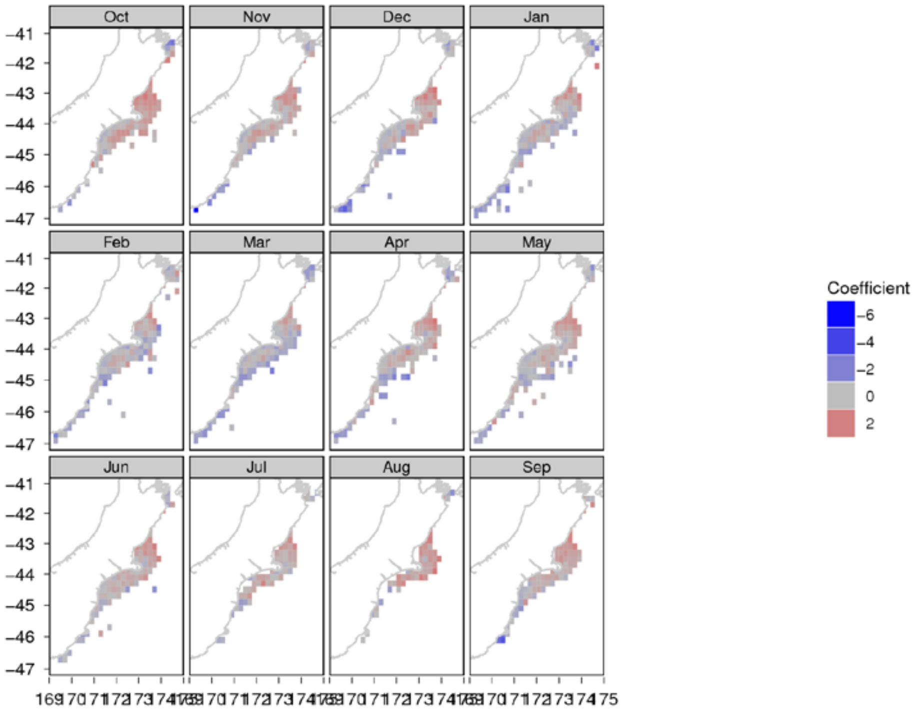

Figure E20: Residual implied coefficients for each position in each month. Implied coefficients are calculated as the sum of the normalised coefficients for any model terms relating to area and month (month, area and area × month terms) plus the mean of the standardised residual for position in each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

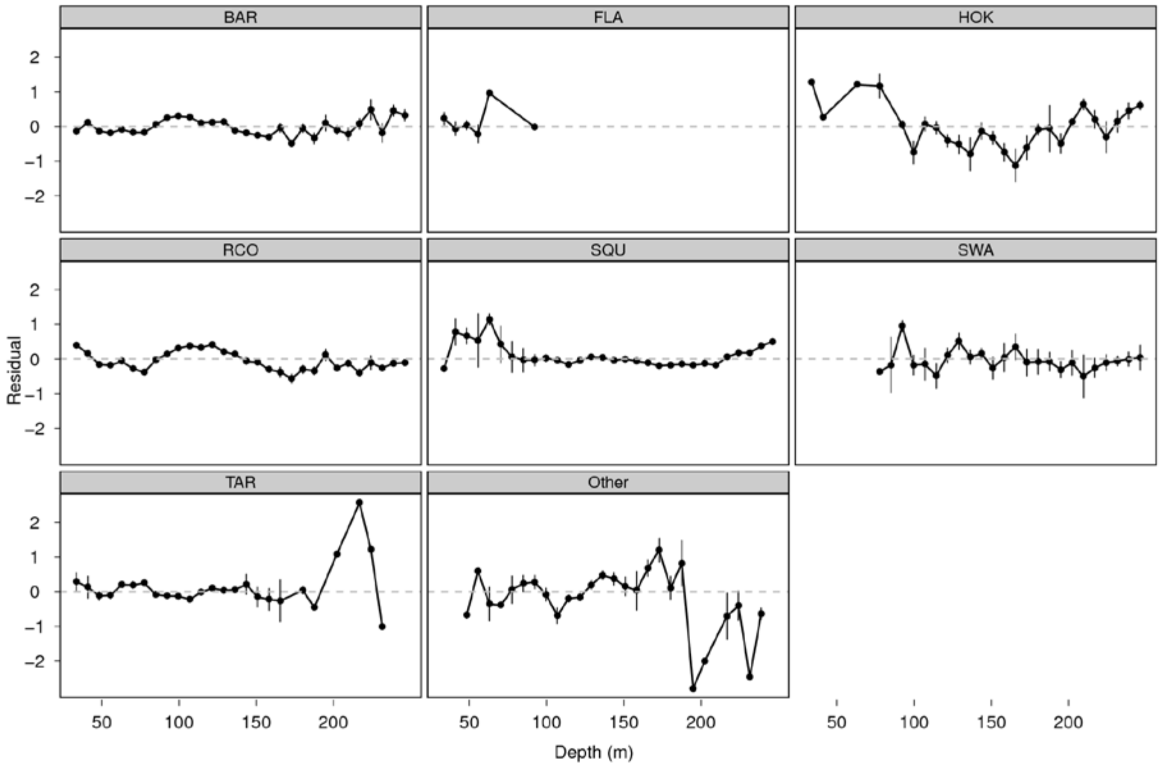

Figure E21: Mean and standard error of residuals by depth and target species.

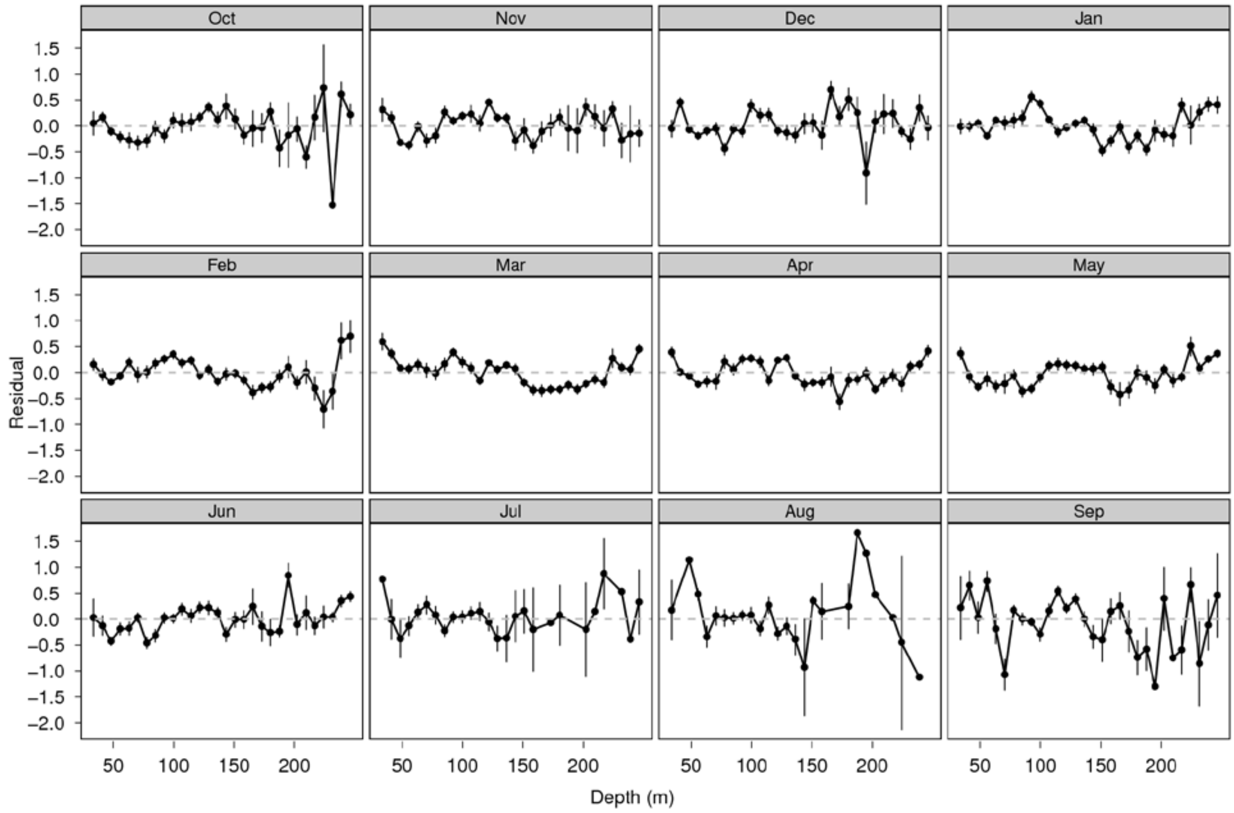

Figure E22: Mean and standard error of residuals by depth and month.

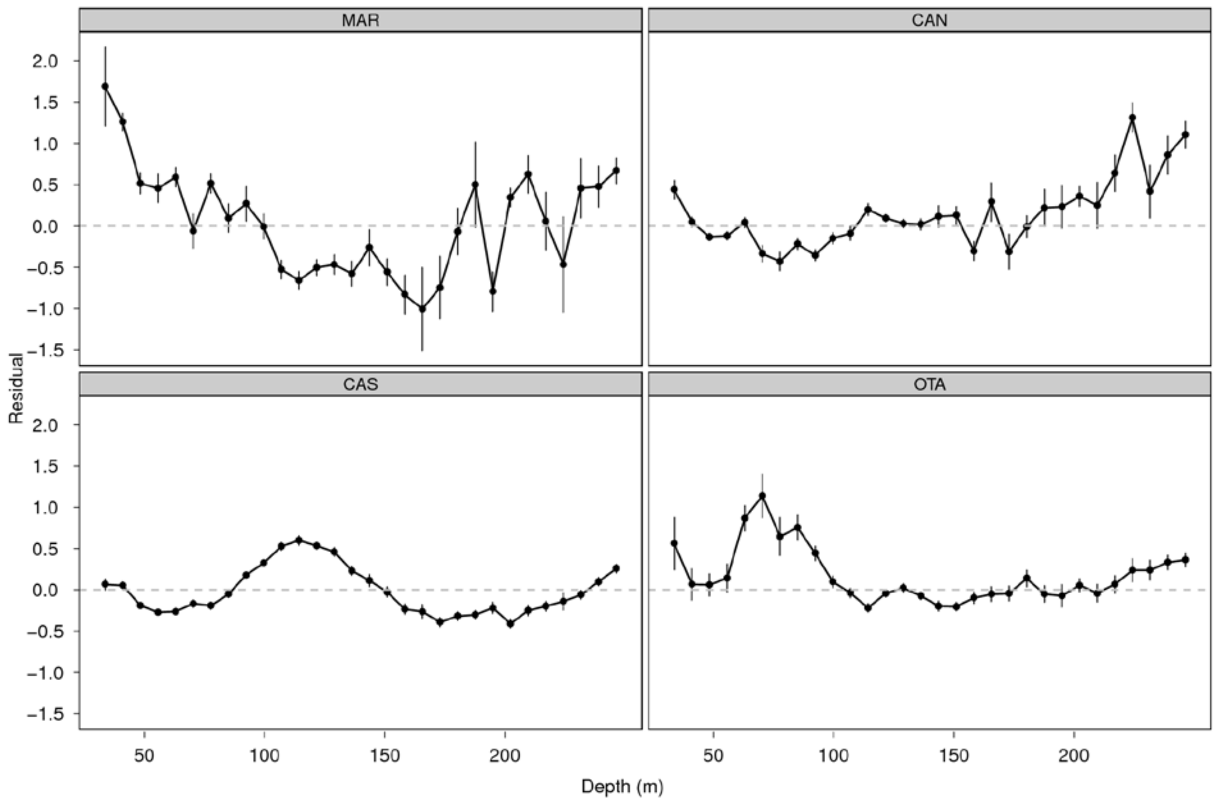

Figure E23: Mean and standard error of residuals by depth and area.

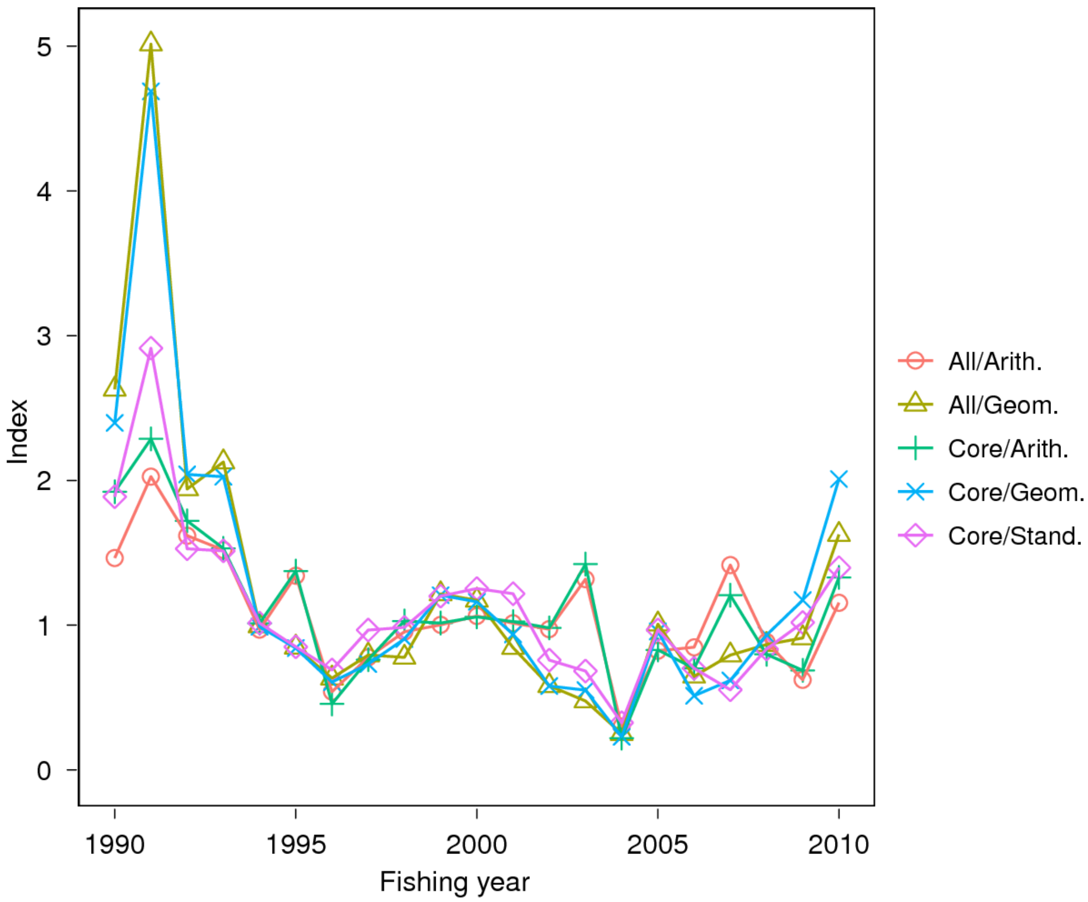

Figure E24: Standardised and unstandardised CPUE indices. All: all vessels, Core: core vessels, Geom.: geometric mean, Arith: arithmetic mean, Stand.: standardised using GLM.

Table E5: 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	1.4644	1.9215	2.6295	2.3972	1.8871	0.08648
1991	2.0261	2.2867	5.0135	4.6875	2.9134	0.09595
1992	1.6185	1.7204	1.9407	2.0414	1.5280	0.06116
1993	1.5194	1.5306	2.1272	2.0257	1.5133	0.05701
1994	0.9697	1.0131	0.9953	0.9902	1.0147	0.05615
1995	1.3419	1.3740	0.8474	0.8417	0.8507	0.06173
1996	0.5405	0.4563	0.6341	0.6071	0.6909	0.05498
1997	0.7782	0.7621	0.7938	0.7320	0.9664	0.05648
1998	0.9546	1.0291	0.7778	0.9053	0.9849	0.05441
1999	1.0024	1.0149	1.2159	1.2071	1.2007	0.06589
2000	1.0635	1.0574	1.1719	1.1616	1.2532	0.06448
2001	1.0142	1.0245	0.8448	0.9368	1.2175	0.07116
2002	0.9723	0.9814	0.5819	0.5800	0.7587	0.06769
2003	1.3177	1.4223	0.4766	0.5514	0.6835	0.06536
2004	0.3012	0.2202	0.2510	0.2292	0.3260	0.06949
2005	0.8228	0.8293	1.0073	0.9573	0.9676	0.08294
2006	0.8477	0.7020	0.6470	0.5126	0.7019	0.08766
2007	1.4153	1.2069	0.7935	0.6184	0.5540	0.11224
2008	0.8851	0.7989	0.8665	0.9317	0.8358	0.07153
2009	0.6229	0.6879	0.9116	1.1732	1.0186	0.07797
2010	1.1553	1.3301	1.6260	2.0095	1.3968	0.07507

16. APPENDIX F: CPUE FOR CHATHAM RISE USING TOWS TARGETTING VARIOUS SPECIES

16.1 Data subset and processing

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

- form was among the set ("TCP", "TCE")
- method was equal to "BT"
- target was among the set ("HOK", "BAR", "TAR", "RCO", "FLA", "SPE", "LIN", "SQU", "HAK", "SCI", "SWA")
- area was among the set ("CRW", "CRN", "CRS", "CRE")
- depth was 250–1200 m
- bottom was 250–1200 m
- height was 1–100 m
- width was 10–200 m
- speed was 2–7 m
- duration was less than 15hrs

Table F1 summarises the number of fishing events, vessels, trips, effort and catch in the resultant dataset. The minimum number of vessels was 29 in 1990. The percentage of poisitive catches ranged from 26% to 58%.

Table F1: Summary by fishing year of the data subset used for this analysis.

Fishing year	Vessels	Trips	Events	Effort (num)	Effort (hrs)	Catch (t)	Events with catch (landed,%)
1990	29	74	1 739	1 739	6 902	97.48	37.67
1991	37	109	3 125	3 125	13 094	191.33	36.29
1992	46	150	5 772	5 772	23 709	379.61	27.72
1993	38	132	5 424	5 424	22 601	289.04	30.66
1994	38	111	3 383	3 383	14 562	135.73	26.46
1995	47	155	5 753	5 753	23 160	320.25	51.71
1996	55	187	4 708	4 708	21 214	338.29	40.40
1997	64	195	5 379	5 379	22 140	253.80	40.53
1998	62	210	7 472	7 472	31 828	733.83	42.76
1999	53	192	9 108	9 108	38 374	902.91	47.29
2000	43	160	6 913	6 913	30 911	788.15	42.08
2001	46	179	8 137	8 137	37 479	894.45	38.29
2002	41	132	7 205	7 205	34 170	918.49	41.39
2003	49	167	8 446	8 446	40 953	1 732.62	50.11
2004	46	135	6 493	6 493	35 177	1 259.61	44.25
2005	37	135	5 932	5 932	33 374	732.32	55.04
2006	37	129	5 439	5 439	30 751	493.40	46.68
2007	31	146	6 210	6 210	37 238	622.47	57.50
2008	29	135	5 504	5 504	33 868	648.94	50.18
2009	29	108	4 070	4 070	24 140	386.20	41.52
2010	31	113	4 231	4 231	23 811	369.68	36.54

16.2 Core vessel selection

Alternative core vessel selection criteria were investigated by considering the reduction in the number of vessels and percentage of catch (Figure F1). 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 five years. To qualify, trips were required to have recorded at least 1 kg of catch. These criteria resulted in a core fleet size of 36 vessels which took 80% of the catch (Figure F1). A histogram of the number of years in which each core vessel had data in the dataset is provided (Figure F2) as is the overlap of data among core vessels (Figure F3).

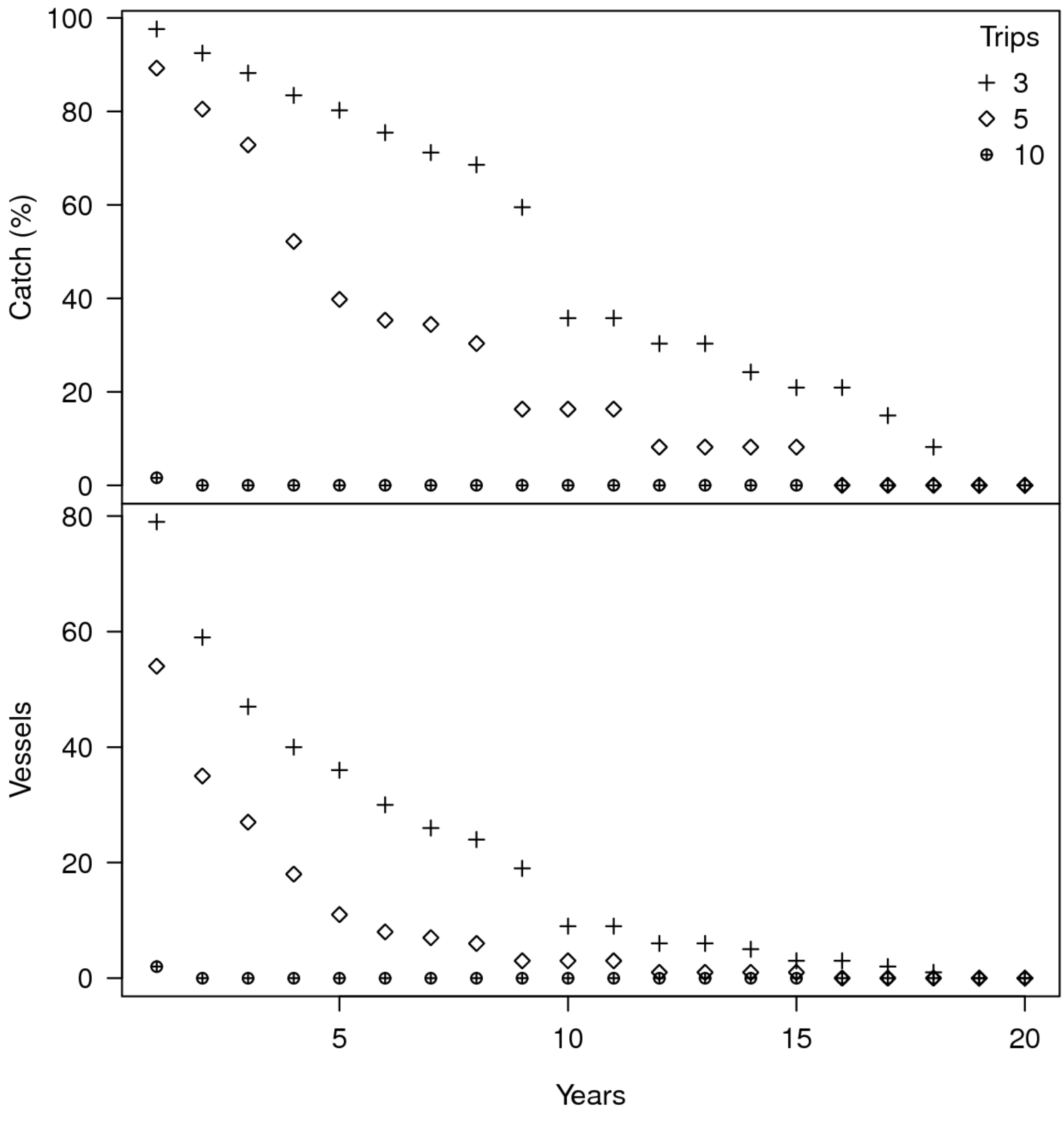

Figure F1: Examination of parameters for defining core vessels.

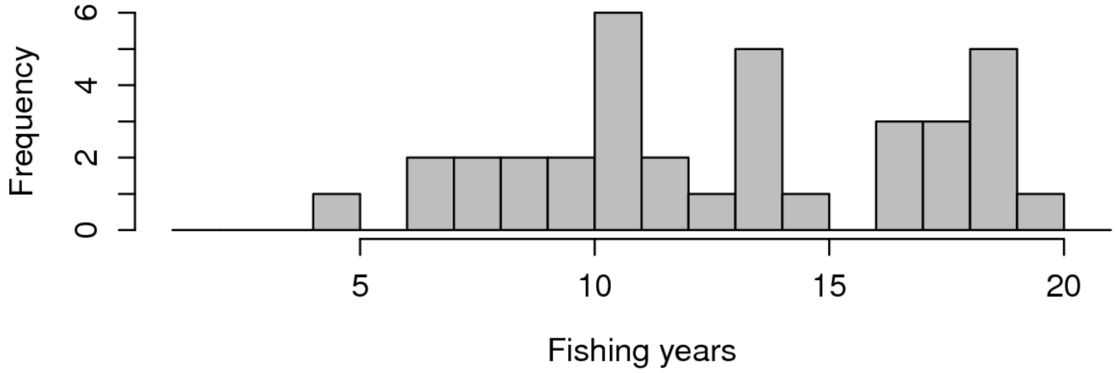

Figure F2: Histogram of the number of years with data for each core vessel.

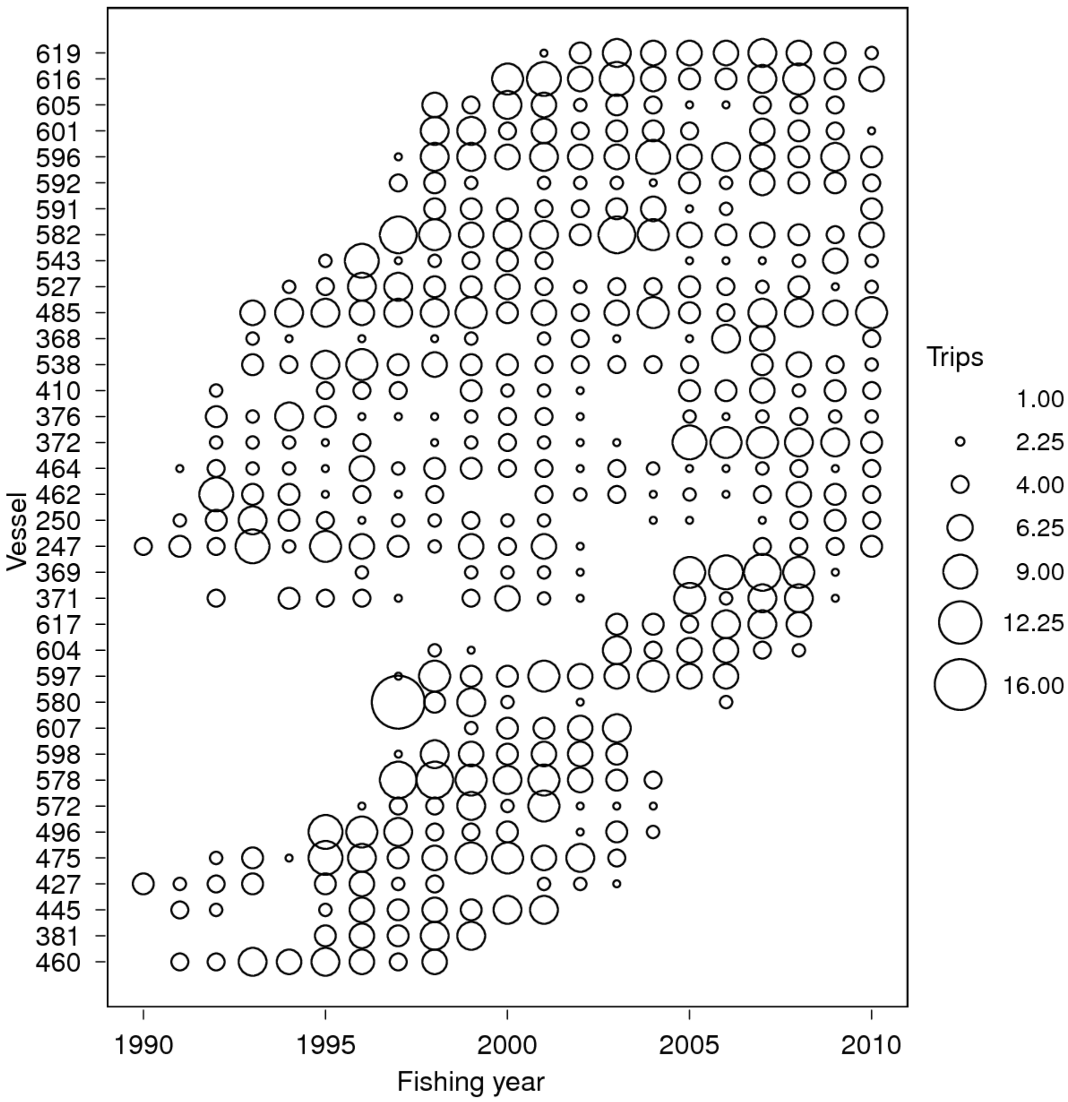

Figure F3: Number of trips by fishing year for core vessels. Area of circles is proportional to the proportion of records over all fishing years and vessel.

Table F2: Summary of core vessel data by fishing year.

Fishing year	Vessels	Trips	Events	Effort (num)	Effort(hrs)	Catch (t)	Trips with catch (%)	Strata with catch (%)
1990	2	9	157	157	809.8	13.80	66.67	32.48
1991	7	22	755	755	3 025.2	13.24	54.55	22.78
1992	13	52	1 890	1 890	7 941.7	38.85	44.23	10.90
1993	13	62	2 437	2 437	10 358.6	66.12	51.61	21.91
1994	16	58	1 834	1 834	8 091.2	47.85	58.62	26.17
1995	19	90	3 844	3 844	14 635.7	175.16	84.44	55.41
1996	23	108	3 076	3 076	13 551.3	209.29	76.85	45.16
1997	32	128	4 143	4 143	16 480.8	182.21	70.31	43.42
1998	33	154	6 474	6 474	26 662.7	547.01	77.92	41.92
1999	32	153	8 096	8 096	34 051.0	826.18	84.97	47.75
2000	29	139	6 582	6 582	29 349.2	767.53	90.65	42.94
2001	33	152	7 500	7 500	34 671.7	802.75	88.82	37.36
2002	31	110	6 481	6 481	30 752.0	804.27	91.82	38.50
2003	32	131	7 305	7 305	35 293.3	1 517.35	90.08	49.09
2004	31	106	5 658	5 658	30 492.6	1 136.85	97.17	44.15
2005	25	110	5 440	5 440	30 756.8	649.39	90.91	54.72
2006	24	103	4 724	4 724	27 197.1	429.05	94.17	46.89
2007	23	123	5 447	5 447	33 241.9	546.48	87.80	58.47
2008	22	115	4 998	4 998	30 676.0	563.39	91.30	48.44
2009	21	88	3 652	3 652	21 181.4	328.36	93.18	41.16
2010	20	82	3 665	3 665	19 996.4	357.47	91.46	37.19

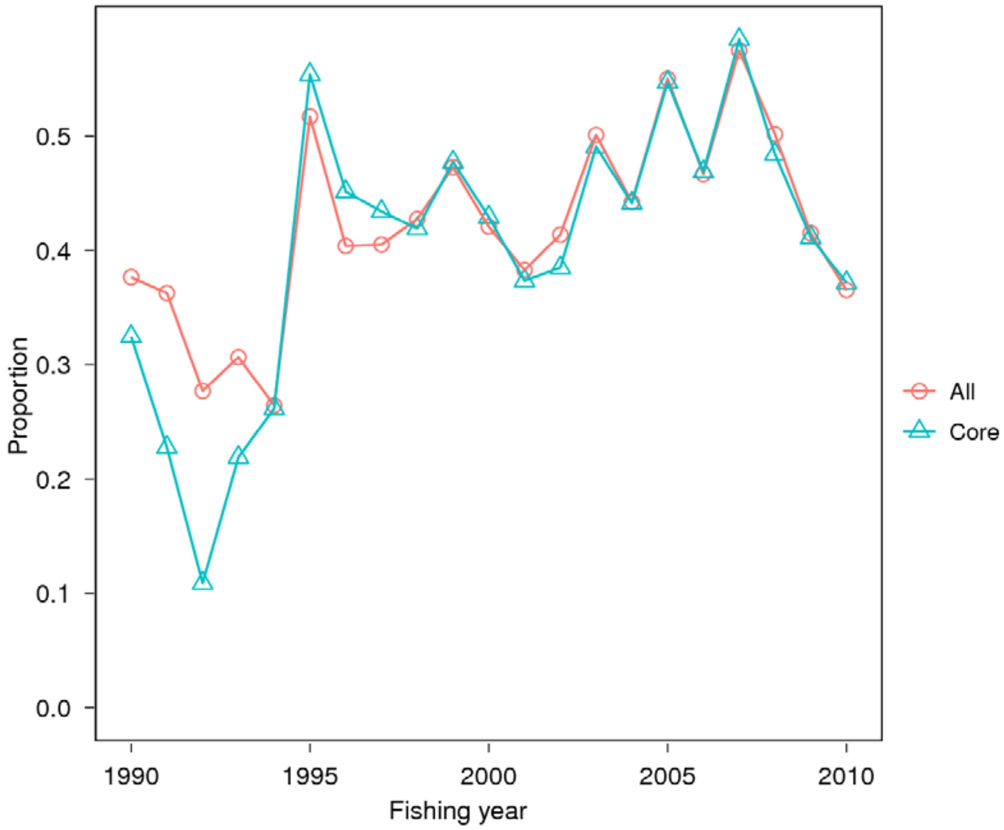

Figure F4: Proportion of positive catches for the entire dataset (All) and core vessels (Core).

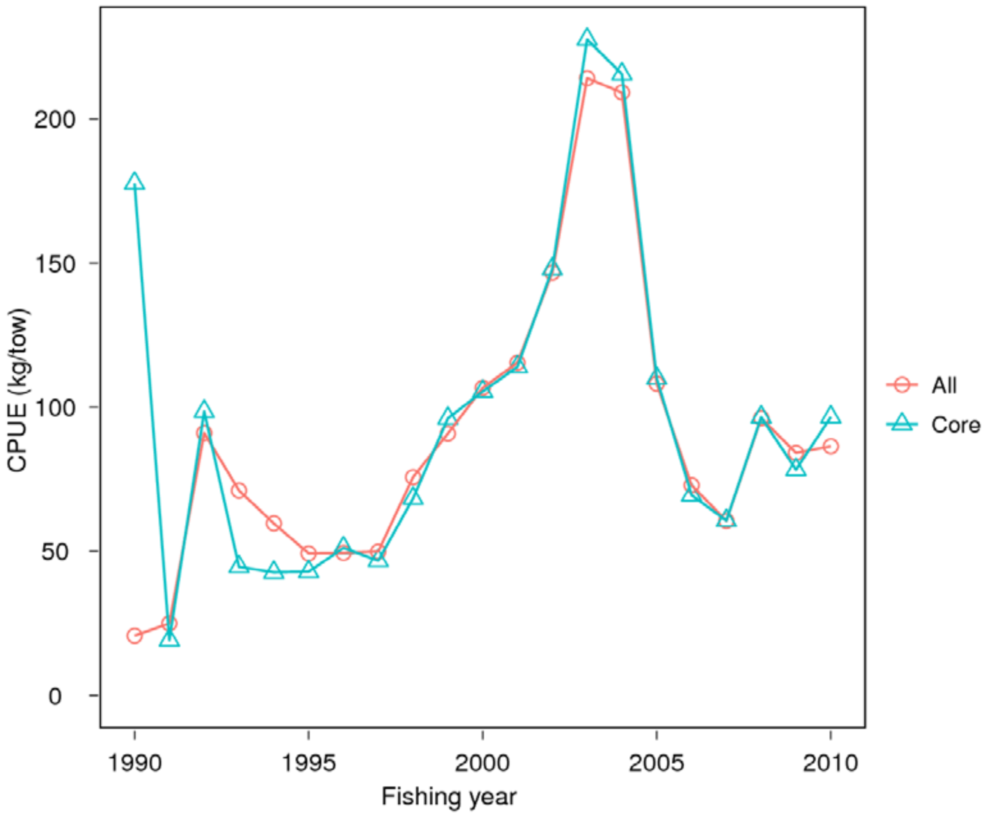

Figure F5: Unstandardised CPUE (geometric mean of positive catches) for the entire dataset (All) and core vessels (Core).

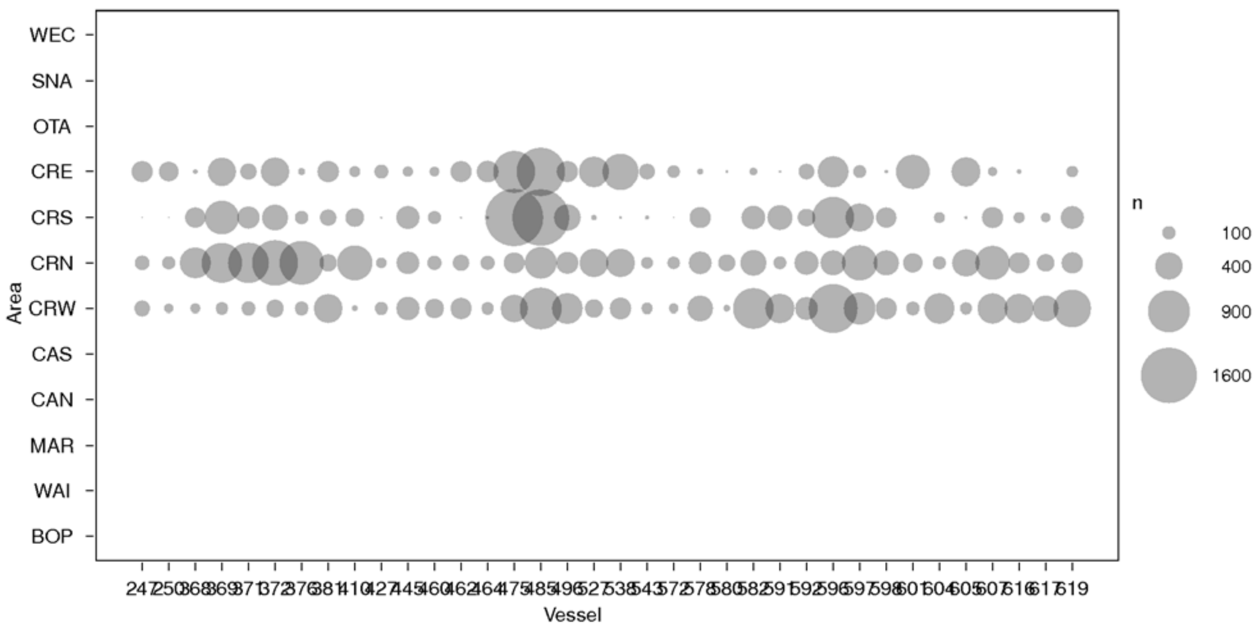

Figure F6: Number of tows by area for each core vessel over all years, 1989–90 to 2009–10.

16.3 Selection of appropriate error distribution

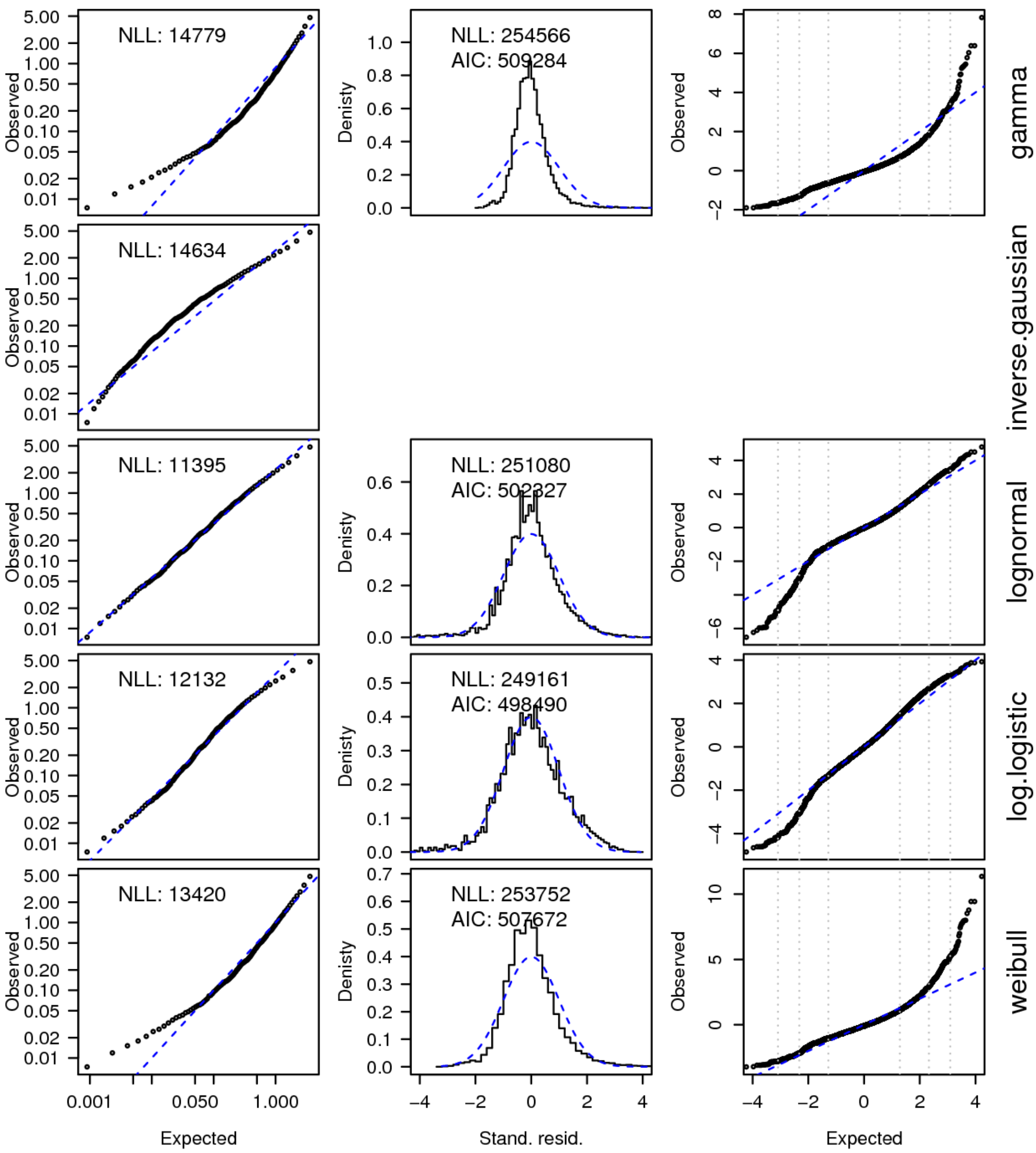

Figure F7: Diagnostics for alternative distributional assumptions for catch. Left: quantile–quantile plot of observed catches (centred (by mean) and scaled (by standard deviation) in log space) versus maximum likelihood fit of distribution (missing panel indicates that the fit failed to converge); Middle: standardised residuals from a generalised linear model fitted using the formula catch ~ fyear + month + area + target + 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.

16.4 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 + target + poly(log(duration), 3) + poly(log(height), 3) + poly(log(width), 3) + poly(log(speed), 3) + poly(log(depth), 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 F3 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 + area + poly(log(depth), 3) + poly(log(duration), 3) + target + month + poly(log(height), 3)

Table F3: 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	–259 171	518 386	13.40	*
vessel	57	–254 402	508 918	31.29	*
area	68	–249 499	499 135	45.84	*
poly(log(depth), 3)	71	–248 835	497 812	47.56	*
poly(log(duration), 3)	74	–248 599	497 346	48.16	*
target	79	–248 417	496 992	48.61	*
month	90	–248 263	496 705	48.99	*
poly(log(height), 3)	93	–248 152	496 490	49.27	*
poly(log(width), 3)	96	–248 072	496 337	49.46	
poly(time, 3)	99	–248 042	496 281	49.54	
poly(log(speed), 3)	102	–248 027	496 258	49.58	
poly(moon, 3)	105	–248 014	496 238	49.61	

16.5 Influence of model terms on annual CPUE indices

Table F4: 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	–262 135	524 275	–	–	–
fyear	20	–259 171	518 386	11.15	13.40	–
vessel	35	–254 402	508 918	15.16	17.89	28.43
area	11	–249 499	499 135	12.76	14.55	5.77
poly(log(depth), 3)	3	–248 835	497 812	2.12	1.72	9.84
poly(log(duration), 3)	3	–248 599	497 346	0.70	0.60	5.81
target	5	–248 417	496 992	0.33	0.46	11.13
month	11	–248 263	496 705	0.31	0.38	1.89
poly(log(height), 3)	3	–248 152	496 490	0.19	0.27	11.20

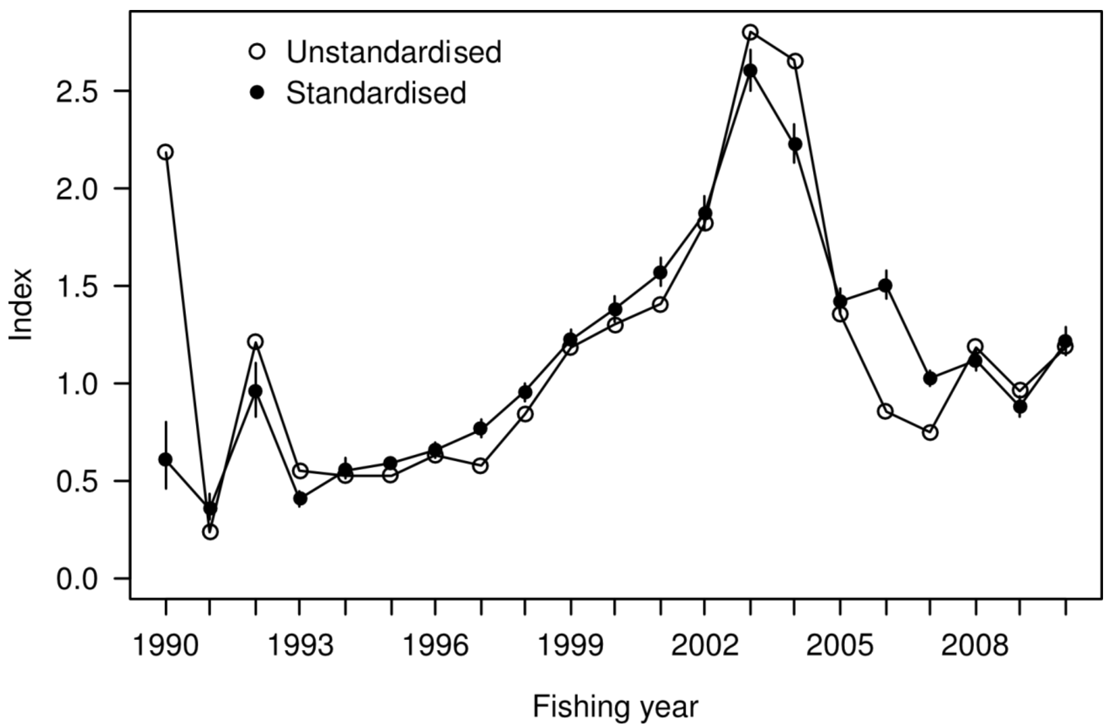

Figure F8: Overall standardisation effect of the model. The unstandardised index is based on the geometric mean of the catch per strata and is not adjusted for effort.

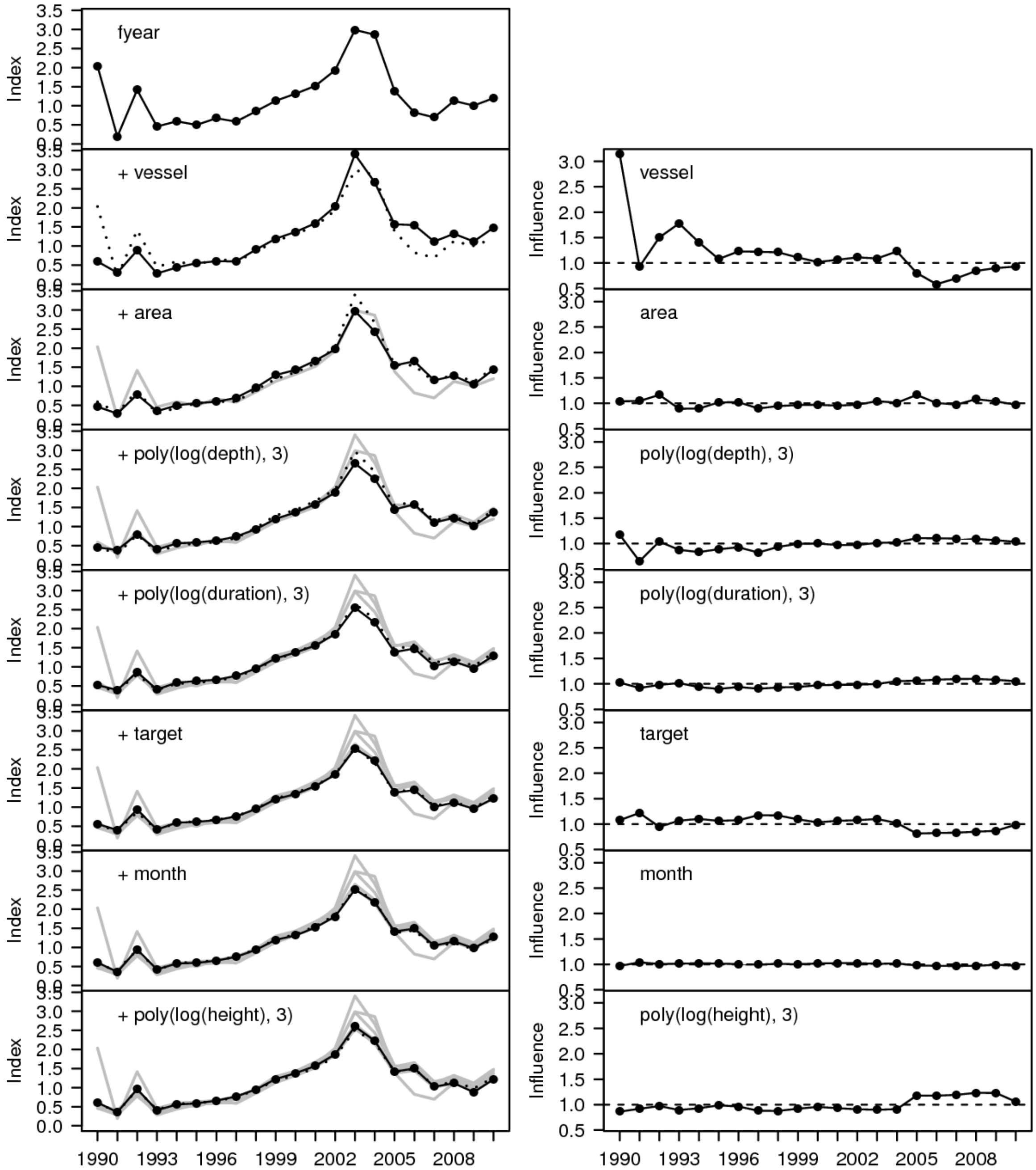

Figure F9: Effect on the standardised index of stepwise addition of model terms (left) and the annual influence of each model term in the final model (right).

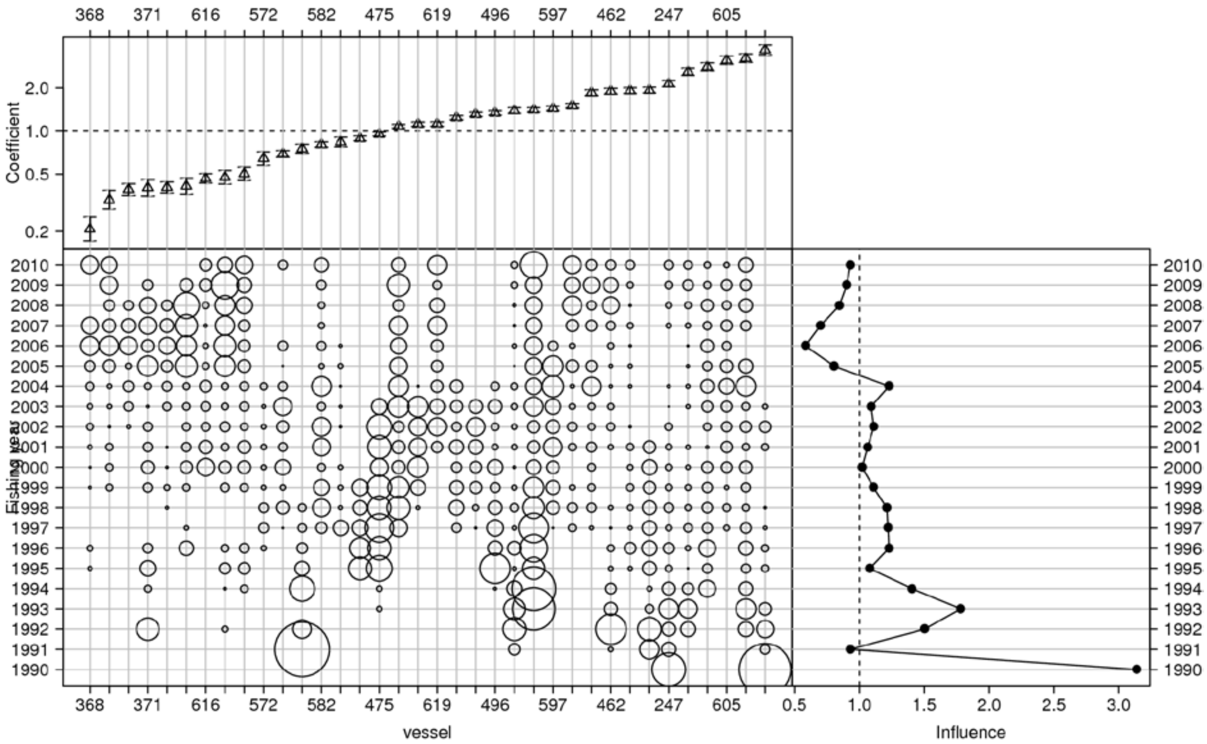

Figure F10: Coefficient–distribution–influence plot for *vessel*.

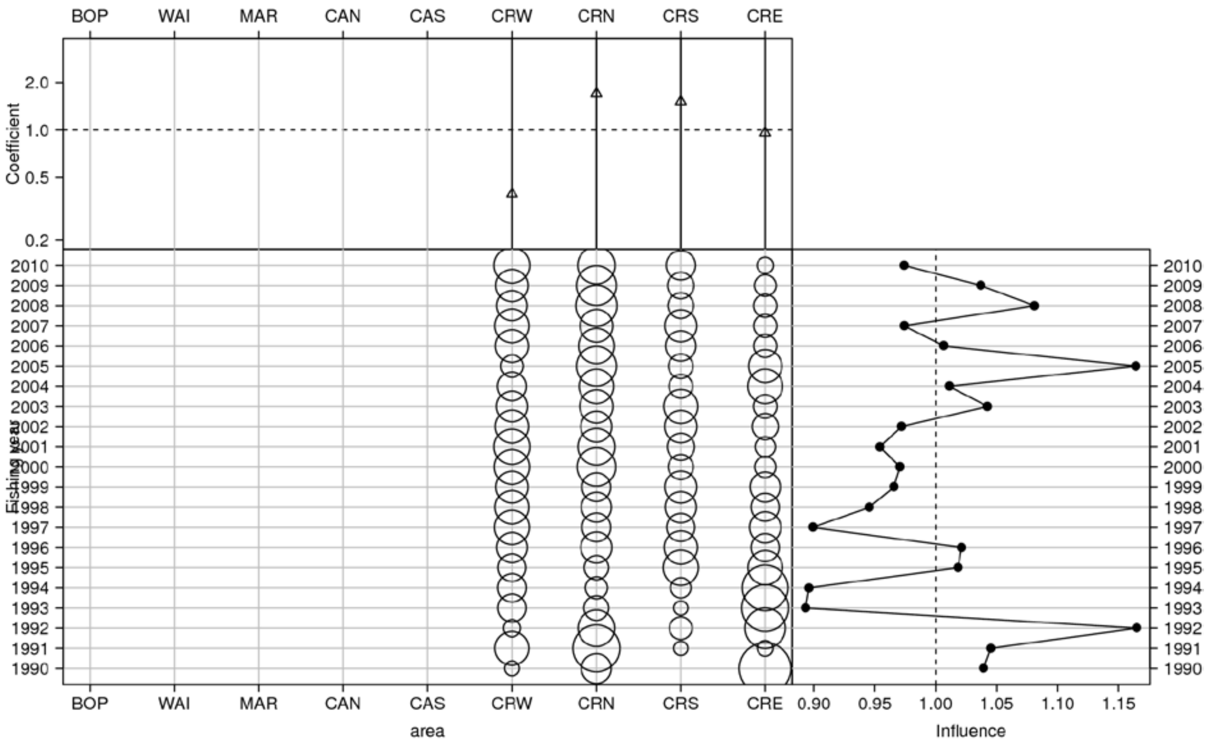

Figure F11: Coefficient–distribution–influence plot for *area*.

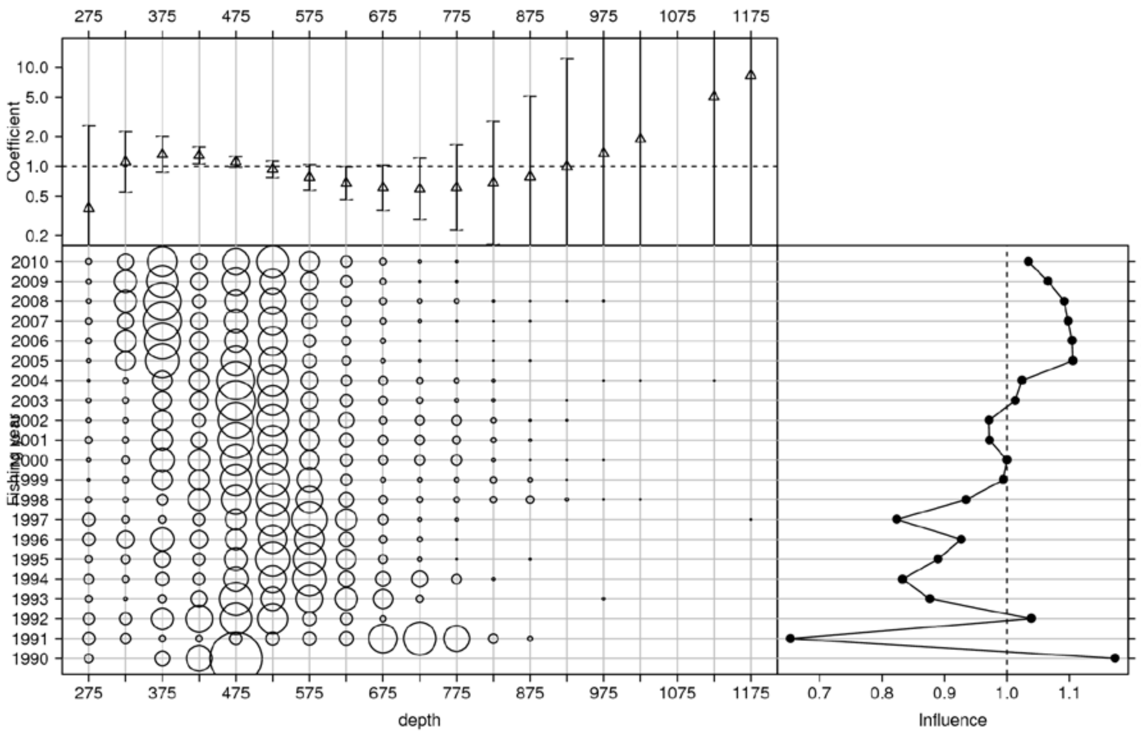

Figure F12: Coefficient–distribution–influence plot for *poly(log(depth), 3)*.

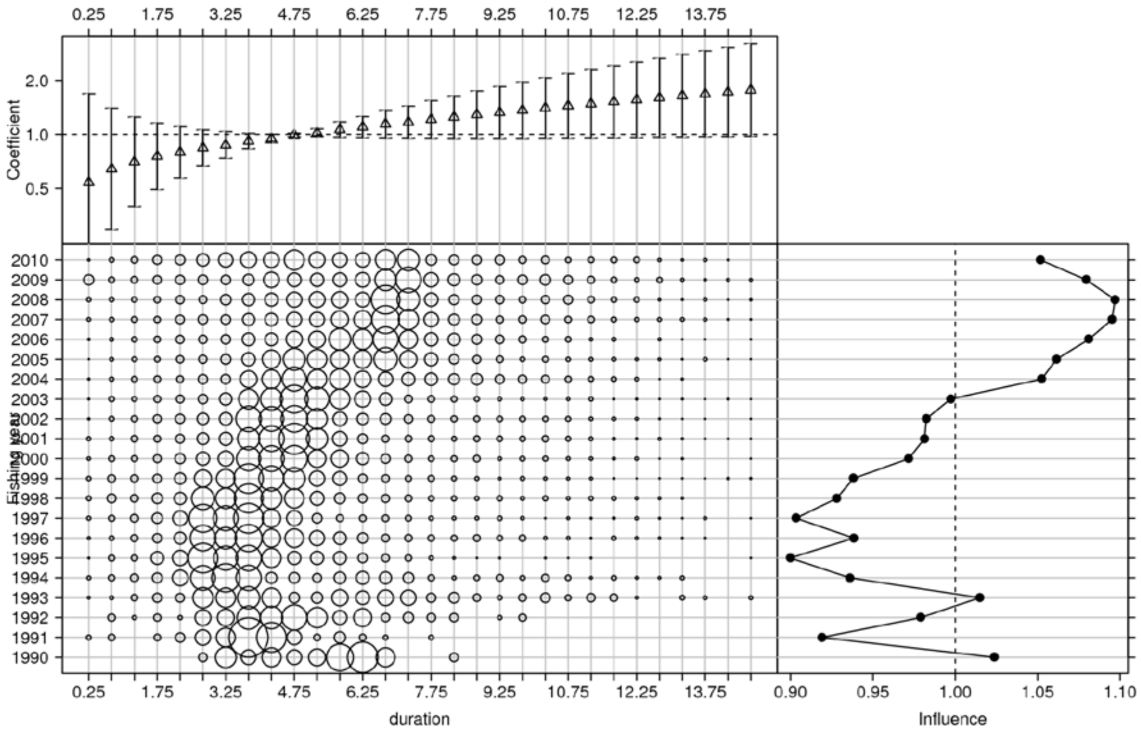

Figure F13: Coefficient–distribution–influence plot for *poly(log(duration), 3)*.

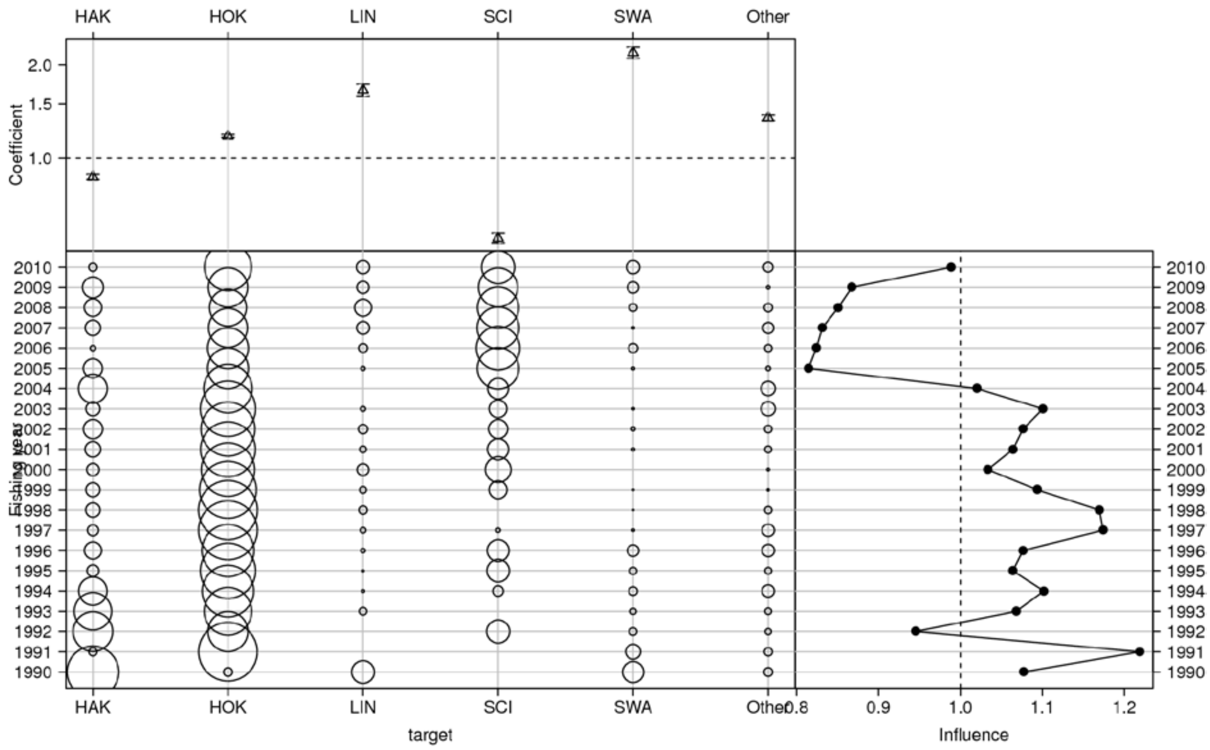

Figure F14: Coefficient–distribution–influence plot for *target*.

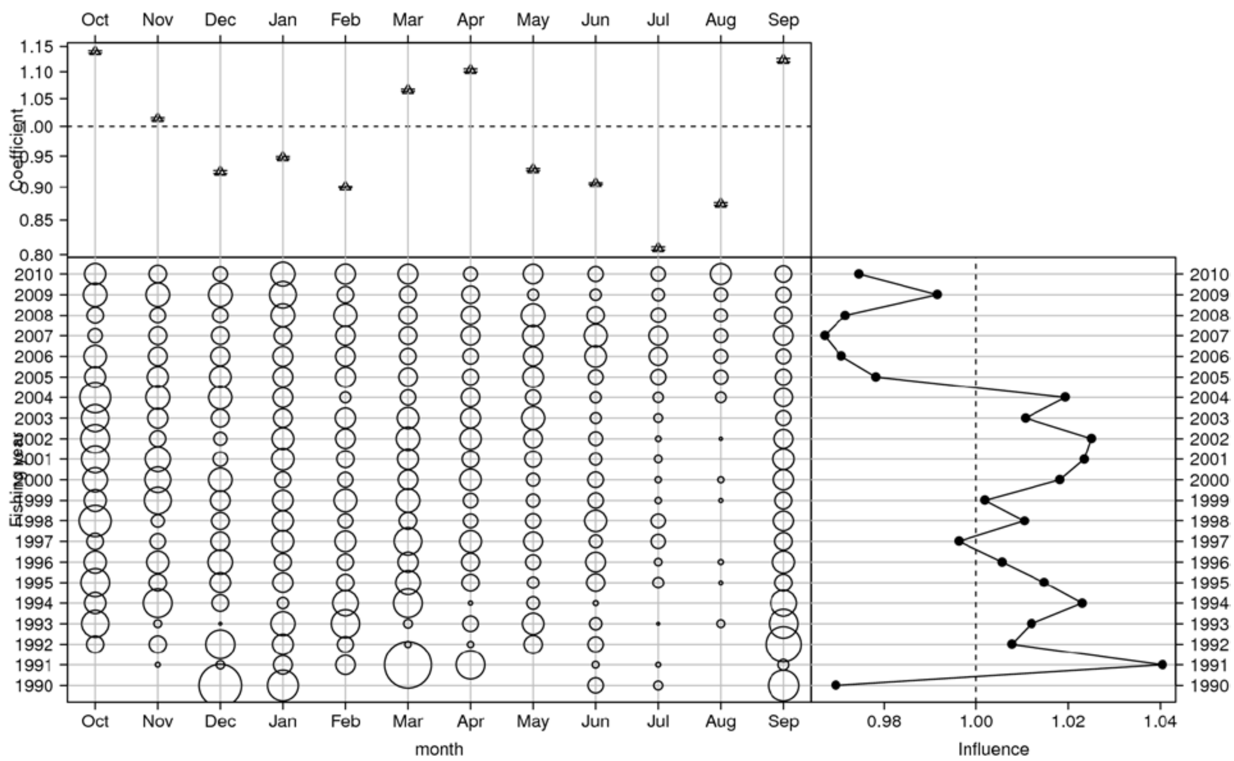

Figure F15: Coefficient–distribution–influence plot for *month*.

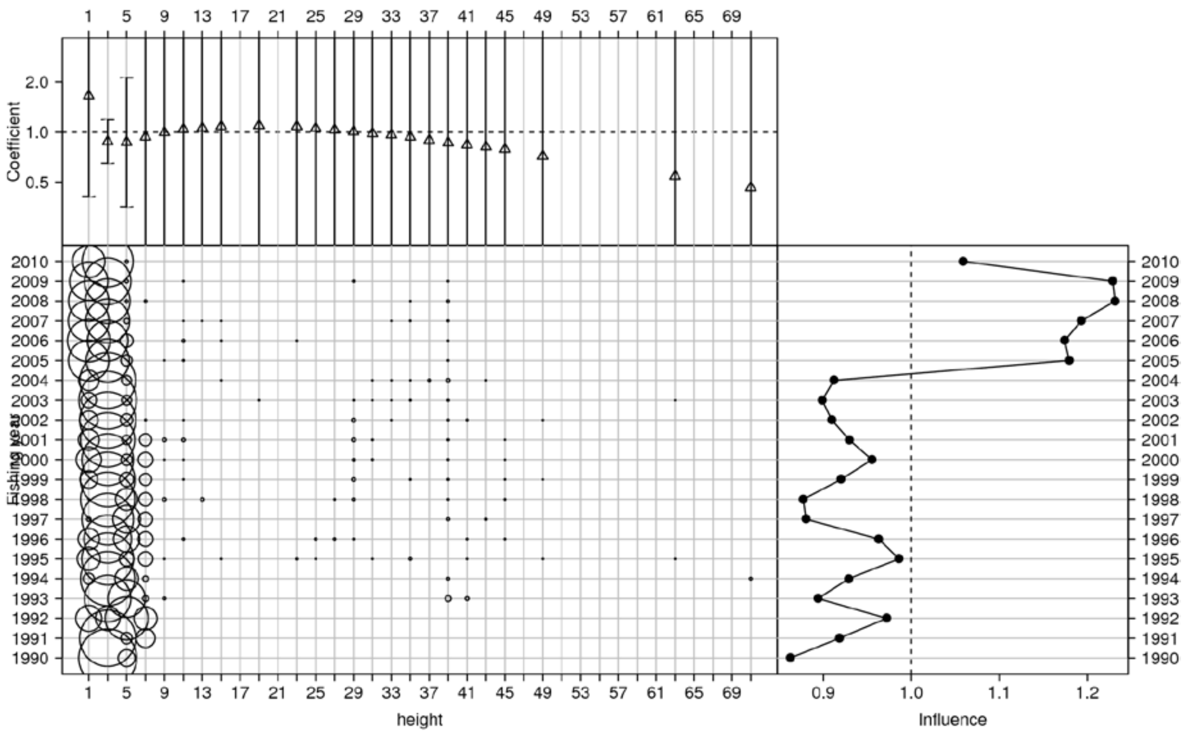

Figure F16: Coefficient–distribution–influence plot for *poly(log(height), 3)*.

16.6 Residual diagostics

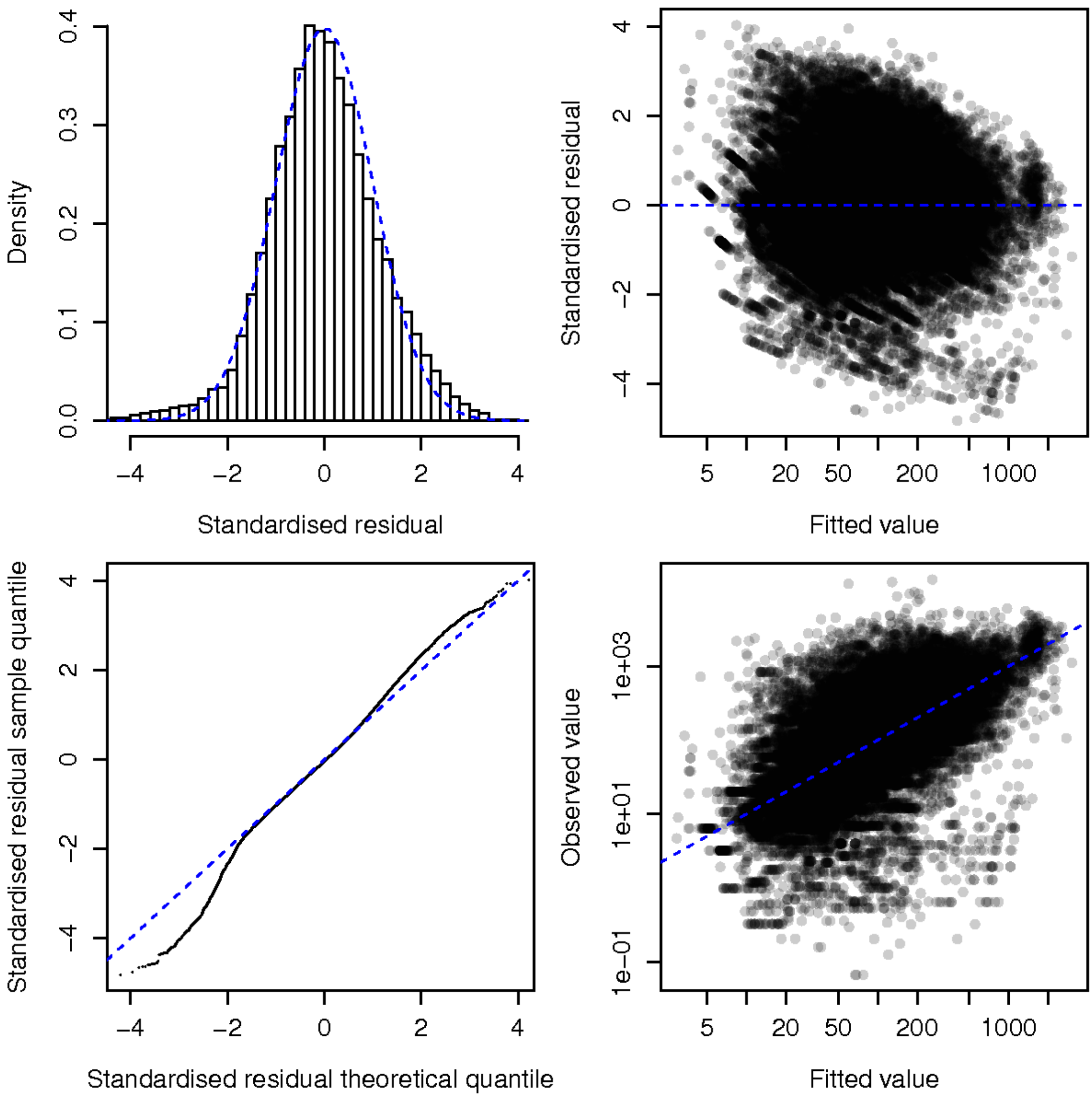

Figure F17: Residual diagnostics. Top left: histogram of standardised residuals compared to standard normal distribution. Bottom left: quantile–quantile plot of standardised residuals. Top right: fitted values versus standardised residuals. Bottom right: observed values versus fitted values.

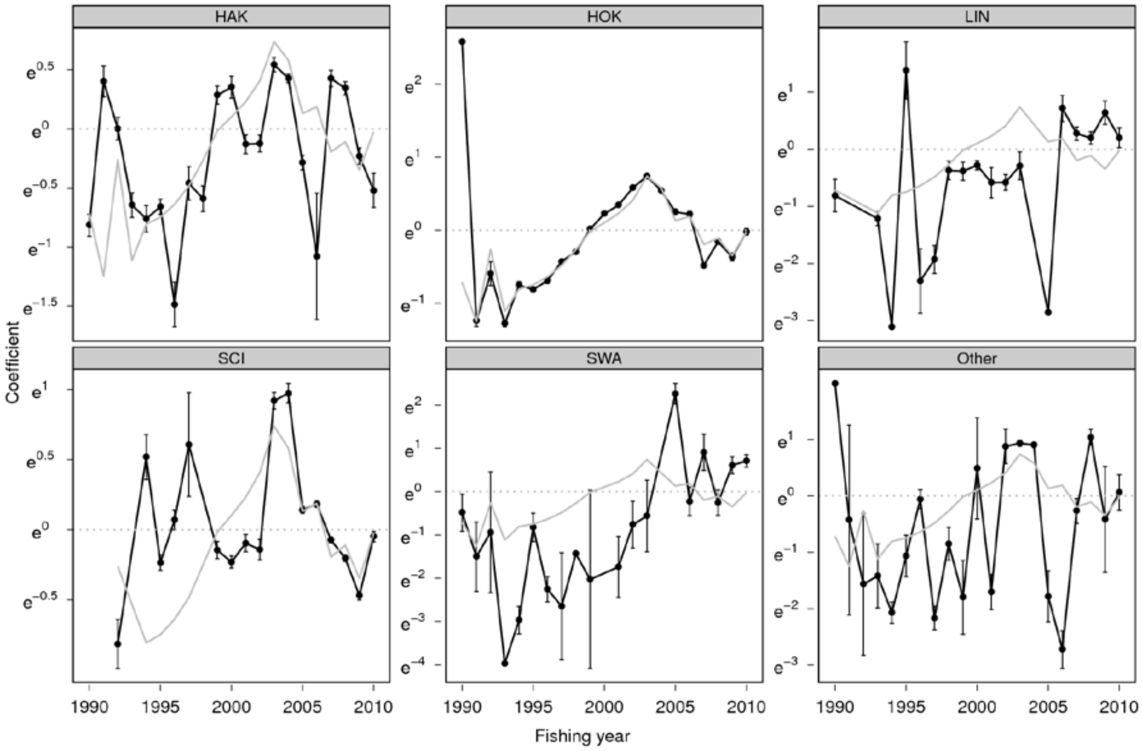

Figure F18: Residual implied coefficients for target × fishing year interactions. Implied coefficients (black points) are calculated as the normalised fishing year coefficient (grey line) plus the mean of the standardised residuals for each target in each fishing year. These values approximate the coefficients obtained when a target × year interaction term is fitted, particularly for those target × year combinations which have a substantial proportion of the records. The error bars indicate one standard error of the standardised residuals.

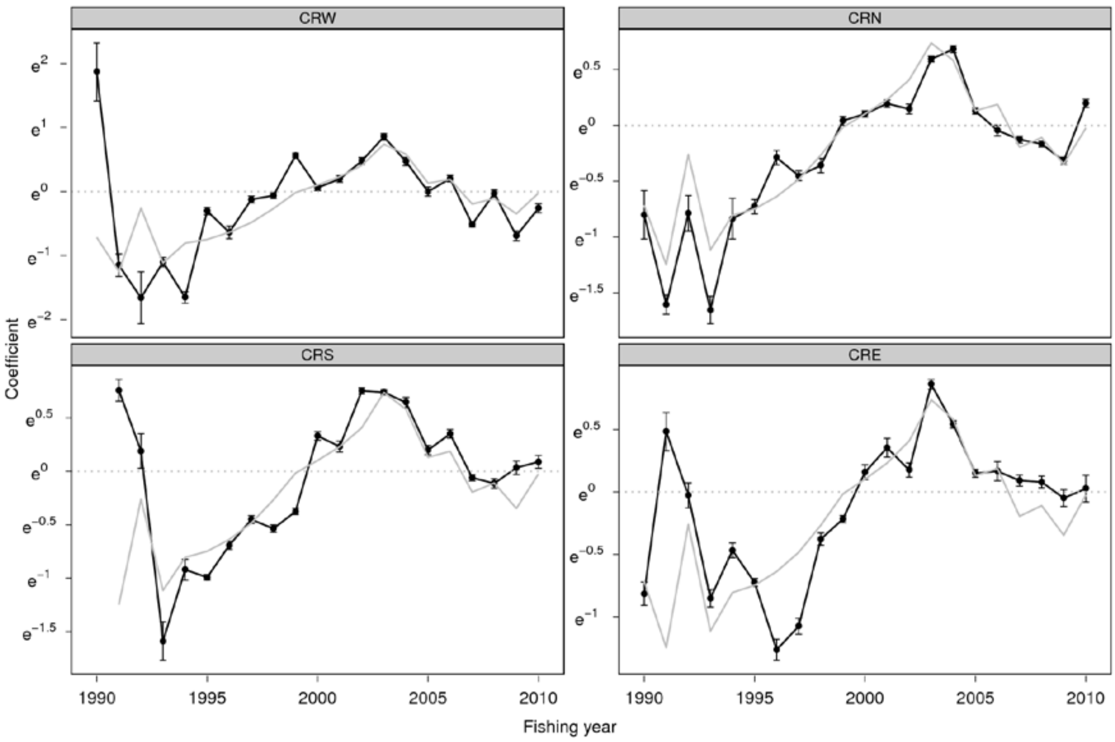

Figure F19: Residual implied coefficients for area × fishing year interactions. Implied coefficients (black points) are calculated as the normalised fishing year coefficient (grey line) plus the mean of the standardised residuals in each fishing year and area.

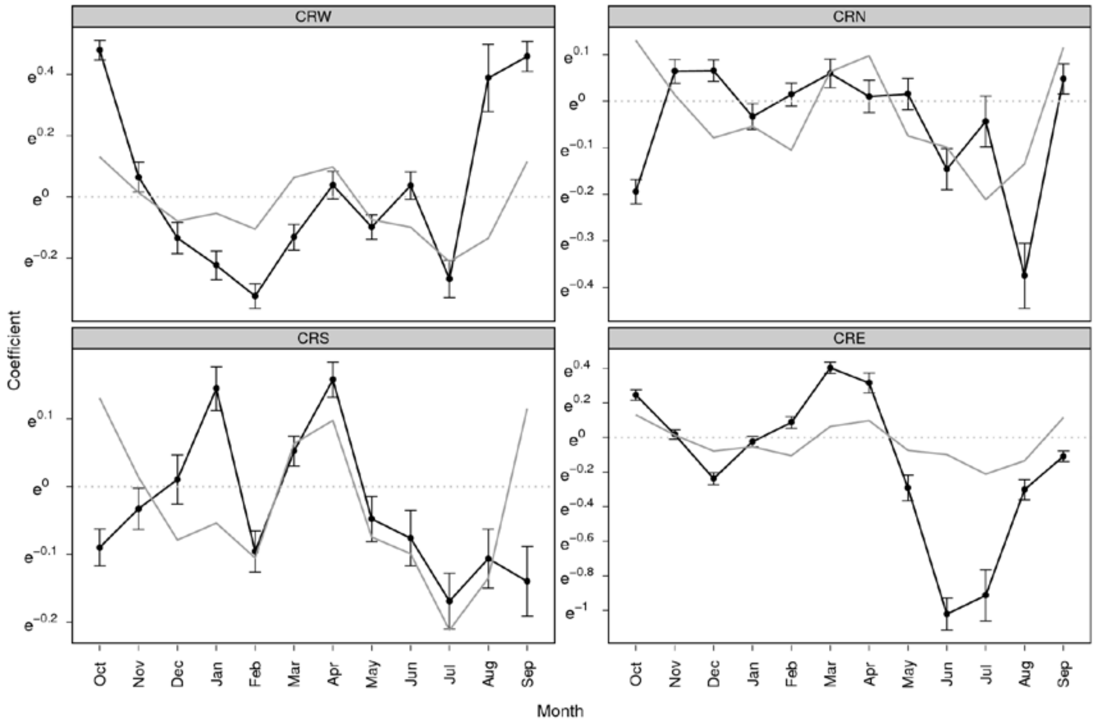

Figure F20: Residual implied coefficients for area × month interactions. Implied coefficients (black points) are calculated as the normalised month coefficients (grey line) plus the mean of the standardised residuals in each month and area.

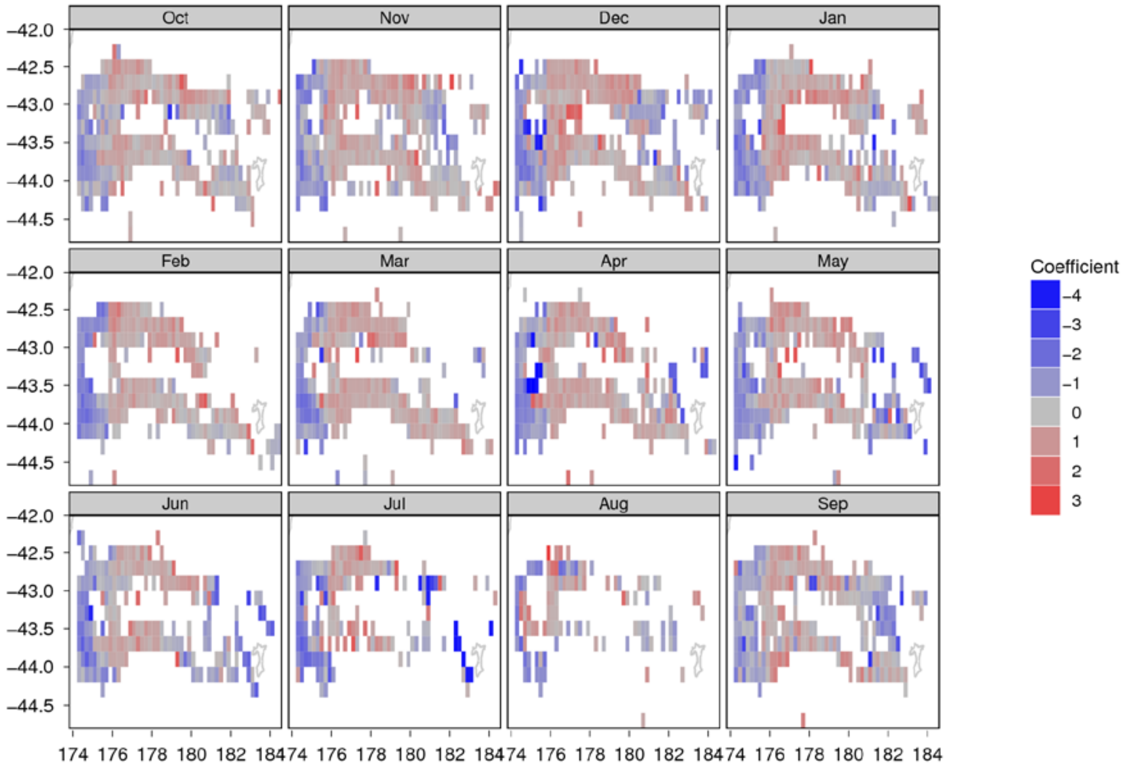

Figure F21: Residual implied coefficients for each position in each month. Implied coefficients are calculated as the sum of the normalised coefficients for any model terms relating to area and month (month, area and area × month terms) plus the mean of the standardised residual for position in each month. This plot is intended to show what the combination of model fit and residuals imply about seasonality in local catch rates.

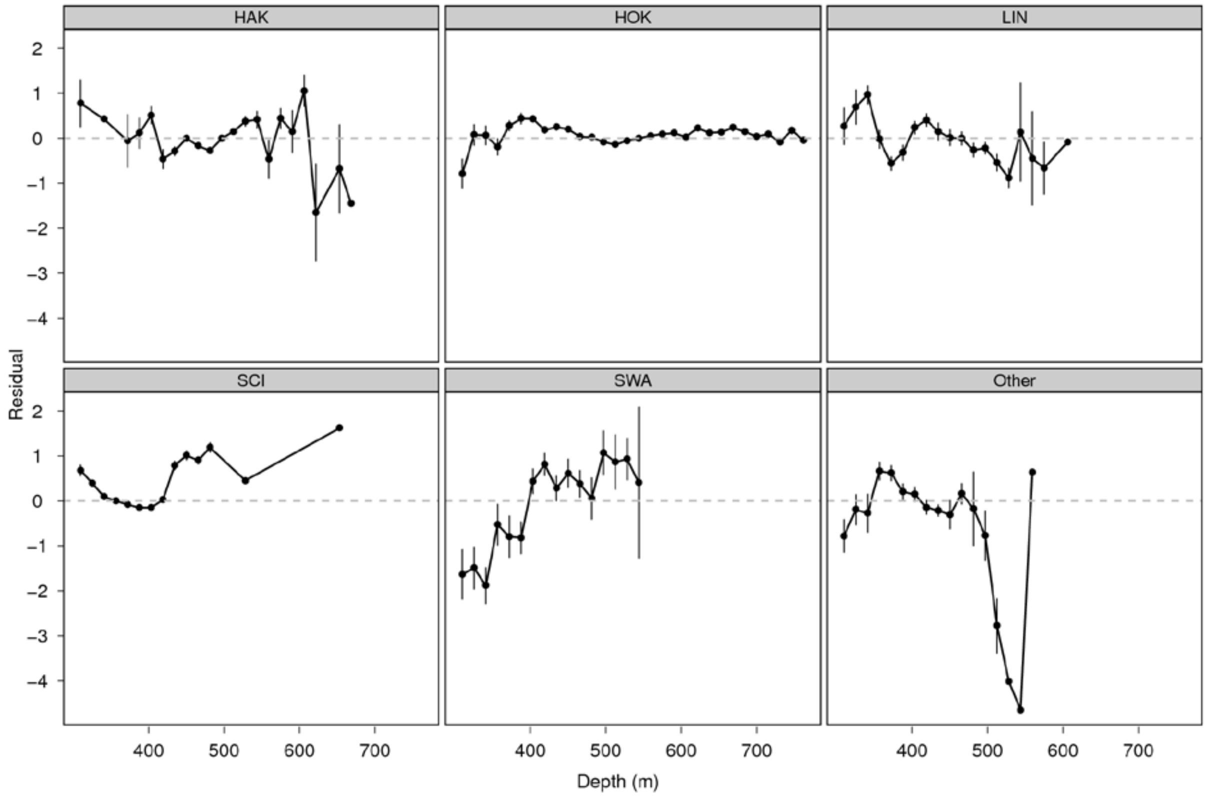

Figure F22: Mean and standard error of residuals by depth and target species.

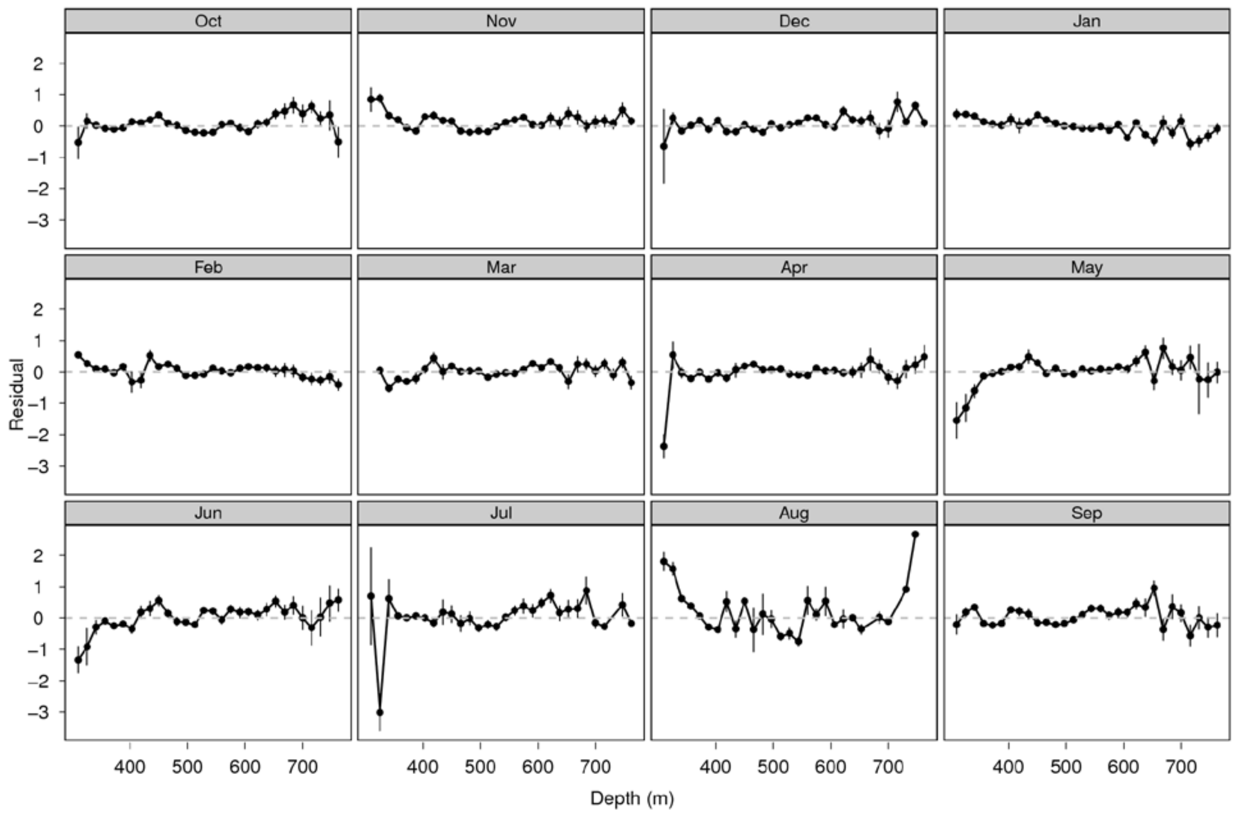

Figure F23: Mean and standard error of residuals by depth and month.

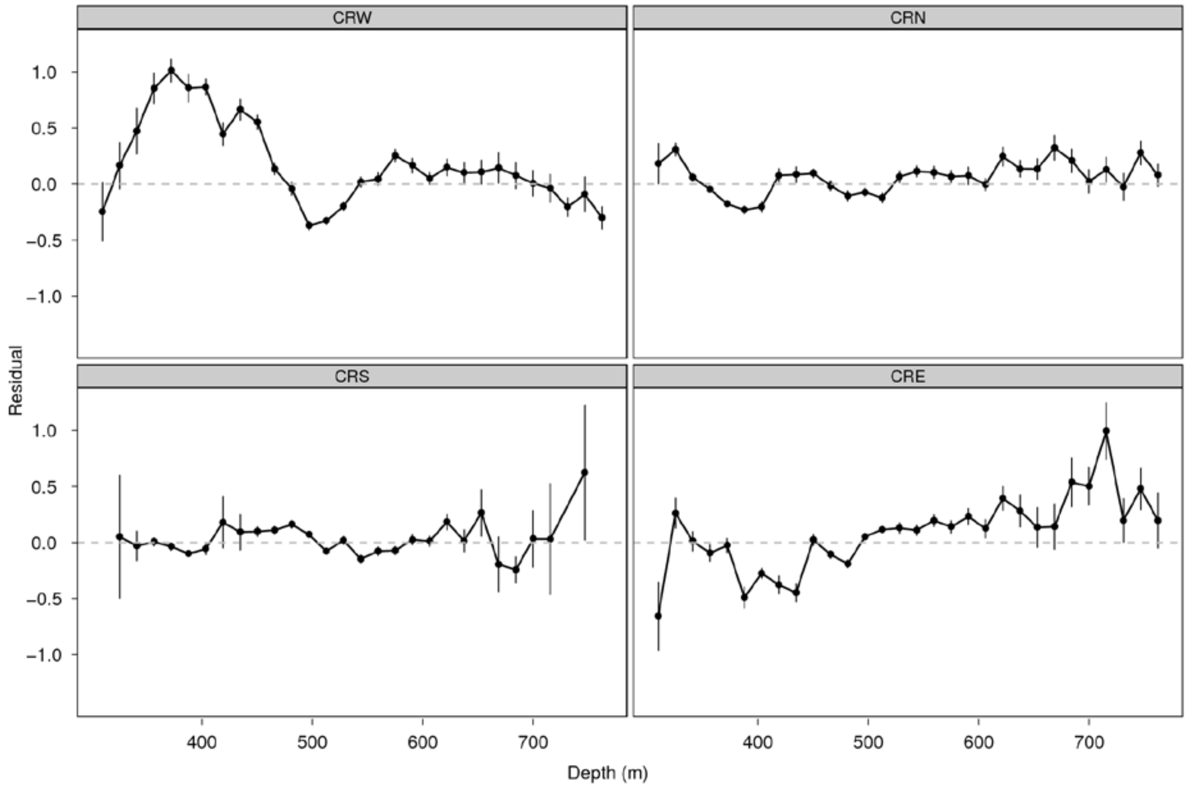

Figure F24: Mean and standard error of residuals by depth and area.

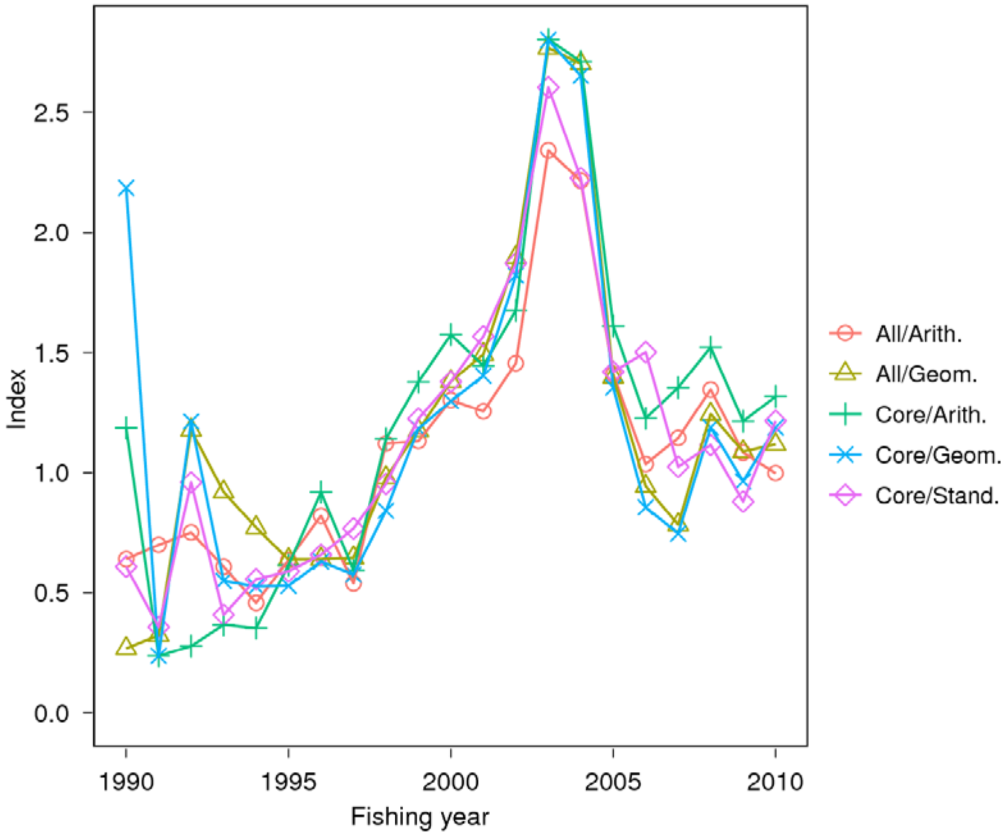

Figure F25: Standardised and unstandardised CPUE indices. All: all vessels, Core: core vessels, Geom.: geometric mean, Arith: arithmetic mean, Stand.: standardised using GLM.

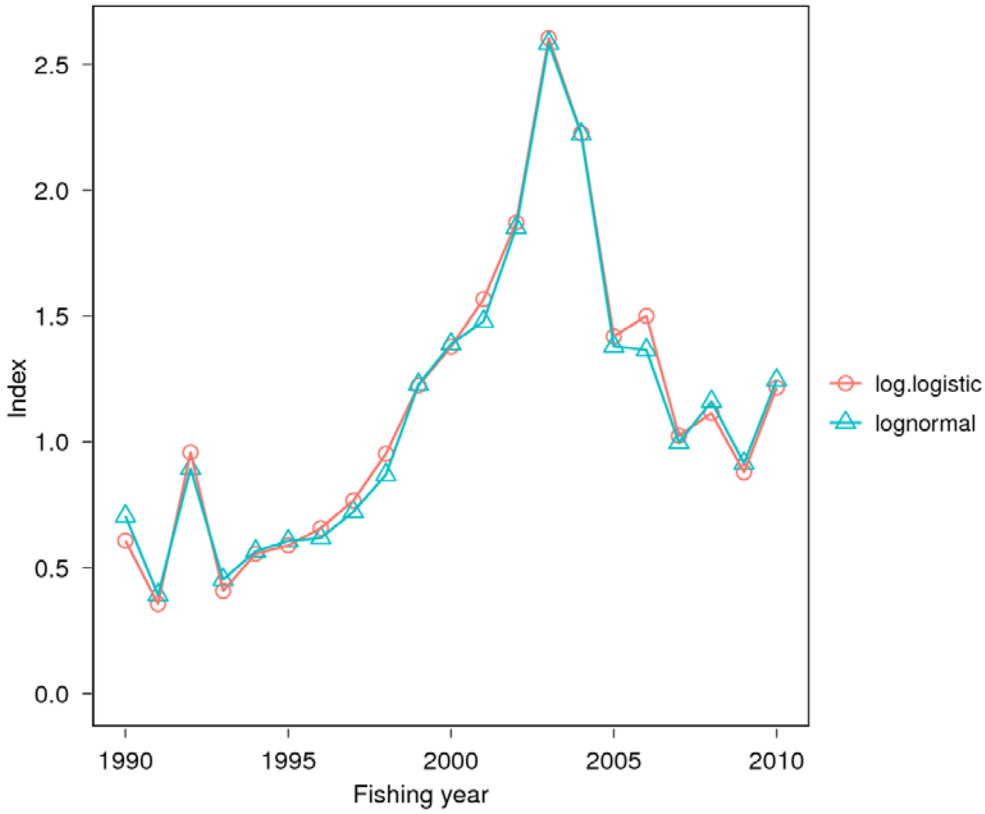

Figure F26: Standardised CPUE obtained from the GLM model when using a log.logistic distribution and a lognormal distribution.

Table F5: 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	0.6400	1.1863	0.2680	2.1862	0.6081	0.13500
1991	0.6990	0.2367	0.3230	0.2365	0.3570	0.09051
1992	0.7509	0.2775	1.1775	1.2126	0.9590	0.07050
1993	0.6084	0.3663	0.9194	0.5493	0.4081	0.04531
1994	0.4581	0.3522	0.7714	0.5255	0.5559	0.04745
1995	0.6355	0.6152	0.6375	0.5282	0.5890	0.02496
1996	0.8204	0.9185	0.6396	0.6299	0.6576	0.02924
1997	0.5387	0.5937	0.6456	0.5754	0.7674	0.02666
1998	1.1213	1.1407	0.9794	0.8413	0.9532	0.02301
1999	1.1318	1.3776	1.1747	1.1829	1.2243	0.01971
2000	1.3017	1.5742	1.3797	1.2977	1.3787	0.02211
2001	1.2550	1.4450	1.4928	1.4031	1.5678	0.02270
2002	1.4554	1.6753	1.8966	1.8210	1.8718	0.02351
2003	2.3421	2.8041	2.7687	2.8010	2.6044	0.02035
2004	2.2148	2.7125	2.7039	2.6527	2.2266	0.02315
2005	1.4095	1.6115	1.3980	1.3543	1.4193	0.02143
2006	1.0357	1.2261	0.9432	0.8554	1.5012	0.02510
2007	1.1444	1.3544	0.7832	0.7465	1.0245	0.02211
2008	1.3461	1.5218	1.2441	1.1881	1.1149	0.02386
2009	1.0833	1.2138	1.0879	0.9640	0.8795	0.02995
2010	0.9975	1.3168	1.1173	1.1886	1.2154	0.03025

17. APPENDIX G: CPUE FOR CHATHAM RISE USING TOWS TARGETTING HOKI

17.1 Data subset and processing

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

- Form type was TCP
- method was BT
- target was HOK
- area was CRW, CRN, CRS, CRE
- depth was 250–800 m
- bottom was 250–800 m
- trawl height was 1–100 m
- trawl width was 10–200 m
- trawl speed was 2–7 m
- trawl duration was less than 15hrs

Table G1 summarises the number of fishing events, vessels, trips, effort and catch in the resultant dataset. The minimum number of vessels was 16 in 2006. The percentage of poisitive catches ranged from 32% to 54%.

Table G1: Summary by fishing year of the data subset used for this analysis.

Fishing year	Vessels	Trips	Events	Effort (num)	Effort (hrs)	Catch (t)	Events with catch (landed,%)
1995	33	103	4 364	4 364	15 652	231.5	54.22
1996	43	132	3 296	3 296	13 606	252.3	43.33
1997	51	167	4 434	4 434	17 160	224.0	44.18
1998	52	178	6 444	6 444	26 439	628.7	43.23
1999	40	150	7 799	7 799	31 986	778.0	45.57
2000	31	120	5 684	5 684	24 372	625.0	37.79
2001	34	134	6 671	6 671	29 679	777.9	36.02
2002	28	94	5 690	5 690	25 712	682.3	37.89
2003	27	113	6 811	6 811	32 147	1 117.0	46.88
2004	27	100	4 605	4 605	22 965	588.6	37.13
2005	21	75	3 477	3 477	17 797	446.5	41.99
2006	16	66	3 095	3 095	15 702	295.8	35.32
2007	19	69	3 056	3 056	14 769	194.9	47.97
2008	20	78	2 393	2 393	11 733	185.9	40.41
2009	18	68	2 119	2 119	9 806	178.9	32.04
2010	20	69	2 410	2 410	11 000	219.1	34.32

17.2 Core vessel selection

Alternative core vessel selection criteria were investigated by considering the reduction in the number of vessels and percentage of catch (Figure G1). 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 1 kg of catch. These criteria resulted in a core fleet size of 29 vessels which took 91% of the catch (Figure G1). A histogram of the number of years in which each core vessel had data in the dataset is provided (Figure G2) as is the overlap of data among core vessels (Figure G3).

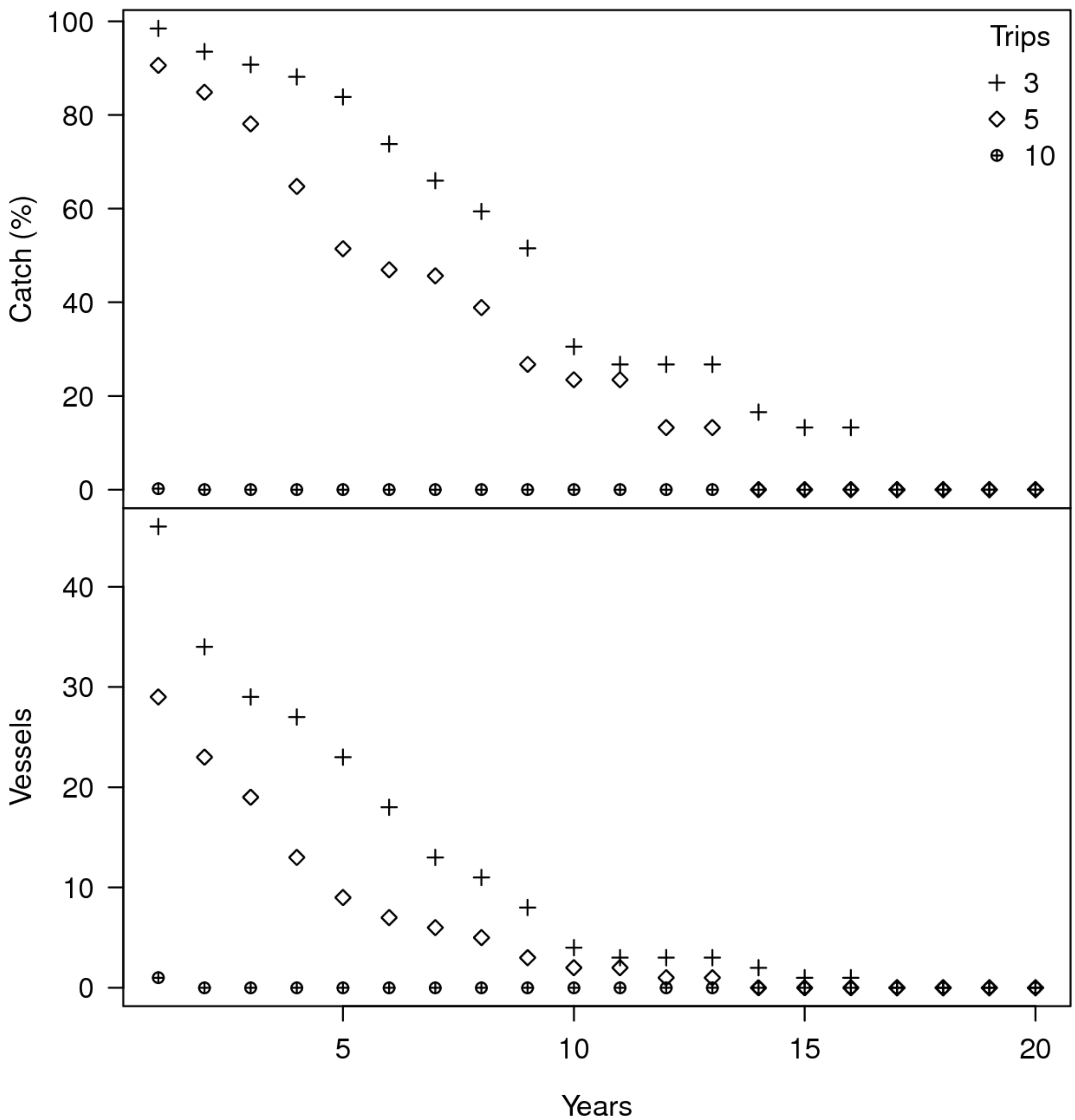

Figure G1: Examination of parameters for defining core vessels.

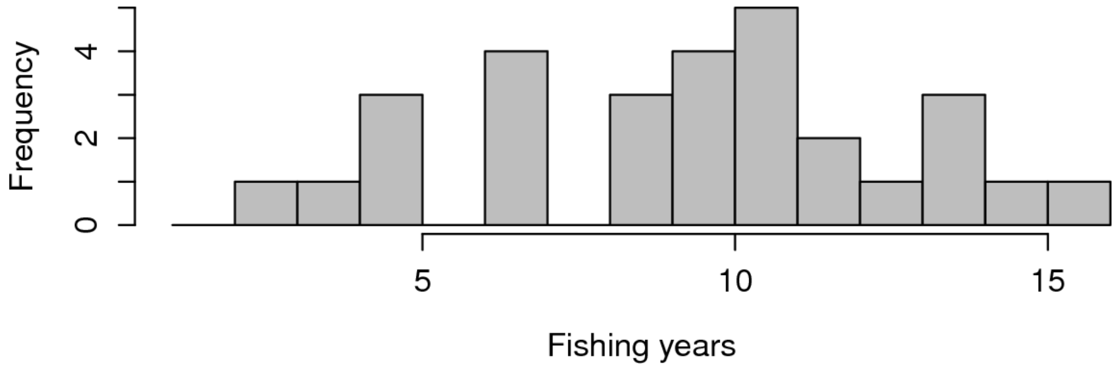

Figure G2: Histogram of the number of years with data for each core vessel.

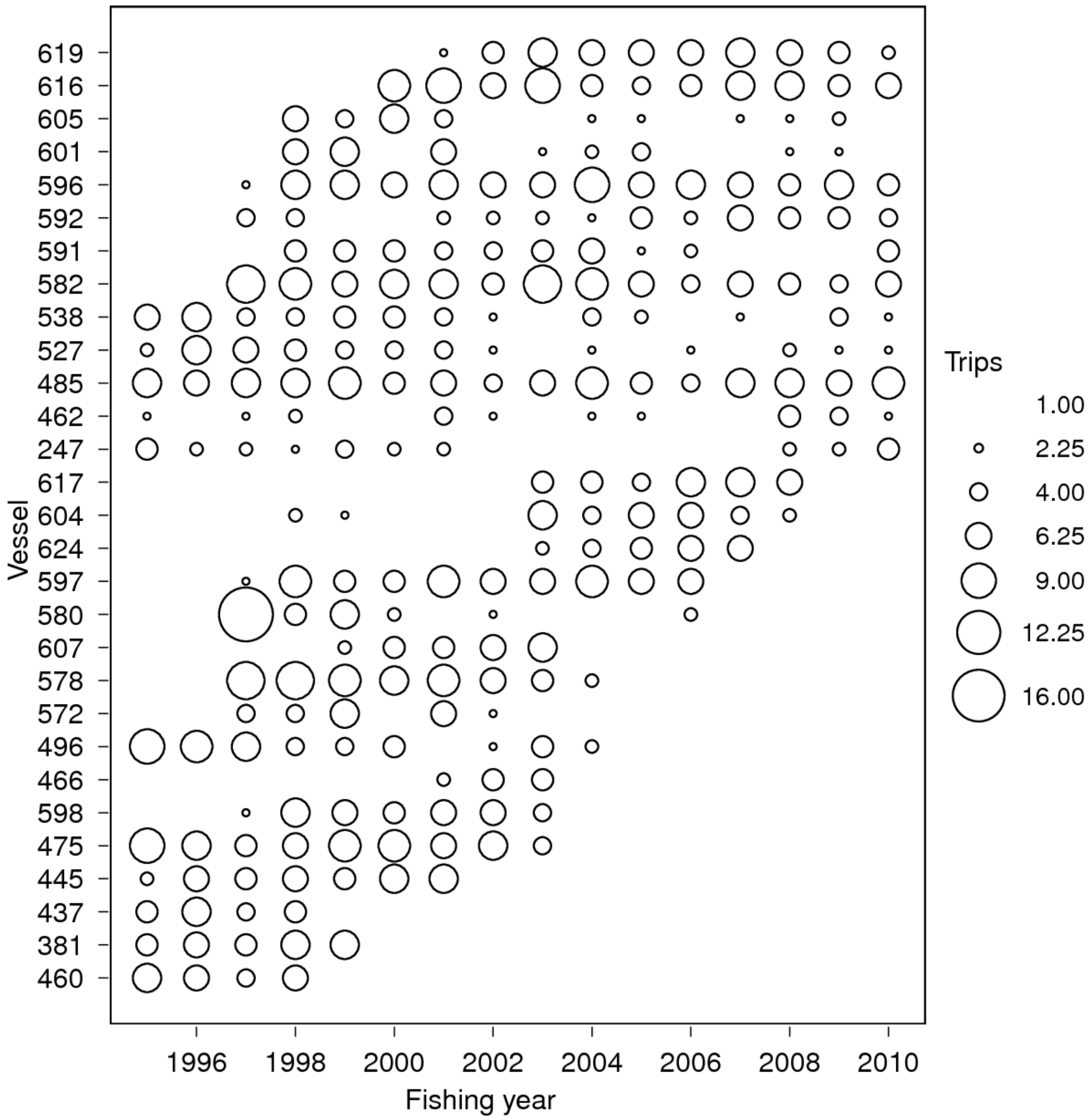

Figure G3: Number of trips by fishing year for core vessels. Area of circles is proportional to the proportion of records over all fishing years and vessels.

Table G2: Summary of core vessel data by fishing year.

Fishing year	Vessels	Trips	Events	Effort (num)	Effort(hrs)	Catch (t)	Trips with catch (%)	Events with catch (%)
1995	11	61	3 344	3 344	11 386	163.4	85.25	55.32
1996	13	65	2 487	2 487	9 852	151.4	83.08	47.97
1997	21	104	3 646	3 646	13 905	170.5	75.00	46.13
1998	24	129	5 936	5 936	23 772	492.5	83.72	42.27
1999	22	114	6 900	6 900	28 175	697.1	85.96	46.45
2000	20	98	5 416	5 416	23 144	605.8	89.80	38.31
2001	24	115	6 382	6 382	28 323	714.5	88.70	35.85
2002	21	83	5 476	5 476	24 618	641.2	92.77	35.79
2003	22	103	6 648	6 648	31 189	1 107.4	90.29	46.84
2004	21	87	4 374	4 374	21 747	548.4	97.70	36.69
2005	16	67	3 385	3 385	17 223	441.0	91.04	41.27
2006	14	63	3 092	3 092	15 682	294.3	90.48	35.28
2007	14	63	3 032	3 032	14 581	187.7	80.95	47.69
2008	14	60	2 247	2 247	10 898	160.3	86.67	38.14
2009	12	50	1 951	1 951	8 762	151.5	86.00	30.86
2010	13	50	2 336	2 336	10 506	211.8	90.00	33.26

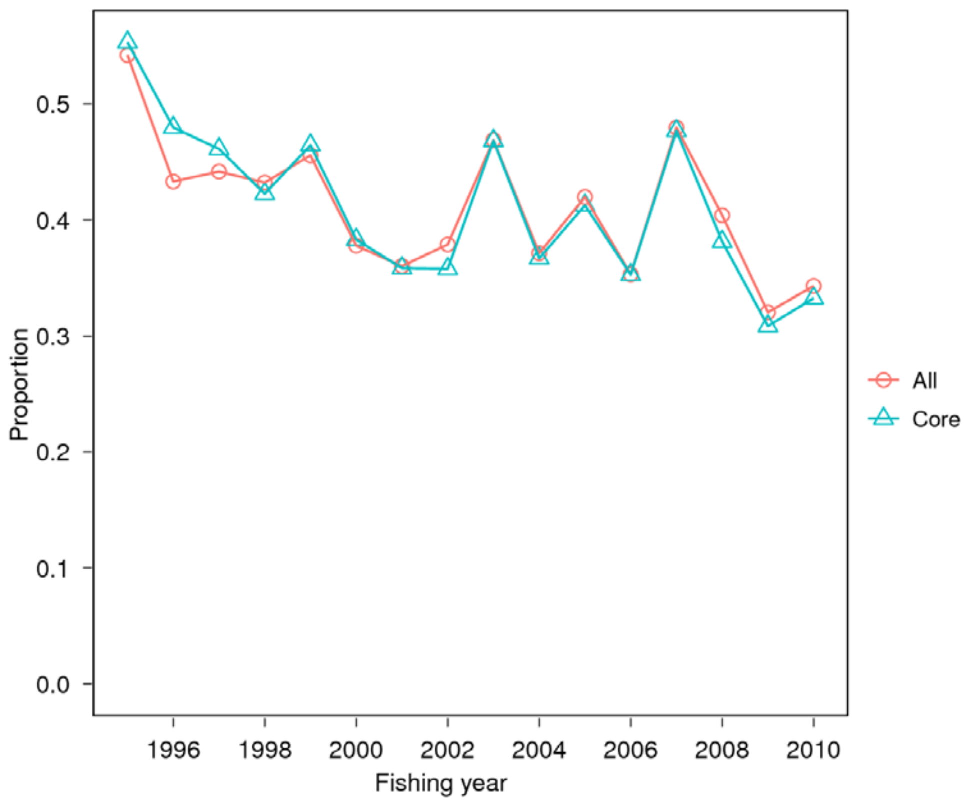

Figure G4: Proportion of positive catches for the entire dataset (All) and core vessels (Core).

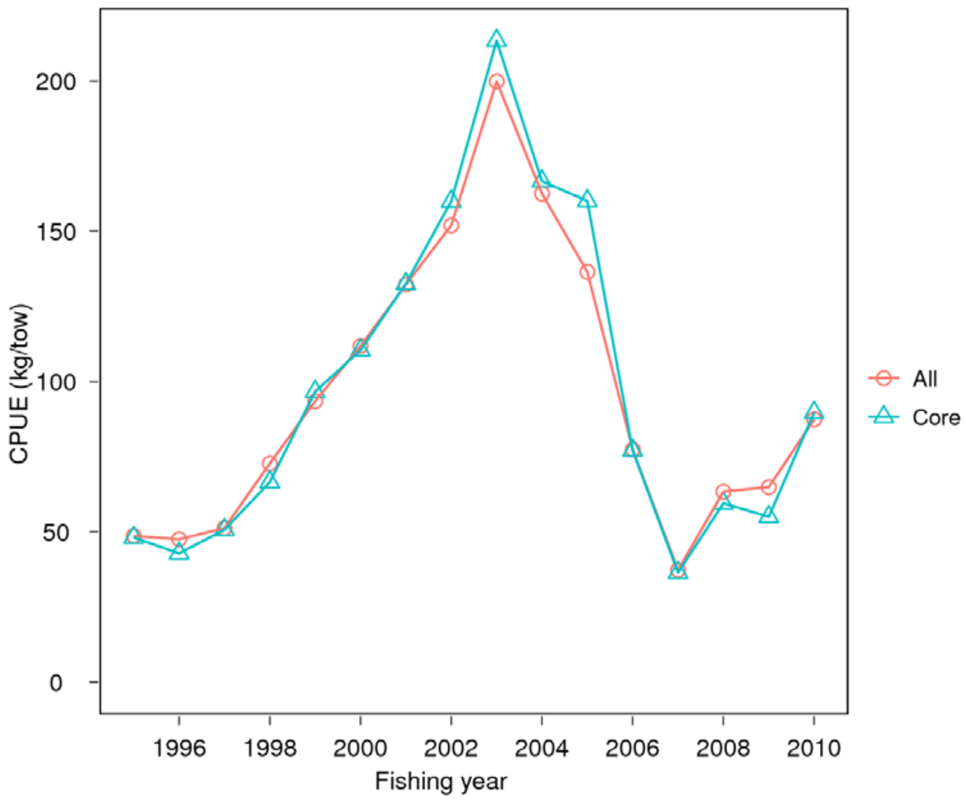

Figure G5: Unstandardised CPUE (geometric mean of positive catches) for the entire dataset (All) and core vessels (Core).

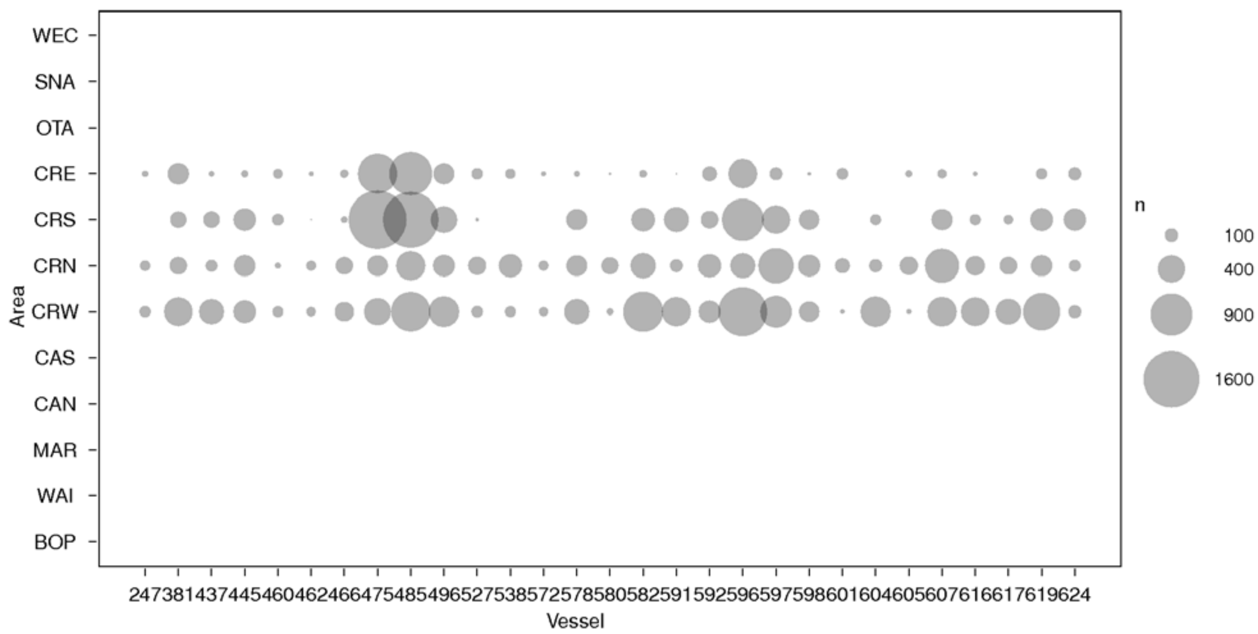

Figure G6: Number of tows by area for each core vessel over all years, 1989–90 to 2009–10.

17.3 Selection of appropriate error distribution

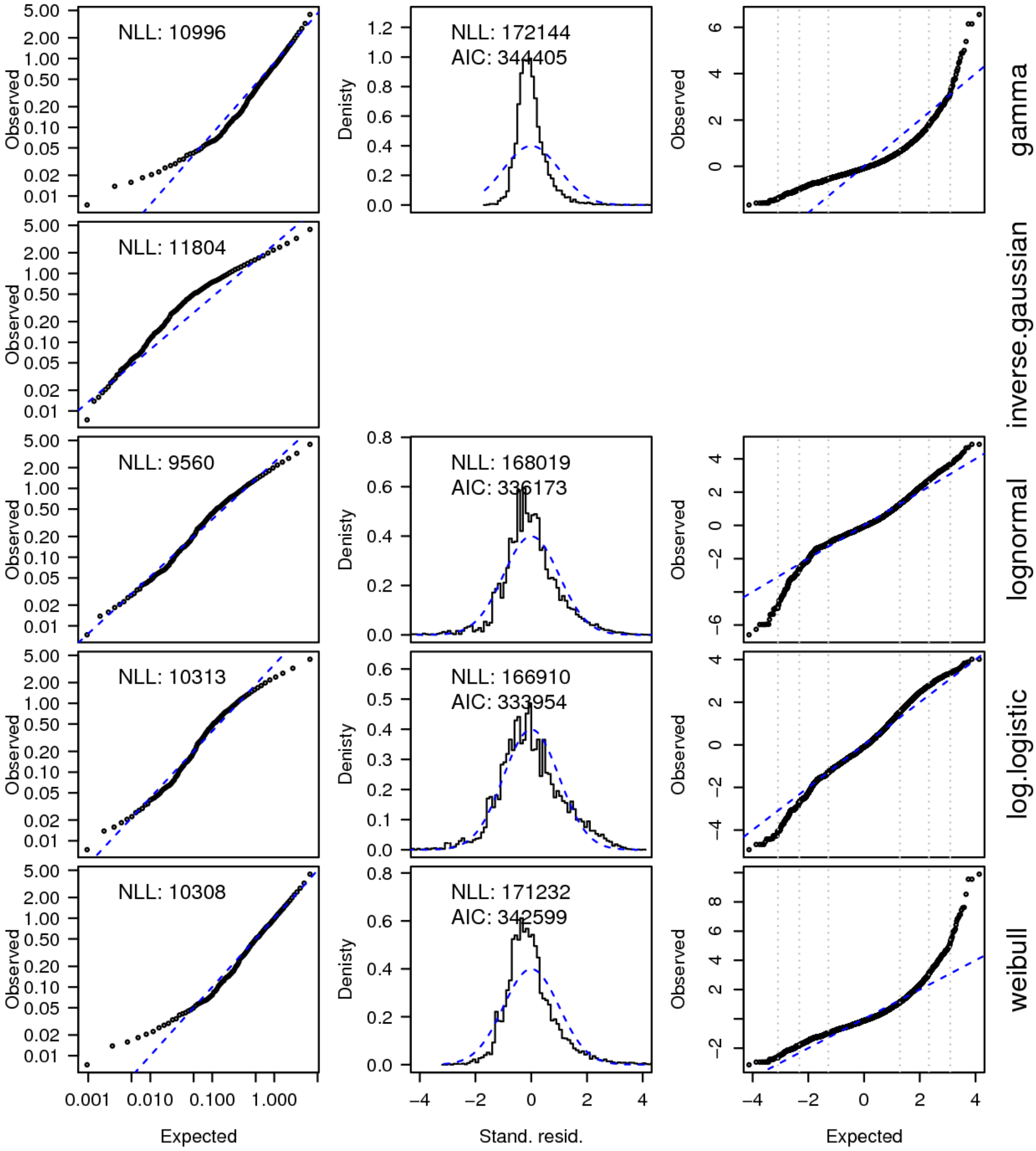

Figure G7: Diagnostics for alternative distributional assumptions for catch. Left: quantile–quantile plot of observed catches (centred (by mean) and scaled (by standard deviation) in log space) versus maximum likelihood fit of distribution (missing panel indicates that the fit failed to converge); Middle: 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.

17.4 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(height), 3) + poly(log(width), 3) + poly(log(speed), 3) + poly(log(depth), 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 G3 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 + area + vessel + poly(log(depth), 3) + poly(log(duration), 3) + month

Table G3: 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	17	–174 520	349 075	16.07 *
area	28	–169 163	338 383	43.03 *
vessel	56	–167 050	334 212	51.11 *
poly(log(depth), 3)	59	–166 648	333 413	52.51 *
poly(log(duration), 3)	62	–166 513	333 151	52.97 *
month	73	–166 385	332 917	53.40 *
poly(log(width), 3)	76	–166 329	332 811	53.59
poly(time, 3)	79	–166 306	332 769	53.67
poly(log(height), 3)	82	–166 288	332 740	53.73
poly(moon, 3)	85	–166 282	332 734	53.75

17.5 Influence of model terms on annual CPUE indices

Table G4: 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	–176 942	353 889	–	–	–
fyear	15	–174 520	349 075	12.71	16.07	–
area	11	–169 163	338 383	24.68	26.96	13.33
vessel	28	–167 050	334 212	7.36	8.07	6.85
poly(log(depth), 3)	3	–166 648	333 413	1.45	1.40	3.64
poly(log(duration), 3)	3	–166 513	333 151	0.48	0.46	3.39
month	11	–166 385	332 917	0.23	0.43	0.91

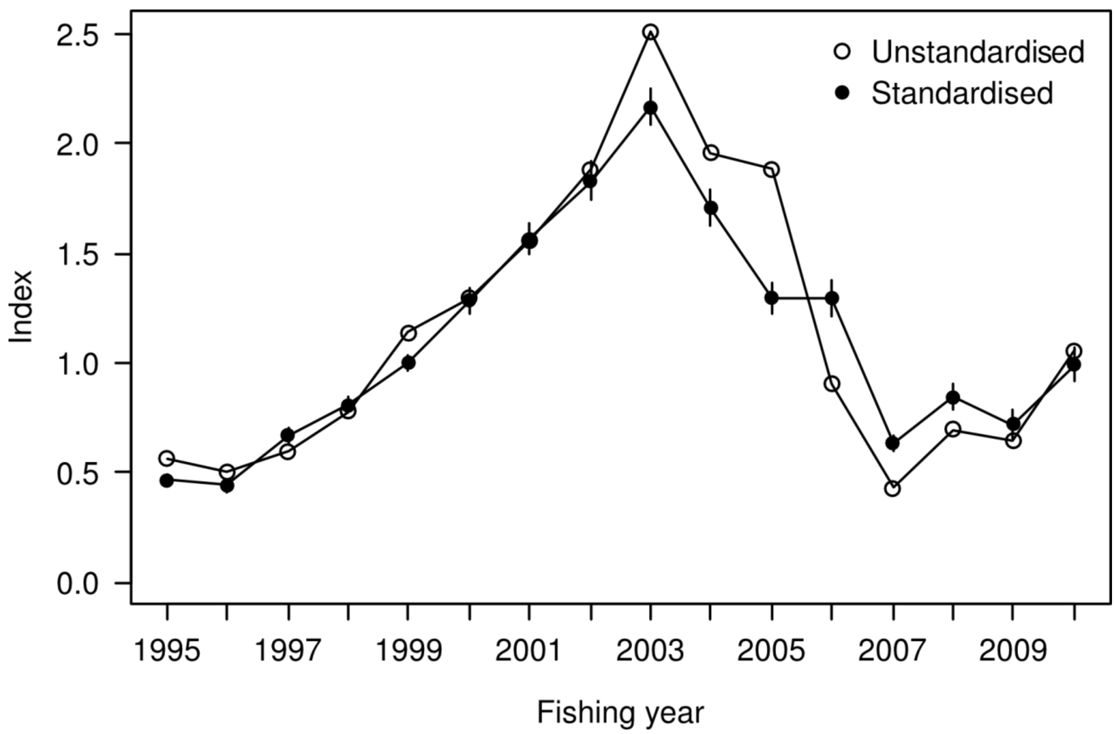

Figure G8: Overall standardisation effect of the model. The unstandardised index is based on the geometric mean of the catch per strata and is not adjusted for effort.

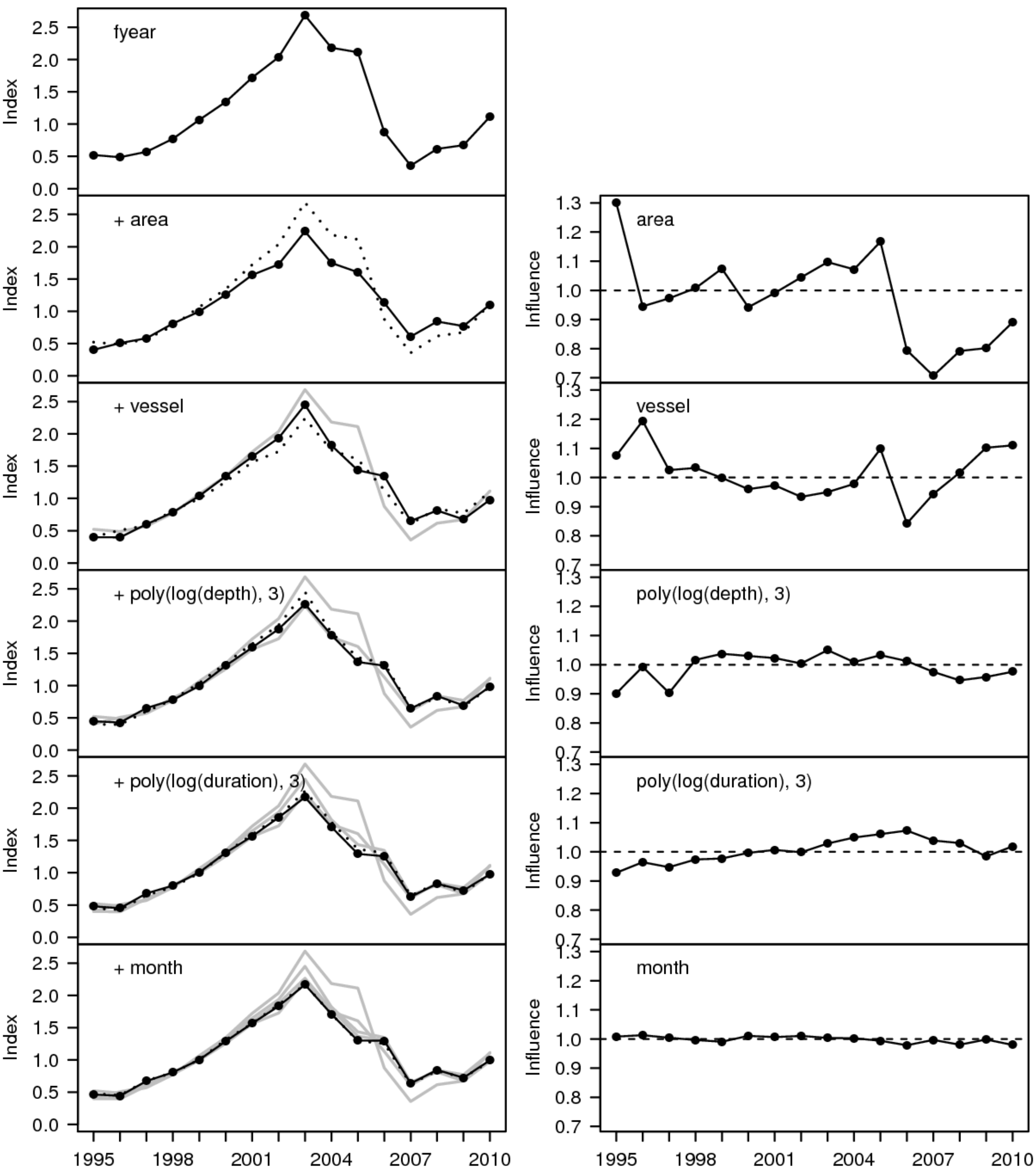

Figure G9: Effect on the standardised index of stepwise addition of model terms (left) and the annual influence of each model term in the final model (right).

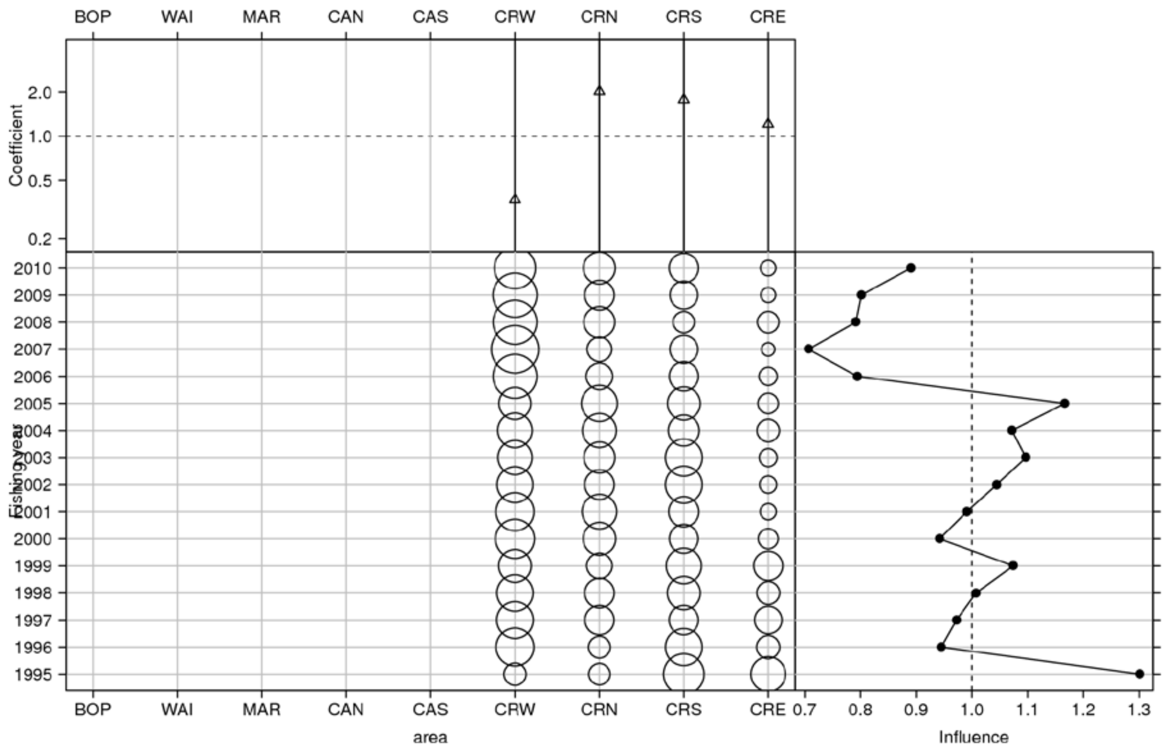

Figure G10: Coefficient–distribution–influence plot for *area*.

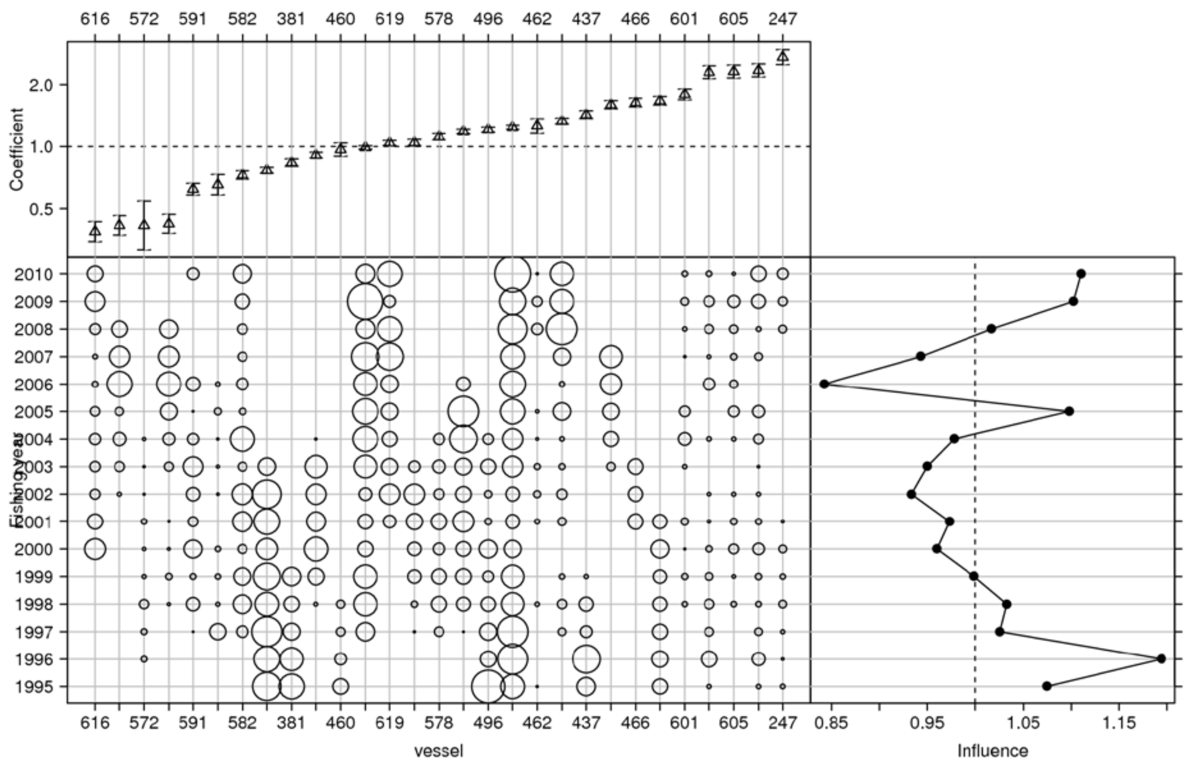

Figure G11: Coefficient–distribution–influence plot for *vessel*.

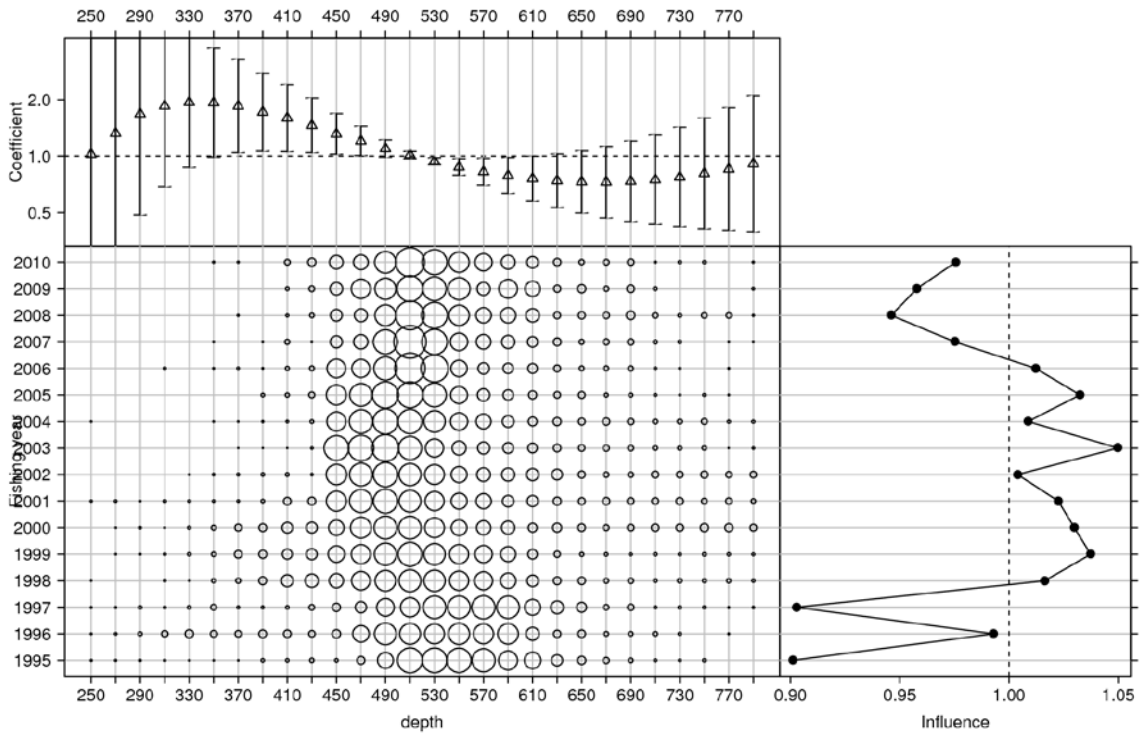

Figure G12: Coefficient–distribution–influence plot for *poly(log(depth), 3)*.

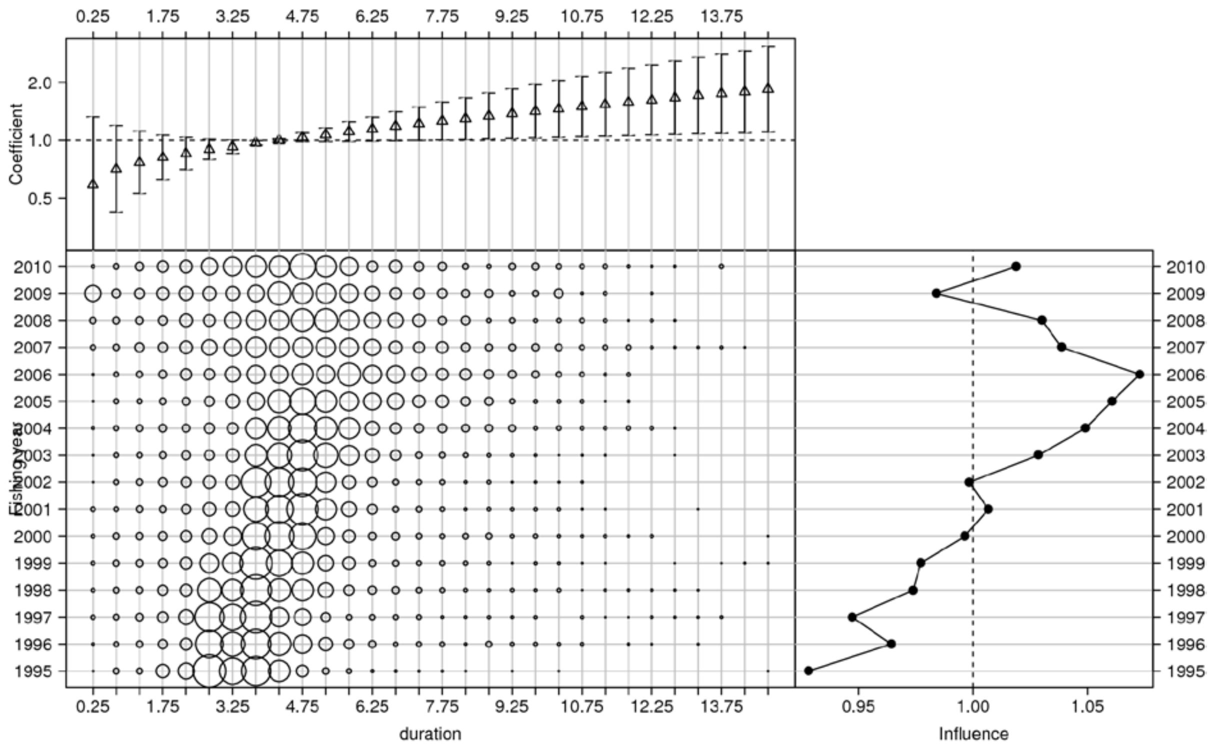

Figure G13: Coefficient–distribution–influence plot for *poly(log(duration), 3)*.

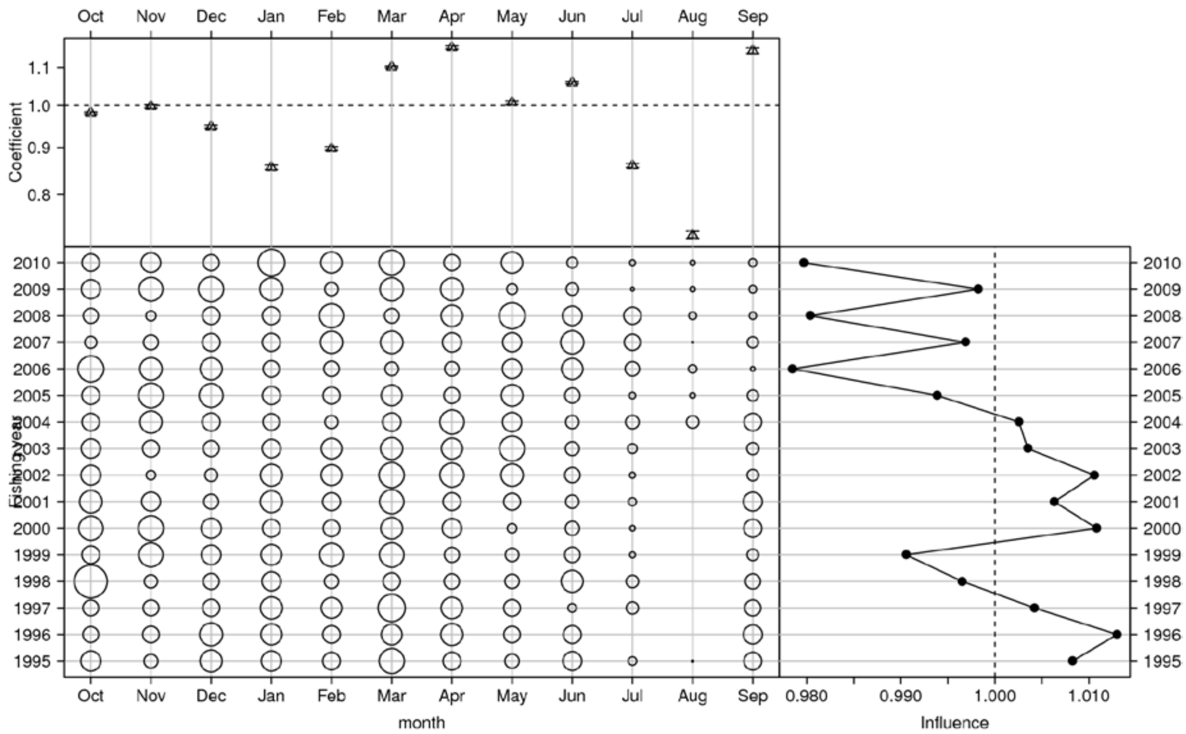

Figure G14: Coefficient–distribution–influence plot for *month*.

17.6 Residual diagostics

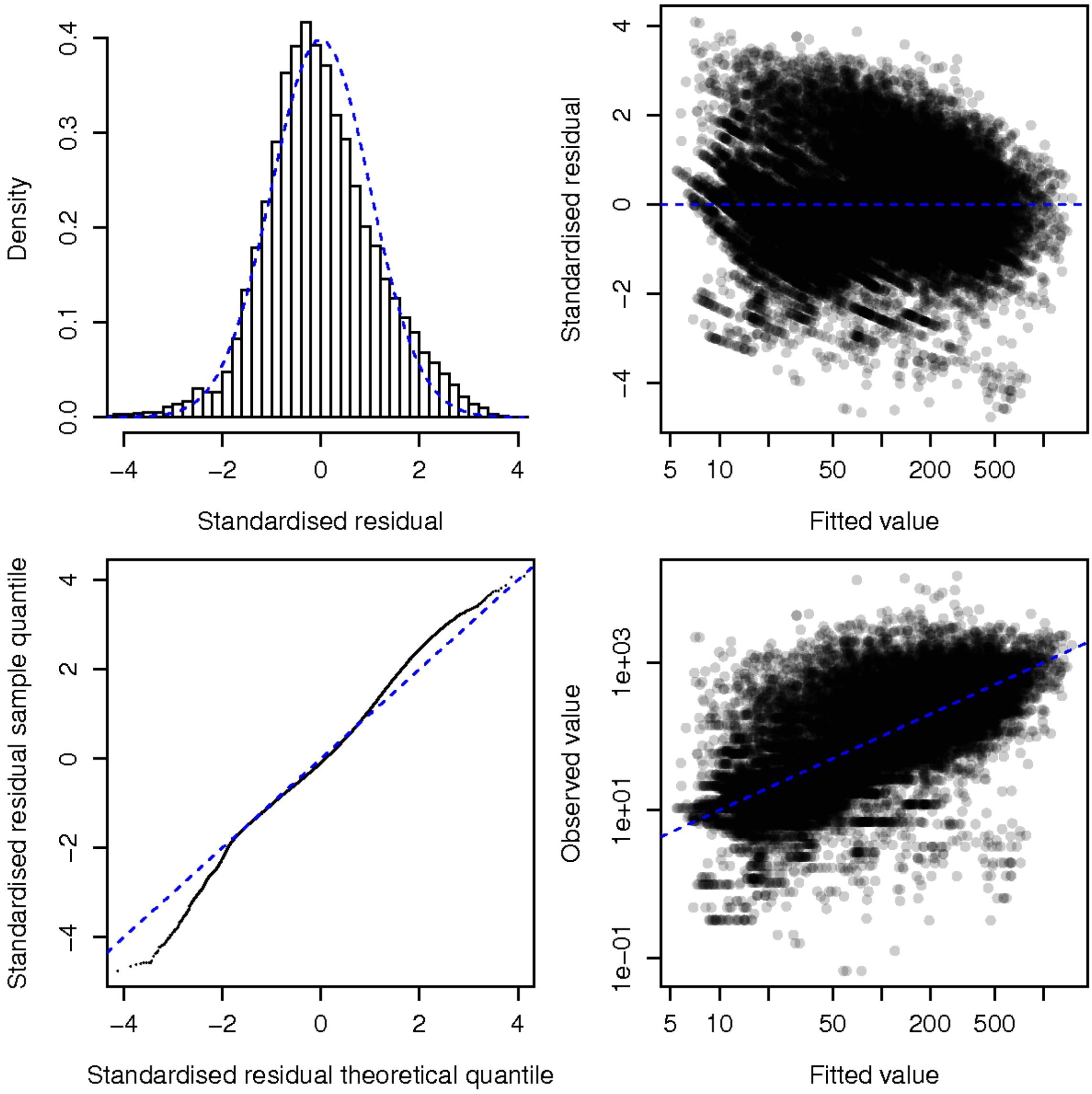

Figure G15: Residual diagnostics. Top left: histogram of standardised residuals compared to standard normal distribution. Bottom left: quantile–quantile plot of standardised residuals. Top right: fitted values versus standardised residuals. Bottom right: observed values versus fitted values.

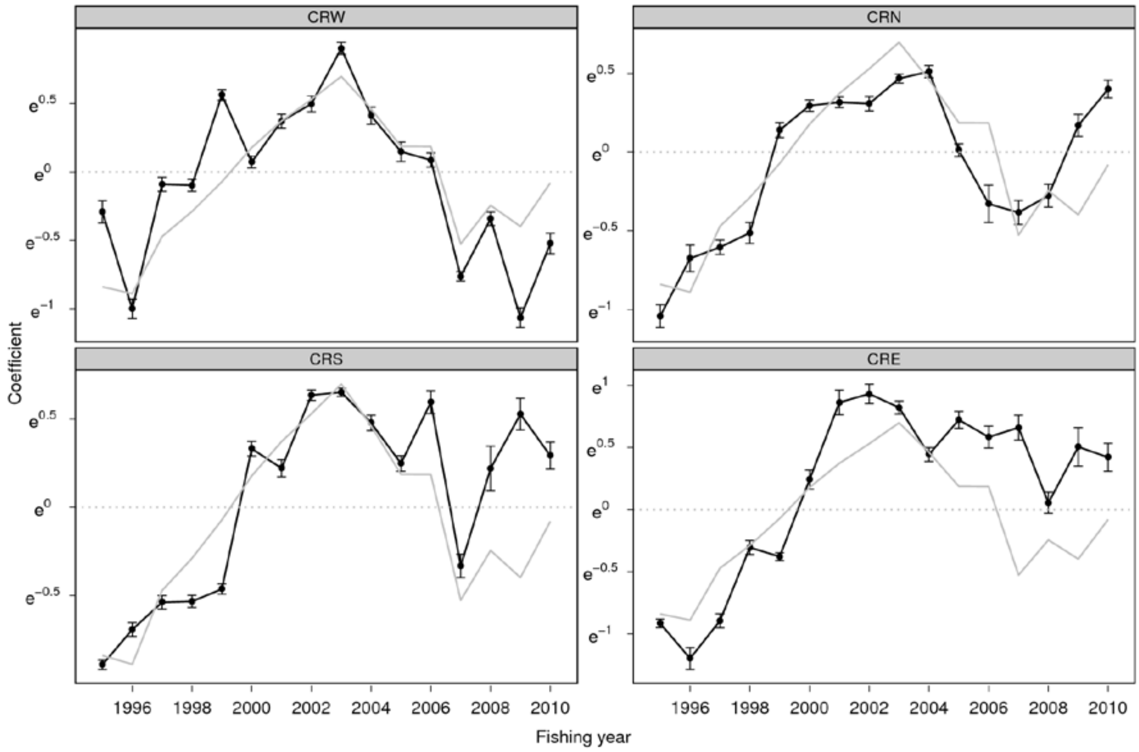

Figure G16: Residual implied coefficients for area × fishing year interactions. Implied coefficients (black points) are calculated as the normalised fishing year coefficient (grey line) plus the mean of the standardised residuals in each fishing year and area. These values approximate the coefficients obtained when an area × year interaction.

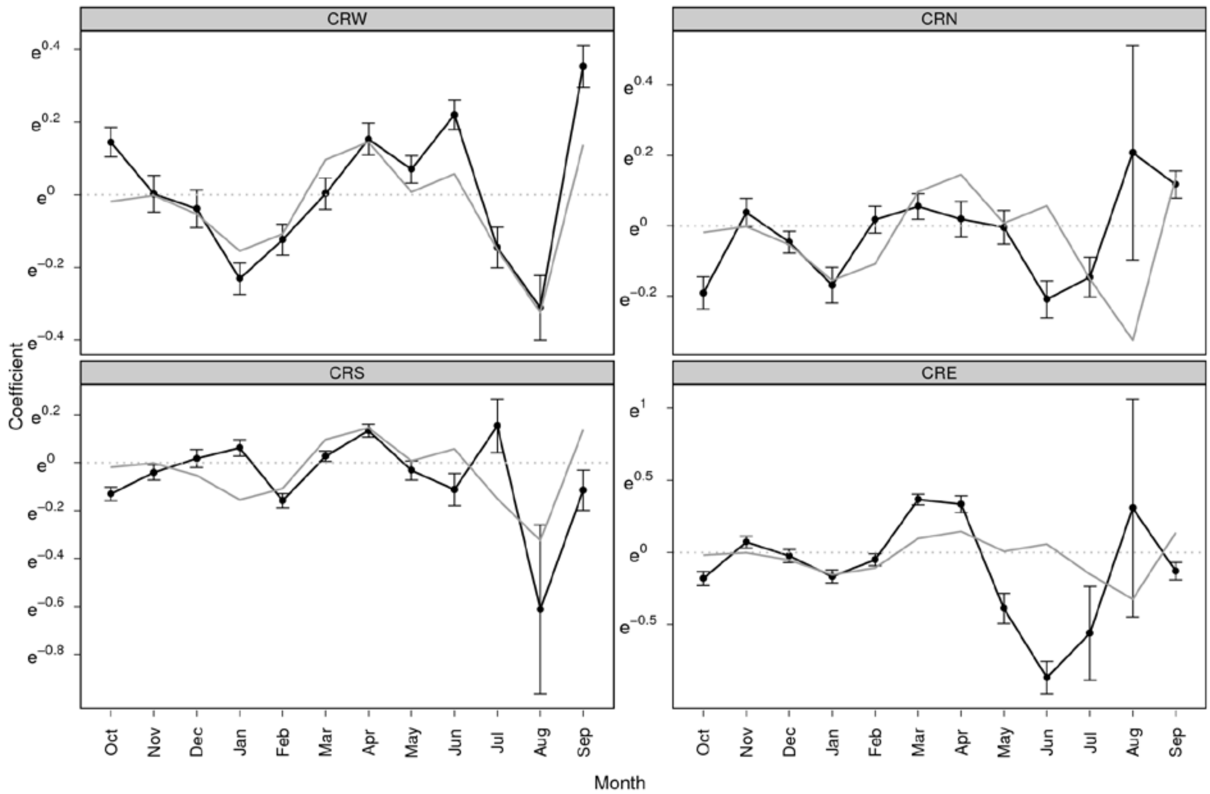

Figure G17: Residual implied coefficients for area × month interactions. Implied coefficients (black points) are calculated as the normalised month coefficients (grey line) plus the mean of the standardised residuals in each month and area.

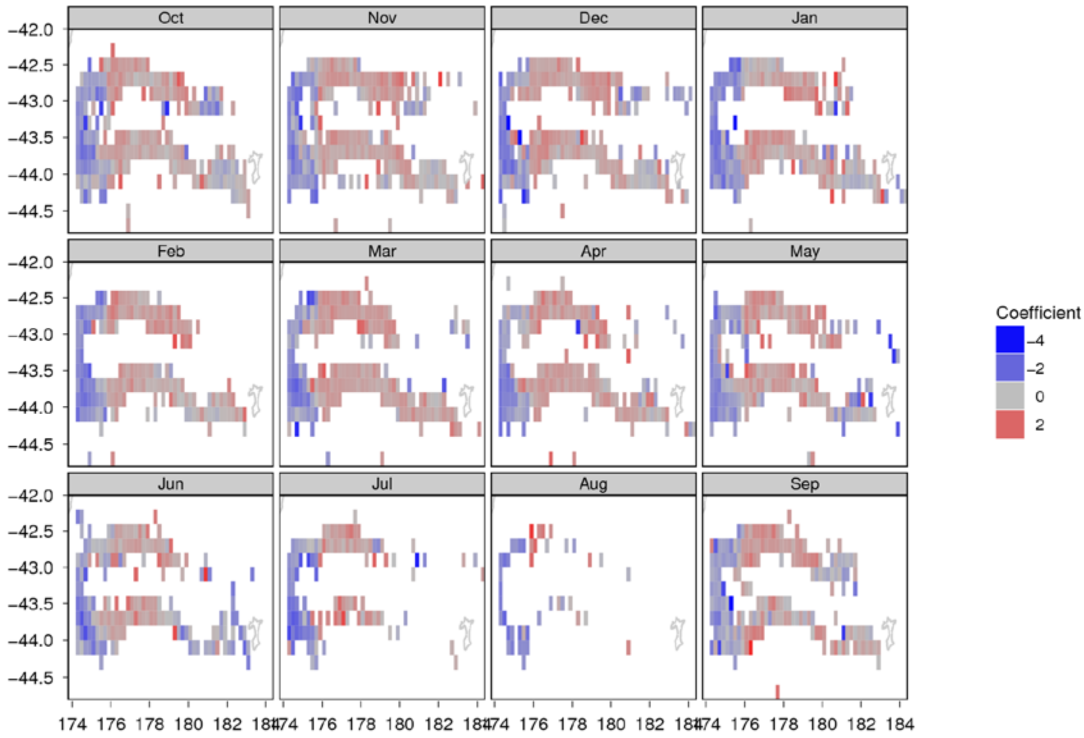

Figure G18: Residual implied coefficients for each position in each month. Implied coefficients are calculated as the sum of the normalised coefficients for any model terms relating to area and month (month, area and area × month terms) plus the mean of the standardised residual for position in each month. This plot is intended to show what the combination of model fit and residuals imply about seasonality in local catch rates.

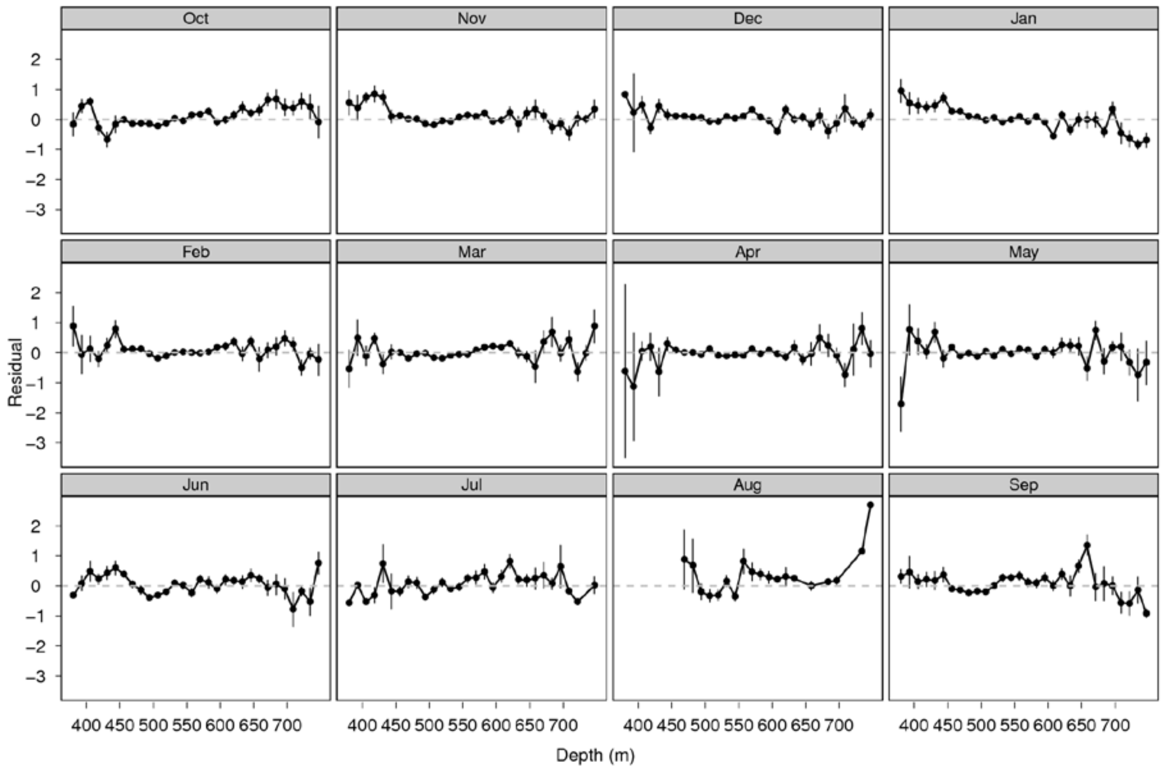

Figure G19: Mean and standard error of residuals by depth and month.

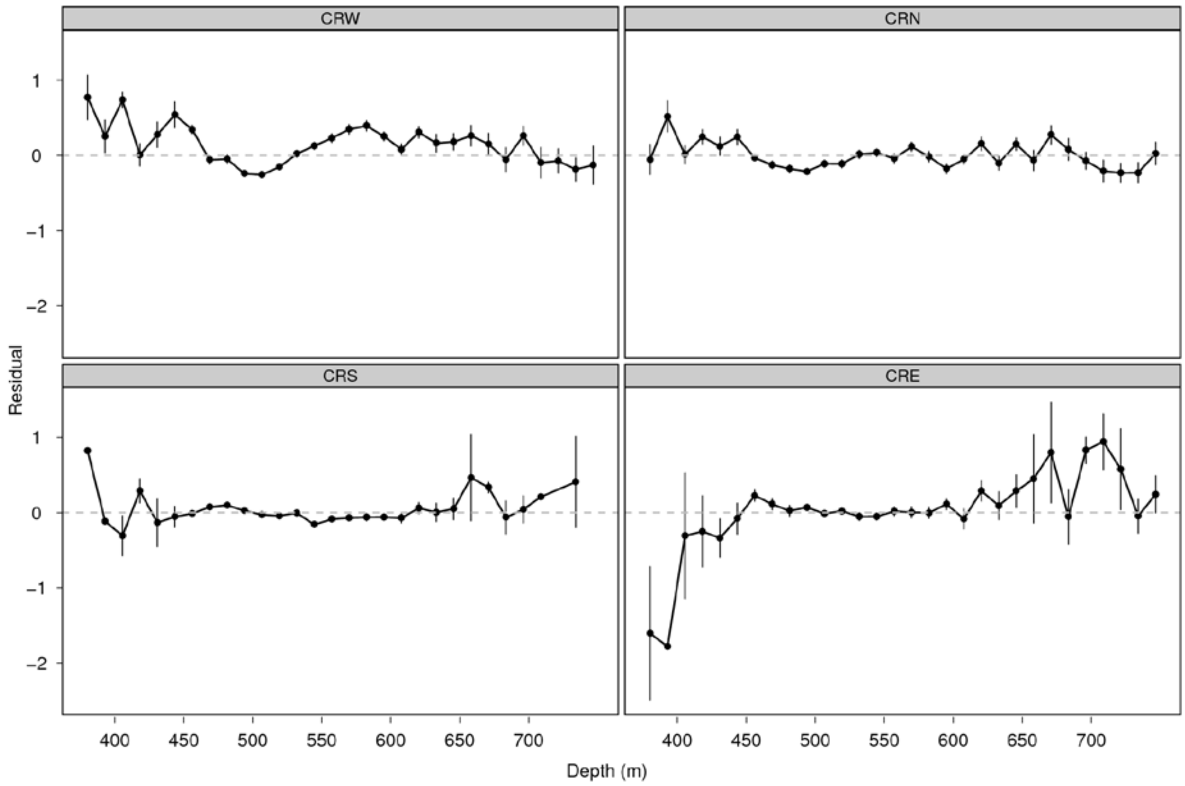

Figure G20: Mean and standard error of residuals by depth and area.

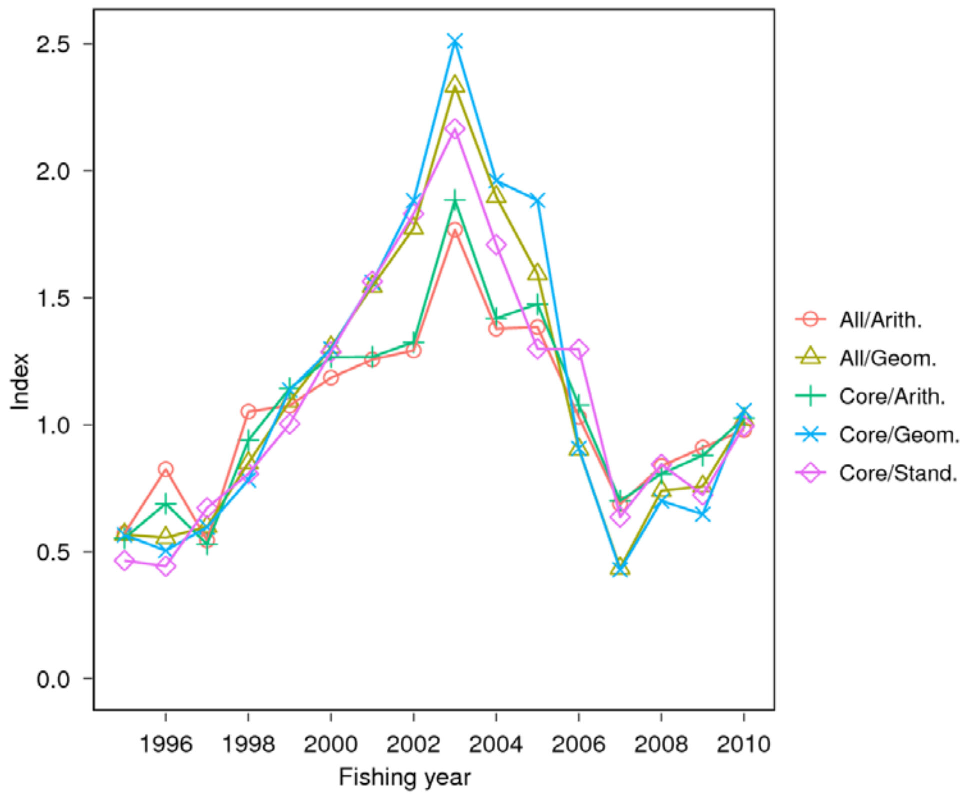

Figure G21: Standardised and unstandardised CPUE indices. All: all vessels, Core: core vessels, Geom.: geometric mean, Arith: arithmetic mean, Stand.: standardised using GLM.

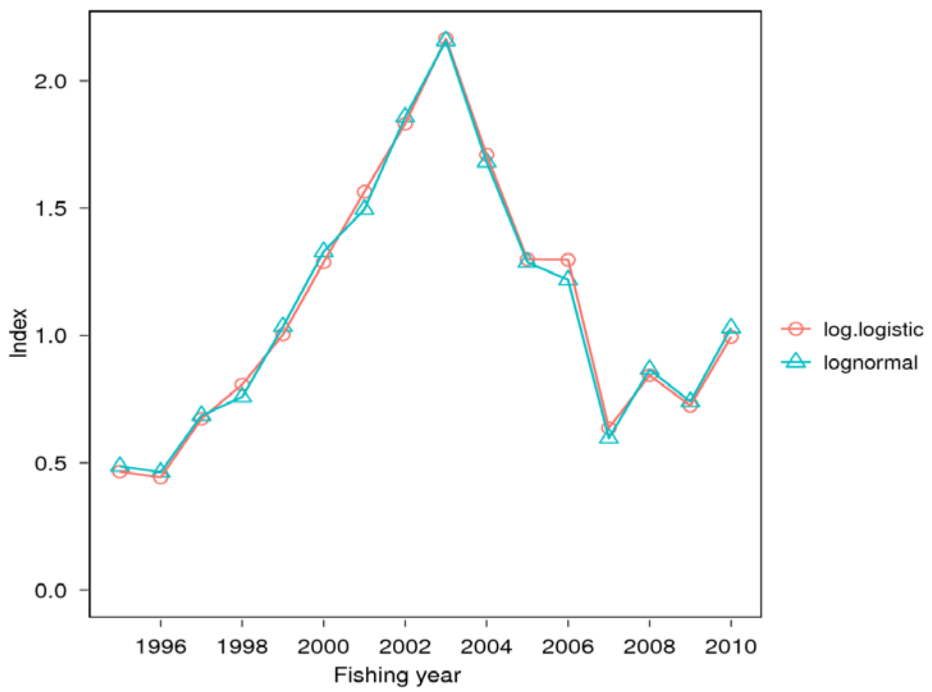

Figure G22: Standardised CPUE obtained from the GLM model when using a log.logistic distribution and a lognormal distribution.

Table G5: 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
1995	0.5720	0.5531	0.5683	0.5662	0.4653	0.02709
1996	0.8253	0.6892	0.5553	0.5043	0.4428	0.03109
1997	0.5446	0.5294	0.5987	0.5968	0.6726	0.02564
1998	1.0518	0.9391	0.8500	0.7830	0.8073	0.02150
1999	1.0755	1.1435	1.0919	1.1376	1.0032	0.01906
2000	1.1854	1.2660	1.3060	1.2990	1.2875	0.02330
2001	1.2572	1.2672	1.5447	1.5598	1.5647	0.02270
2002	1.2928	1.3253	1.7747	1.8828	1.8312	0.02404
2003	1.7681	1.8856	2.3342	2.5116	2.1661	0.01935
2004	1.3781	1.4191	1.8980	1.9611	1.7094	0.02549
2005	1.3846	1.4747	1.5936	1.8839	1.2992	0.02704
2006	1.0303	1.0773	0.9040	0.9071	1.2976	0.03229
2007	0.6874	0.7009	0.4357	0.4288	0.6364	0.02773
2008	0.8374	0.8073	0.7405	0.7003	0.8440	0.03421
2009	0.9100	0.8791	0.7579	0.6472	0.7240	0.04345
2010	0.9800	1.0262	1.0207	1.0558	0.9950	0.03689