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The fishery for black cardinalfish: characterisation and CPUE analyses, 1989–90 to 2013–14

New Zealand Fisheries Assessment Report 2016/66

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EXECUTIVE SUMMARY

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Black cardinalfish (CDL) have been caught commercially at depths of 500–1000 m since the early 1980s, initially as a bycatch of bottom trawling (BT) for orange roughy with smaller amounts from midwater trawling (MW) for hoki (HOK) and alfonsino (BYX), but also increasingly as a target species. From 2000–01 to 2013–14, 80% of the black cardinalfish catch was taken by bottom trawling targeting CDL.

Most catches were from the east coast of North Island and north-east coast of South Island associated with underwater features, but small catches were recorded throughout the EEZ. In this study, we characterised the fishery in nine zones around the features with the highest concentrations of catches. Catches peaked in the early 1990s in the Tuaheni High zone, and there were also substantial catches in the Ritchie-Rockgarden zone. In the mid-1990s, catches increased rapidly in the Mercury-Colville, White Island, and East Cape zones. In most zones, catches and effort have declined since 1999–2000, with the fishery contracting to concentrate effort around the historically most important features.

Analyses of catch-per-unit-effort (CPUE) were carried out using data recorded on TCEPR forms from a core fleet using bottom trawling (BT) or midwater trawling (MW) at depths of 470–980 m within the nine zones. Generalised linear models (GLM) were developed to standardise for (a) the probability of a catch and (b) the magnitude of positive catches.

The probability of catch declined from a peak of 30% of tows in 1999–2000 to less than 15% in 2013–14 with the effect of standardisation steepening the observed decline. The magnitude of catches declined by about 75% in the first decade to a new level where it remained relatively stable over the following decade.

CPUE trends were broadly consistent across zones and target species, with some evidence of less steep declines in northern zones, Mercury Colville (MC) and White Island (WI), and of recent increases in more southerly zones Wairarapa (WA) and Kaikoura (KK), that lifted the overall index from its lowest point in 2007–08 (about 47% of the mean for the time series), to nearer 80% in 2013–14.

The Chatham Rise *Tangaroa* bottom trawl survey time series caught small cardinalfish (20–40 cm). Relative abundance estimates increased from a low in 1996 to fluctuate around 100 t since the 2009 survey but with very high coefficients of variation. The mid-east coast survey *Tangaroa* bottom trawl survey for orange roughy caught black cardinalfish that were similar in size to those measured from commercial catches (40–70 cm) and abundance estimates were higher than for the Chatham Rise surveys but with very high coefficients of variation.

Length and gonad stage data for commercial catches from the Ministry for Primary Industries Observer Programme showed length frequency distributions that were unimodal with most fish 50–70 cm. The proportion of maturing and running ripe gonads peaked in March and the proportion of spent gonads peaked in July, consistent with spawning occurring in autumn-early winter. There are potentially numerous spawning locations including: off the east coast of the North Island, the Bay of Plenty, the West-Norfolk Ridge, the Challenger Plateau and the Lord Howe Rise. No running ripe fish and few mature female gonads were sampled from the Chatham Rise, Kaikoura or Wairarapa fishing areas.

1. INTRODUCTION

1.1 Identification, distribution and habit

Black cardinalfish (*Epigonus telescopus*), also known as deepsea cardinalfish is a member of the family Epigonidae, or deepwater cardinalfishes. The species is widely distributed throughout temperate oceans including the North and south-east Atlantic, the Indian Ocean and the south-west Pacific (McMillan et al. 2011).

Black cardinalfish does not appear to be caught in substantial quantities outside of New Zealand. Several other species of *Epigonus* are found in New Zealand waters, but only black cardinalfish reaches a marketable size and is found in commercial concentrations (Ministry for Primary Industries 2014).

Adult black cardinalfish are benthopelagic occurring most commonly at depths of 500–1000 m. They feed on small mesopelagic fish and planktonic invertebrates including natant decapod prawns and octopus (Stevens et al. 2011). It is thought that juveniles are mesopelagic until they attain a length of about 12 cm (equivalent to about 5 years of age) (Neil et al. 2008). Larger juveniles are caught in bottom trawls at depths of 400–700 m, extending their range into deeper water as they grow (Dunn 2009).

1.2 Ageing, mortality and growth

Black cardinalfish were aged using otolith thin sections and the estimates were corroborated by both radiometric and bomb chronometer methods (Andrews & Tracey 2007, Neil et al. 2008). Most of the commercial catch was estimated to be 35–55 years old with a maximum estimated age of over 100 years. The rate of natural mortality was estimated at 0.03 yr^{-1} (Tracey et al. 2000) but due to uncertainty in this estimate, and evidence that fish aged more than 60 years may be under-aged, previous stock assessments used a range of estimates (0.027–0.06 yr^{-1}).

Growth parameters were estimated to be similar between males and females with a von Bertalanffy growth coefficient (k) of 0.03 and an asymptotic length of 70.8 cm for both sexes combined (Tracey et al. 2000).

1.3 Reproduction and stock structure

Analysis of gonad samples suggests a length of 50% maturity of around 50 cm, corresponding to an age of approximately 35 years (Field & Clark 2001). Changes in δ13C within otoliths suggested similar maturity at age of between 26 and 44 years (Neil et al. 2008).

Previous analyses of gonad stage data from research surveys and observer samples suggested that spawning occurs between November and July. Spawning locations were identified in CDL 1, CDL 2, CDL 7 and CDL 9 and outside the EEZ (e.g., North Challenger Plateau, Lord Howe Rise and West Norfolk Ridge). There is evidence that a spawning stock exists in CDL 2, with three geographically close spawning locations identified, on Tuaheni High, Ritchie Bank, and Rockgarden (Dunn 2009). No spawning grounds were identified on the Chatham Rise, where adult fish are relatively rare (Ministry for Primary Industries 2014).

1.4 Fishery

Black cardinalfish have been caught commercially since the early 1980s, initially as a bycatch of target trawling for other high value species (the depth range of black cardinalfish overlaps with the depth range of alfonsino and bluenose in shallower water and orange roughy in deeper water), but later also as a target species. Fillets are mostly sold into the domestic market (Ministry for Primary Industries 2014).

Most black cardinalfish landings were from the east coast of the North Island (QMA 2). Landings from this area increased rapidly in 1986–87, associated with the development of the orange roughy fishery around the Ritchie Banks and Tuaheni High. It may also be that there was an increase in targeted fishing to establish a catch history when it was anticipated that black cardinalfish was to become a quota managed species. Landings from the Bay of Plenty (QMA 1) and from outside the EEZ (mostly on the northern Challenger Plateau and the Lord Howe Rise) were also substantial, although less consistent than the landings from QMA 2 (Ministry for Primary Industries 2014).

Black cardinalfish was introduced into the QMS on 1 October 1998 and total allowable commercial catches (TACCs) were set for QMAs 2 to 8. TACCs were set for QMAs 1 and 9 for the 1999–00 fishing year. The TACC for CDL 2 was reduced to 1620 t in 2009–10, to 1020 t in 2010–11 and to 440 t in 2011–12 (Ministry for Primary Industries 2014).

1.5 Previous work

An initial review by Field et al. (1997) was followed by detailed analyses for QMA 2 (Field & Clark 2001) and QMA 1 (Phillips 2002). Updated analyses were provided by Dunn (2005), Dunn (2007) and Dunn & Bian (2009). The most recent black cardinalfish stock assessment, for CDL 2–4 was completed in 2009 (Dunn 2009).

2. DATA SOURCES AND METHODS

2.1 Catch and effort data

The catch effort data extract from the MPI database “warehou” defined qualifying trips as those that landed to any black cardinalfish (CDL) Fishstock, or that used bottom or midwater single or pair trawl. For these trips we obtained all effort data whether or not black cardinalfish was landed, so that all, and not just successful effort could be included in the calculation of CPUE. Landings and estimated catch data for any CDL Fishstock associated with those trips were also obtained.

The fishery characterisation analyses for this study were carried out on landed greenweight of black cardinalfish as reported at the end of the fishing trip, either on the bottom part of the general Catch Effort Landing Returns (CELR), or, where fishing was reported on the more detailed Trawl Catch Effort and Processing Return (TCEPR/TCE), on the associated Catch Landing Return (CLR).

Landed greenweight of black cardinalfish was linked to effort proportionate to estimated catch using two variations on the method of Starr (2007). Effort, estimated catch, and landings data were groomed separately before allocation. Landings were re-scaled in the dataset to equal the verified totals from Monthly Harvest Returns (MHR) or, before October 2001, from Quota Management Returns (QMR). For the CPUE standardisation part of this study, records for which any field was corrected or replaced during grooming were dropped.

The finer spatial scale analyses of CPUE were based on TCEPR/TCER format data analysed at original resolution. Catch was also based on landed rather than estimated catch, but was allocated to effort at the resolution at which effort was recorded, not amalgamated to trip-stratum, and thus included more detailed variables, such as latitude, longitude, bottom depth and tow speed, that were either only reported for tow-by-tow data, or lost if that data were amalgamated to trip-stratum.

2.1.1 Defining zones

Spatial areas (zones) were used to characterise the heavily concentrated nature of the black cardinalfish fishery. The zones used in this study are similar to those used by Dunn & Bian (2009), except that a separate zone was defined to encompass the north and south Madden banks off the Wairarapa coast. Dunn & Bian (2009) used rectangular areas, but we used polygons to more narrowly define the area around high catch concentrations associated with underwater features. Dunn and Bian also restricted their CPUE analyses to tows within 16 n. miles of the “nearest known feature” and a bottom depth range of 470–980 m. In this study, we only used the depth range criterion to select tows.

2.1.1 Core fleet definitions

The data sets used for the standardised CPUE analyses were further restricted to those vessels that participated with some consistency in the defined fishery. Core vessels were selected by specifying two variables: the number of trips that determined a qualifying year, and the number of qualifying years that each vessel participated in the fishery.

The core fleet was selected by choosing variable values that resulted in the fewest vessels while maintaining the largest catch of cardinalfish. The core data set was examined for representativeness and for adequate overlap of vessels across years.

2.1.2 Effort variable restrictions

The data sets used for the standardised CPUE analyses were further restricted to remove missing and outlying values for effort variables used in the standardisation models. There were relatively large numbers of records with missing values for 'bottom' and 'width' (and therefore 'swept_area' and 'swept_volume'). Since all tows in this analysis were from bottom trawl we did not remove records that were missing 'bottom' but instead used 'depth'. In a preliminary analysis we only included records if they had the 'width' variable. However, neither 'width', 'swept_area', nor 'swept_volume' entered preliminary models, and the Middle Depths Working Group expressed concerns regarding the accuracy with which these variables were measured. This restriction was not applied in the final analysis so that more data could be retained.

2.1.3 Models for CPUE standardisation

A generalised linear model (GLM) was developed to standardise the probability of cardinalfish catch (i.e., the proportion of tows with at least some cardinalfish catch) and fitted to the total dataset, including records that reported a zero catch of cardinalfish. A binomial error distribution was used. The dependent variable for the binomial model was set to ‘1’ for records which had associated CDL catch and set to ‘0’ for records with no catch.

A GLM was also developed to standardise the magnitude of catches and was fitted to successful catches of cardinalfish, excluding zero catches. Various diagnostics were used to assess alternative statistical distributions for use in the standardisation model but in this case the dependant variable was log of catch per trawl tow. This model was offered the same explanatory variables as the binomial model.

The explanatory variables offered to the models were: fishing year (always forced as the first variable), month (of landing), zone, fishing method, and a unique vessel identifier. The logs of the depth of net, depth of the bottom, and net headline height were also offered as explanatory variables and the logs of the total duration of fishing, and distance swept were included as measures of effort to explain catch per tow. Forward stepwise selection of model terms was carried out using the Akaike Information Criterion (AIC). Terms were only added to the model if they increased the percent deviance explained by 0.5 %. The year effects were extracted as canonical coefficients so that confidence bounds could be calculated for each year.

These two models were combined into a single set of indices by multiplying the standardised probability of catch series with the standardised magnitude of catch series and the combined indices are included without detailed diagnostics or comment in this report.

2.2 Non fishery data

Data on cardinalfish are available from the Chatham Rise *Tangaroa* bottom trawl survey time series and the mid-east coast survey *Tangaroa* bottom trawl survey for orange roughy. Length and gonad stage data for commercial catches were sourced from the Ministry for Primary Industries Observer Programme.

3. FISHERY CHARACTERISATIONS

The majority of black cardinalfish (CDL) catches were taken in CDL 2 and CDL 1 (Table 1, Figure 1). Catches from extra-territorial waters (ET) peaked at almost 1000 t in 1999–2000 but were then negligible. Due to their low magnitude, catches from ET are not considered further in this report. See Dunn & Bian (2009) for the most recent characterisation of catches from extra-territorial waters. Catches in CDL 3 and CDL 4 were annually less than 100 t since 2004–05.

Most catches were taken by bottom trawling that targeted black cardinalfish or orange roughy (ORH) Figure 2). A smaller proportion of catches were taken by bottom (BT) or midwater (MW) trawling that targeted hoki (HOK) or alfonsino (BYX).

There was a change in the relative contribution of each target species to cardinalfish catches. Prior to and including 1999–2000, most catches were taken from trawl tows targeting orange roughy. Since that time, most catches came from cardinalfish target tows. From 2000–01 to 2013–14, 80% of the catch was taken by bottom trawling that targeted cardinalfish. These changes in target species may be a reflection of real changes in fishing practices but could also reflect changes in reporting behaviours associated with target species (Figure 3).

There was no pronounced seasonality in black cardinalfish catches (Figure 4). However, since 2009–2010, most catches were from the first part of the fishing year, October to May.

Most black cardinalfish was caught between 500 and 1000 m. Catches from CDL target tows peaked at around 750 m whereas the depth distribution of catches from ORH tows was shifted toward deeper waters. The majority of catches of black cardinalfish in tows targeting other species was taken in shallow water around 500 m (Figure 5).

Records of CDL caught as bycatch to HOK and ORH tows are widespread throughout the New Zealand EEZ, but catches are mostly off the east coast of North Island and north-east coast of South Island (Figure 6, Figure 7). Finer spatial areas (zones) were therefore used to characterise the heavily concentrated nature of the black cardinalfish fishery (Figure 8).

Figure 9 summarises the catches by fishing year for each of the nine zones and for all other locations. During the early 1990s, catches were highest in the Tuaheni-High zone, reaching over 1500 t in 1991–92. At the same time there were also substantial catches in the Ritchie-Rockgarden zone. In the mid-1990s catches increased rapidly in the Mercury-Colville, White Island, and East Cape zones. Catches peaked during the 1990s in most zones but then declined.

The depth distribution of cardinalfish catches within the zones is similar to that across all areas. Although the zone polygons are relatively small, they do include habitat which may not be prime cardinalfish habitat. There is a substantial proportion of trawling effort at other depths within the zones (Figure 10).

Table 1: Landings (t) of black cardinalfish by FMA/QMA, 1989–90 to 2013–14. Data source varies by year: landings part of catch effort data, 1989–90 to 1997–98; Quota Management Returns, 1998–99 to 2000–01; Monthly Harvest Returns, 2001–02 to 2013–14. –, no data.

Fishing year	CDL 1	CDL 2	CDL 3	CDL 4	CDL 5	CDL 6	CDL 7	CDL 8	CDL 9	ET
1989	0	0	0	0	0	0	0	0	0	2
1990	597	1 649	20	17	0	0	15	0	0	1
1991	233	3 471	598	1	1	0	1	0	0	0
1992	7	1 651	146	3	0	2	11	0	0	17
1993	21	1 319	475	2	0	0	1	0	0	270
1994	364	2 311	290	10	4	0	6	0	0	829
1995	1 056	2 183	46	6	1	0	46	0	0	231
1996	1 418	2 616	57	4	10	0	26	0	0	340
1997	2 001	1 911	100	7	0	0	27	0	0	522
1998	1 094	1 191	43	33	0	0	22	0	0	405
1999	24	1 269	181	41	0	0	16	0	0	390
2000	980	2 158	215	36	0	0	27	0	0	962
2001	294	1 135	99	35	74	0	2	0	3	571
2002	455	1 693	146	29	18	0	3	0	5	490
2003	583	1 845	172	80	9	0	27	0	5	275
2004	481	966	96	148	27	0	2	0	6	58
2005	267	1 102	43	49	15	1	2	0	1	204
2006	643	2 153	50	53	0	0	1	0	2	44
2007	415	1 692	66	31	10	0	1	0	1	2
2008	202	861	7	23	20	0	2	0	19	1
2009	197	1 135	52	58	11	0	1	0	2	17
2010	49	1 046	45	15	3	0	0	0	5	0
2011	84	736	17	19	5	0	1	0	1	0
2012	148	376	79	44	93	1	0	0	0	0
2013	35	470	40	10	14	1	2	0	4	0
2014	160	282	68	11	19	0	1	0	1	–

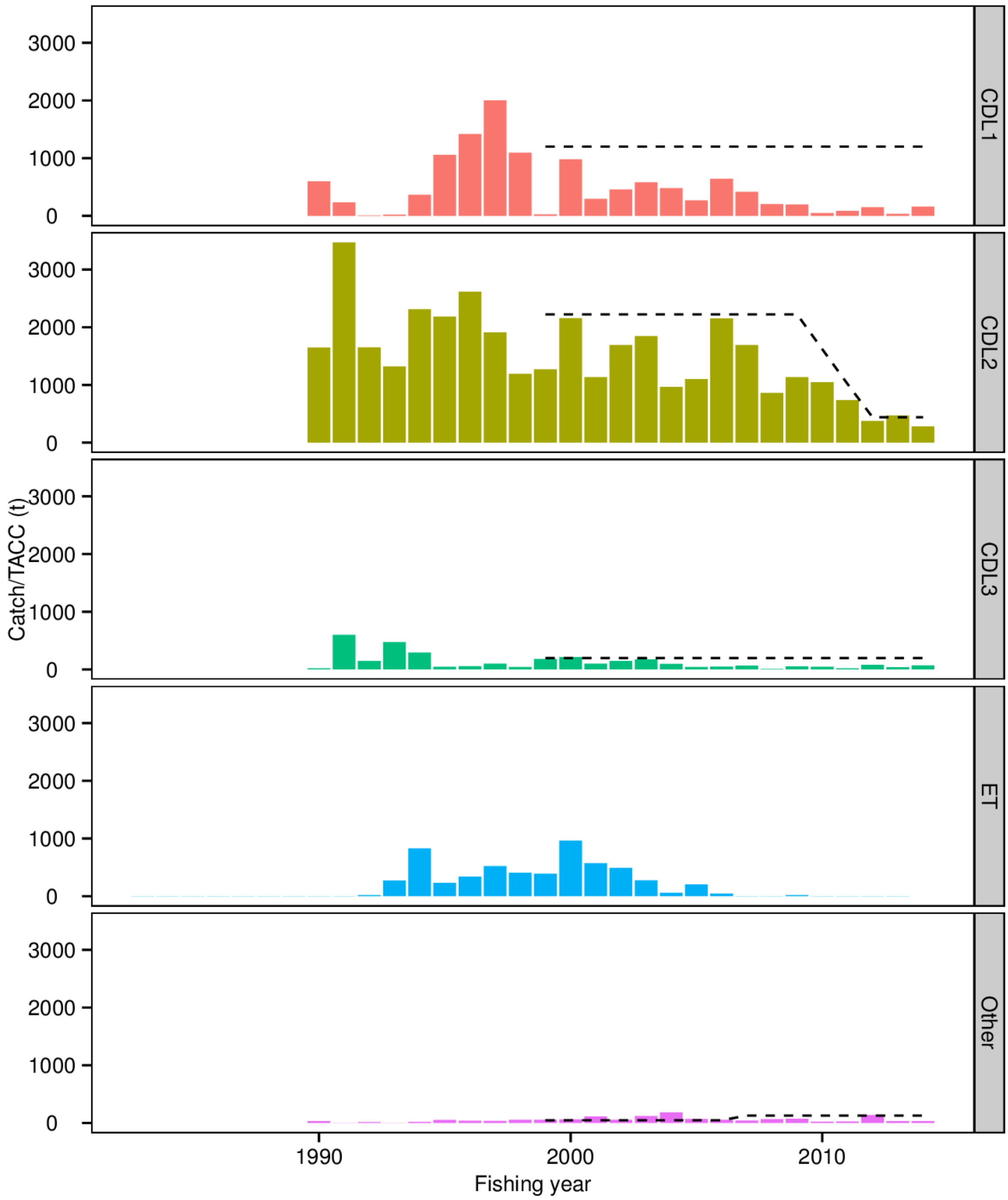

Figure 1: Annual catch of black cardinalfish by quota management area, 1989–90 to 2013–14. Data source varies by year: landings part of catch effort data, 1989–90 to 1997–98; Quota Management Returns, 1998–99 to 2000–01; Monthly Harvest Returns, 2001–02 to 2013–14. TACC (t), dashed line.

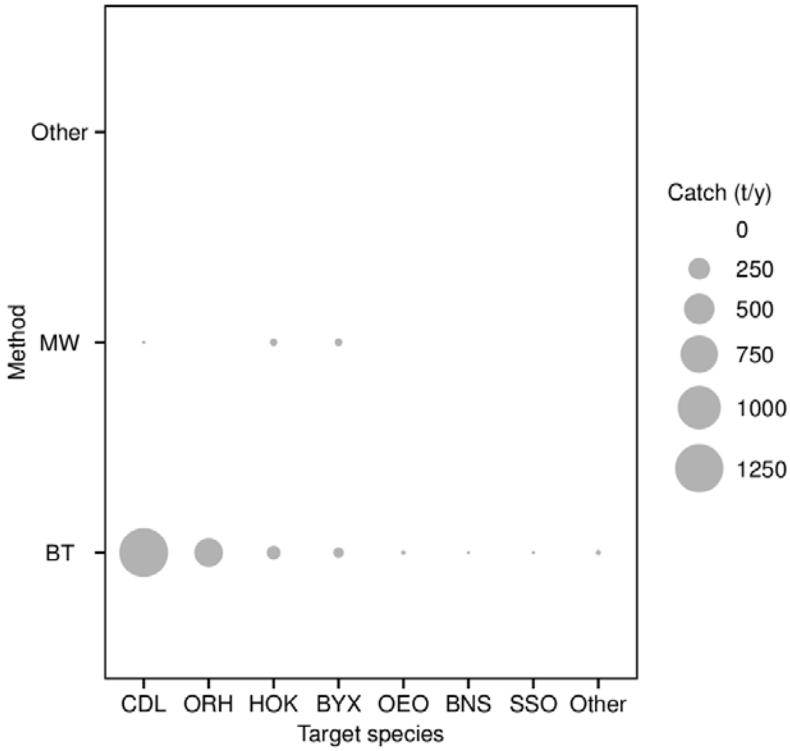

Figure 2: Mean annual catch (t) of black cardinalfish by fishing method and target species, 1989–90 to 2013–14.

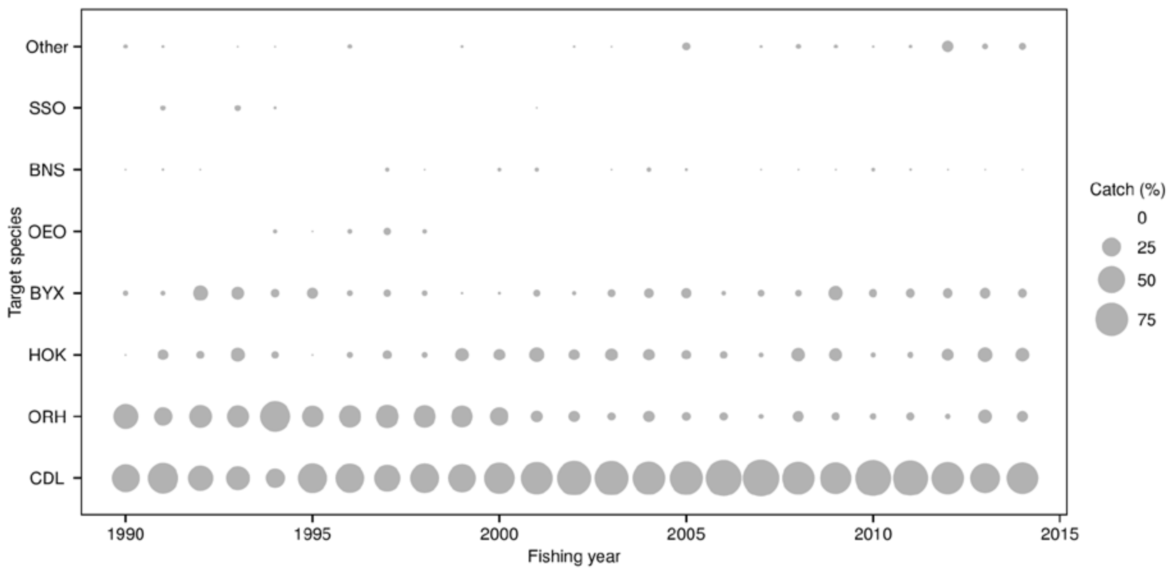

Figure 3: Catch of black cardinalfish by target species in each fishing year, 1989–90 to 2013–14.

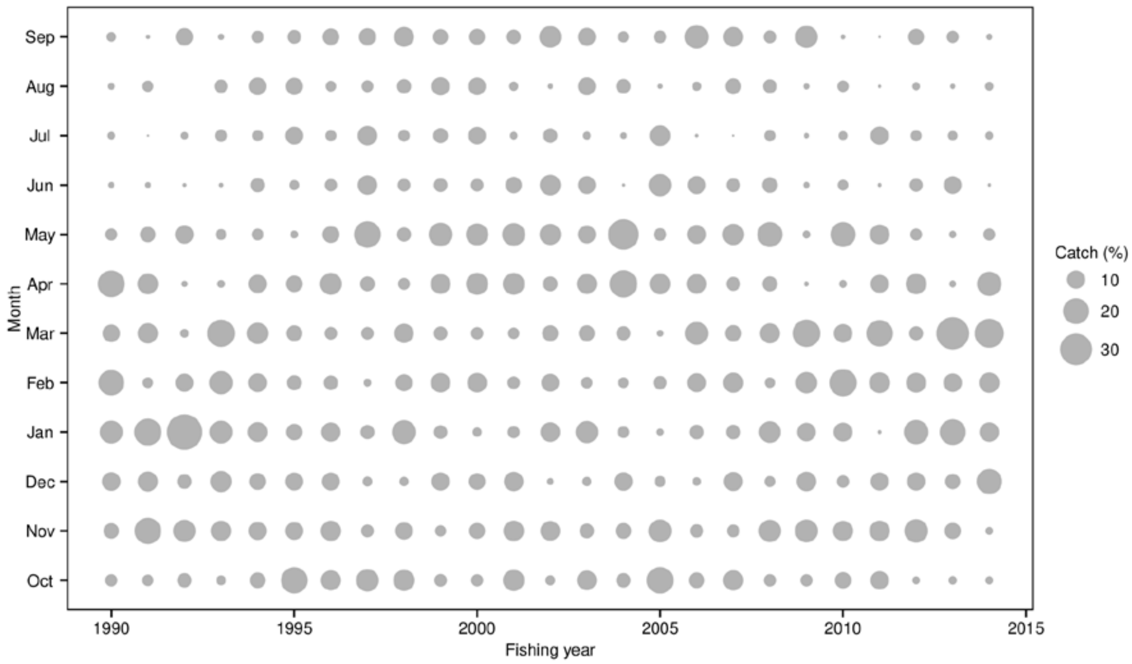

Figure 4: Catch of black cardinalfish by month in each fishing year, 1989–90 to 2013–14.

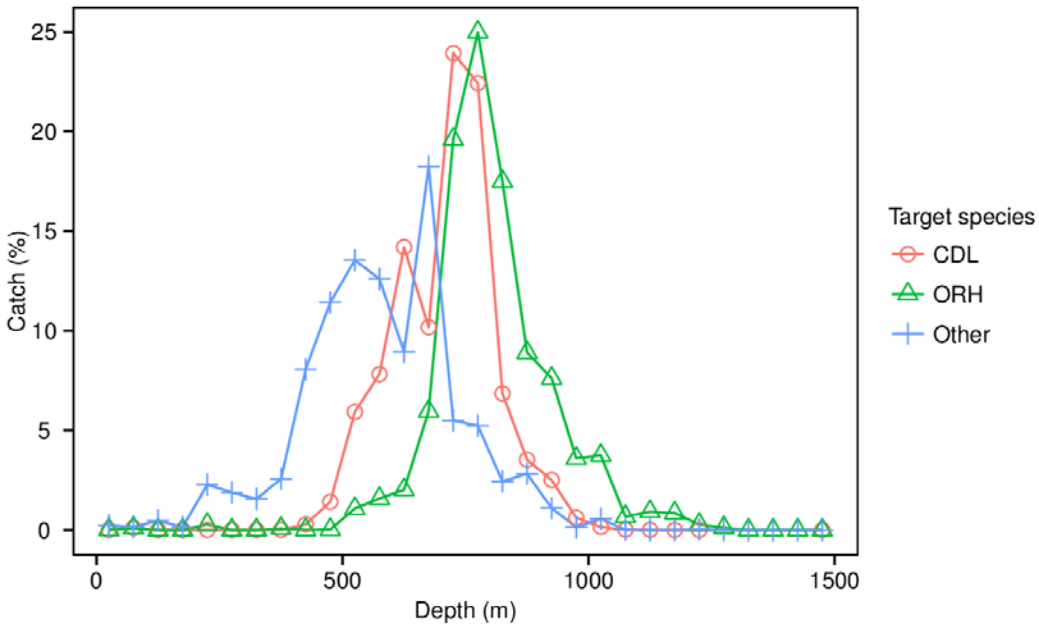

Figure 5: Distributions of black cardinalfish catch from trawling by depth and target species, 1989–90 to 2013–14. The depth of tows are binned into 50 m intervals. The percentage is calculated across each target species.

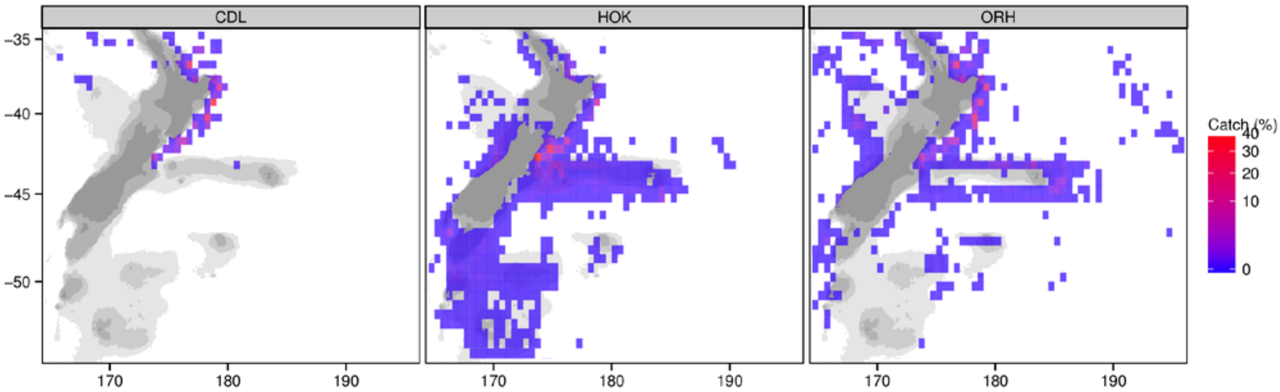

Figure 6: Percentage of black cardinalfish catch by 0.5 degree cell for the three main target species, 1989–90 to 2013–14. The percentage is calculated across a target species. Only cells with at least 3 records are shown.

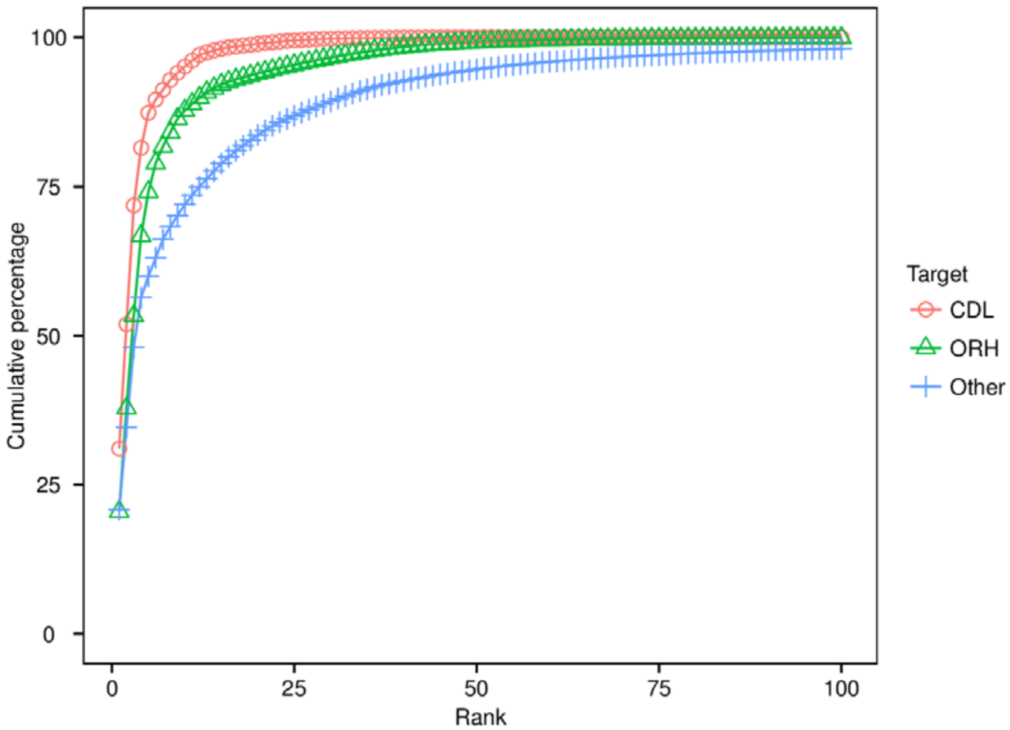

Figure 7: Cumulative percentage of cardinalfish catch by 0.5 degree cell for CDL, ORH and other target trawl tows.

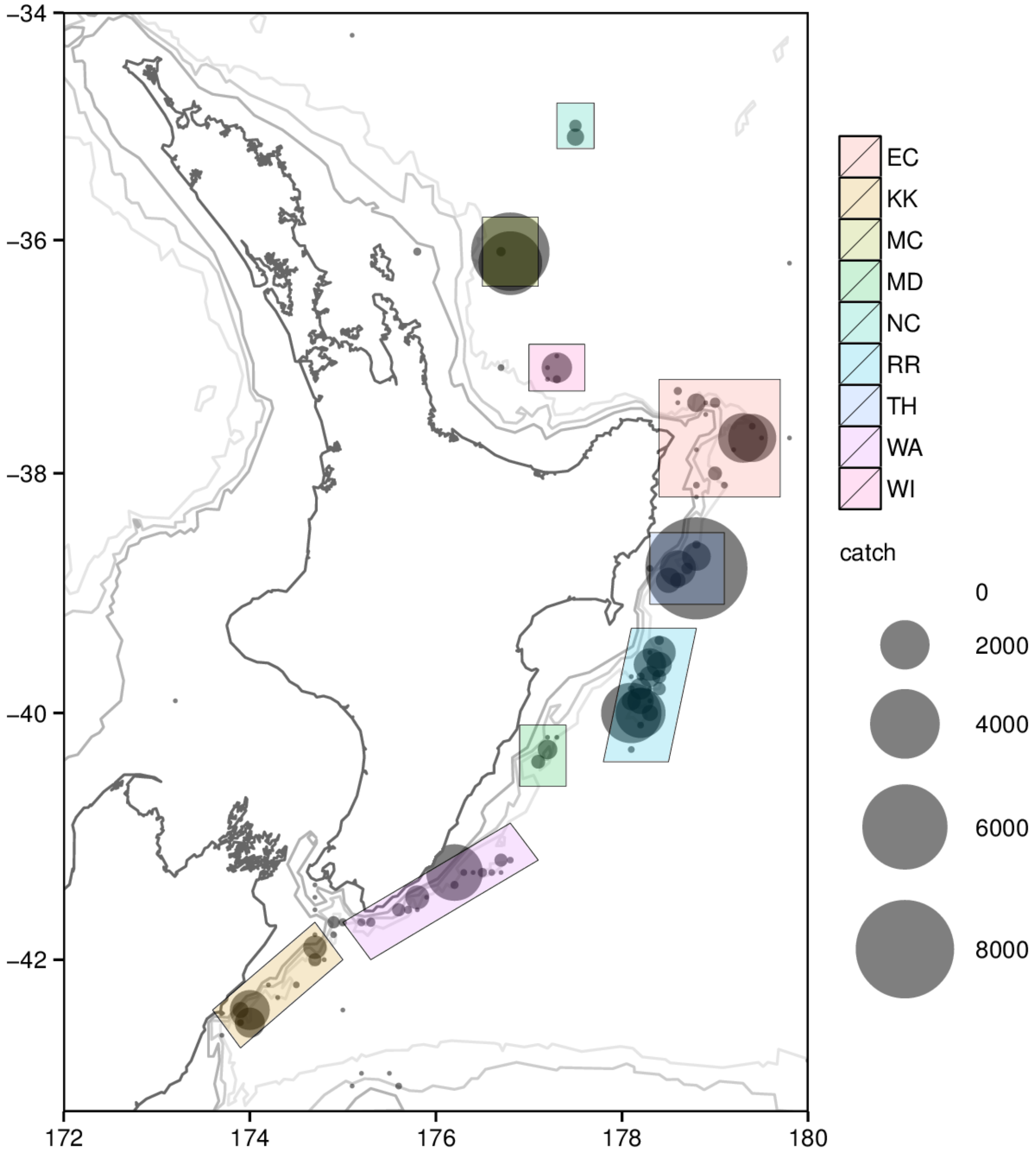

Figure 8: Zone polygons for cardinalfish catch and descriptive CPUE. Cumulative catch (t) 1989–90 to 2013–14. From top down (North to South), NC North Colville, MC Mercury-Colville, WI White Island, EC East Cape, TH Tuahine High, RR Ritchie-Rockgarden, MD Madden, WA Wairarapa, KK Kaikoura.

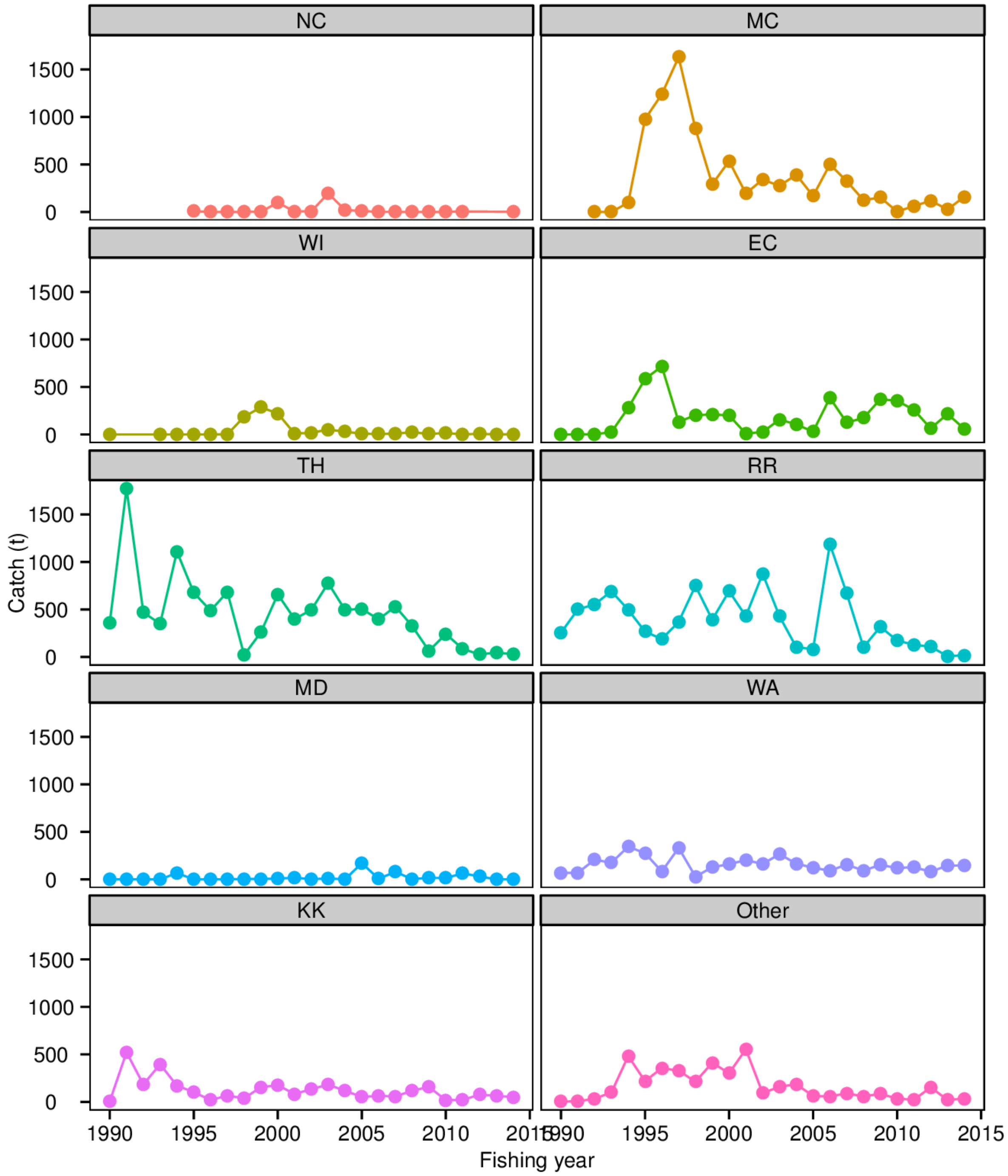

Figure 9: Annual catches (t) 1989–90 to 2013–14 by zone. NC North Colville, MC Mercury-Colville, WI White Island, EC East Cape, TH Tuahine High, RR Ritchie-Rockgarden, MD Madden, WA Wairarapa, KK Kaikoura.

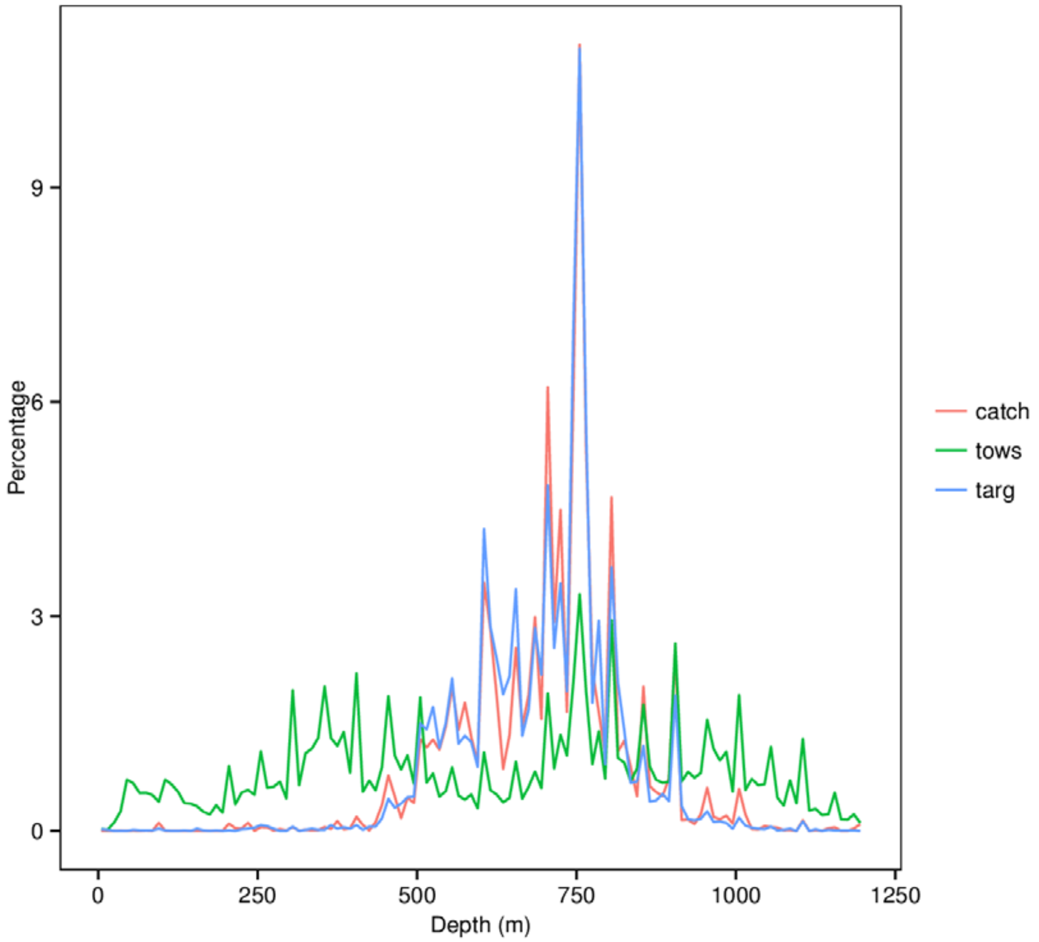

Figure 10: Depth distribution inside the defined zones of cardinalfish catch, tows that recorded a cardinalfish catch, and target (CDL) tows.

The following summaries of the areas of prime interest were produced by only including trawl tows from 470–980 m. This depth range encompasses 95% of the catch.

For each of the zones we present two figures that characterise the fishery from 1989–90 to 2013–14 in that zone. The first figure provides annual summaries of key statistics separated into five panels:

- Vessels – the number of tows by vessel (restricted to vessels that made at least 30 tows in the zone across all years); the number of vessels operating in a zone and the predominance of each.
- Tows – the number of tows by target species; the magnitude of effort, and the relative contribution of recorded target species.
- Catch (t) – the catch of cardinalfish by reported target species; the magnitude of catch, and the relative contribution of recorded target species.
- Caught (%) – the percentage of tows that caught cardinalfish for CDL target tows (red circles), ORH target tows (green triangles) and all target species combined (blue crosses). Size of the symbols is proportional to the number of tows.
- CPUE (t/tow) – the geometric mean of the catch of black cardinalfish per tow; "Caught (%)" values are provided for CDL, ORH and all target tows.

The second figure is the spatial distribution of tows and their catch per unit effort. These show if the pattern of exploitation is consistent with serial depletion i.e., fishing effort moving away from one location to another location once catch rates have fallen. Each circle in this figure represents the geometric mean of catch per tow for each 0.01 degree cell, i.e., only includes tows that caught cardinalfish. Each panel represents a separate period, 1989–90 to 1997–98, 1998–99 to 2008–09 and 2009–10 to 2013–14. Only locations where there were at least 30 tows within the period are shown.

3.1 North Colville (NC)

One vessel accounted for most of the effort. From 1999–2000 to 2004–05 most of the effort was targeted on CDL with a smaller proportion of ORH target tows. Catch quantities varied substantially from one year to the next. In the early to mid-2000s there was a general reduction in both the percentage of tows that caught cardinalfish and the catch per tow of cardinalfish. Both of these quantities increased in 2009–10 after a period of reduced fishing effort (Figure 11, Figure 12).

3.2 Mercury-Colville (MC)

Ten vessels had more than 30 tows within this zone, although most of the catch history was attributable to two vessels. The number of tows and the catch peaked in 1996–97 to 1997–98 and most effort was directed at orange roughy. Since the late 1990s, both effort and catches declined and most effort was directed towards cardinalfish. There was a general, although fluctuating, decline in the proportion of tows that caught cardinalfish. There was also a substantial decline in the unstandardised CPUE, from around 1 t per tow in the mid 1990s, to less than 0.1 t per tow in 2009–10 (Figure 13). There is no evidence of serial depletion within the Mercury-Colville zone at the scales examined. Catches were concentrated on a specific underwater feature and CPUE decreased on this feature over time (Figure 14).

3.3 White Island (WI)

The historical pattern of effort and catches was similar to that for Mercury-Colville. Both the number of tows and catch peaked in the late 1990s. Most of the effort was targeted at orange roughy. There was a large variation in the proportion of tows which caught CDL but a decline in the catch per tow (Figure 15).

There was some change in fishing location over time. During the 2000s, a considerable proportion of the tows were located on an underwater feature to the south of the original feature fished (Figure 16).

3.4 East Cape (EC)

A relatively large number of vessels have fished the zone over the past 20 years. However, since 2008–09, most of the effort was by four vessels. During the mid to late 1990s effort peaked with most tows targeted at orange roughy. There was a shift to greater targeting of CDL and catches of black cardinalfish have remained at similar levels (Figure 17).

The proportion of tows catching black cardinalfish was consistently higher for CDL target tows than for ORH target tows and remained relatively consistent at around 50% in contrast to other zones. There was a reduction in unstandardised CPUE from 1993–94 to 2000–01 for CDL target tows, but CPUE has since fluctuated without trend (Figure 17).

From 2009–10 to 2013–14, there was a contraction of fishing effort to the main features historically fished (Figure 18).

3.5 Tuaheni High (TH)

This zone contributed most of the New Zealand black cardinalfish catch during the early 1990s, with most taken from CDL target tows, particularly since the early 2000s. Both the effort and catch has declined substantially since the mid-2000s (Figure 19).

The proportion of CDL target tows which caught cardinalfish fluctuated from 25–75% over time. There was a substantial decline in unstandardised CPUE from a high of more than 10 t per tow in 1991–92 to less than 0.1 t per tow in 2011–12 (Figure 19).

There is some evidence of "exploratory" fishing on other features during the 2000s. But most tows since then were conducted on the main Tuaheni High feature (Figure 20).

3.6 Ritchie-Rockgarden (RR)

A large number of vessels fished in this zone. However, since 2007–08, most of the effort was from only two vessels. During the 1990s, most tows targeted orange roughy. There was an increasing proportion of tows that targeted CDL during the early to mid-2000s and a corresponding increase in CDL catch (Figure 21).

Most effort was on the Rockgarden area. This feature also had the highest catch rates. With the reduction of effort the remaining effort was largely restricted to this feature (Figure 22).

3.7 Madden (MD)

The effort in this zone was mostly targeted at species other than black cardinalfish. However, in some years, particularly 2004–05, cardinalfish catches were substantial (Figure 23, Figure 24).

3.8 Wairarapa (WA)

Catches primarily came from tows reported as targeting CDL although tows mostly target other species. Catches remained around 100 t since the early 2000s (Figure 25). There was a reduction in number of vessels fishing in the zone and a contraction in the location of tows catching CDL to the feature with the highest CPUE (Figure 26).

3.9 Kaikoura (KK)

There was very little targeting of cardinalfish. Catches were sporadic and mainly as bycatch from hoki target trawling (Figure 27). There was a reduction in the unstandardised CPUE from over 1 t per tow during the early 1990s to almost 0.1 t per tow by the late 1990s. However since that time, catch rates have increased and stabilised. Over time, the number of tows declined and were concentrated at specific locations (Figure 28).

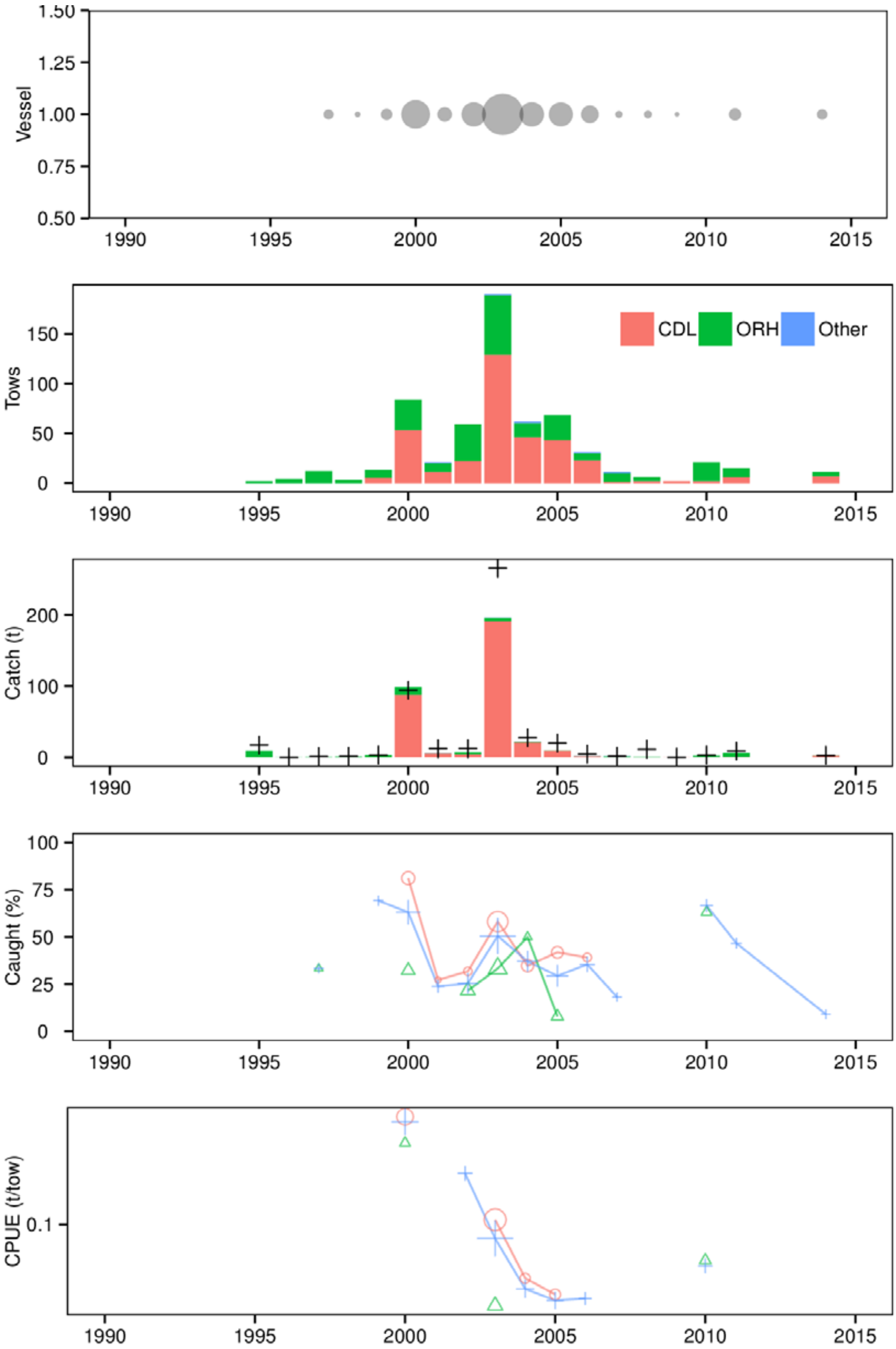

Figure 11: Annual summary for the North Colville (NC) zone. a) The number of tows by vessel, b) number of tows by target species, c) catch by target species, bars represent the estimated catches, crosses represent the catch based on allocated landings, d) the percentage of tows that caught cardinalfish by target, target tows (red circles), ORH target tows (green triangles) and all target species combined (blue crosses), size of the symbols is proportional to the number of tows. e) CPUE geometric mean of catch (t) per tow by target, symbols as in d).

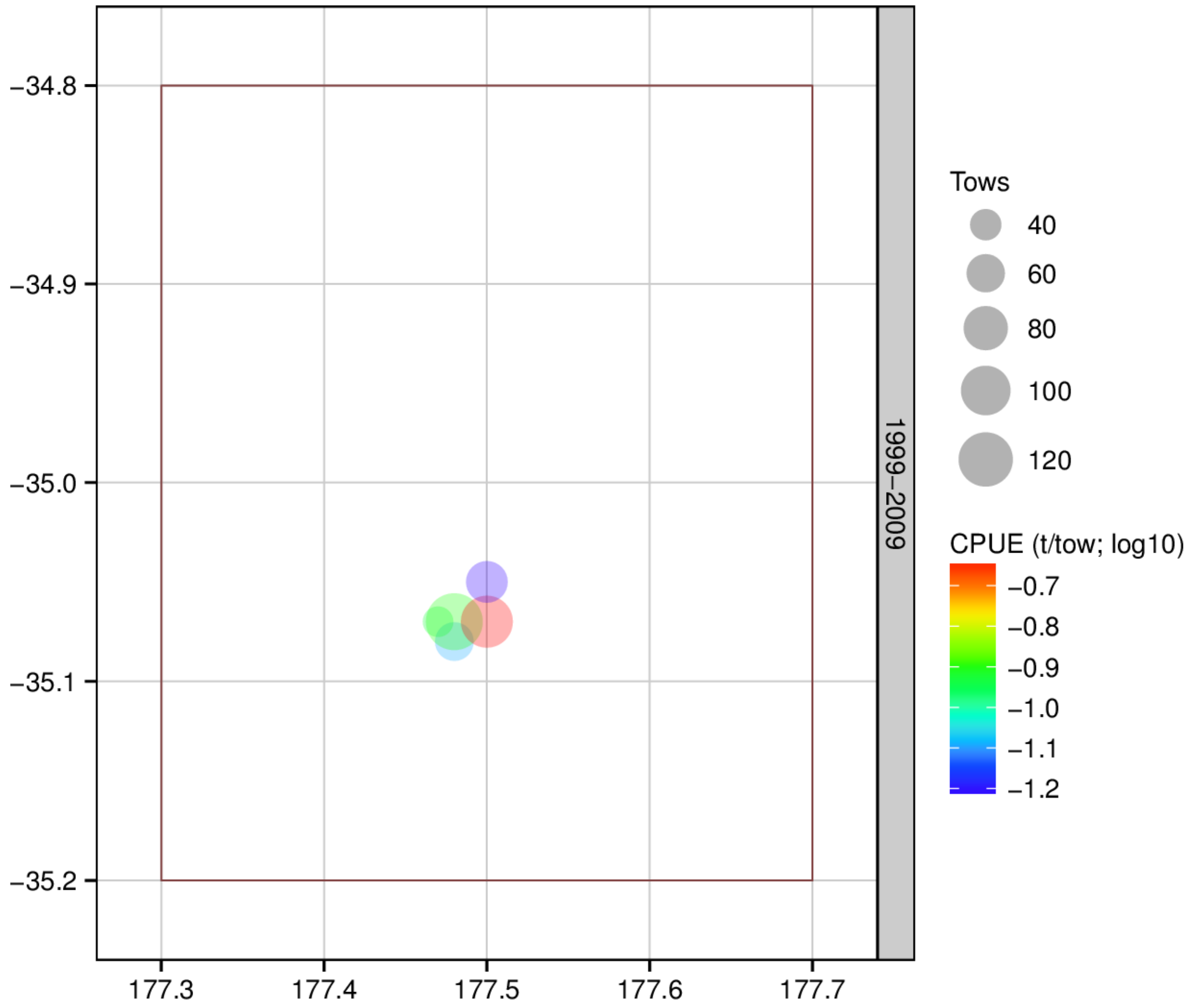

Figure 12: Number of tows and geometric mean CPUE by latitude and longitude (0.01 degree cells) for the North Colville (NC) zone over three periods; 1989–90 to 1997–98, 1998–99 to 2008–09, and 2009–10 to 2013–14. Only locations where there were at least 30 tows within the period are shown.

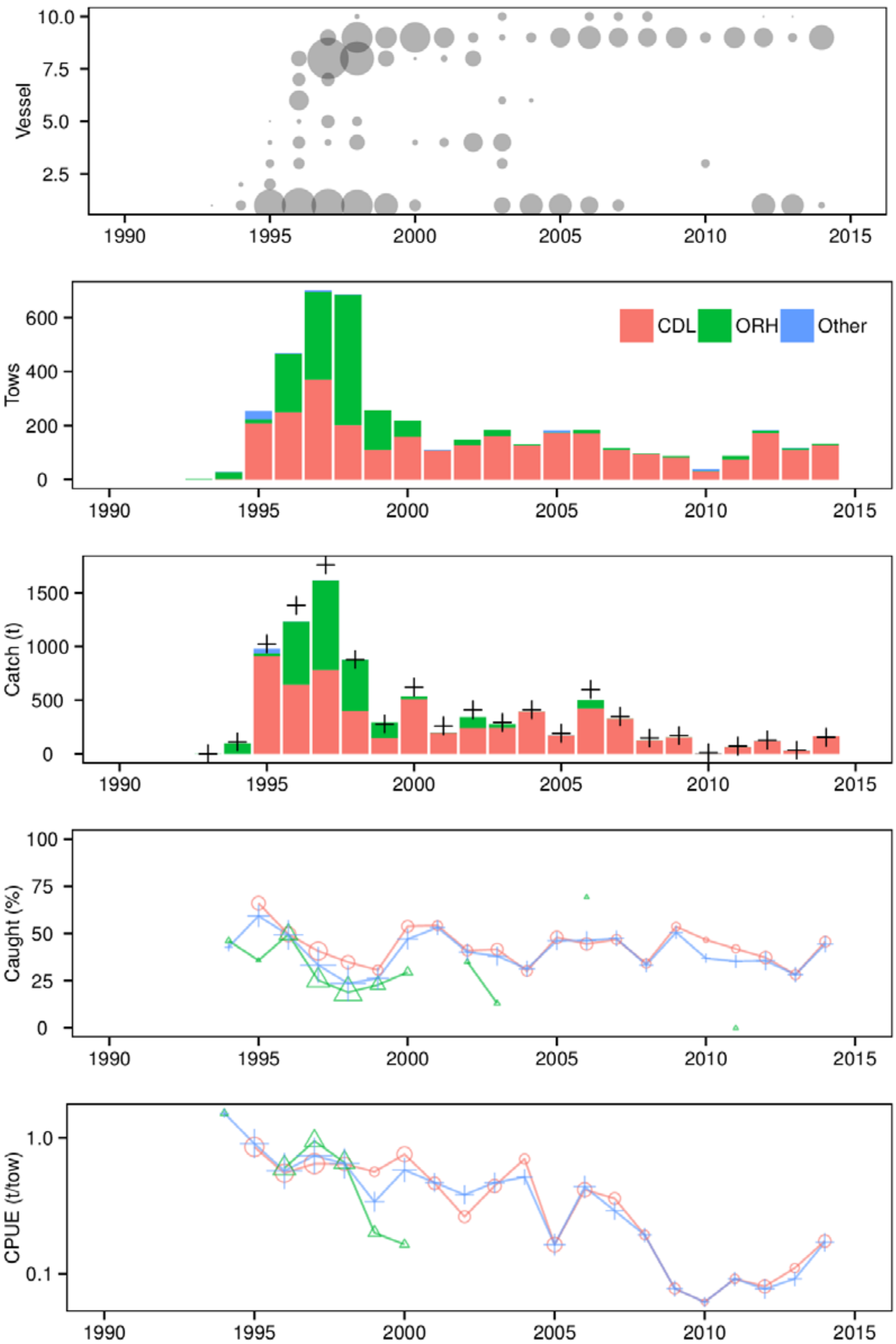

Figure 13: Annual summary for the Mercury-Colville (MC) zone. a) The number of tows by vessel, b) number of tows by target species, c) catch by target species, bars represent the estimated catches, crosses represent the catch based on allocated landings, d) the percentage of tows that caught cardinalfish by target, target tows (red circles), ORH target tows (green triangles) and all target species combined (blue crosses), size of the symbols is proportional to the number of tows. e) CPUE geometric mean of catch (t) per tow by target, symbols as in d).

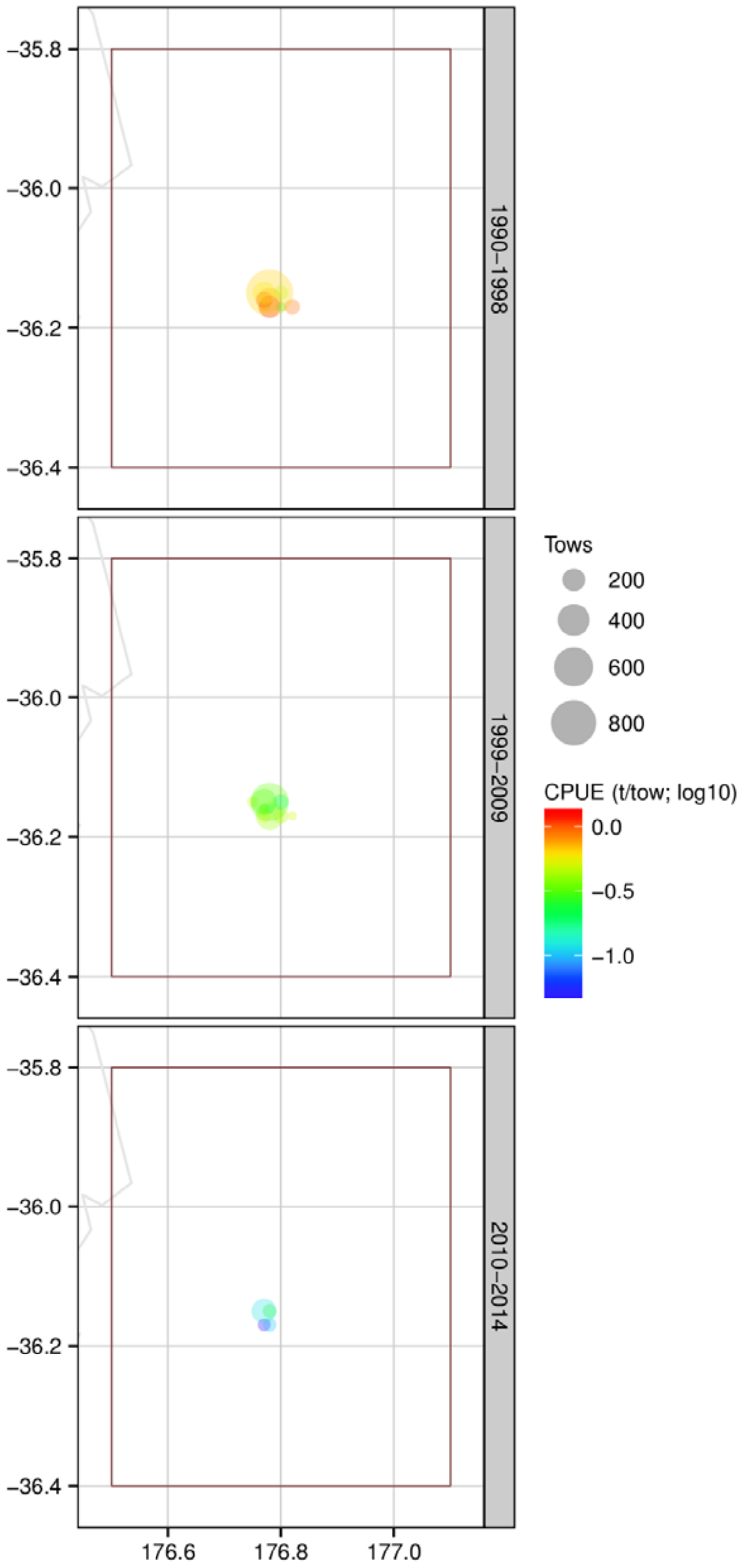

Figure 14: Number of tows and geometric mean CPUE by latitude and longitude (0.01 degree cells) for the Mercury-Colville (MC) zone over three periods; 1989–90 to 1997–98, 1998–99 to 2008–09, and 2009–10 to 2013–14. Only locations where there were at least 30 tows within the period are shown.

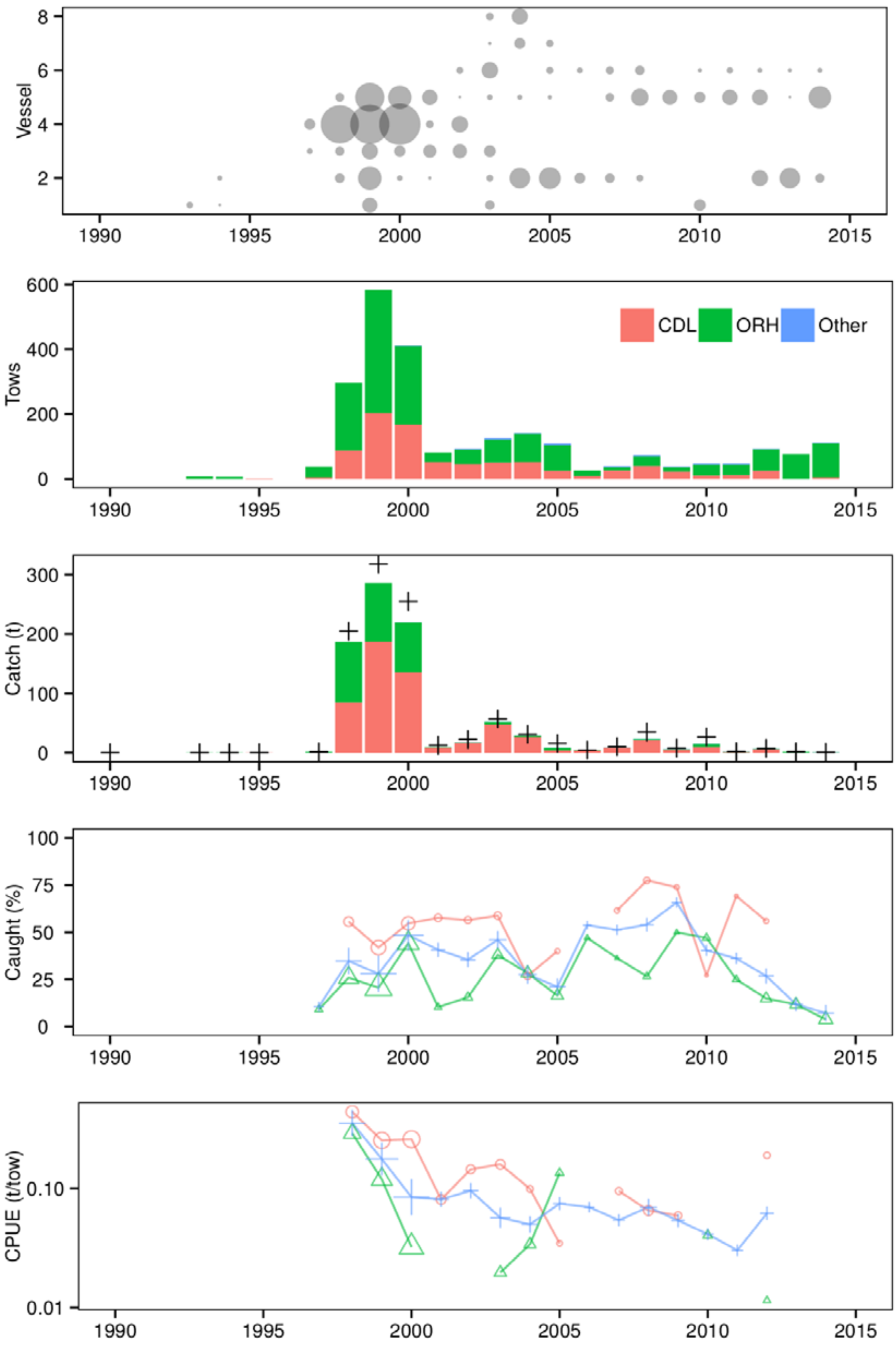

Figure 15: Annual summary for the White Island (WI) zone. a) The number of tows by vessel, b) number of tows by target species, c) catch by target species, bars represent the estimated catches, crosses represent the catch based on allocated landings, d) the percentage of tows that caught cardinalfish by target, target tows (red circles), ORH target tows (green triangles) and all target species combined (blue crosses), size of the symbols is proportional to the number of tows. e) CPUE geometric mean of catch (t) per tow by target, symbols as in d).

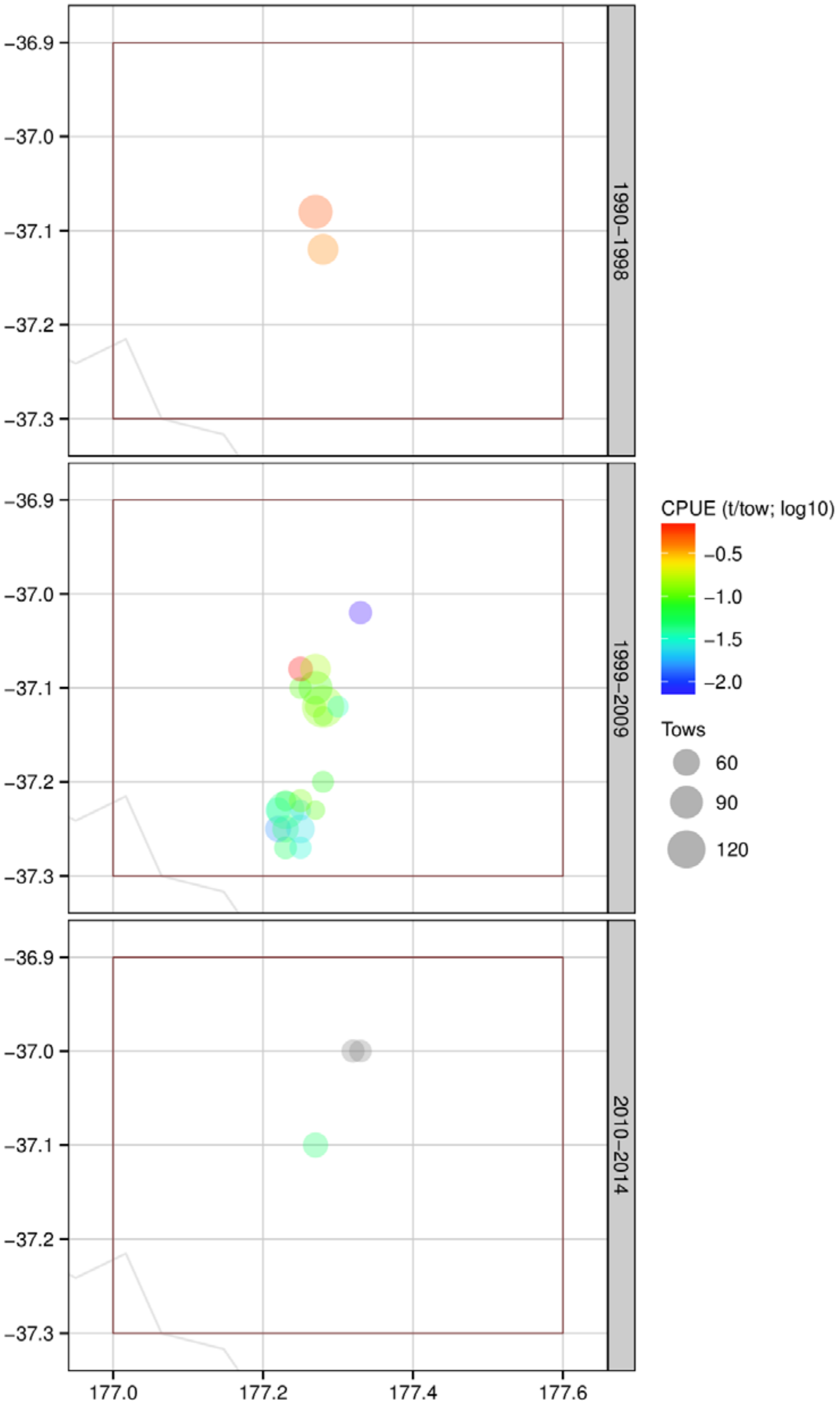

Figure 16: Number of tows and geometric mean CPUE by latitude and longitude (0.01 degree cells) for the White Island (WI) zone over three periods; 1989–90 to 1997–98, 1998–99 to 2008–09, and 2009–10 to 2013–14. Only locations where there were at least 30 tows within the period are shown.

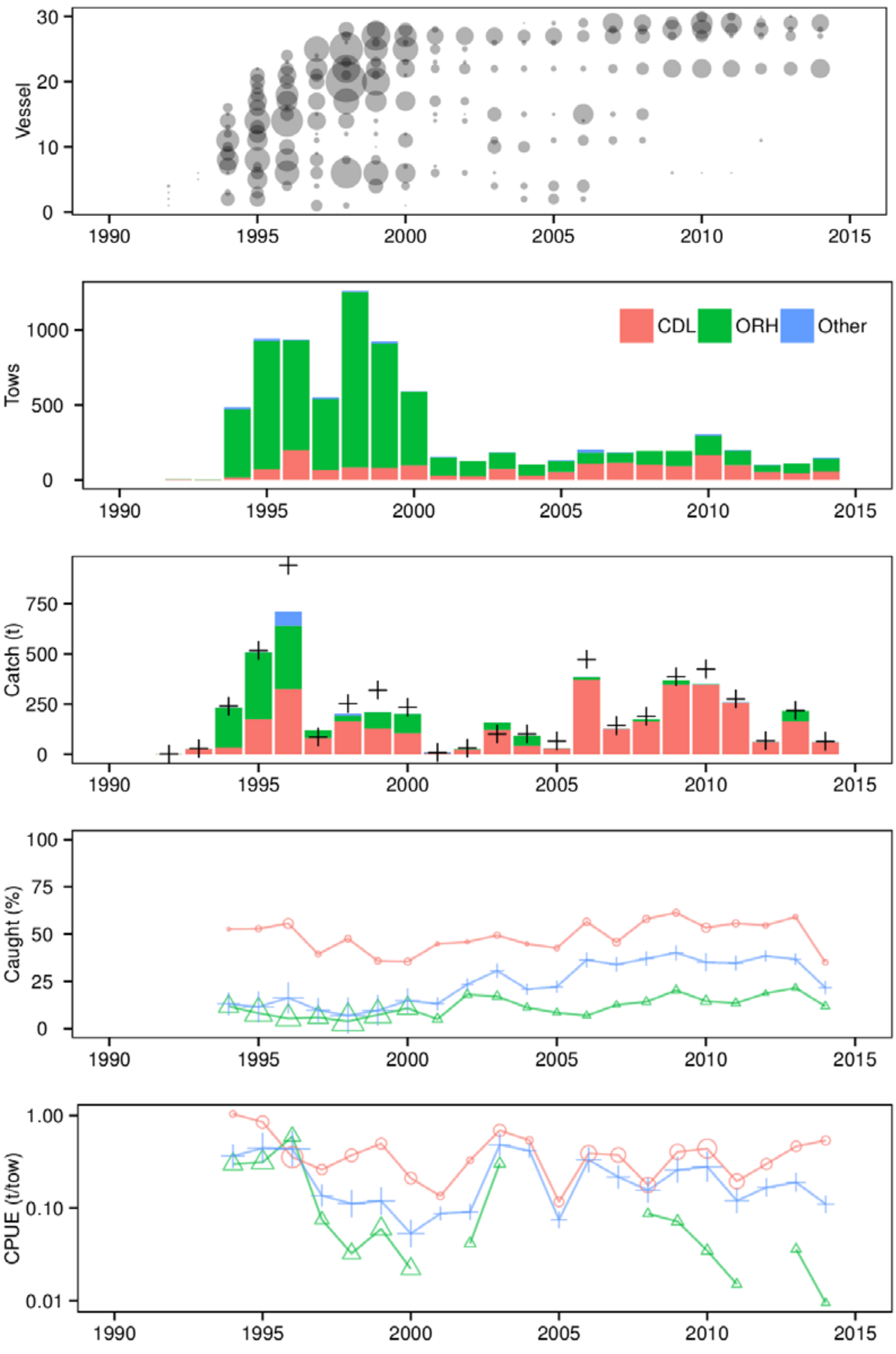

Figure 17: Annual summary for the East Cape (EC) zone. a) The number of tows by vessel, b) number of tows by target species, c) catch by target species, bars represent the estimated catches, crosses represent the catch based on allocated landings, d) the percentage of tows that caught cardinalfish by target, target tows (red circles), ORH target tows (green triangles) and all target species combined (blue crosses), size of the symbols is proportional to the number of tows. e) CPUE geometric mean of catch (t) per tow by target, symbols as in d).

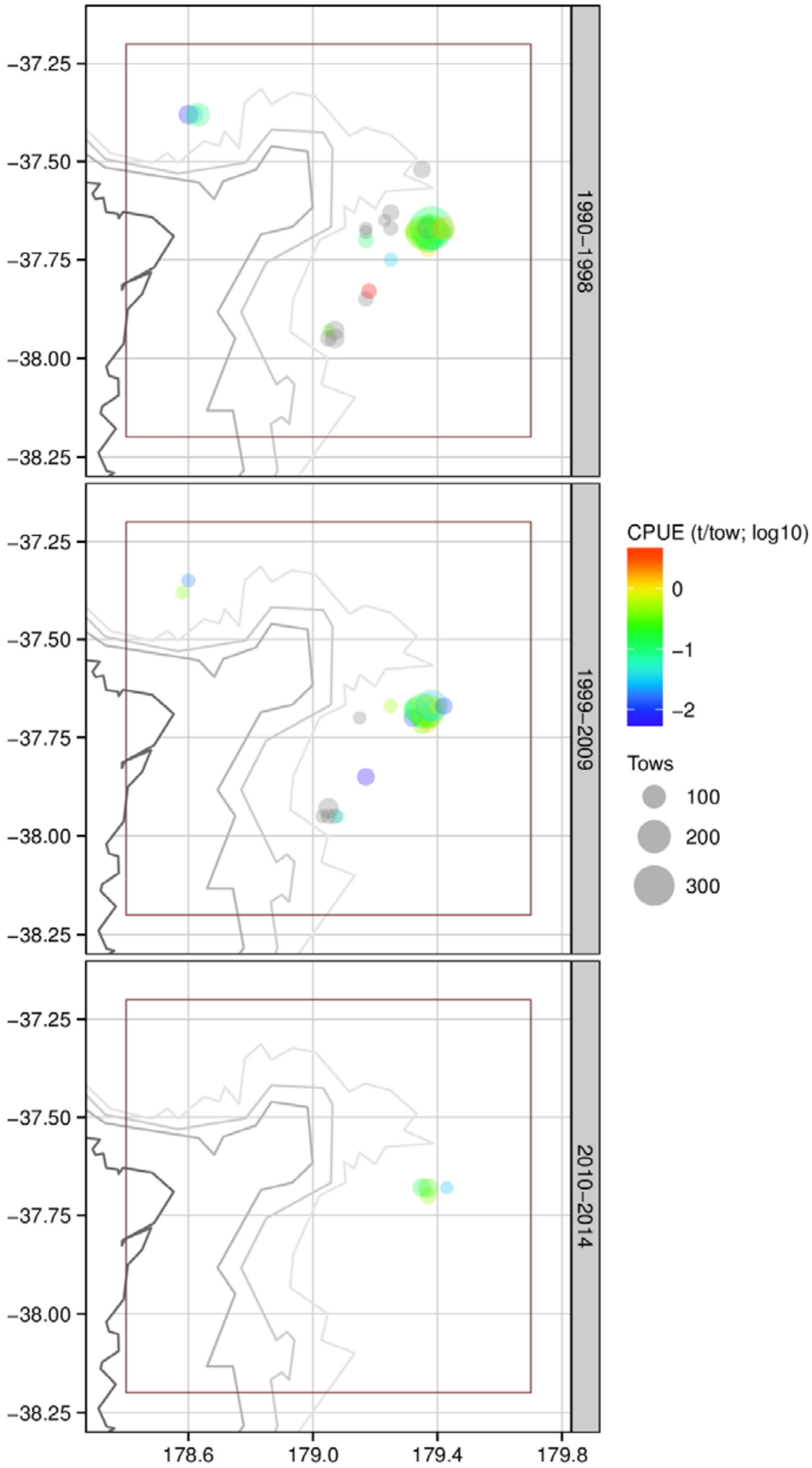

Figure 18: Number of tows and geometric mean CPUE by latitude and longitude (0.01 degree cells) for the East Cape (EC) zone over three periods; 1989–90 to 1997–98, 1998–99 to 2008–09, and 2009–10 to 2013–14. Only locations where there were at least 30 tows within the period are shown.

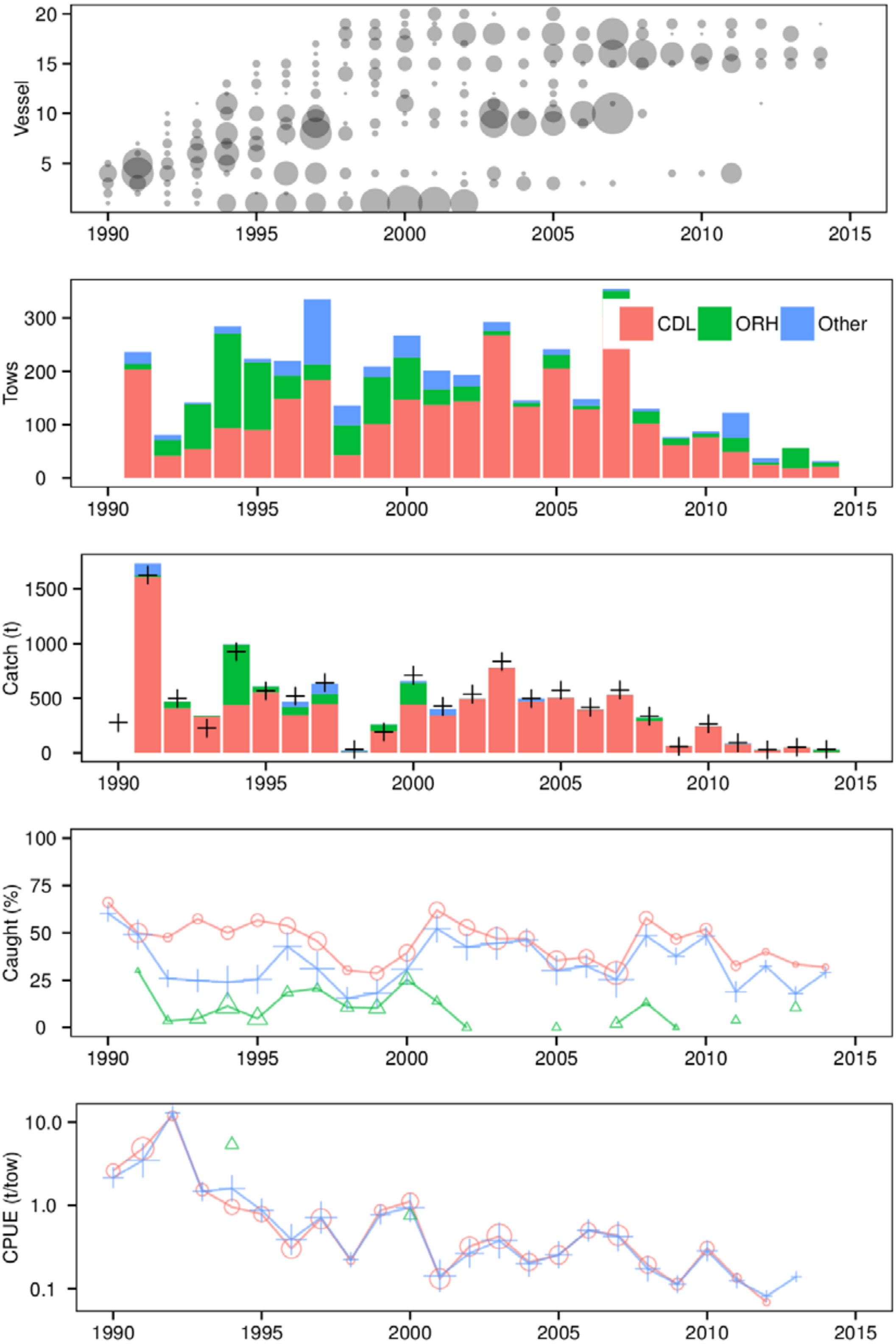

Figure 19: Annual summary for the Tuahine High (TH) zone. a) The number of tows by vessel, b) number of tows by target species, c) catch by target species, bars represent the estimated catches, crosses represent the catch based on allocated landings, d) the percentage of tows that caught cardinalfish by target, target tows (red circles), ORH target tows (green triangles) and all target species combined (blue crosses), size of the symbols is proportional to the number of tows. e) CPUE geometric mean of catch (t) per tow by target, symbols as in d).

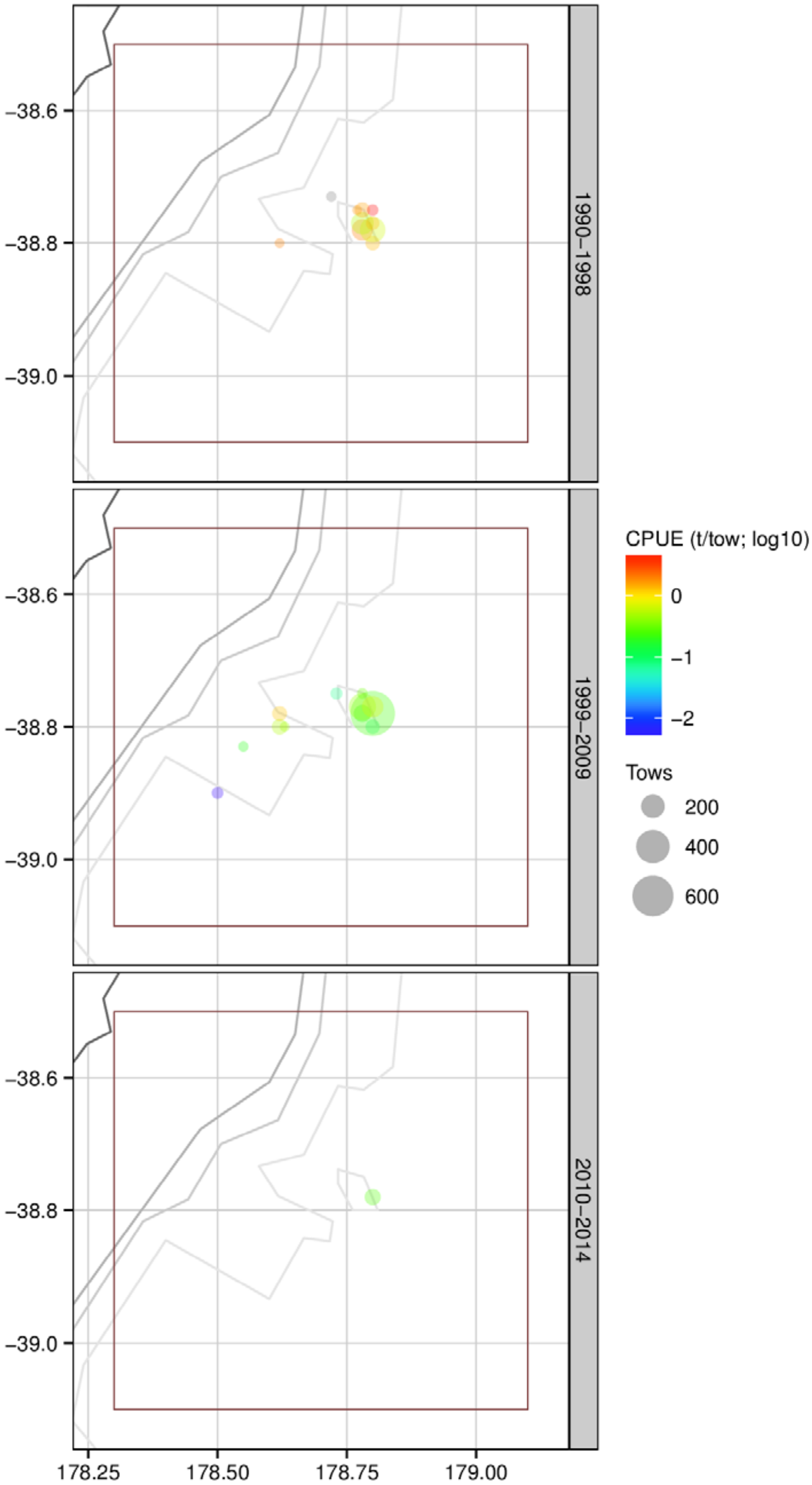

Figure 20: Number of tows and geometric mean CPUE by latitude and longitude (0.01 degree cells) for the Tuahine High (TH) zone over three periods; 1989–90 to 1997–98, 1998–99 to 2008–09, and 2009–10 to 2013–14. Only locations where there were at least 30 tows within the period are shown.

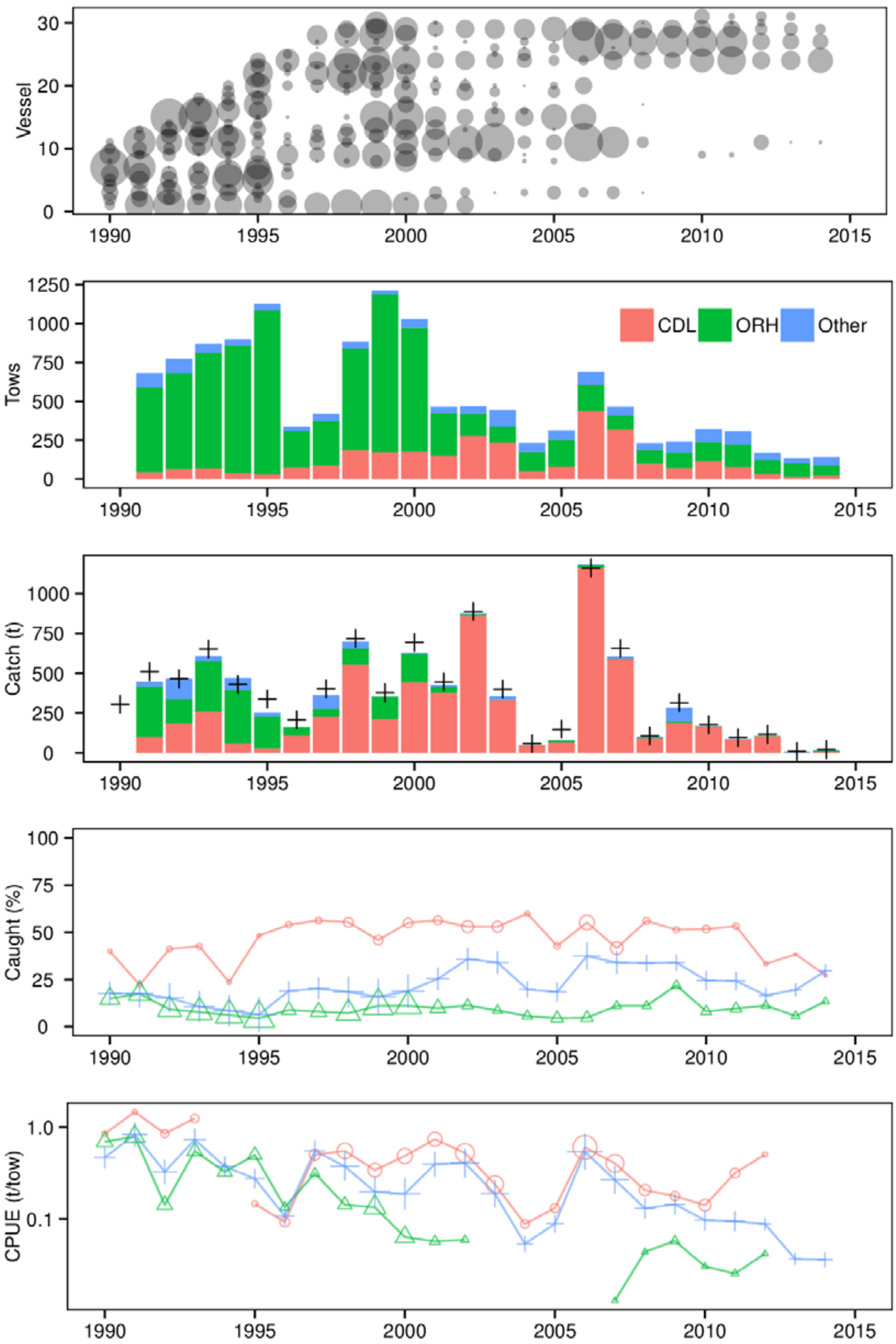

Figure 21: Annual summary for the Ritchie-Rockgarden (RR) zone. a) The number of tows by vessel, b) number of tows by target species, c) catch by target species, bars represent the estimated catches, crosses represent the catch based on allocated landings, d) the percentage of tows that caught cardinalfish by target, target tows (red circles), ORH target tows (green triangles) and all target species combined (blue crosses), size of the symbols is proportional to the number of tows. e) CPUE geometric mean of catch (t) per tow by target, symbols as in d).

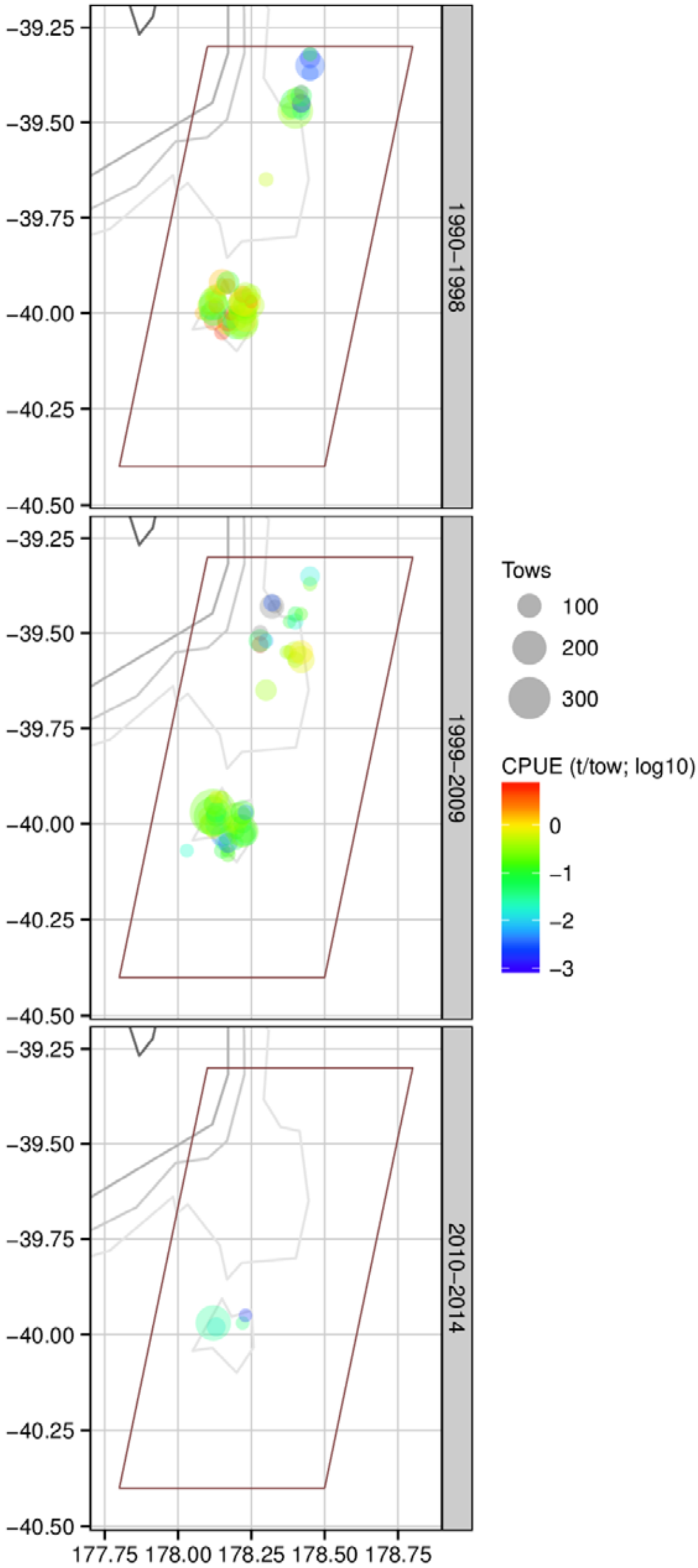

Figure 22: Number of tows and geometric mean CPUE by latitude and longitude (0.01 degree cells) for the Ritchie-Rockgarden (RR) zone over three periods; 1989–90 to 1997–98, 1998–99 to 2008–09, and 2009–10 to 2013–14. Only locations where there were at least 30 tows within the period are shown.

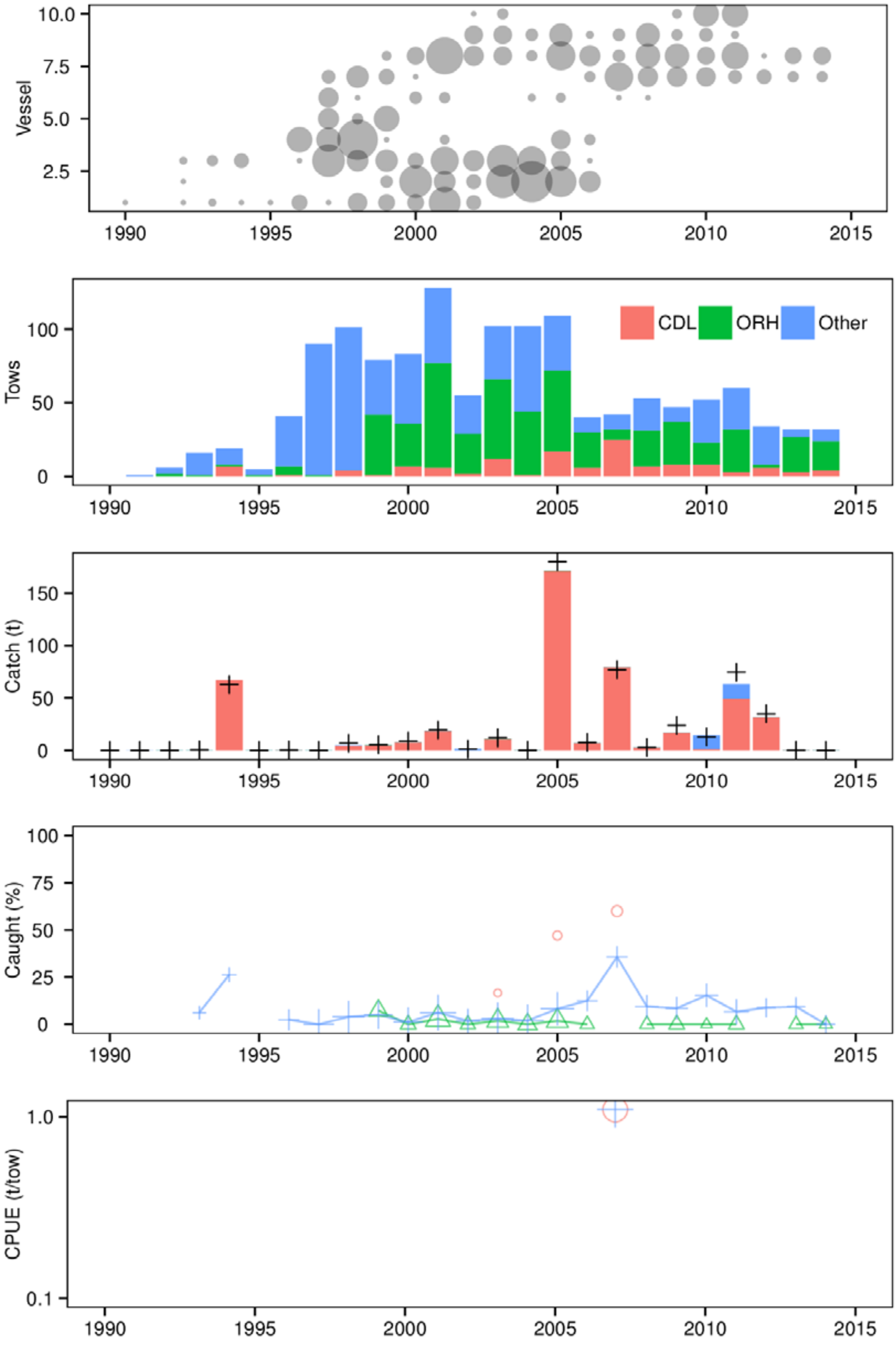

Figure 23: Annual summary for the Madden (MD) zone. a) The number of tows by vessel, b) number of tows by target species, c) catch by target species, bars represent the estimated catches, crosses represent the catch based on allocated landings, d) the percentage of tows that caught cardinalfish by target, target tows (red circles), ORH target tows (green triangles) and all target species combined (blue crosses), size of the symbols is proportional to the number of tows. e) CPUE geometric mean of catch (t) per tow by target, symbols as in d).

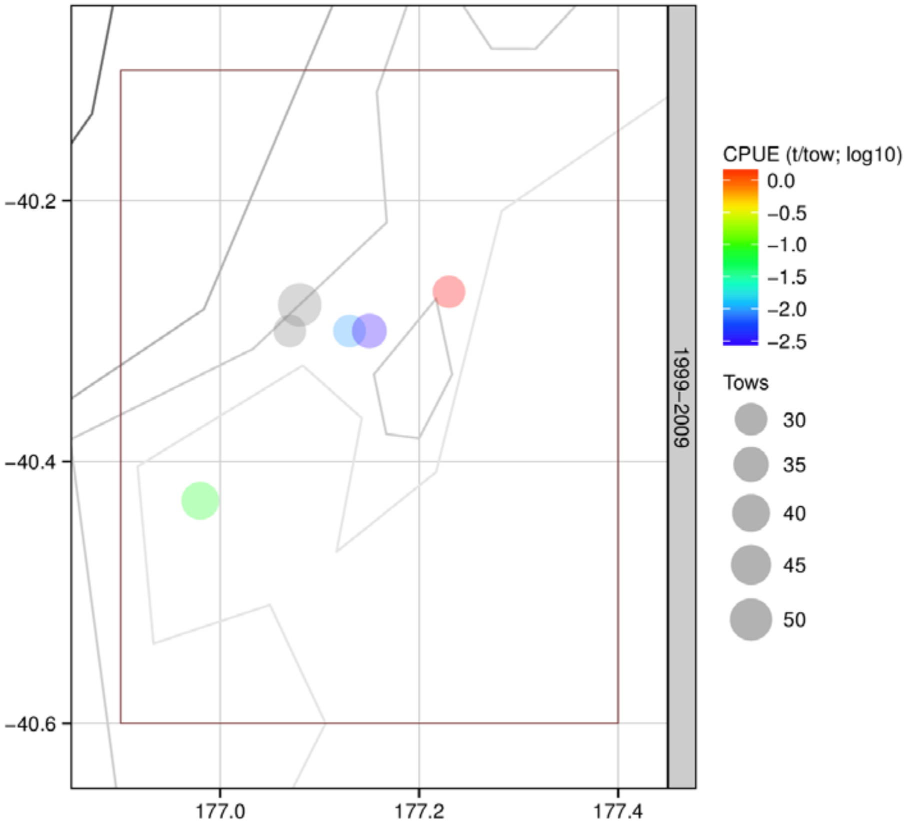

Figure 24: Number of tows and geometric mean CPUE by latitude and longitude (0.01 degree cells) for the Madden (MD) zone over three periods; 1989–90 to 1997–98, 1998–99 to 2008–09, and 2009–10 to 2013–14. Only locations where there were at least 30 tows within the period are shown.

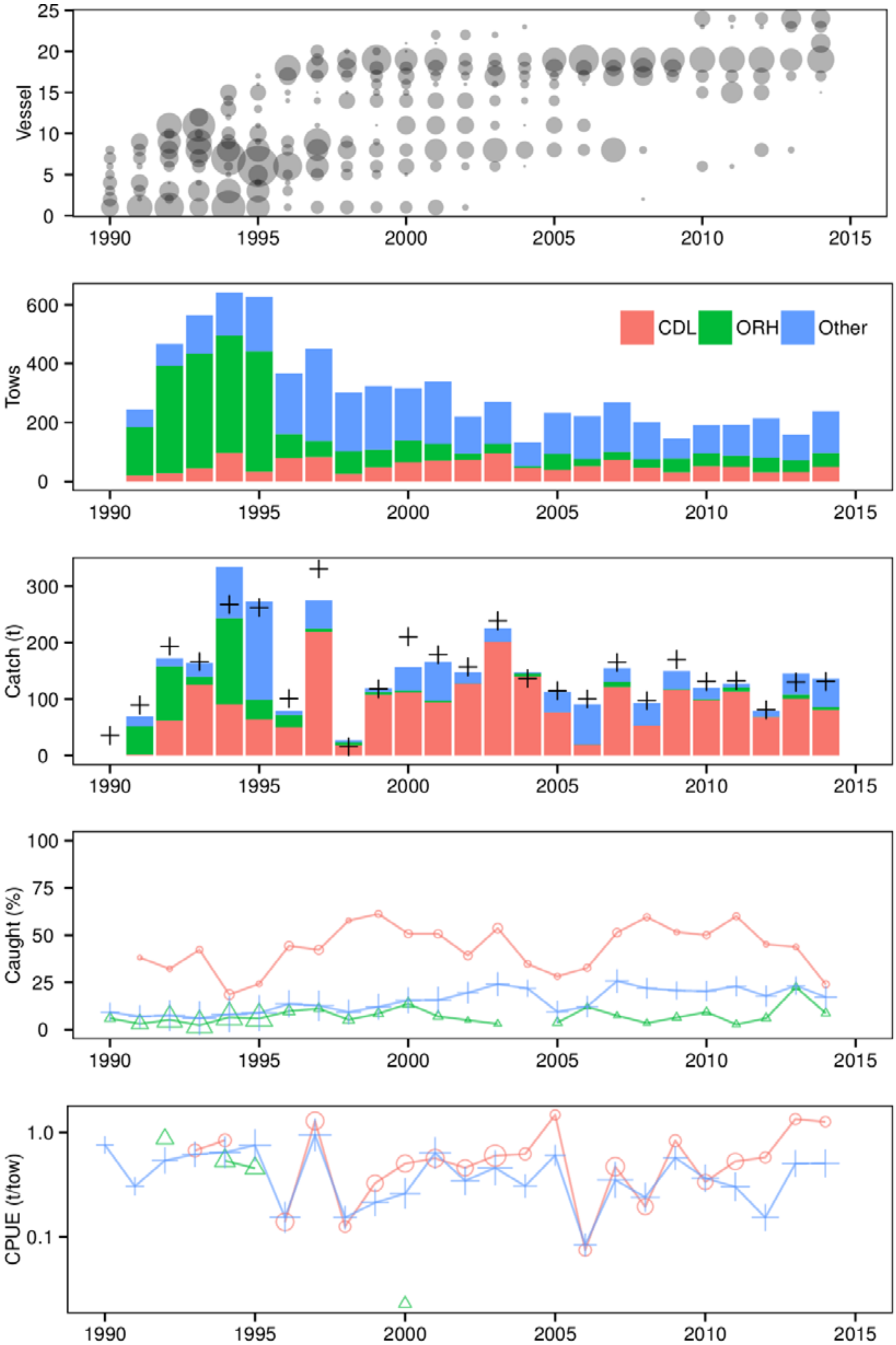

Figure 25: Annual summary for the Wairarapa (WA) zone. a) The number of tows by vessel, b) number of tows by target species, c) catch by target species, bars represent the estimated catches, crosses represent the catch based on allocated landings, d) the percentage of tows that caught cardinalfish by target, target tows (red circles), ORH target tows (green triangles) and all target species combined (blue crosses), size of the symbols is proportional to the number of tows. e) CPUE geometric mean of catch (t) per tow by target, symbols as in d).

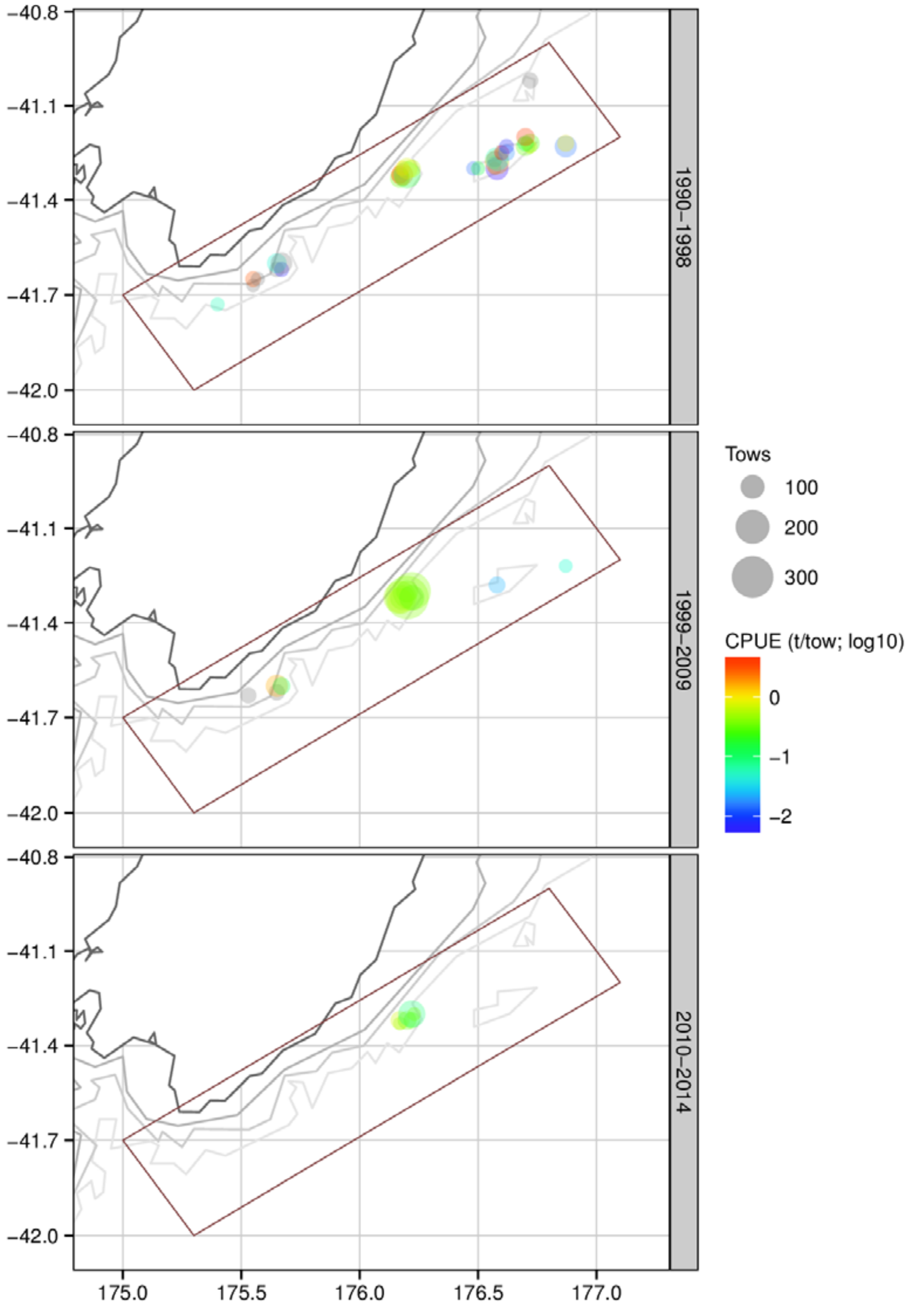

Figure 26: Number of tows and geometric mean CPUE by latitude and longitude (0.01 degree cells) for the Wairarapa (WA) zone over three periods; 1989–90 to 1997–98, 1998–99 to 2008–09, and 2009–10 to 2013–14. Only locations where there were at least 30 tows within the period are shown.

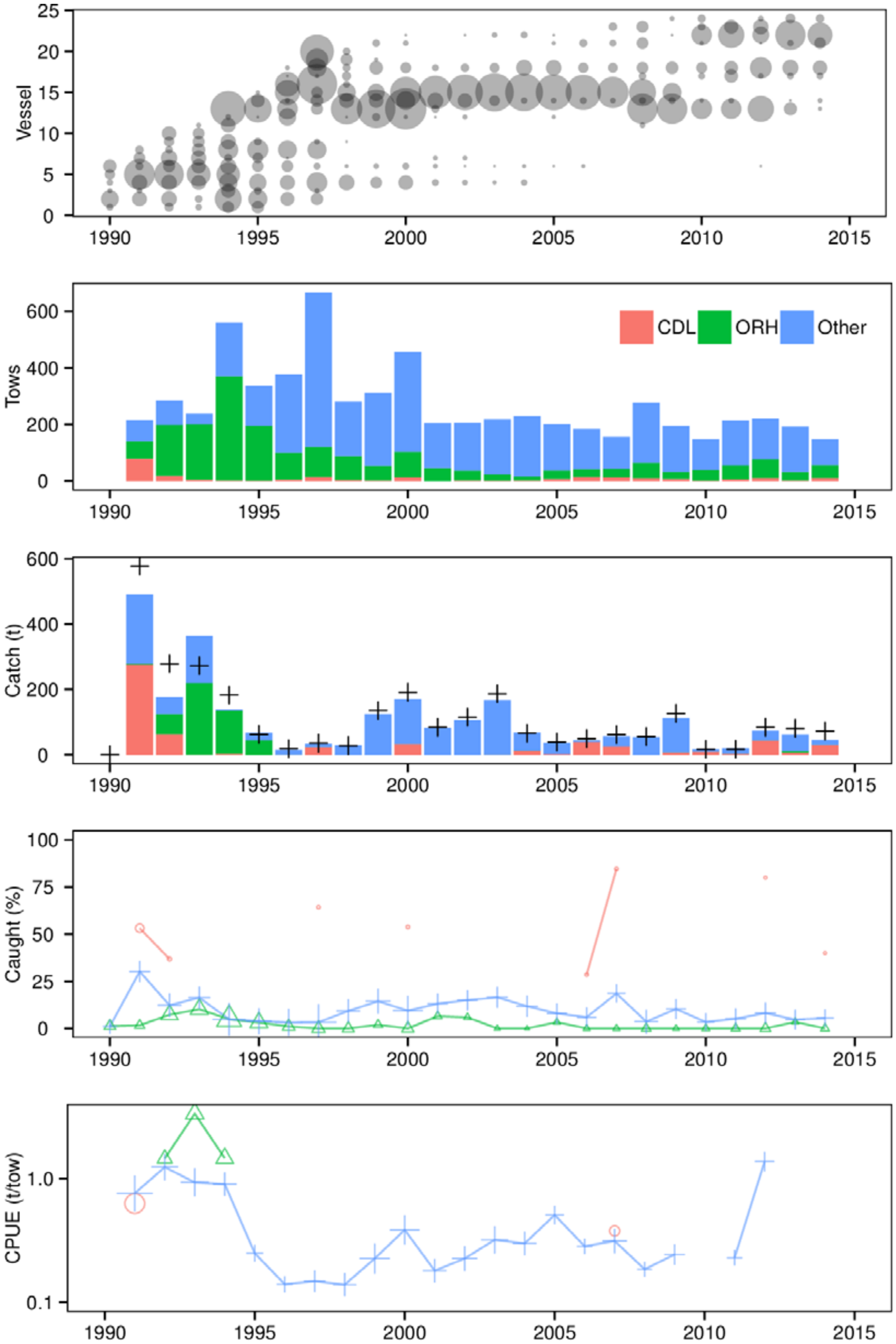

Figure 27: Annual summary for the Kaikoura (KK) zone. a) The number of tows by vessel, b) number of tows by target species, c) catch by target species, bars represent the estimated catches, crosses represent the catch based on allocated landings, d) the percentage of tows that caught cardinalfish by target, target tows (red circles), ORH target tows (green triangles) and all target species combined (blue crosses), size of the symbols is proportional to the number of tows. e) CPUE geometric mean of catch (t) per tow by target, symbols as in d).

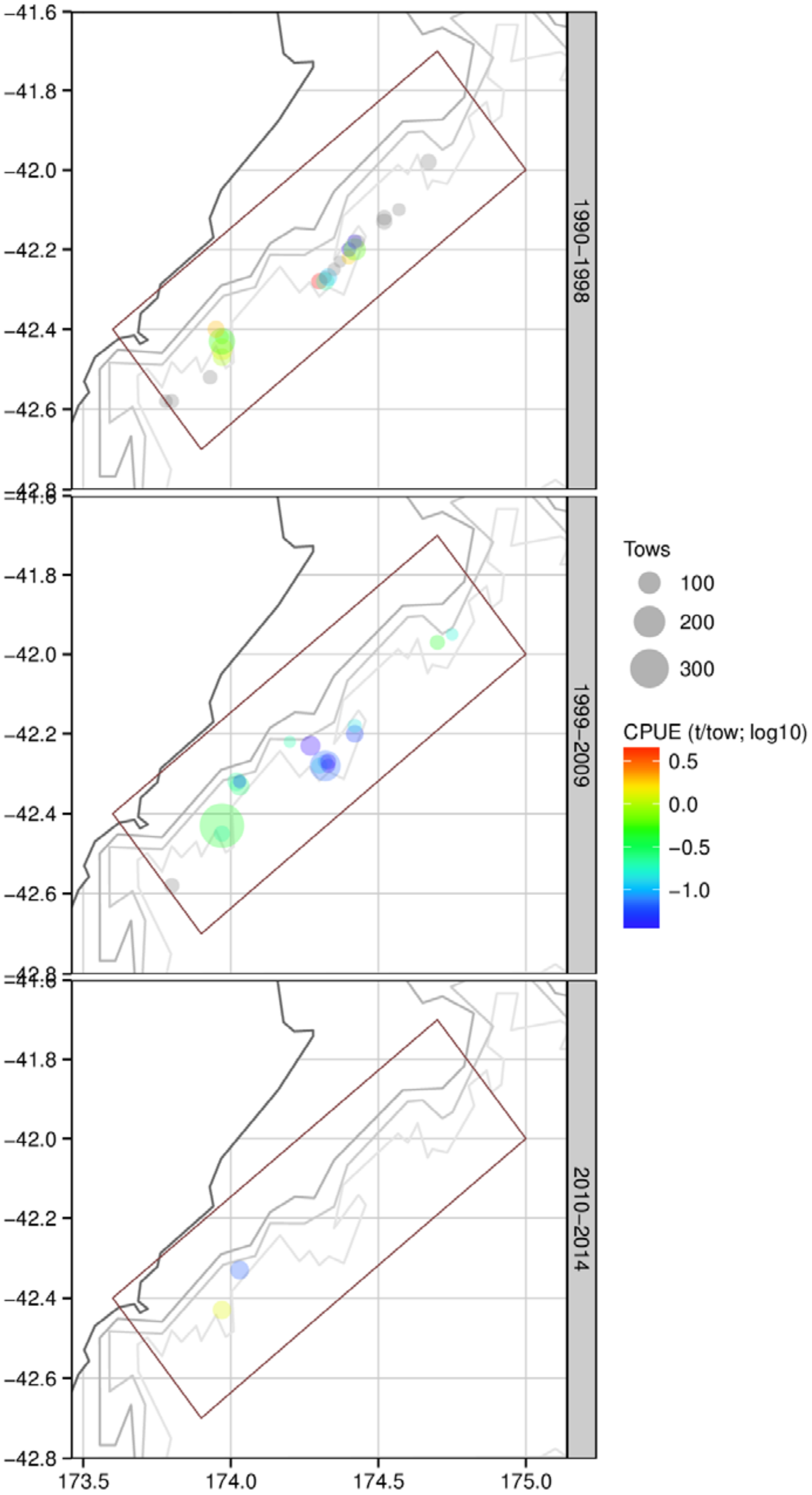

Figure 28: Number of tows and geometric mean CPUE by latitude and longitude (0.01 degree cells) for the Kaikoura (KK) zone over three periods; 1989–90 to 1997–98, 1998–99 to 2008–09, and 2009–10 to 2013–14. Only locations where there were at least 30 tows within the period are shown.

4. CATCH PER UNIT EFFORT ANALYSES

Analyses of catch-per-unit-effort (CPUE) used data from bottom trawling (BT) or midwater trawling (MW) recorded on TCEPR forms that occurred within the nine zones previously defined at depths of 470–980 m.

4.1 Core vessel selection

Criteria for selection of core vessels were investigated by considering the associated reductions in the number of vessels and percentage of total catch (Figure 29). The most appropriate combination of criteria was 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 19 vessels which took 90% of the catch. Further examination of the years in the fishery criterion was carried out to ensure that the core fleet represented a large proportion of the fishery, particularly in later years (Figure 30). There was good overlap of data among core vessels (Figure 31). The core vessel data set was up to 17 vessels in 1997–98 but included only 8 vessels in the most recent years (Table 2). There was close agreement between the whole fleet and the selected core fleet for temporal changes in the proportion of tows with cardinalfish catch and in the unstandardised CPUE (Figure 32). There was also reasonably good overlap of vessels across zones suggesting that it would be feasible to estimate independent zone coefficients without confounding from vessel coefficients (Figure 33).

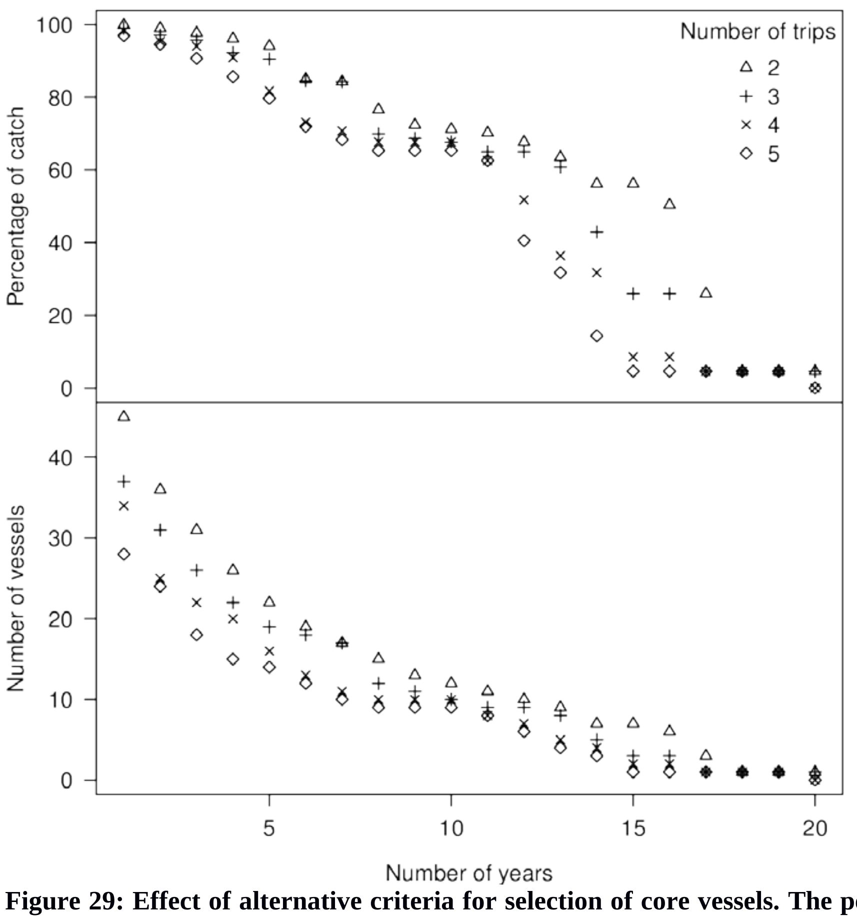

Figure 29: Effect of alternative criteria for selection of core vessels. The percentage of total catch [upper panel] and the number of vessels [lower panel] that would be retained in the data set given alternative definitions of the core fleet based on vessel participation a) a minimum number of years fished (x-axis) and b) a minimum number of trips per year (legend and symbols).

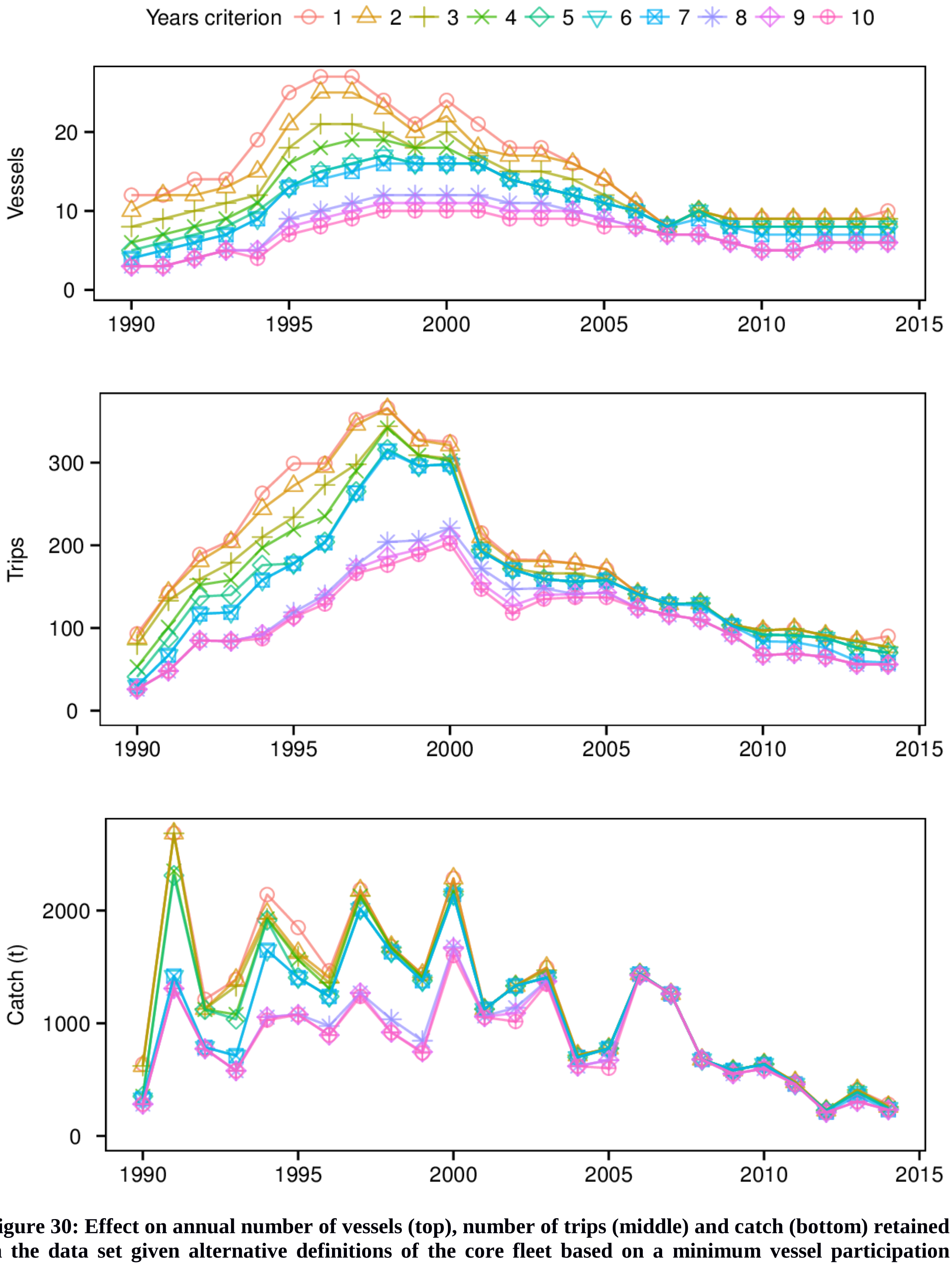

Figure 30: Effect on annual number of vessels (top), number of trips (middle) and catch (bottom) retained in the data set given alternative definitions of the core fleet based on a minimum vessel participation (number of years) with at least three trips per year.

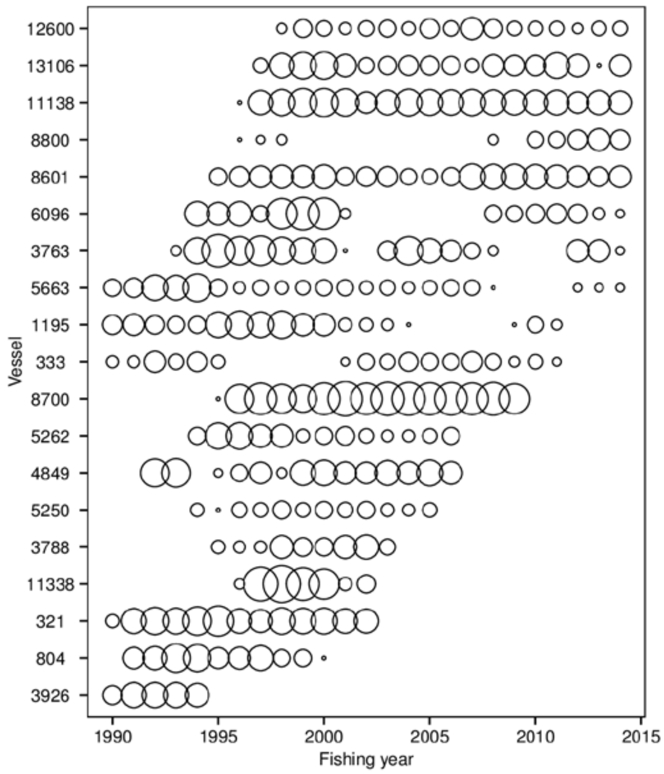

Figure 31: Participation of selected core vessels. Number of trips by each vessel (ID on y-axis) in each fishing year. The area of the circles is proportional to the number of trips for a vessel in a fishing year. Fishing years are labelled by the later calendar year e.g. 1990 = 1989–90.

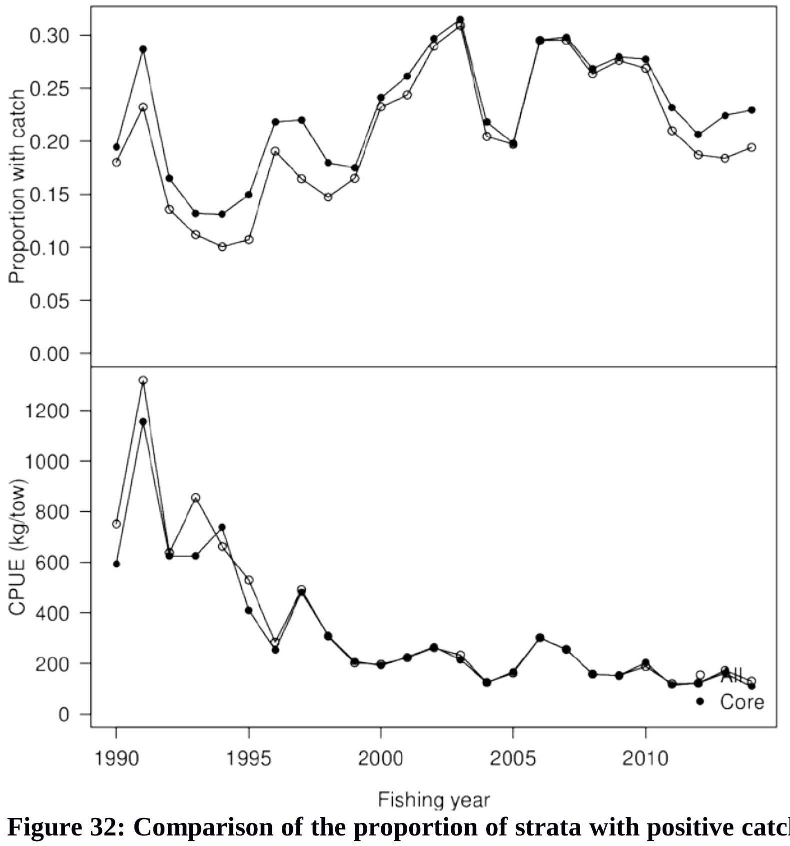

Figure 32: Comparison of the proportion of strata with positive catch (upper) and unstandardised CPUE (geometric mean of catch divided by effort where catch was positive; lower) for all vessels, and for core vessels.

Table 2: Summary of the core vessel data by fishing year. Data were used in their original resolution (not amalgamated) and therefore strata = tows. Fishing years are labelled by the later calendar year e.g. 1990 = 1989–90.

Fishing year	Vessels	Trips	Strata	Effort (tows)	Effort (hrs)	Catch (t)	Trips with catch (%)	Strata with catch (%)
1990	5	41	298	298	316.8	351.8	41.46	19.46
1991	6	88	896	896	847.5	2 310.5	68.18	28.68
1992	7	138	1 190	1 190	1 396.5	1 121.6	48.55	16.47
1993	8	140	1 143	1 143	1 306.5	1 034.9	47.14	13.21
1994	10	176	1 794	1 794	2 125.9	1 912.9	51.14	13.10
1995	13	178	1 692	1 692	2 001.5	1 404.5	61.24	14.95
1996	15	204	1 604	1 604	1 906.6	1 237.4	47.06	21.82
1997	16	265	2 032	2 032	2 472.3	2 012.6	48.68	22.00
1998	17	316	2 805	2 805	3 054.3	1 632.3	48.10	17.97
1999	16	296	3 157	3 157	3 909.7	1 376.5	54.73	17.52
2000	16	298	2 968	2 968	3 212.5	2 140.4	56.04	24.09
2001	16	193	1 434	1 434	1 477.1	1 124.6	52.85	26.15
2002	14	171	1 254	1 254	1 033.7	1 331.7	59.65	29.67
2003	13	159	1 398	1 398	1 137.2	1 405.3	61.64	31.47
2004	12	156	890	890	904.1	697.6	51.92	21.80
2005	11	158	1 278	1 278	1 125.0	776.5	55.06	19.80
2006	10	141	1 330	1 330	1 120.4	1 436.5	48.94	29.55
2007	8	129	1 281	1 281	914.2	1 259.8	63.57	29.82
2008	10	130	1 013	1 013	941.9	678.2	47.69	26.85
2009	8	103	794	794	771.5	582.9	58.25	27.96
2010	8	92	876	876	719.6	637.4	63.04	27.74
2011	8	91	953	953	909.4	460.9	70.33	23.19
2012	8	88	669	669	572.9	227.1	54.55	20.63
2013	8	76	526	526	482.4	387.9	55.26	22.43
2014	8	70	563	563	459.6	246.2	62.86	22.91

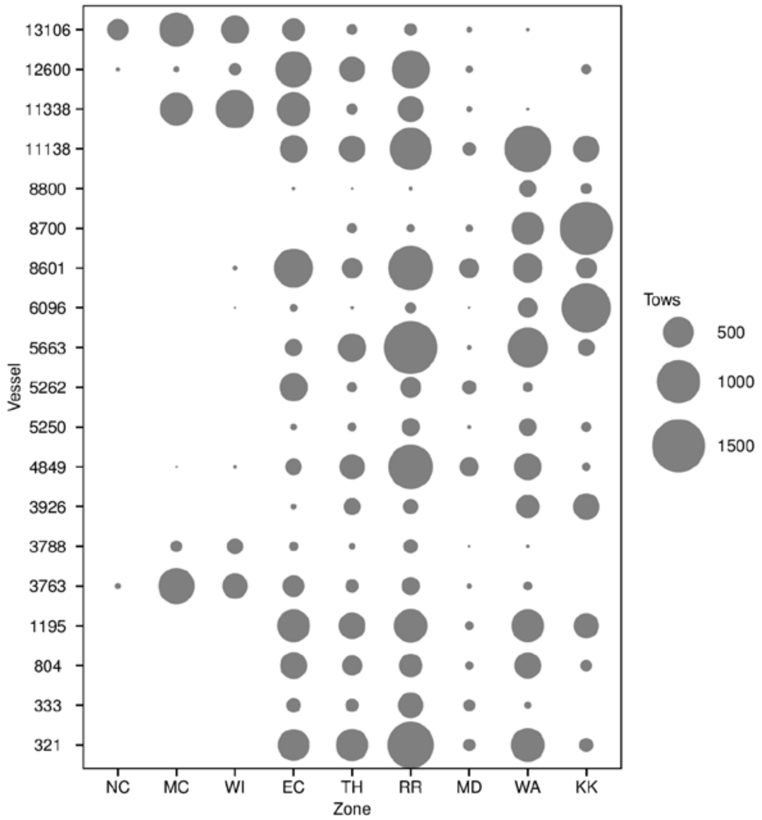

Figure 33: Number of qualifying tows by core vessels (ID on y-axis) by zone over all years, 1989–90 to 2013–14. NC North Colville, MC Mercury-Colville, WI White Island, EC East Cape, TH Tuahine High, RR Ritchie-Rockgarden, MD Madden, WA Wairarapa, KK Kaikoura. The size of the circles is proportional to the total number of tows conducted by a vessel in a zone.

4.2 Effort variable restrictions

Data were further restricted to remove missing and outlying values for effort variables used in the standardisation models. The effect of the data restrictions (Table 3, Figure 34) on catch and effort by fishing year is provided (Figure 35). Key tow characteristics were summarised by target species and fishing year to see if there was evidence of systematic misreporting of target species (Figure 36).

Table 3: Restrictions on data prior to GLM showing the number of records and catch affected. The applied column shows whether the restriction was applied or not. The number of records and catch for each restriction was calculated from the data prior to any restrictions being applied.

Variable	Restriction	Applied	Records (missing values)	Catch (missing values; t)	Records (outside range)	Catch (outside range; t)
Duration (hrs)	duration>=0.1 & duration<=6	1	0	0.00	241	342.94
Tow depth (m)	depth>=460 & depth<=1000	1	0	0.00	0	0.00
Bottom depth (m)	bottom>=400 & bottom<=1500	1	87	89.96	118	6.75
Net headline height (m)	height>=0.5 & height<=25	1	54	84.02	1 483	624.10
Tow speed (knots)	speed>=2 & speed<=5	1	35	14.18	25	38.55
Swept_distance (km)	0.5 <= swept_distance <=50	1	35	14.18	196	329.79

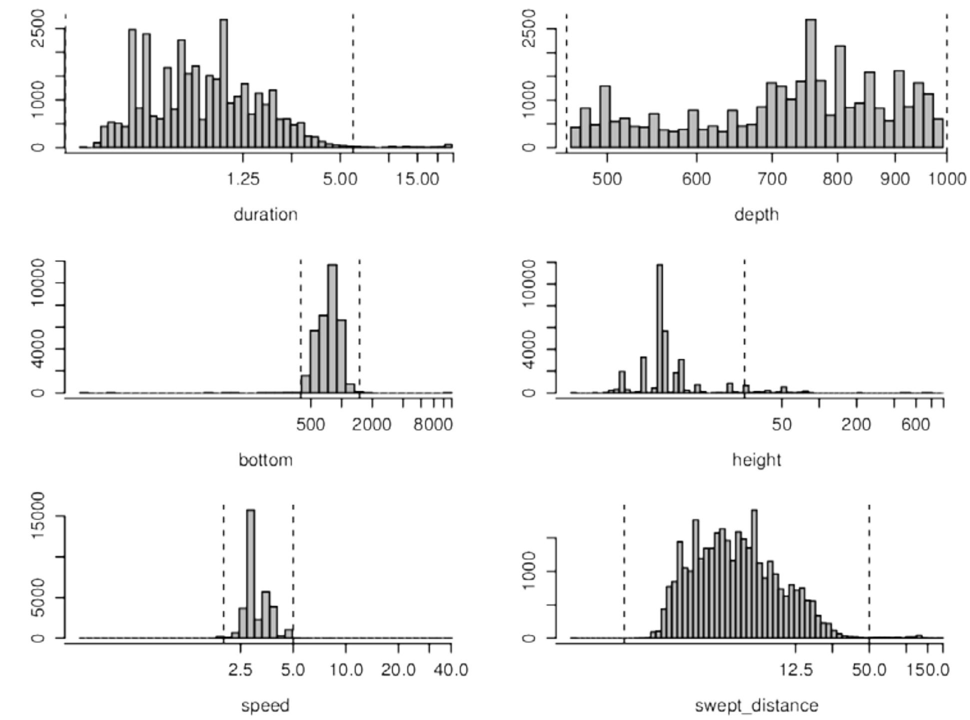

Figure 34: Distribution of variables in the dataset prior to removing outlying values. The vertical dashed lines indicate the minimum and maximum values for inclusion applied for each variable. Duration (hrs), tow depth (m), bottom depth (m), net headline height (m), tow speed (knots), swept distance (km).

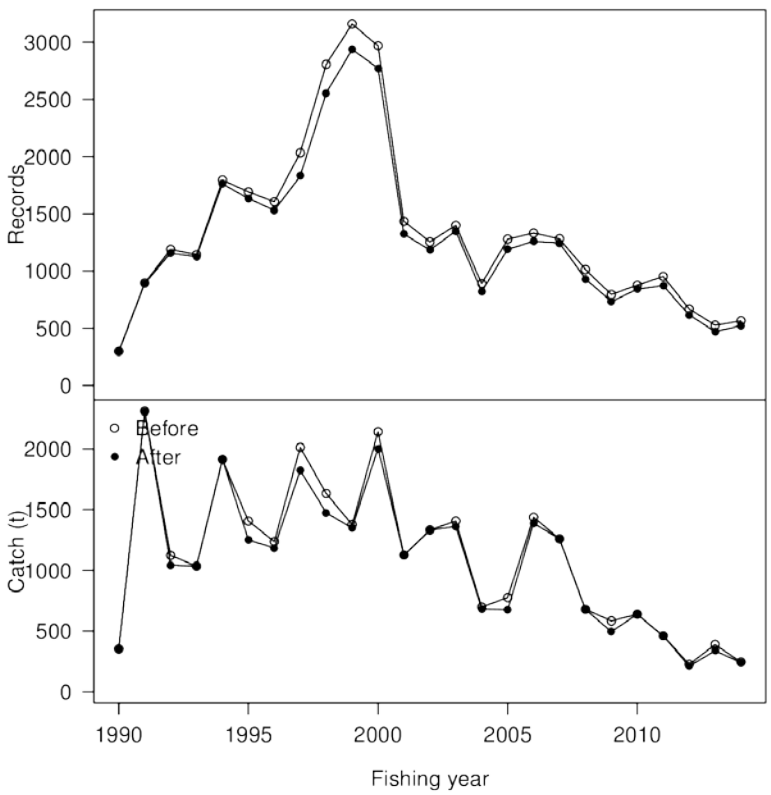

Figure 35: The effect of data restrictions on the number of records, and the tonnage of catch retained in the core dataset in each fishing year.

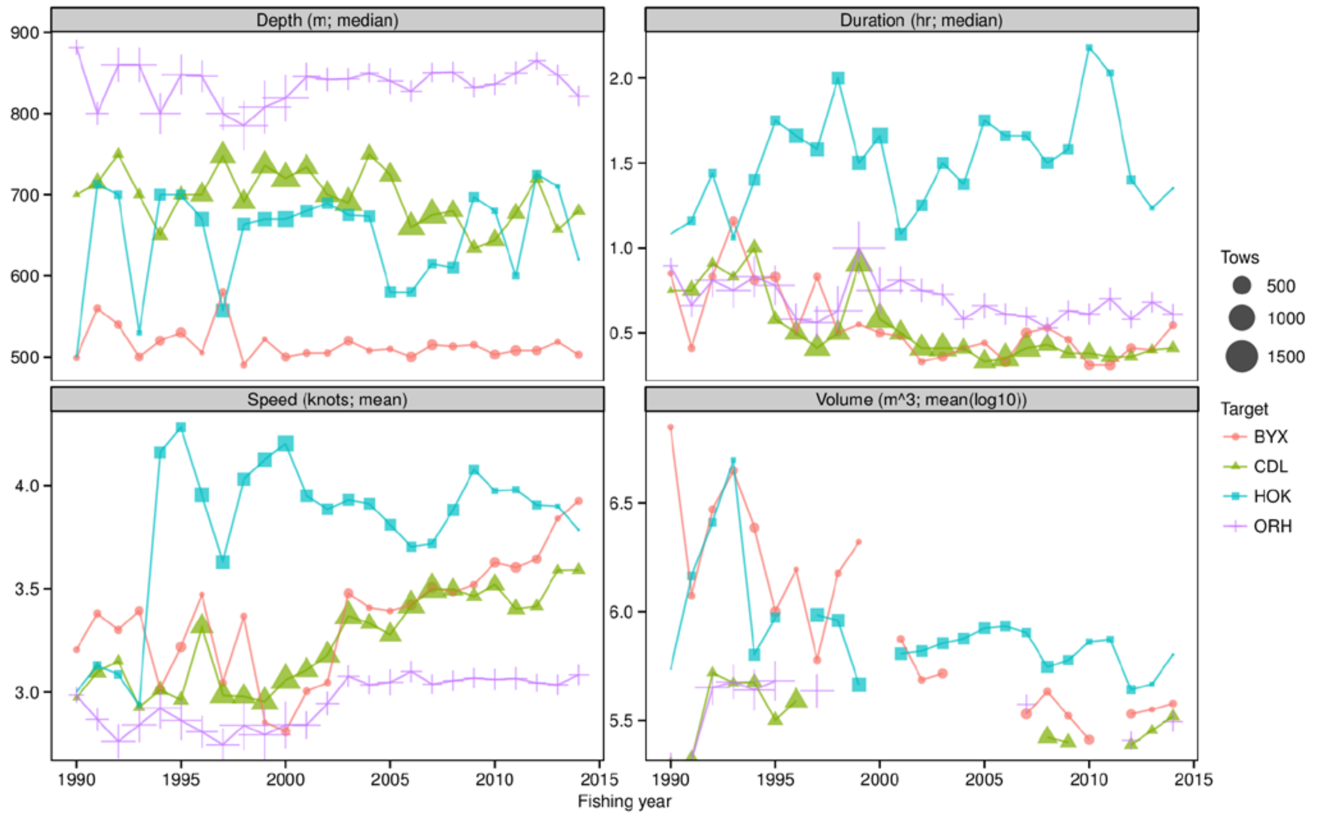

Figure 36: Key tow characteristics by reported target species and fishing year. Volume was calculated from the product of the tow duration, speed, headline height and gear width.

4.3 Standardisation of the probability of cardinalfish catch

A generalised linear model (GLM) was developed to standardise the probability of cardinalfish catch (i.e., the proportion of tows with at least some cardinalfish catch). Terms were only added to the model if they increased the percent deviance explained by 0.5 %. Table 4 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) + area + vessel + poly(log(swept_distance), 3) + poly(log(duration), 3) + method

Standardised and unstandardised probabilities of catch occurrence were compared for fishing year (Figure 37), zone (Figure 38), and vessel (Figure 39). In some fishing years, the standardisation effect was relatively large but there was not a large change in the overall trend except from 2000–01 to 2013–14 which the standardisation made steeper (Figure 37). There was a pronounced trend of reductions in both standardised and unstandardised catch probabilities from northern to southern zones Figure 38).

Sensitivity to alternative models

Alternative models were fitted to test the sensitivity of the series of standardised probabilities to different data subsets and model formulations. These alternative models included (a) excluding the vessel with the highest estimated coefficient and the two vessels with the lowest coefficients (see further discussion in following section) (b) including target species as a standardisation term and (c) including target species as a standardisation term for only the most recent period.

The fluctuations in the standardised probabilities were similar, however, when target species was added there was a slightly steeper trend to the overall decline (Figure 40). This is likely to be caused by the fact that in the early 1990s there were more tows that targeted orange roughy which are likely to have a lower probability of catching cardinalfish. When target species is added to the model it is able to standardise for this, thereby elevating the standardised probabilities during this period.

Table 4: Summary of stepwise selection of terms for the generalised linear model developed to standardise the probability of cardinalfish catch 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-R2 (%)	
fyear	25	-16 680	33 409	3.04	*
poly(log(depth), 3)	28	-15 564	31 183	13.15	*
area	36	-14 899	29 870	18.84	*
vessel	54	-14 532	29 171	21.89	*
poly(log(swept_distance), 3)	57	-14 344	28 803	23.41	*
poly(log(duration), 3)	60	-14 259	28 639	24.10	*
method	61	-14 183	28 488	24.71	*
month	72	-14 135	28 413	25.10	
poly(log(bottom), 3)	75	-14 105	28 359	25.34	

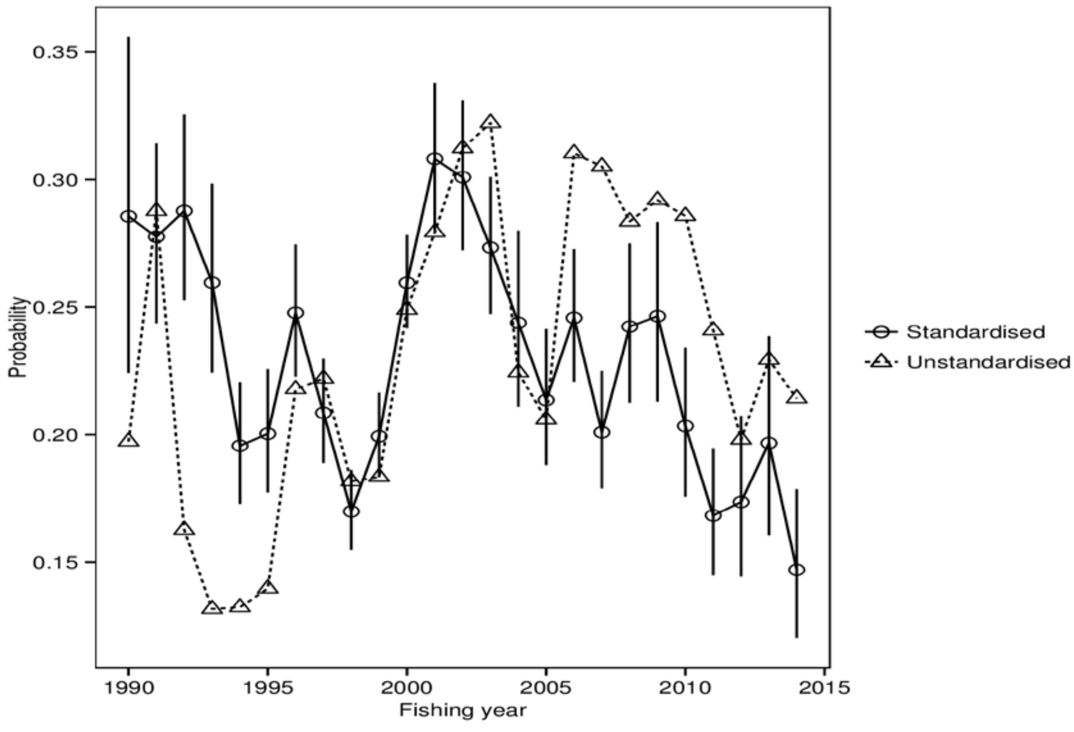

Figure 37: Standardised (using binomial model) and unstandardised probabilities of occurrence of positive catches by fishing year.

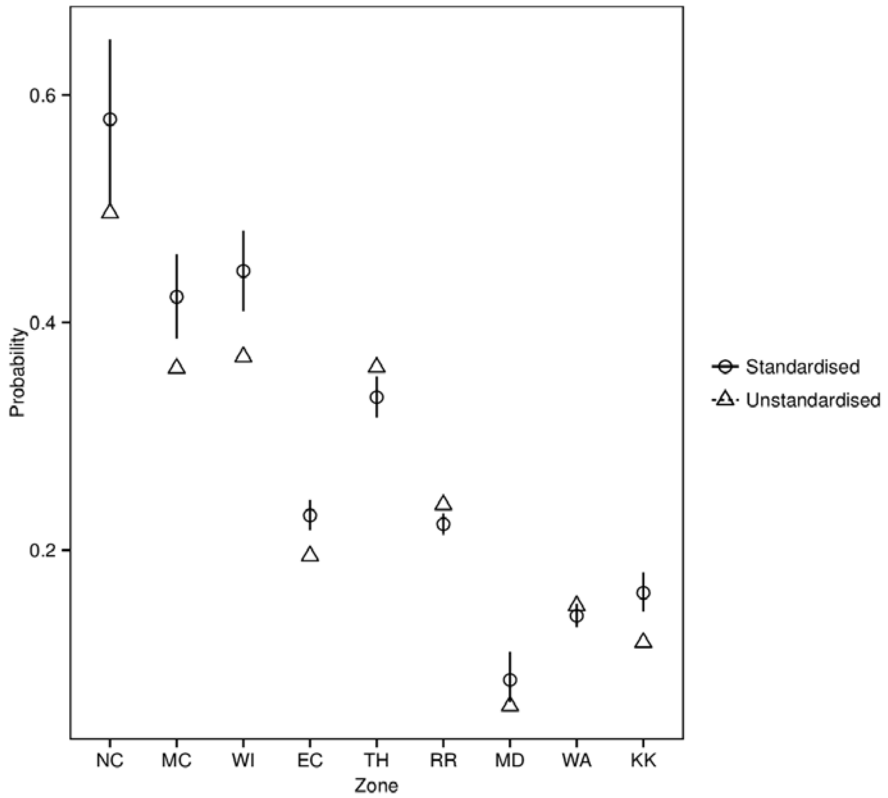

Figure 38: Standardised (using binomial model) and unstandardised probabilities of occurrence of positive catches by zone. NC North Colville, MC Mercury-Colville, WI White Island, EC East Cape, TH Tuahine High, RR Ritchie-Rockgarden, MD Madden, WA Wairarapa, KK Kaikoura.

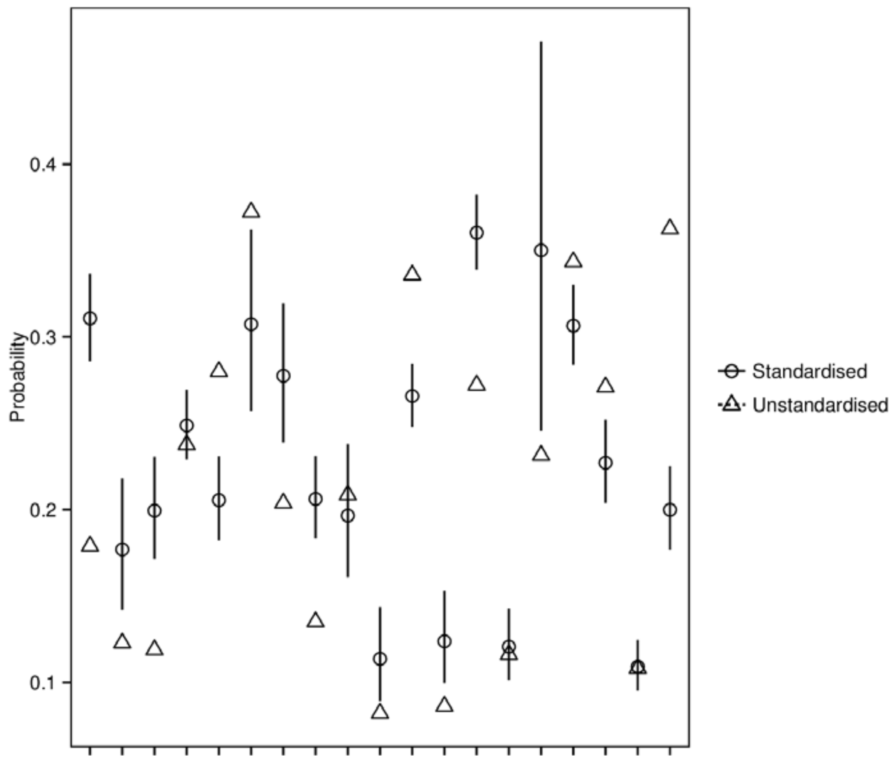

Figure 39: Standardised (using binomial model) and unstandardised probabilities of occurrence of positive catches by vessel (vessel IDs on x-axis not shown).

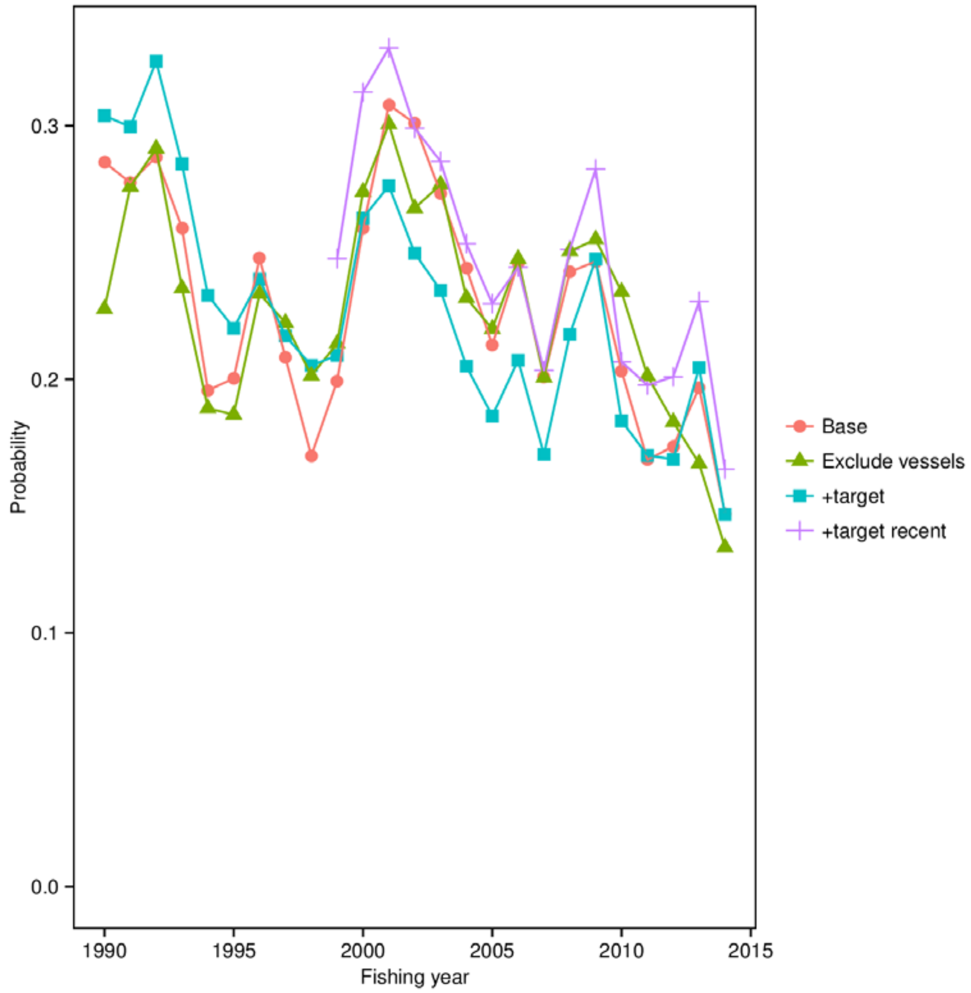

Figure 40: Sensitivity of standardised probabilities of cardinalfish catch to alternative generalised linear models using the binomial error distribution. Base, base case (all data). Exclude vessels, excluded the vessel with the highest estimated coefficient and the two vessels with the lowest coefficients. +target, included target species as a standardisation term. +target recent, included target species as a standardisation term for only the most recent period.

4.4 Standardisation of magnitude of cardinalfish catches

A GLM was also developed to standardise the magnitude of positive catches of black cardinalfish. Various diagnostics were used to assess the suitability of alternative statistical distributions for use in the standardisation model (Figure 41). According to the criterion of the distribution with the lowest AIC for a simple GLM (including only fishing year, month, zone and vessel effects) the most appropriate distribution was the log-normal distribution.

Forward stepwise selection of model terms was carried out on the basis of the Akaike Information Criterion (AIC). Terms were only added to the model if they increased the percent deviance explained by 0.5 %. Table 5 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,

catch ~ fyear + vessel + area + poly(log(depth), 3)

The overall standardisation effect was small relative to the large decline in the index (Figure 42). Nonetheless, the most influential term *vessel*, had an influence of 19% (i.e., changes in fleet composition caused CPUE to deviate by an average of 19% across years) (Table 6). In 2005–06, a year in which effort was dominated by vessels with high coefficients (i.e., all else being equal, higher catch rates), the *vessel* term is estimated to have inflated unstandardised CPUE by more than 60% (Figure 43, Figure 44). Overall there was a decline in the influence of the *area* term associated primarily with a shift away from Tuaheni High, the zone with the highest coefficient (Figure 45). The influence of depth was relatively minor (Figure 46).

Residual diagnostics showed some evidence of departures from normality (Figure 47). Summaries of residuals suggest that there were broadly consistent CPUE trends across zones (Figure 48) and target species (Figure 49). However, there was some evidence of less steep declines in northern zones, Mercury Colville (MC) and White Island (WI) and of recent increases in more southerly zones, Wairarapa (WA) and Kaikoura (KK).

Table 5: Summary of stepwise selection of terms for standardisation of the magnitude of cardinalfish catches. Model terms are listed in the order of acceptance to the model. Log likelihood and AIC values are for the fit as each term is successively added. AIC: Akaike Information Criterion; *: Term included in final model.

Term	DF	Log likelihood	AIC	Nagelkerke pseudo-R^2 (%)	
fyear	26	-57 092	114 236	3.91	*
vessel	44	-56 783	113 654	11.83	*
area	52	-56 716	113 535	13.47	*
poly(log(depth), 3)	55	-56 684	113 478	14.22	*
poly(log(bottom), 3)	58	-56 669	113 454	14.58	
poly(log(height), 3)	61	-56 654	113 431	14.93	
month	72	-56 639	113 423	15.28	
method	73	-56 638	113 422	15.31	

Table 6: Summary of the explanatory power and influence of each term in the standardisation model of the magnitude of cardinalfish catches. Coefficients is the number of coefficients associated with the term added. Coefficient of determination (R^2) values represent the change in R^2 from the previous model. R^2: square of the correlation coefficient between log(observed) and log(fitted).

Term	Coefficients	Negelkerke pseudo-R^2 (%)	Overall influence (%)
intercept	1	-	-
fyear	24	3.91	-
vessel	18	7.92	19.00
area	8	1.63	12.34
poly(log(depth), 3)	3	0.75	4.48

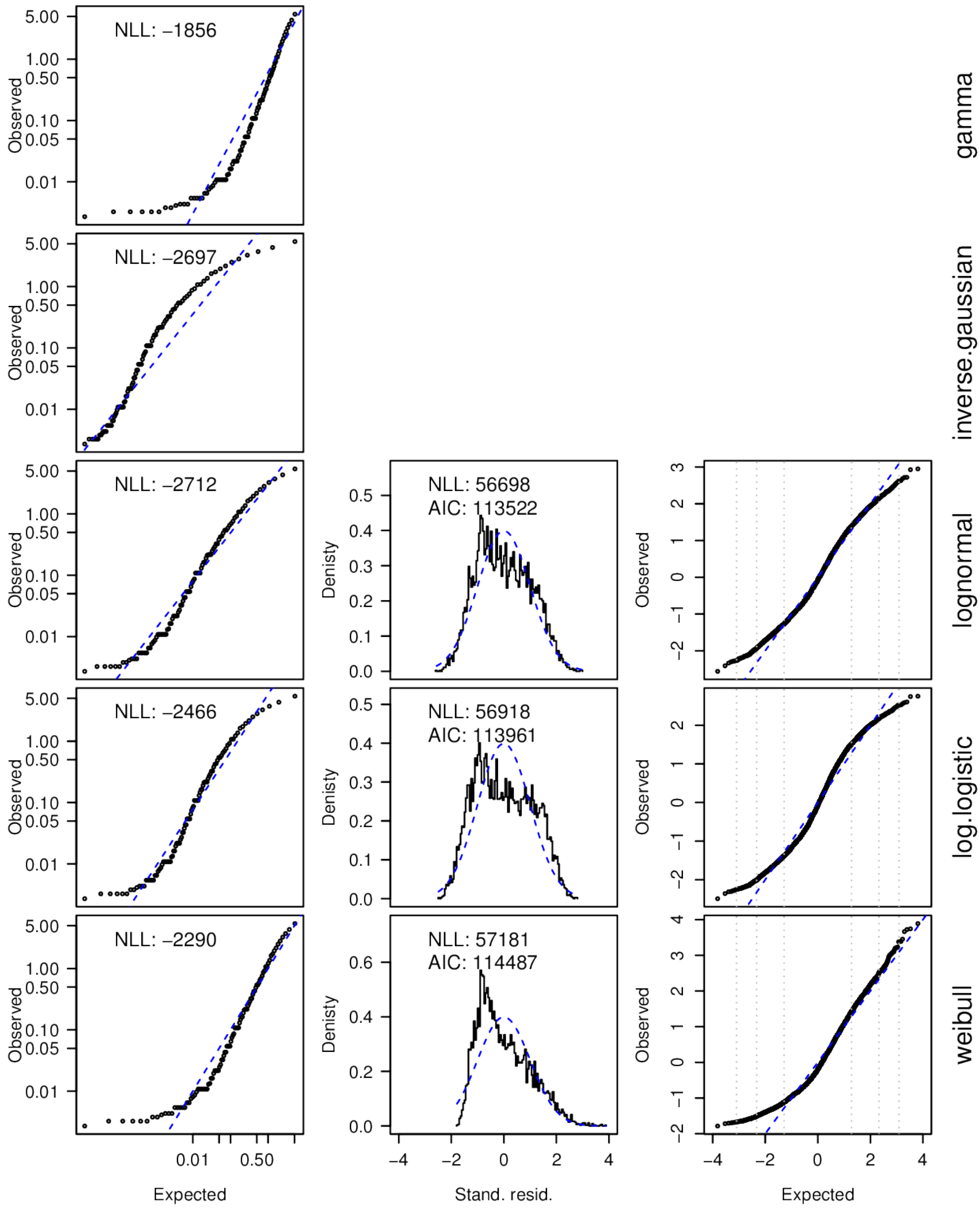

Figure 41: Diagnostics for alternative assumptions regarding the statistical distribution of the response variable for standardisation of the magnitude of cardinalfish catches. Left: quantile-quantile plot of observed response values (centred, by mean) and scaled (by standard deviation, in log space) versus a maximum likelihood fit of the distribution to those values. Middle: standardised residuals from a generalised linear model fitted using the formula catch ~ fyear + month + zone + vessel and the distribution (missing panel indicates 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). A missing panel indicates the fit failed to converge. NLL = negative log-likelihood; AIC = Akaike Information Criterion.

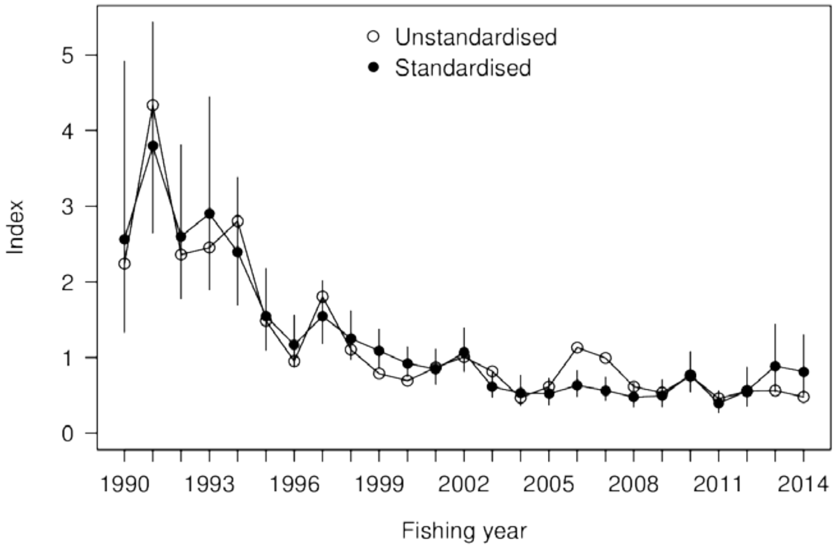

Figure 42: Overall standardisation effect of the model from the GLM of positive catches. The unstandardised index is based on the geometric mean of the catch per strata and is not adjusted for effort.

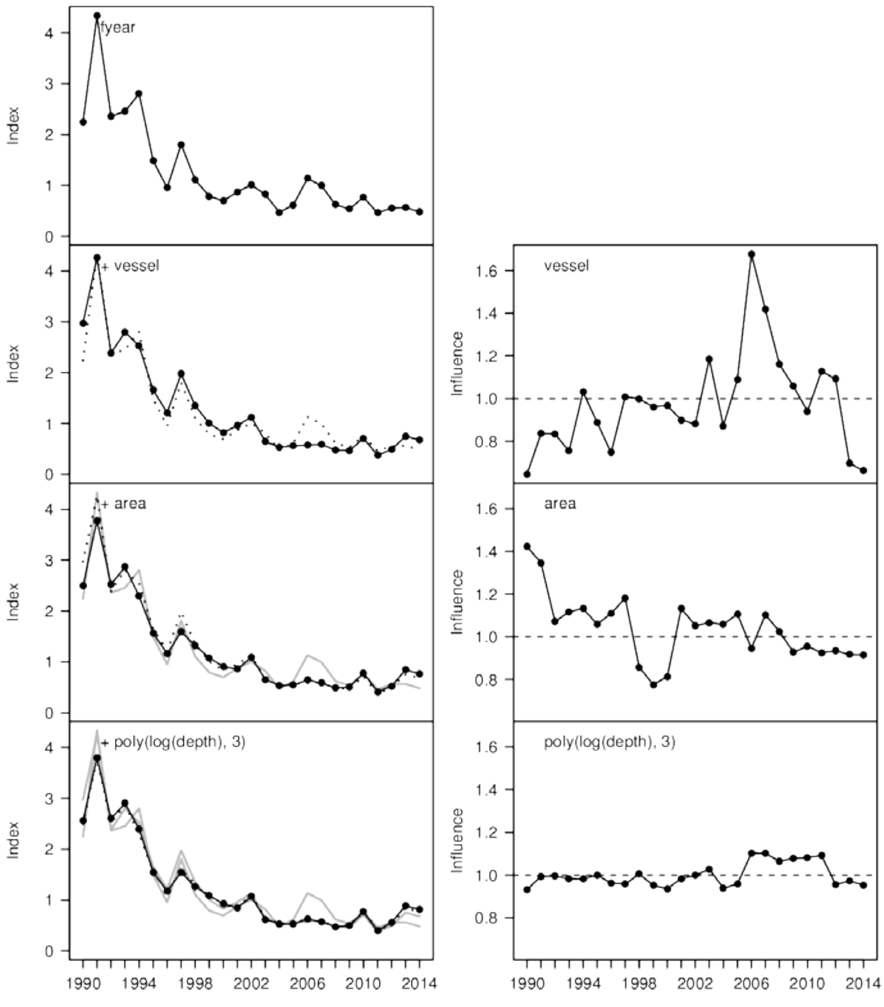

Figure 43: Step and annual influence plot. (a) CPUE index at each step in the selection of variables for standardisation of the magnitude of cardinalfish catches. The index obtained in the previous step (if any) is shown by a dotted line and for steps before that by grey lines. (b) Annual influence on observed catches

arising from a combination of its GLM coefficients and its distributional changes over years, for each explanatory variable in the final model.

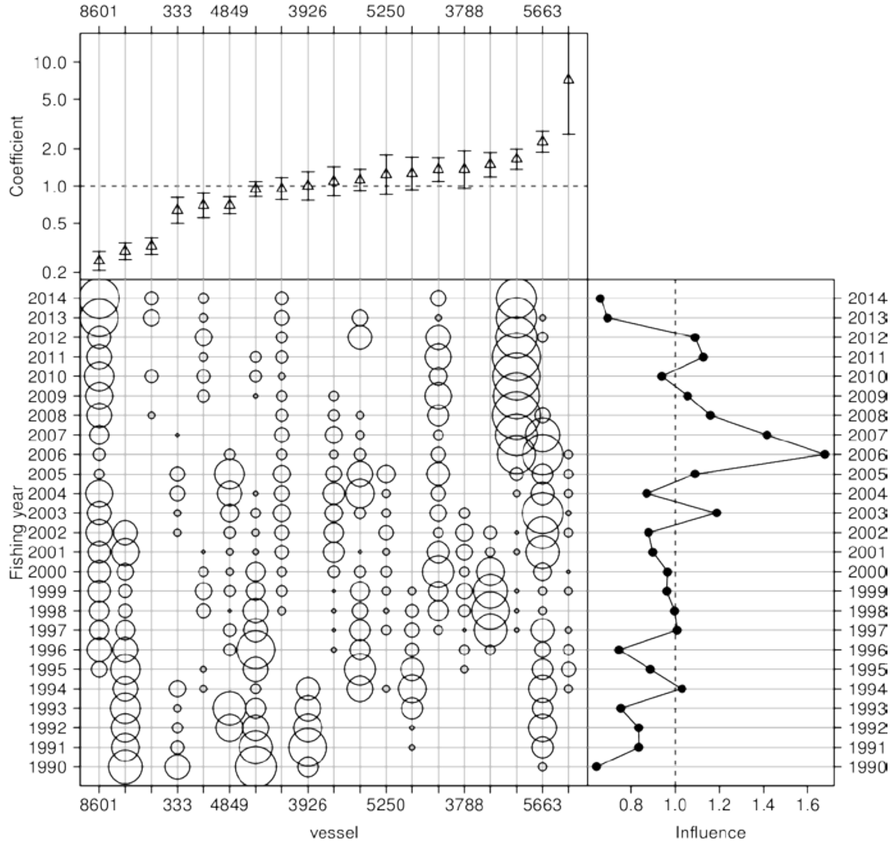

Figure 44: Coefficient-distribution-influence plot for *vessel*.

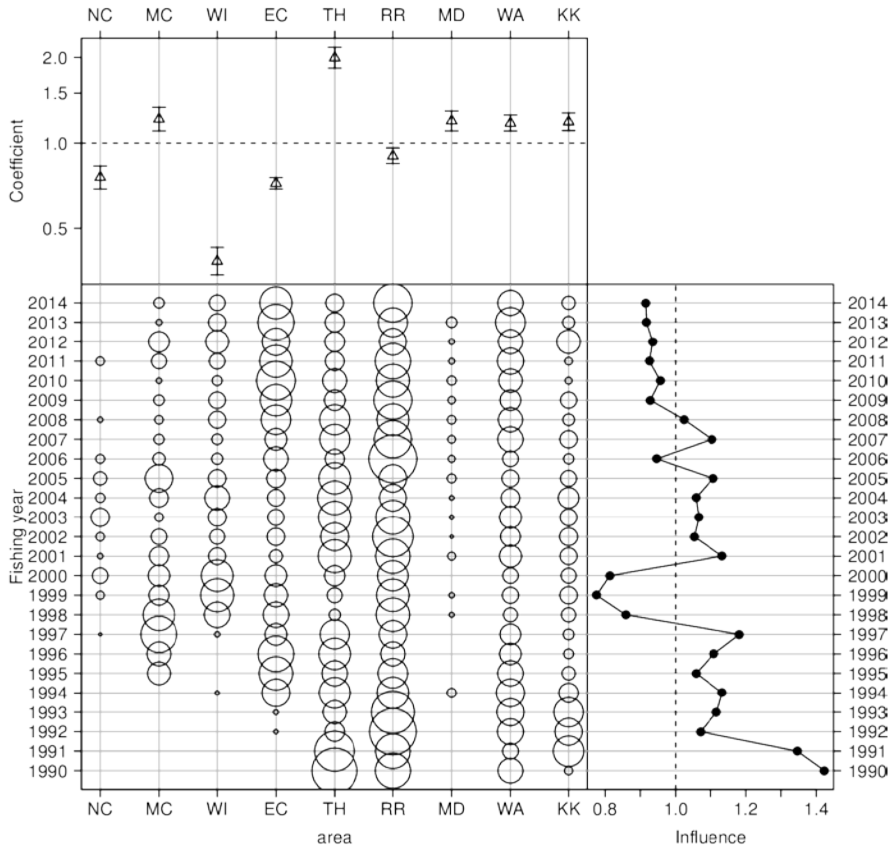

Figure 45: Coefficient-distribution-influence plot for *area*.

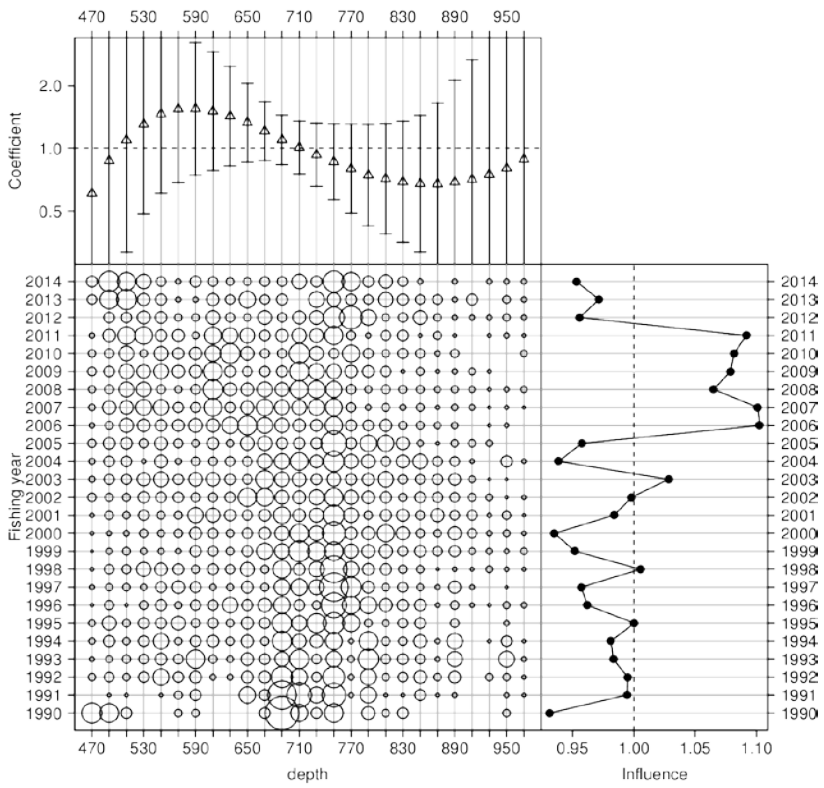

Figure 46: Coefficient-distribution-influence plot for *poly(log(depth), 3)*.

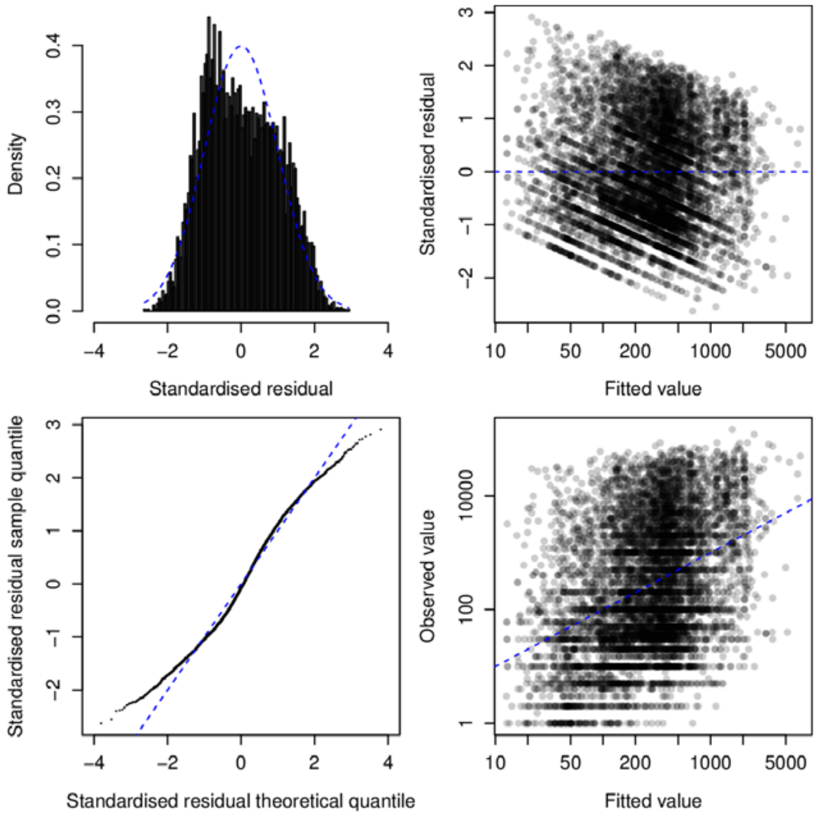

Figure 47: Residual diagnostics from the GLM of positive catches. Top left: histogram of standardised residuals compared to standard normal distribution. Bottom left: quantile-quantile plot of standardised residuals. Top right: fitted values versus standardised residuals. Bottom right: observed values versus fitted values.

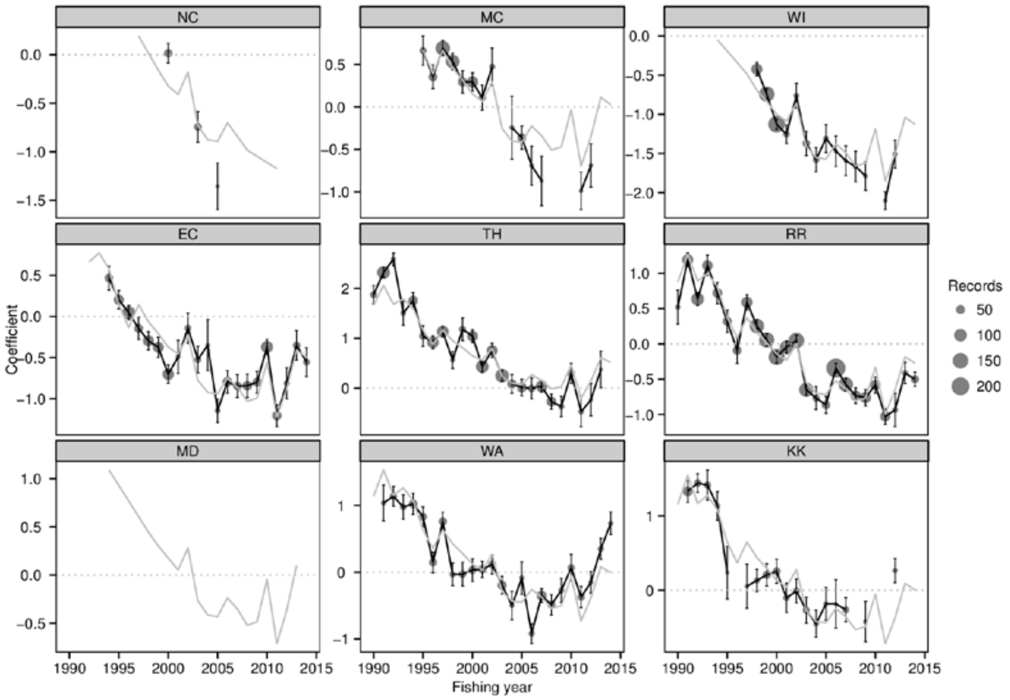

Figure 48: Residual implied coefficients (in log space) for area × fishing year interactions from the GLM of positive catches. Implied coefficients (points) are calculated as the normalised fishing year coefficient (grey line) plus the mean of the standardised residuals in each fishing year and area. These values approximate the coefficients obtained when an area × year interaction term is fitted, particularly for those area × year combinations which have a substantial proportion of the records. The error bars indicate one standard error of the standardised residuals. Combinations with fewer than 10 records are not shown.

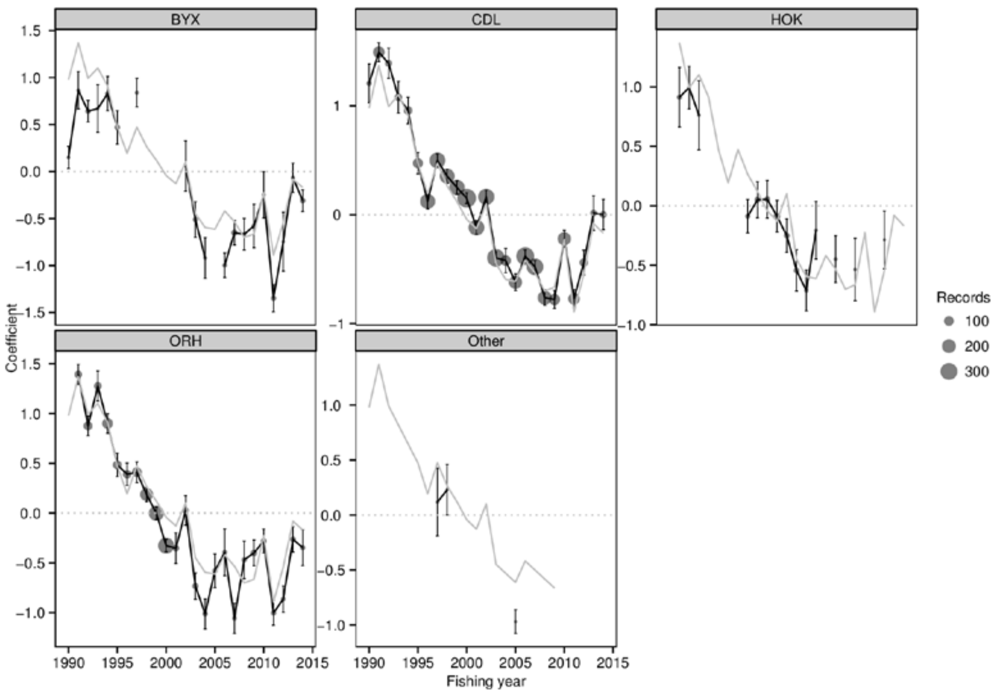

Figure 49: Residual implied coefficients (in log space) for target × fishing year interactions from the GLM of positive catches. Implied coefficients (points) are calculated as the normalised fishing year coefficient (grey line) plus the mean of the standardised residuals in each fishing year and target These values approximate the coefficients obtained when an 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. Combinations with fewer than 10 records are not shown.

Including a zone × year interaction term
To investigate further whether there were differences in CPUE trends amongst zones a GLM model was fitted that was the same as the one above but with the addition of a *zonexfyear* interaction term. This model produced individual zone indices (Figure 50) that were similar to those implied by residuals with more pronounced decreases in the MC zone and recent increases in WA and KK zones. The strongest positive correlation in CPUE indices were between the Tuaheni High zone and the North Colville, Mercury Colville and Ritchie-Rockgarden zones and between the White Island and Mercury Colville zones (Figure 51). The Wairarapa and Kaikoura zones had positive correlation with each other but weak correlation with most other zones and negative correlation with some of the most northern zones.

Separate indices for CDL 1 and CDL 2
In previous studies, CPUE indices were calculated separately for CDL 1 and CDL 2. The analyses described above were performed across both of these QMAs. This was partly done because all of the core vessels fishing in CDL 1 also fished in CDL 2 so a combined analysis potentially provides more power for estimating vessel coefficients. The zone × year interaction model allowed separate indices to be generated for each zone.

But the two QMAs have a different exploitation history and are managed separately so it is appropriate to provide separate indices for each. A model of catch magnitude using the same final formula for the combined model was fitted to data from CDL 1 and CDL 2 separately. The CDL 1 index was consistent with the previous observation that indices from the more northern zones exhibited a steeper decline from 1994–95 to 2008–09 (Figure 52). The index for CDL 2 was similar to the overall index.

Separate indices for a North, Central and South regions
The preceding analyses suggested that the Wairarapa zone was more similar to the Kaikoura zone than the other zones in CDL 2. So separate indices were generated for three regions: North (NC, MC and WI zones; corresponds to CDL 1), Central (EC, TH, RR, MD zones), and South (WA, KK zones). An integrated GLM was fitted so that vessel coefficients were estimated using all of the available data at one time using the formula:

catch ~ vessel + poly(log(depth),3) + fyear:region+zone

The resulting indices for the North and Central regions are similar to the individually estimated CDL 1 and CDL 2 indices respectively (Figure 53). However, the Central index did not exhibit the same magnitude of increase in the final two years. Residual diagnostics for this model are similar to those for the overall model (Figure 54).

Closer examination of vessel coefficients
The vessel term was the most influential in the standardisation model. In one year, the influence of vessel was over 1.6 (Figure 44). Because of the high influence of this term, the relation between vessel coefficients and vessel characteristics (e.g., overall length, experience in the fishery) was examined to check that differences in estimated vessel coefficients reflected differences among vessels and were not spurious (for example due to confounding of zone and vessel). There was a weak correlation between the vessels coefficient and the total number of tows and target tows (Figure 55). There were two vessels which had a high number of tows but low coefficients but these vessels were smaller. Conversely, the vessel with the highest coefficient had relatively few tows but was one of the newest and the largest vessels in the fleet. Thus, the estimated vessel coefficients did appear to reflect underlying differences in vessel characteristics that are expected to reflect their catching efficiency.

Effect of including target species
The main analysis excluded target species because there were concerns that it may not accurately reflect the actual target species. Two sensitivity analyses were performed to investigate the effect of including target species. In the first, target species was added as a term to the base case model. This

made the decline in standardised indices steeper during the early 1990s (Figure 56). In the second, the target term was added but the dataset was restricted to the period 1998–99 to 2013–14 during which cardinalfish was part of the QMS and target species may have been recorded more accurately. The resulting standardised index was very similar to that from the base case model (Figure 56).

Comparison with previous analyses

The standardised CPUE series estimated for CDL 2 was compared to those estimated for the same area (but also including Kaikoura in CDL 3) by Dunn & Bian (2009). The Dunn & Bian series for 1990–91 to 1997–98 was similar to the CDL series from this study. Overall the Dunn & Bian series for 1998–99 to 2007–08 exhibited a steeper decline than the CDL series but this was primarily caused by differences in the indices for the first and last years and the fluctuations in the two series during intervening years were very similar (Figure 57).

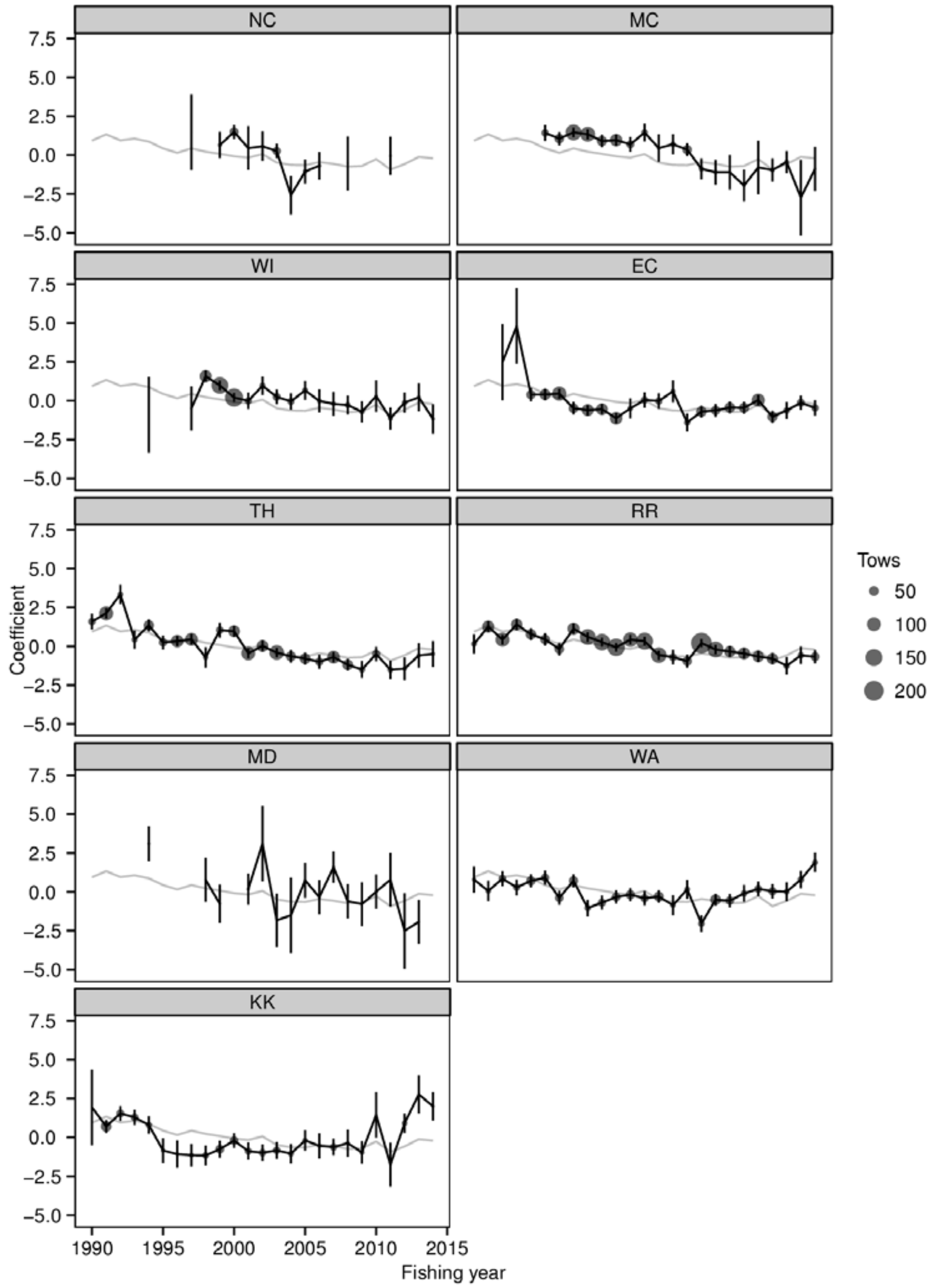

Figure 50: Estimated annual coefficients for each zone from the GLM of positive catches with a zone-fishing year interaction term added. For reference, the grey line is the series of annual coefficients estimated by the GLM without the interaction term.

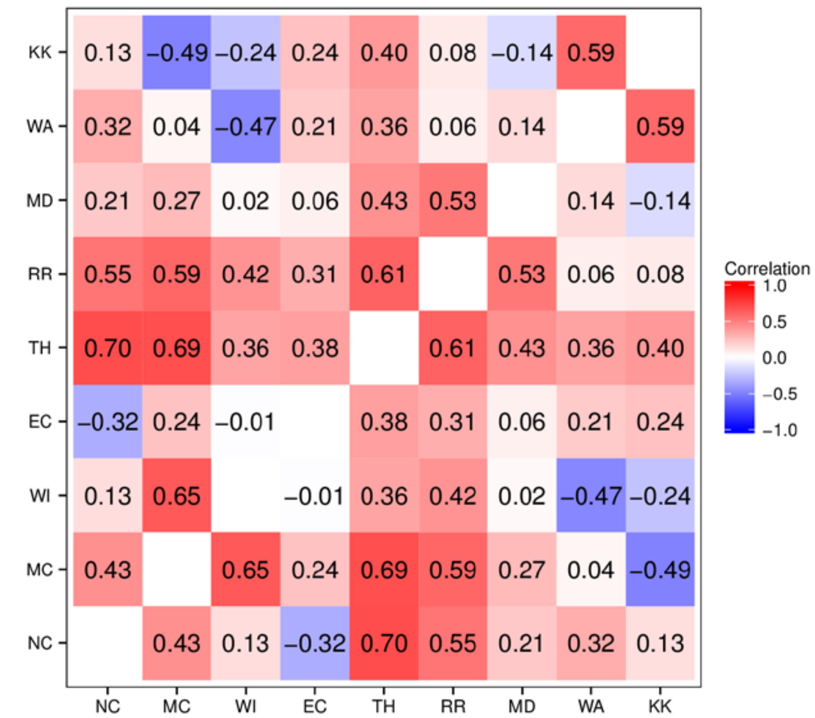

Figure 51: Matrix of correlations among CPUE indices generated for individual zones using a zone × interaction term. NC North Colville, MC Mercury-Colville, WI White Island, EC East Cape, TH Tuahine High, RR Ritchie-Rockgarden, MD Madden, WA Wairarapa, KK Kaikoura.

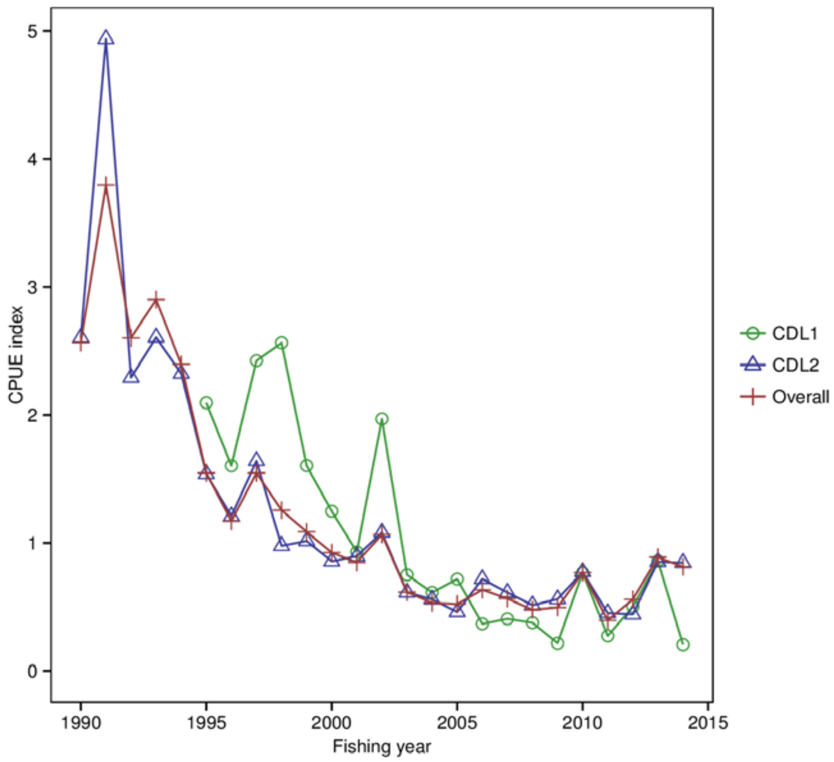

Figure 52: Comparison of CPUE indices obtained from CDL 1 (zones NC, MC, WI), CDL 2 (zones EC, TH, RR, MD and WA) and overall (all zones including KK) models. NC North Colville, MC Mercury-Colville, WI White Island, EC East Cape, TH Tuahine High, RR Ritchie-Rockgarden, MD Madden, WA Wairarapa, KK Kaikoura.

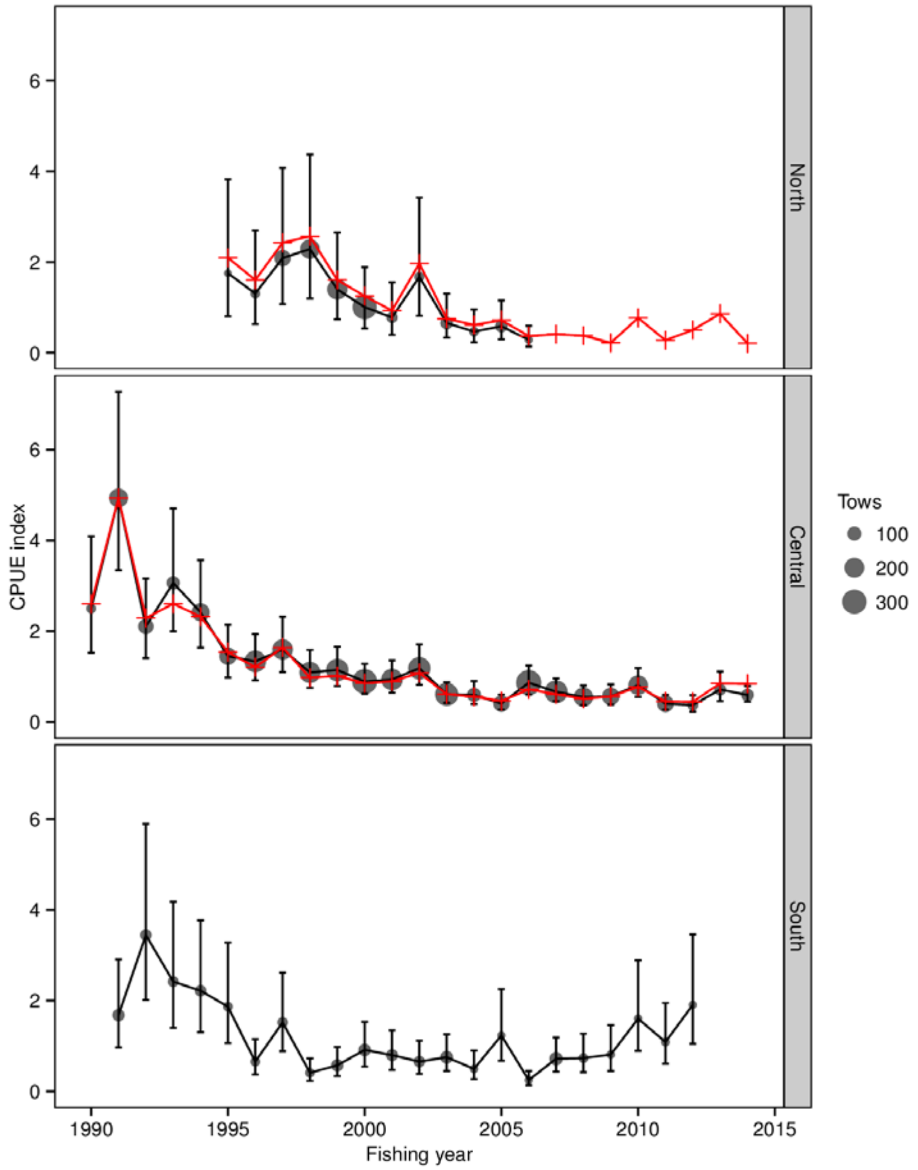

Figure 53: CPUE indices by region. North: NC, MC and WI zones, Central: EC, TH, RR, MD zones, South: WA, KK zones. For comparison, QMA based indices for CDL 1 and CDL 2 are provided for the North and South zones. Region/year combinations with fewer than 30 tows are not shown. Error bars indicate +/- one standard error.

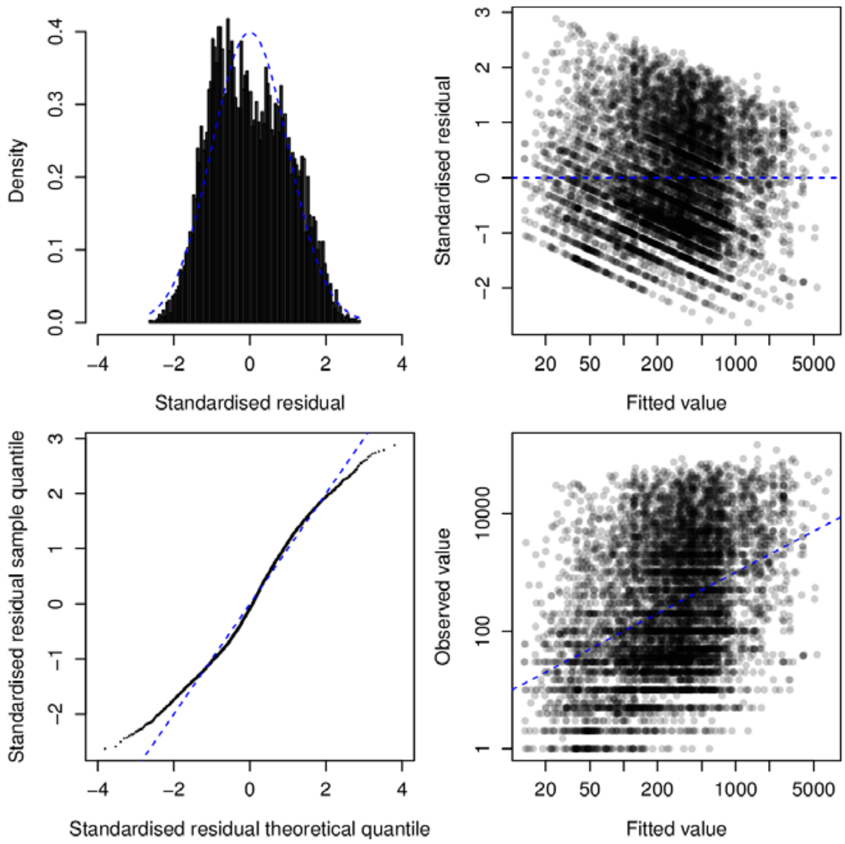

Figure 54: Residual diagnostics for the three region GLM model of catch magnitude. Top left: histogram of standardised residuals compared to standard normal distribution. Bottom left: quantile-quantile plot of standardised residuals. Top right: fitted values versus standardised residuals. Bottom right: observed values versus fitted values.

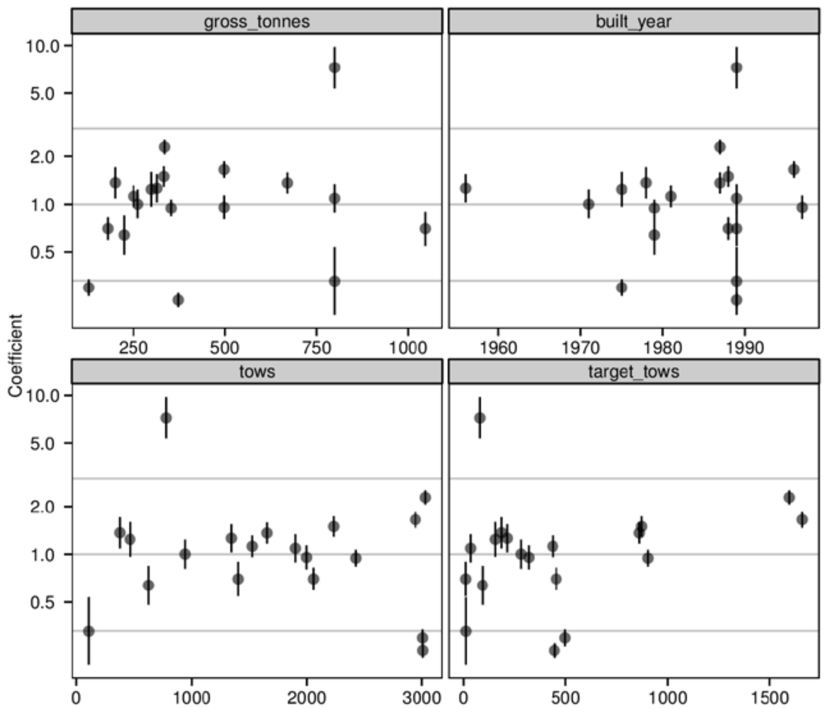

Figure 55: Vessel coefficients versus some vessel characteristics.

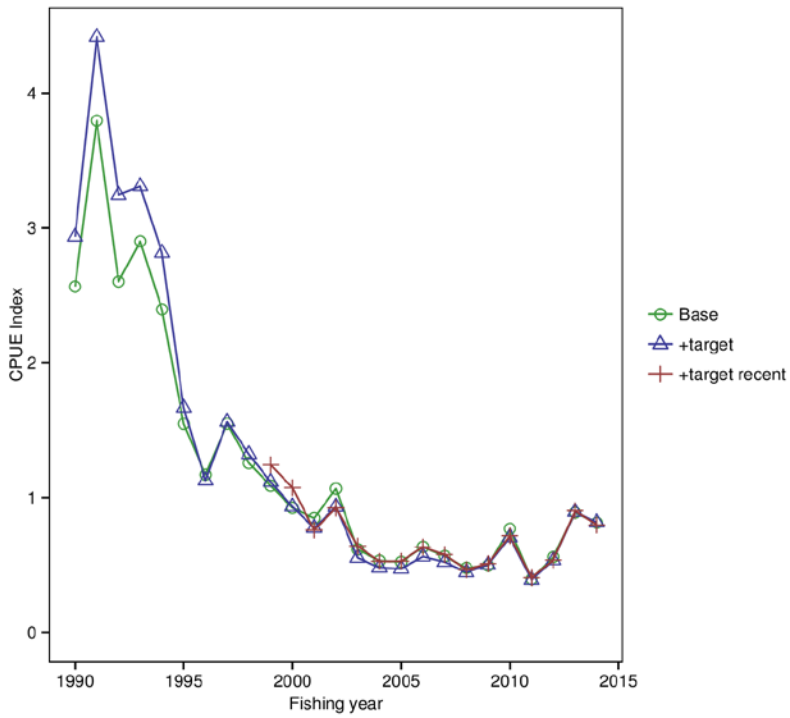

Figure 56: Comparison of CPUE indices obtained from models with alternative treatment of target species. Base, base case (final model). +target, included target species as a standardisation term. +target recent, included target species as a standardisation term for only the most recent period.

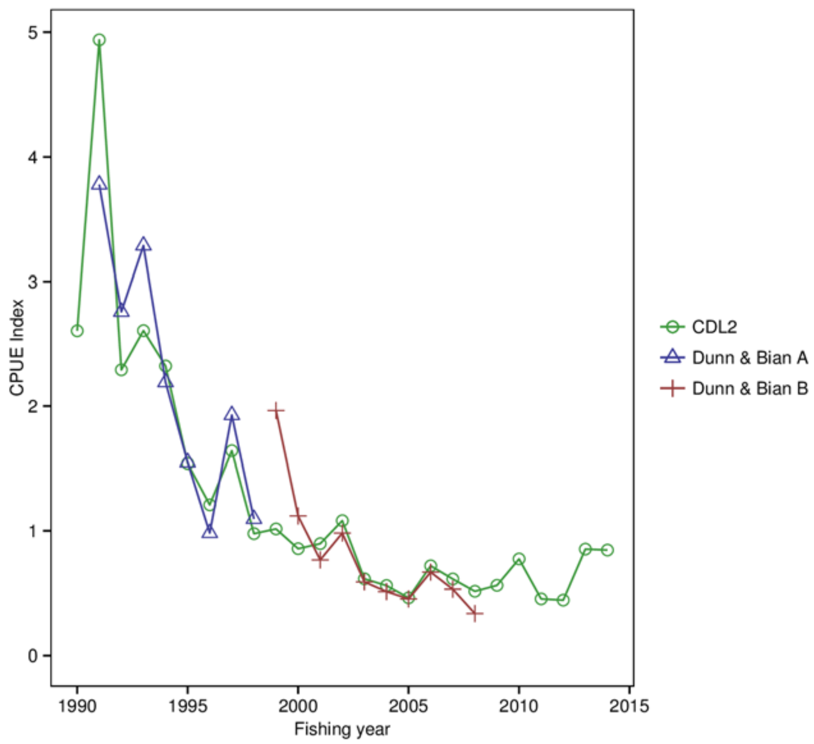

Figure 57: Comparison of CPUE indices obtained from the CDL 2 model with those from Dunn & Bian (2009). Each of the Dunn and Bian indices was rescaled by the geometric mean of the CDL 2 series from this study for the overlapping period.

4.5 Combined index of expected cardinalfish catch

A combined index of the standardised, expected catch per tow of cardinalfish was calculated by multiplying the standardised probability of catch series with the standardised magnitude of catch series (Figure 58, Table 7). Due to the overall decline in the standardised probability series, the combined series exhibits a steeper decline than the magnitude index, peaking at 4.66 in 1990–91 and reaching a nadir of 0.29 in 2010–11 before increasing to 0.53 in 2013–14.

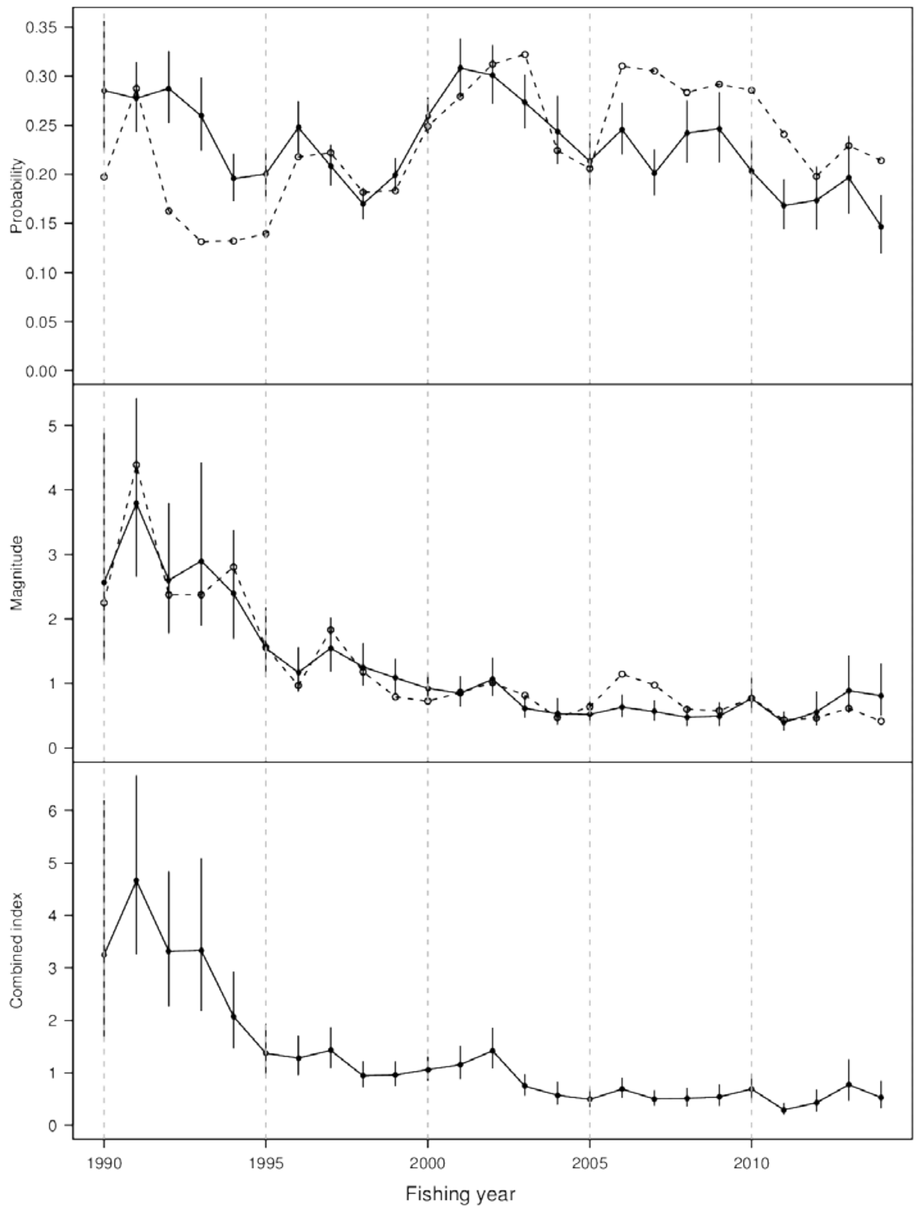

Figure 58: Standardised (solid line) and unstandardised (dashed line) indices for probability of cardinalfish catch (top), magnitude of cardinalfish catch (middle) and combined index (i.e. expected catch, probability × magnitude normalised; bottom). Error bars indicated +/- one standard error. The standard errors for the combined index are based on the standard errors for the magnitude index only and thus underestimate uncertainty around the combined index.

Table 7: Standardised and unstandardised CPUE indices. Fishing year labelled by later calendar year e.g. 1990=1989–90. All: all vessels, Core: core vessels, Geom.: geometric mean, Arith: arithmetic mean, Probability: standardised probability of positive catch, Magnitude: standardised magnitude of positive catch, SE: standard error. Combined: combined index.

Fishing year	All Arith.	Core Arith.	All Geom.	Core Geom.	Probability	Magnitude	Magnitude SE	Combined	Combined SE
1990	1.2173	1.4984	2.7219	2.2513	0.2856	2.5654	0.3256	3.2433	0.3256
1991	2.9334	3.2730	4.7788	4.3912	0.2775	3.7953	0.1797	4.6635	0.1797
1992	1.1662	1.1963	2.3109	2.3755	0.2877	2.6017	0.1905	3.3135	0.1905
1993	1.2037	1.1492	3.0990	2.3765	0.2596	2.9011	0.2130	3.3344	0.2130
1994	1.0951	1.3534	2.3975	2.8073	0.1956	2.3951	0.1730	2.0741	0.1730
1995	0.8495	1.0536	1.9184	1.5598	0.2003	1.5468	0.1708	1.3719	0.1708
1996	0.9067	0.9792	1.0292	0.9667	0.2477	1.1697	0.1442	1.2830	0.1442
1997	1.0697	1.2571	1.7833	1.8283	0.2085	1.5472	0.1329	1.4284	0.1329
1998	0.6721	0.7386	1.1139	1.1792	0.1698	1.2559	0.1273	0.9443	0.1273
1999	0.5555	0.5534	0.7320	0.7935	0.1993	1.0875	0.1182	0.9597	0.1182
2000	1.0249	0.9153	0.7151	0.7285	0.2596	0.9240	0.1049	1.0619	0.1049
2001	1.0471	0.9954	0.8073	0.8587	0.3081	0.8476	0.1347	1.1563	0.1347
2002	1.4893	1.3479	0.9512	1.0120	0.3009	1.0660	0.1340	1.4201	0.1340
2003	1.4579	1.2759	0.8460	0.8177	0.2733	0.6156	0.1285	0.7449	0.1285
2004	1.0111	0.9948	0.4553	0.4749	0.2438	0.5316	0.1843	0.5738	0.1843
2005	0.8511	0.7712	0.5871	0.6394	0.2135	0.5222	0.1643	0.4936	0.1643
2006	1.5534	1.3709	1.0917	1.1463	0.2458	0.6339	0.1331	0.6898	0.1331
2007	1.4023	1.2482	0.9275	0.9739	0.2009	0.5655	0.1353	0.5030	0.1353
2008	0.9456	0.8497	0.5725	0.6012	0.2423	0.4776	0.1616	0.5124	0.1616
2009	1.0443	0.9319	0.5515	0.5791	0.2465	0.4958	0.1765	0.5410	0.1765
2010	0.9574	0.9235	0.6790	0.7735	0.2033	0.7684	0.1707	0.6917	0.1707
2011	0.6428	0.6139	0.4387	0.4362	0.1682	0.3949	0.1784	0.2941	0.1784
2012	0.4438	0.4308	0.4454	0.4676	0.1735	0.5593	0.2238	0.4298	0.2238
2013	0.8875	0.9361	0.6266	0.6169	0.1967	0.8884	0.2409	0.7736	0.2409
2014	0.5663	0.5550	0.4727	0.4162	0.1469	0.8137	0.2362	0.5293	0.2362

5. RESEARCH TRAWL SURVEYS

5.1 Chatham Rise survey

The annual summer Chatham Rise *Tangaroa* bottom trawl survey time series, which started in 1991, is the longest running ongoing survey that has consistently caught and measured black cardinalfish. Relative biomass estimates for the Chatham Rise time series increased from a low in 1996 and fluctuated around 100 t since the 2009 survey but with very high coefficients of variation (Figure 59). Estimates were greatest in the 400–600 m depth strata (Figure 60) which is shallower than the peak in commercial catches at around 750 m. Estimates from the Chatham Rise time series were also divided into regions east and west of 176° east. Recent increases in biomass estimates occurred in both the western and eastern parts (Figure 61). The increases in biomass estimates from this survey have similar timing and are of similar magnitude to the increases in CPUE indices from the Kaikoura and Wairarapa zones.

Numbers of black cardinalfish measured for length frequency distributions on the Chatham Rise surveys were generally low with the highest being 264 in 2012. Most fish of both sexes were 20–40 cm (Figure 62) which is smaller than those taken by the mid-east coast survey (40–70 cm) and by commercial vessels (50–70 cm). This is consistent with the biomass in this survey peaking at 400–600 m and the hypothesis that cardinalfish move to deeper water as they age (Dunn 2009).

Tracking cohorts through time is difficult but there is some evidence of an increase in mean size over time associated with one or more strong cohorts. In 2005, there was a peak in lengths around 20 cm. By 2007, this peak was centred around 25 cm, by 2011 around 30 cm, and by 2014 the modal length was 32 cm (Figure 62). This increase in modal length is consistent with a hypothesis of the observed increase in biomass estimates being due to the increase in weight of one or more strong cohorts of similar age.

5.2 Mid-east coast survey

The mid-east coast survey *Tangaroa* bottom trawl survey for orange roughy also caught and measured black cardinalfish. Relative biomass estimates were higher than for the Chatham Rise but with very high coefficients of variation (Figure 63). The number of cardinalfish measured during this survey series was low. Most fish measured were 40–70 cm (Figure 64), longer than those measured on the Chatham Rise, and similar to those measured from commercial catches.

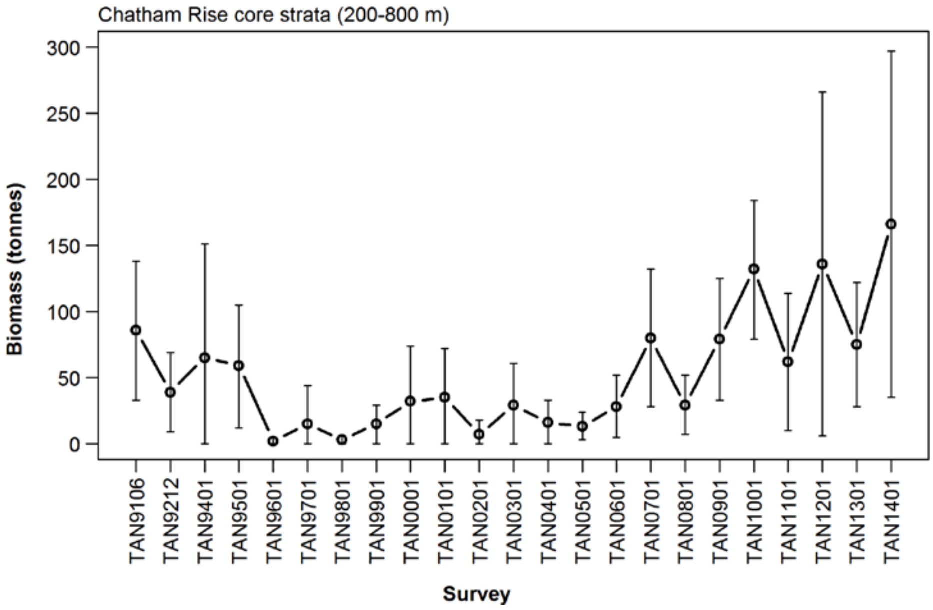

Figure 59: Doorspread biomass estimates for the Chatham Rise, from *Tangaroa* surveys from 1991 to 2014.

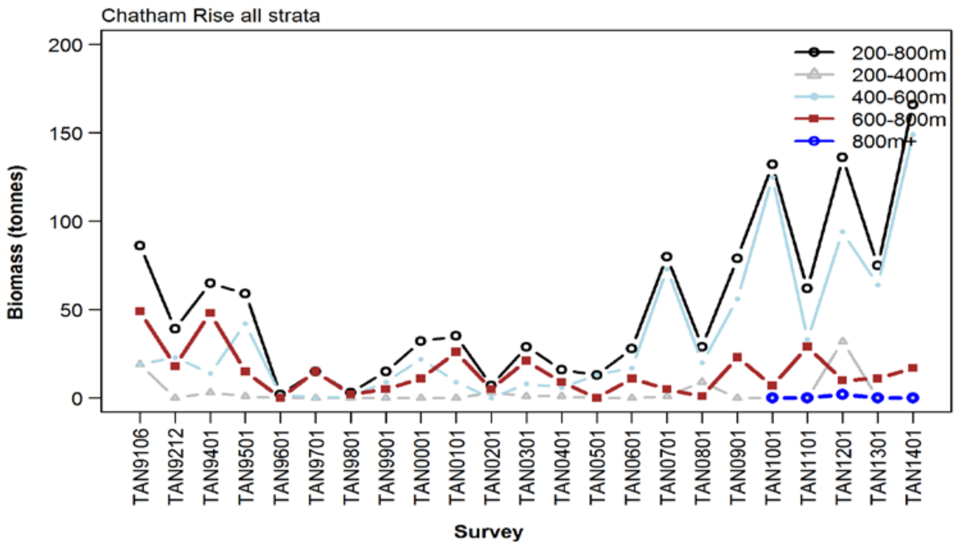

Figure 60: Doorspread biomass estimates by depth strata for the Chatham Rise, from *Tangaroa* surveys from 1991 to 2014.

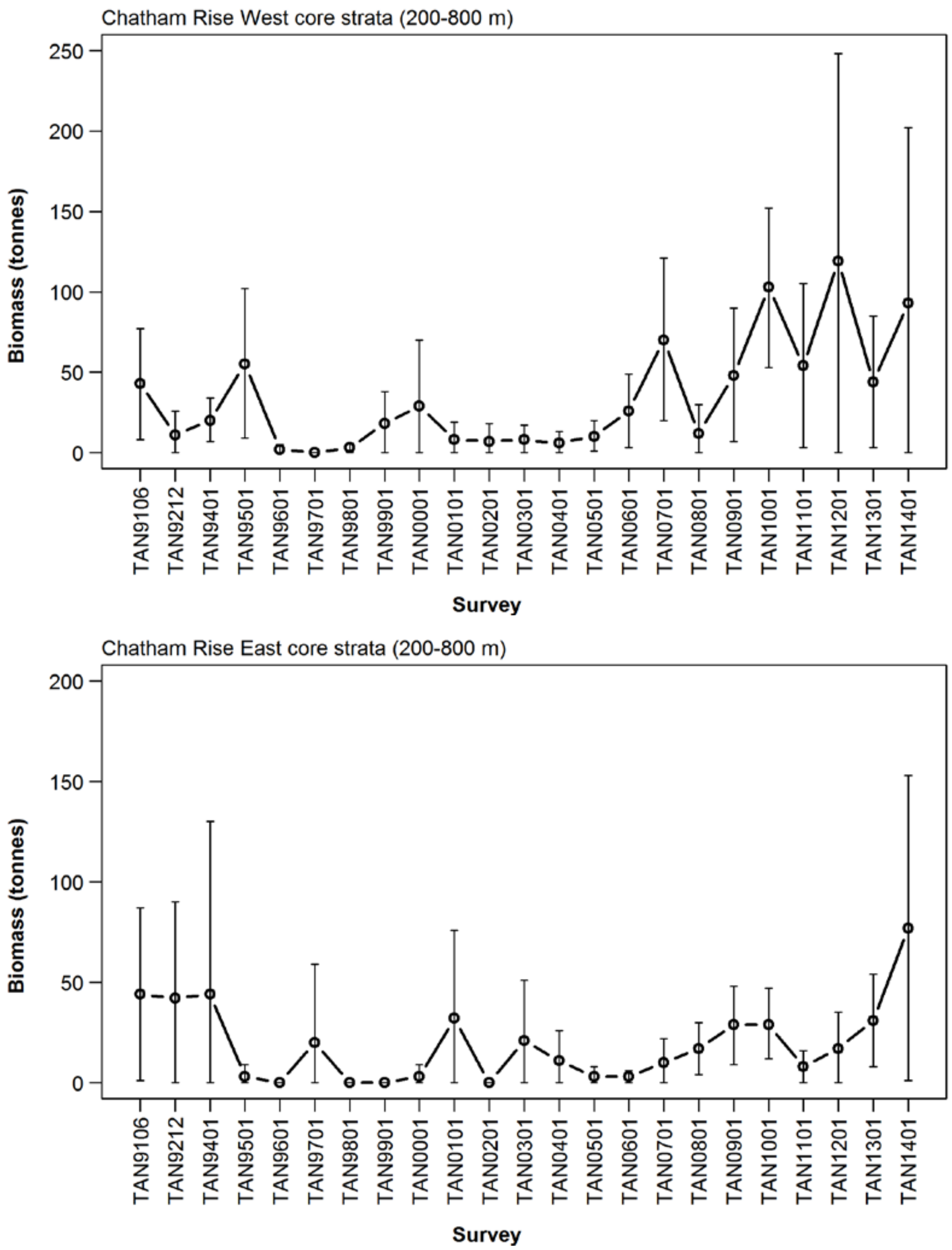

Figure 61: Doorspread relative biomass estimates for the west (top) and east (bottom) Chatham Rise, from *Tangaroa* surveys from 1991 to 2014.

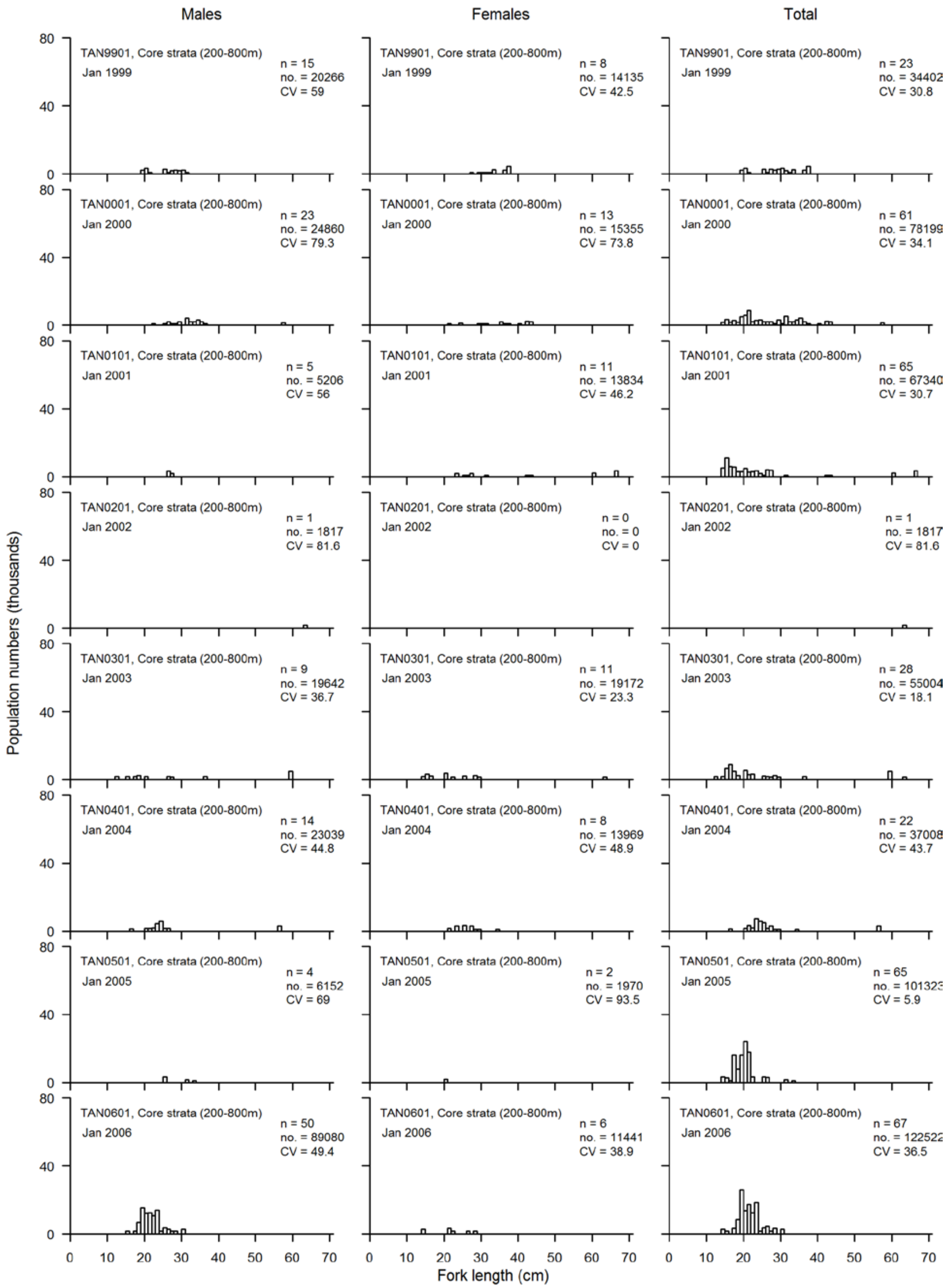

Figure 62: Scaled population length frequency distributions by sex of black cardinalfish from the Chatham Rise from *Tangaroa* surveys from 1999 to 2014.

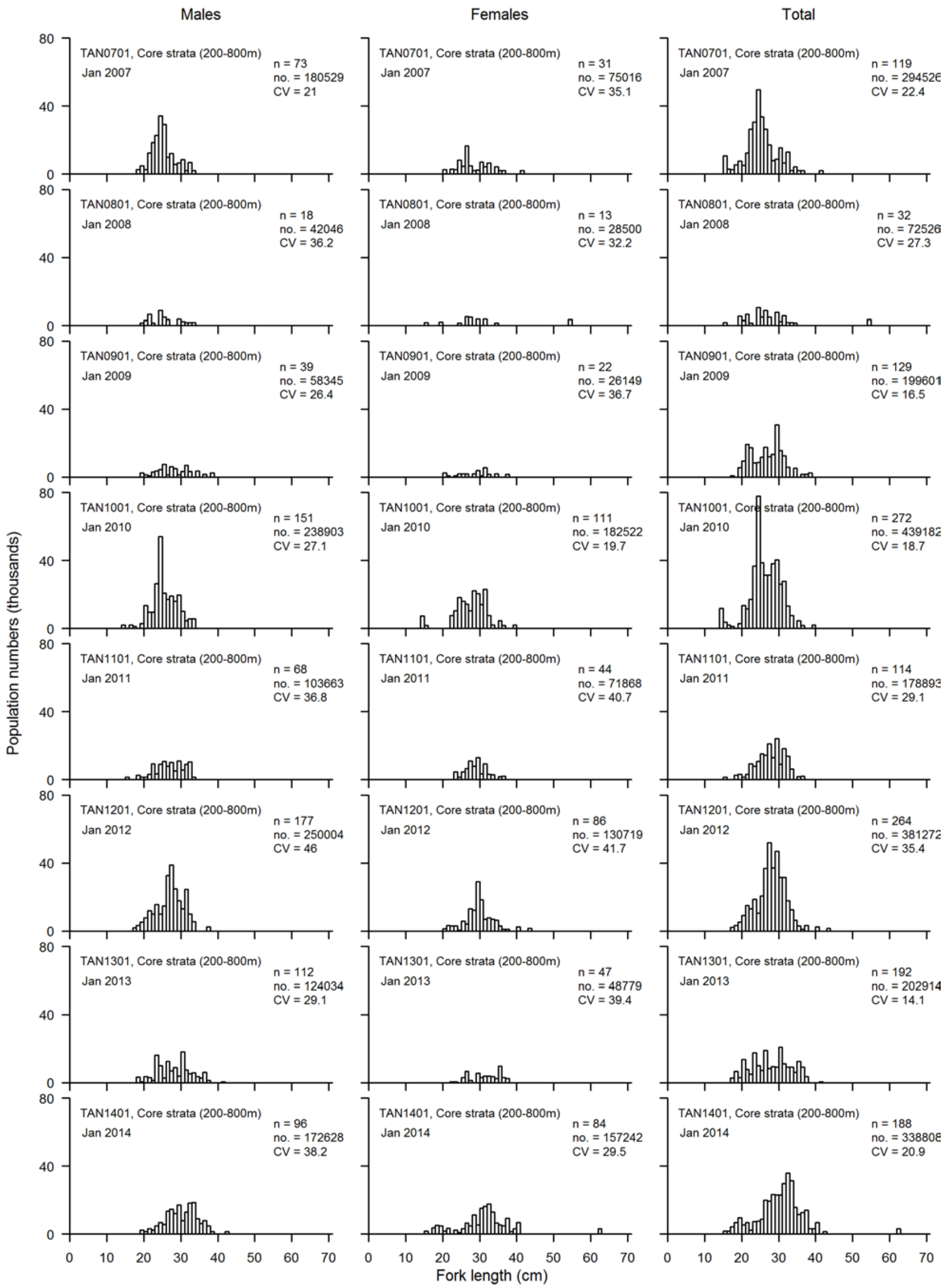

Figure 62 continued.

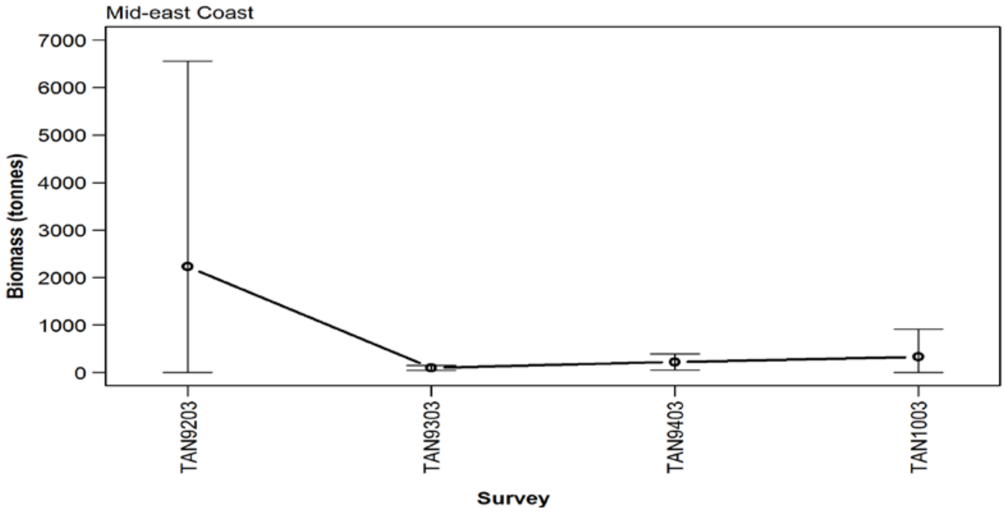

Figure 63: Doorspread biomass estimates for the mid-East coast from *Tangaroa* surveys from 1992 to 2010.

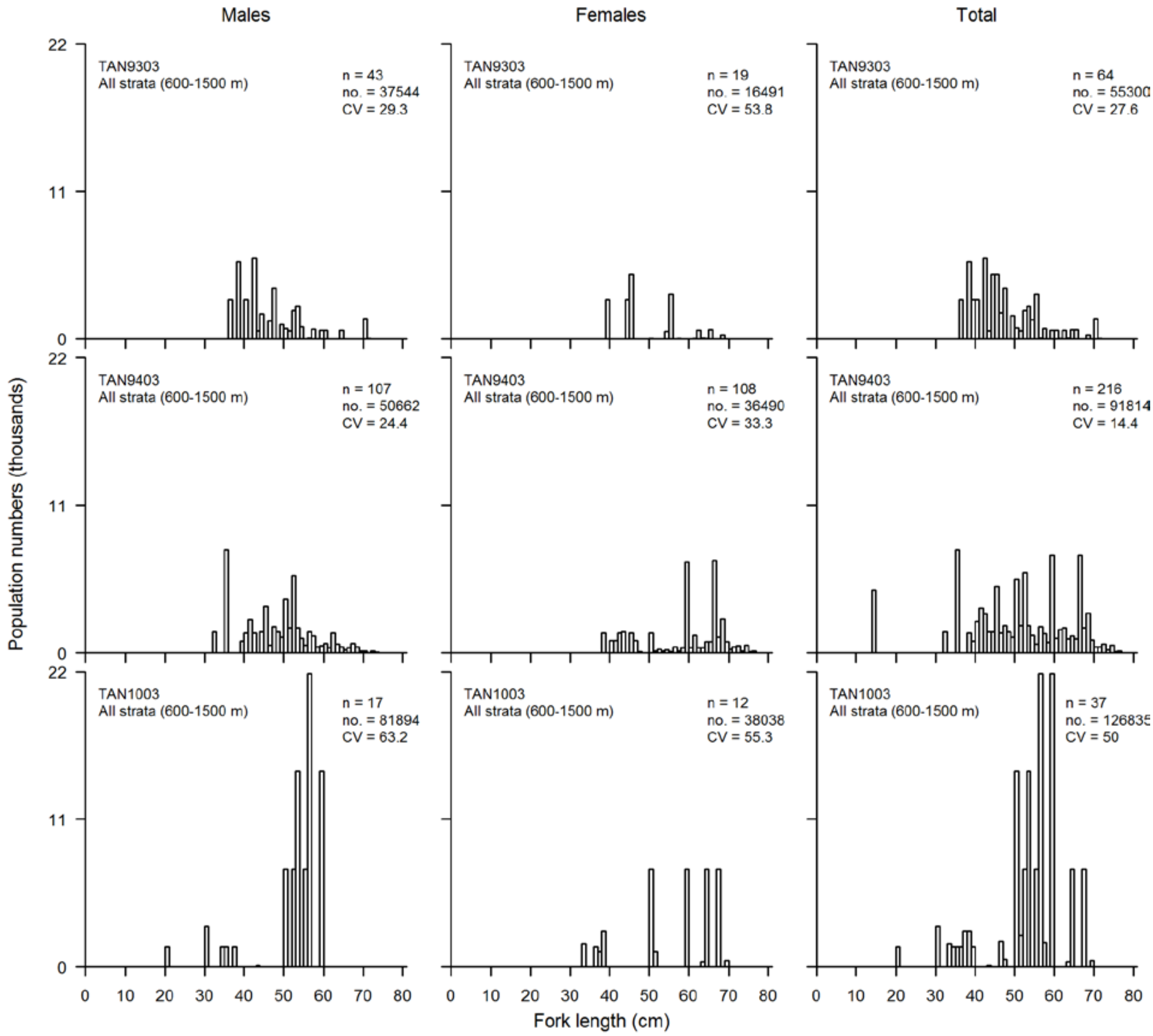

Figure 64: Scaled population length frequency distributions by sex of black cardinalfish from the mid-East coast from *Tangaroa* surveys from 1993 to 2010.

6. OBSERVER SAMPLING

The Ministry for Primary Industries Observer Programme has collected black cardinalfish length and weight data from commercial trawl fisheries since the 1989–90 fishing year. Summaries of these data were prepared by statistical areas grouped into four areas: Bay of Plenty (BP, 008–010,107), East Cape (EC, 011–013, 204), Wairarapa (WA, 014–106) and Kaikoura (KK, 018).

The representativeness of the observer sampling of black cardinalfish catches was evaluated by plotting the proportion of landed catch for each year by area and month as circles, and overlaying this with the proportion of the observed catch for those same cells as crosses (Figure 65). If the proportions are similar, the circles and crosses are similar in diameter; if over- or under-sampling has occurred, the crosses are either larger or smaller than the circles. Relative to commercial catches, observer sampling has tended to under-sample the East Cape, Kaikoura and Wairarapa areas (Figure 65).

Scaled length frequency distributions were determined using the ‘catch.at.age’ software (Bull 2002) which scales the length frequency from each catch up to the tow catch, sums over catches in each stratum, scales up to the total stratum catch, and then sums across the strata to yield overall length frequency distributions. Numbers of black cardinalfish for each fishery were estimated from catch weights using the length-weight relationship given in the Ministry for Primary Industries' May 2014 Plenary Report. No summaries were made for the Wairarapa and Kaikoura areas because of the very low levels of observer coverage.

The length frequency distributions of sampled black cardinalfish from the Bay of Plenty and East Cape areas were unimodel with most fish between 50 and 70 cm (Figure 66, Figure 67). There was no evidence of length modes associated with cohorts moving through these distributions.

Female black cardinalfish were examined for gonad maturity by the observer programme. The proportion of maturing and running ripe gonads peaked in March and the proportion of spent gonads peaked in July (Figure 68). This is consistent with spawning occurring in autumn-early winter.

Examination of gonad stages by location indicate that there are potentially numerous spawning locations including off the east coast of the North Island, the Bay of Plenty, the West-Norfolk Ridge, the Challenger Plateau and the Lord Howe Rise (Figure 69). No running ripe fish and few mature female gonads were sampled from the Chatham Rise, Kaikoura or Wairarapa areas.

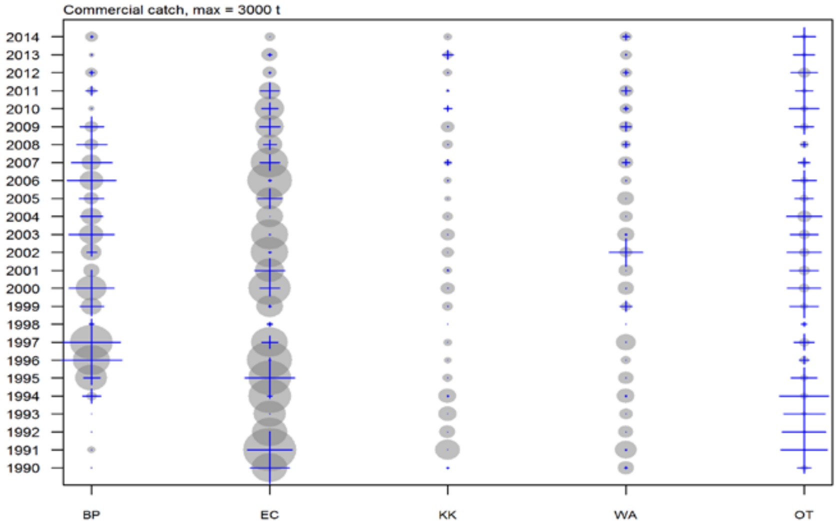

Figure 65: Representativeness of observer sampling of black cardinalfish catch by fishing year and region for fishing years 1989/1990–2010/11. Circles show the proportion of commercial catch by area within a year; crosses show the proportion of observed target catch for the same cells. Representation is demonstrated by how closely the crosses match the diameters of the circles.

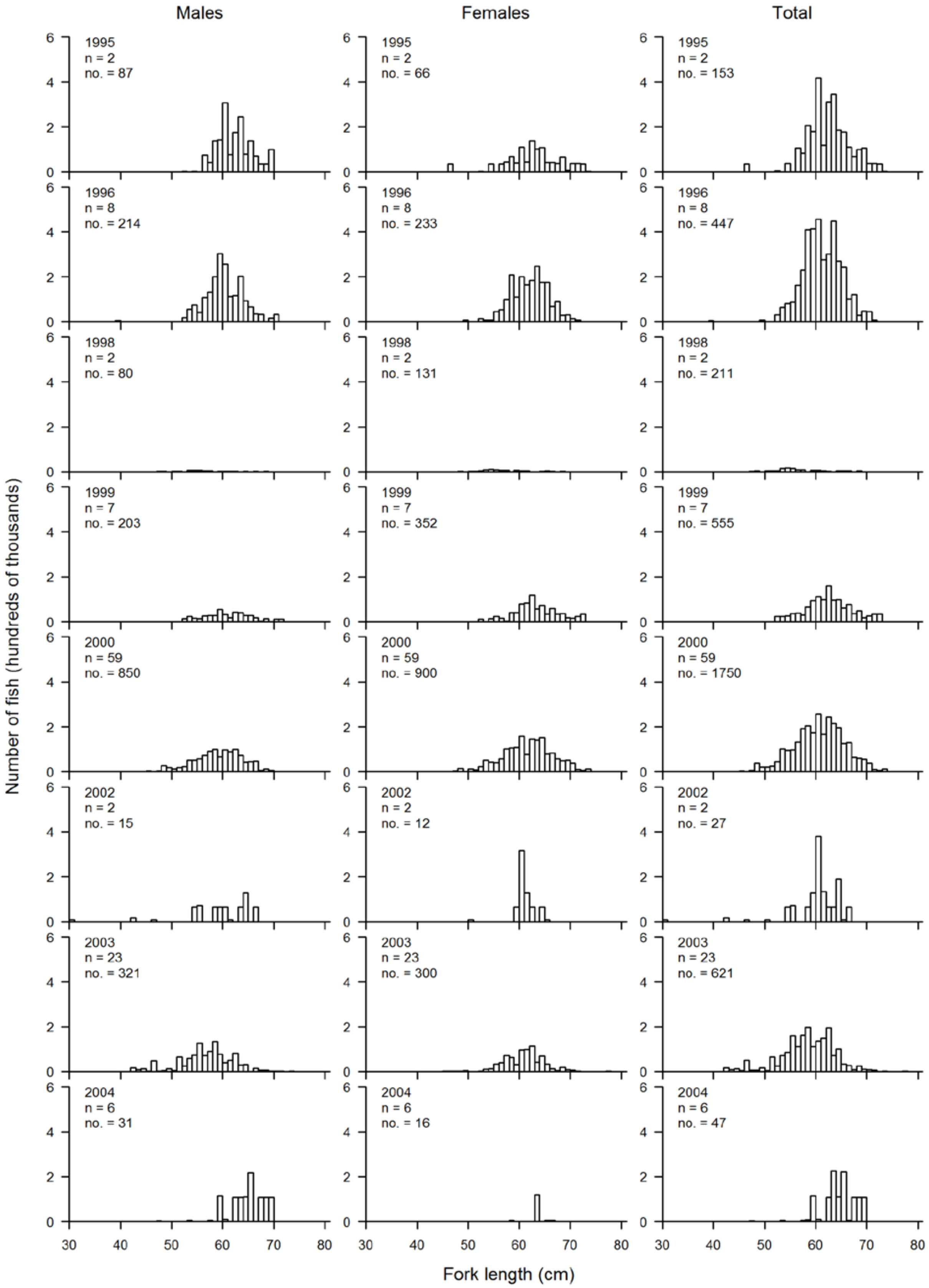

Figure 66: Scaled length frequency distributions of black cardinalfish taken from the Bay of Plenty (BP) area for available fishing years sampled by the Observer Programme. n, number of tows sampled; no., number of fish measured.

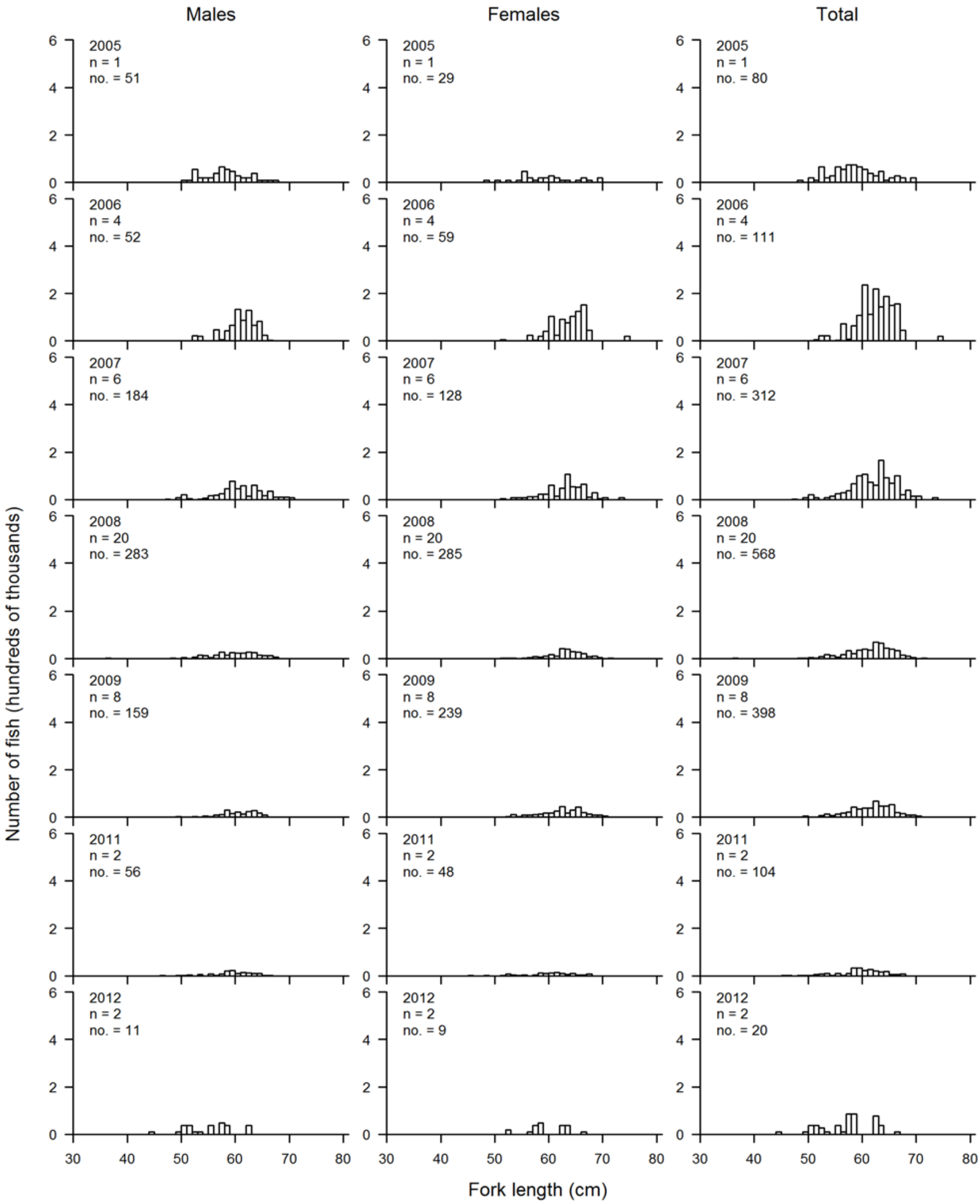

Figure 66: continued.

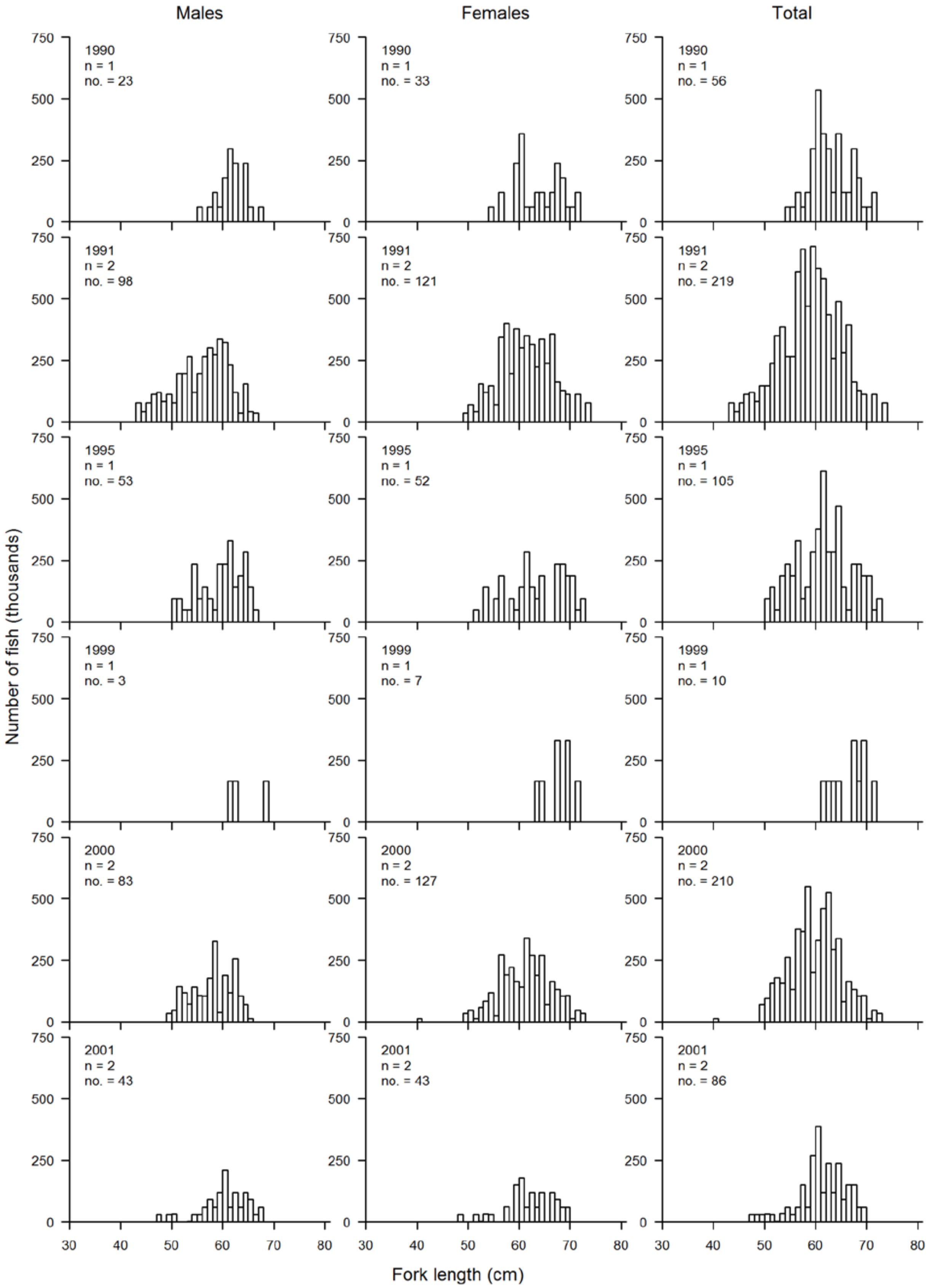

Figure 67: Scaled length frequency distributions of black cardinalfish taken from the East Cape (EC) area for available fishing years sampled by the Observer Programme. n, number of tows sampled; no., number of fish measured.

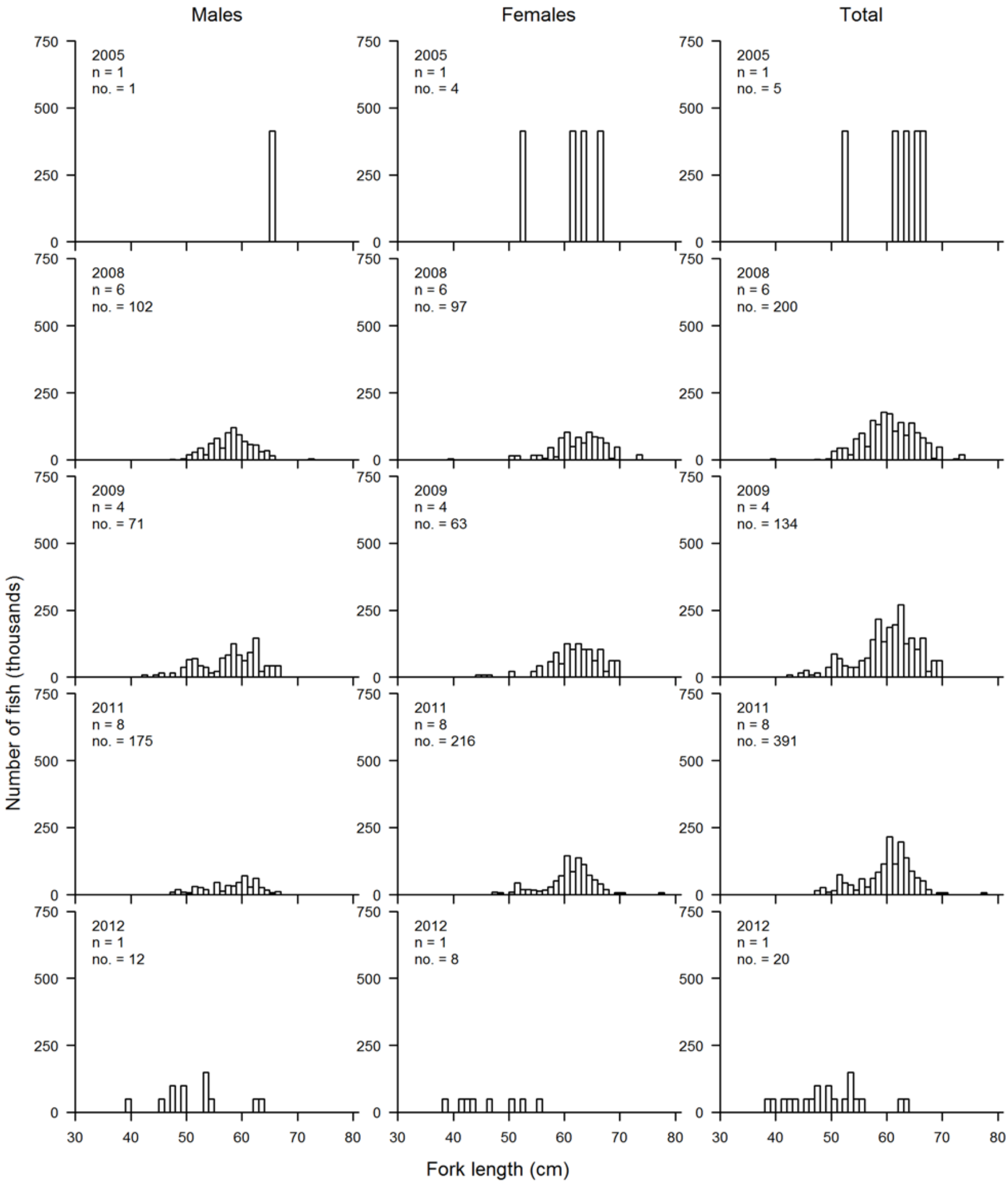

Figure 67: continued.

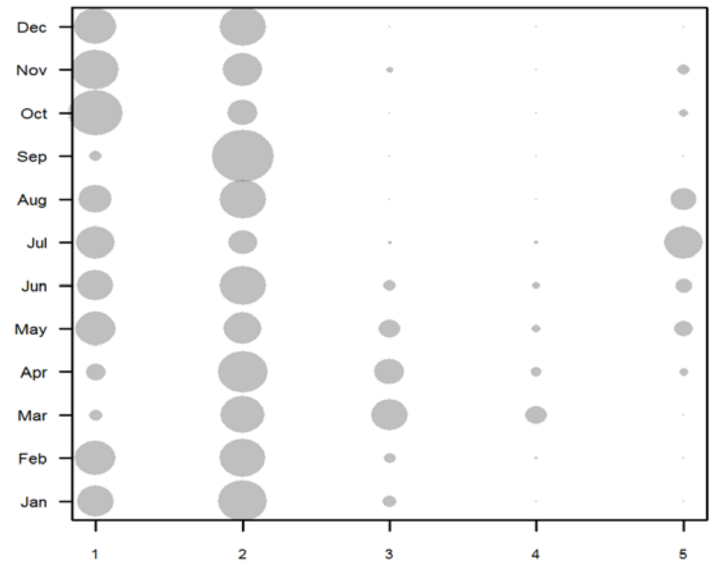

Figure 68: Proportion of female gonad stages by month for all available fishing years. 1 = immature/resting; 2 = maturing; 3 = mature; 4 = running ripe; 5 = spent.

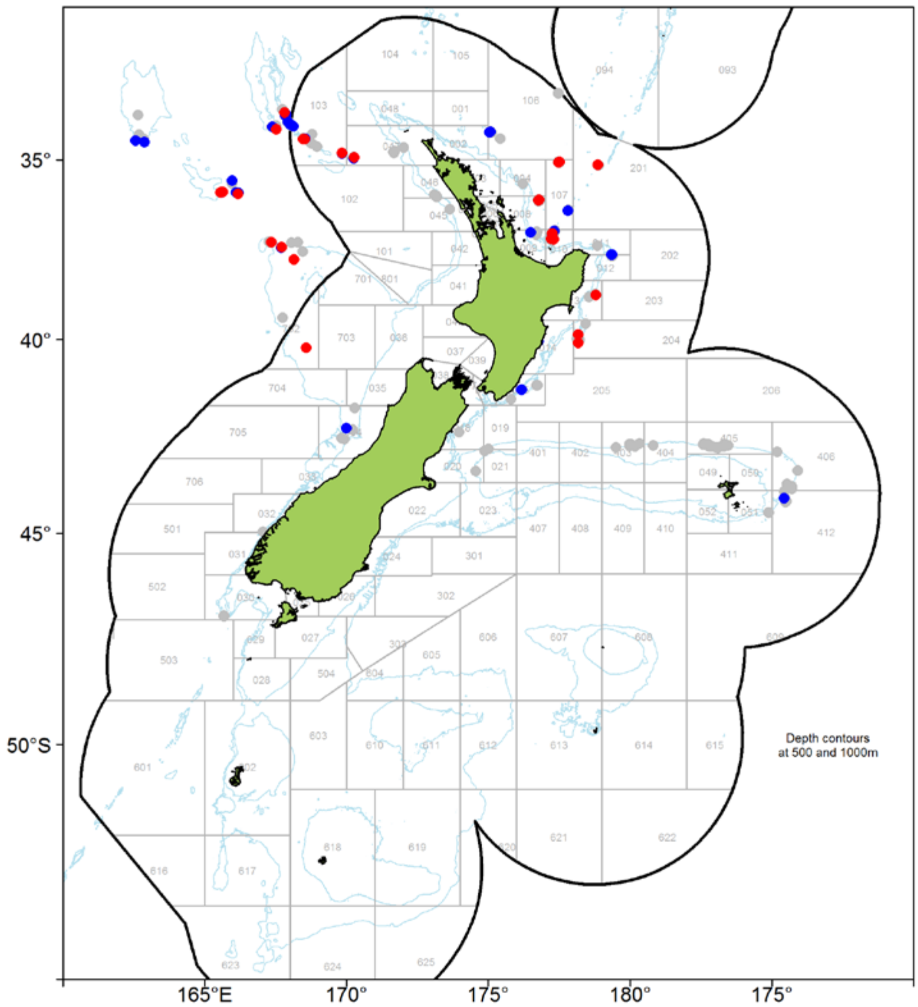

Figure 69: Locations of female gonad stages for all available fishing years. Grey dots = gonad stages 1, 2, and 5 (immature/resting, maturing, spent), blue dots = stage 3 (mature), red dots = stage 4 (running ripe).

7. DISCUSSION

This study extends the series of characterisations and CPUE analyses conducted for black cardinalfish in New Zealand over the last two decades (e.g. Field et al. 1997, Phillips 2002, Dunn & Bian 2009). The fishery focused on underwater features off the north and north-east coasts of the North Island and, since the early 2000s, most of the catch of cardinalfish came from target tows.

As seen in previous studies, there was a substantial reduction in CPUE in most areas during the 1990s and early 2000s. However, this study found that since 2004–05 standardised CPUE indices have remained relatively flat. This may reflect the lower TACC for CDL 2 and lower catches in other quota management areas.

CPUE indices for the Wairarapa and Kaikoura zones increased in the early 2010s, although due to small amounts of data these indices are uncertain. The relative biomass estimates from the *Tangaroa* survey on the nearby Chatham Rise, which sampled smaller cardinalfish than the main commercial fishery, showed a similar increase. It may be that the CPUE indices from the Wairarapa and Kaikoura zones, as well as the biomass estimates from the Chatham Rise survey reflect the abundance of pre-recruits rather than recruited biomass.

8. ACKNOWLEDGMENTS

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