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Fishery characterisation and Catch-Per-Unit-Effort indices for giant stargazer in STA 7

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The STA 7 catch is primarily taken by the bottom trawl fishery operating off the west coast of the South Island in the 50–200 m depth range. Stargazer is caught in conjunction with a range of other demersal finfish species, primarily barracouta, red cod, tarakihi, blue warehou, ling and red gurnard. The fishing fleet is comprised of inshore trawl vessels and some of the main vessels have operated in the fishery for over 20 years.

The STA 7 fishstock is primarily monitored by the West Coast South Island (WCSI) inshore trawl survey. Standardised CPUE indices derived from daily aggregated catch and effort data reported in CELR format are not consistent with the time-series of trawl survey abundance indices, particularly during the late 1990s and early 2000s. Based on changes in the species composition of the landed catches from the trawl fleet it is postulated that these CPUE indices were influenced by changes in the degree of fishing effort directed at areas of higher stargazer abundance. These observations provide support for the previous decision by the SINS Working Group to reject the time series of CPUE indices derived from the daily aggregate (CELR format) data.

Since 2007/08, trawl based catch and effort (TCER) data have been available from the WCSI trawl fishery. A time series of standardised CPUE indices was derived from these data using generalised linear modelling of the positive stargazer catches and the presence/absence of stargazer in the individual trawl catches. The explanatory variables incorporated in both models included a spatial component as a relatively strong predictor of both stargazer presence in the catch and the magnitude of the stargazer catch.

The combined trawl based CPUE indices are relatively stable for the limited time series (6 years to 2012/13). The SINS WG concluded that the individual trawl based CPUE indices may, in the longer term, provide a reliable index of stock abundance for STA 7. The reliability of the CPUE indices will be evaluated based on a comparison with the stargazer biomass estimates derived from the ongoing time series of WCSI trawl surveys. It is anticipated that a minimum of 10 years of CPUE indices and trawl survey biomass estimates from five biennial surveys would be required to assess the comparability of the two sets of indices. A more definitive evaluation would be possible if there was significant contrast in the abundance indices during the evaluation period.

1 INTRODUCTION

Giant stargazer (*Kathetostoma giganteum*) in STA 7 is primarily caught by the inshore trawl fleet operating off the west coast of the South Island. The fishery catches giant stargazer in association with a range of target species, primarily barracouta, red cod, tarakihi and blue warehou (Bentley et al. 2013). The TACC for STA 7 was 702 t from 1992/93 to 2001/02, although catches were considerably higher than the TACC during 1998/99–2001/02 (MPI 2014). The TACC was increased in 2002/03 to 997 t and increased again in 2011/12 to 1042 t. Since 2004/05, annual catches from STA 7 have been maintained at 1000–1100 t (MPI 2014).

Monitoring of STA 7 has essentially been conducted based on the biennial inshore WCSI trawl survey by RV *Kaharoa* from 1992 to 2013 (MacGibbon & Stevenson 2013). The relative abundance estimates of stargazer from the trawl surveys were incorporated in a stock assessment of STA 7 conducted by Manning (2008). The assessment also incorporated age composition data from the commercial fishery and from the trawl surveys (Manning & Sutton 2007). The stock assessment included data up to the 2004/05 fishing year and has not been updated with the data from the more recent trawl surveys.

Under the Adaptive Management Programme, Starr et al. (2007) conducted an analysis of STA 7 catch and effort data from the mixed west coast South Island target species (stargazer, barracouta, red cod and tarakihi) fishery. The resulting CPUE indices were *"not accepted by the AMP WG as an indicator of STA 7 abundance. The Inshore and AMP Fishery Assessment Working Groups (FAWG) have concerns over using bycatch fisheries to monitor stargazer abundance in these areas due to possible changes in recording and fishing practices* (MPI 2014)".

The current study characterises the STA 7 fishery during the 1989/90–2012/13 fishing years. The potential for monitoring STA 7 based on CPUE indices is also re-examined, particularly utilising the recent time-series of activity (tow) based catch and effort data available from the inshore trawl fishery since 2007–08. The study was funded by Southern Inshore Fisheries Management Company Limited.

2 DATA SOURCES AND METHODS

Commercial catch and effort data from the STA 7 fishery were sourced from the Ministry for Primary Industries (MPI) database *warehou*. The data extract was based on qualifying fishing trips that landed STA 7 and/or conducted fishing events that targeted a range of inshore species (ELE, GUR, JDO, STA, GSH, RCO, TAR, BAR, WAR, JMA, SPD and FLA) within a statistical area valid for STA 7. For the qualifying trips, all effort data records were obtained regardless of whether or not stargazer was landed. The estimated catch and landed catch records, for all species, were also sourced for the qualifying fishing trips. Data were complete to the end of the 2012/13 fishing year.

From 1989/90 to 2006/07, most inshore fishing vessels reported catch and effort data via the Catch Effort Landing Return (CELR) which records fishing effort and the estimated catch of the top five species. For trawl fisheries, fishing effort and catch was required to be recorded for each target species and statistical area fished during each day, although typically catch and effort data were aggregated by fishing day (Langley 2014). The verified landed greenweight that is obtained at the end of the trip was recorded on the bottom section of the CELR form.

Since 1989/90, larger trawlers have reported on the Trawl, Catch, Effort and Processing, Return (TCEPR) at the resolution of a single trawl. In 2007/08, a similar event-based form was introduced for the inshore trawl fleet, replacing the CELR form. The Trawl, Catch and Effort Return (TCER) records detailed fishing activity, including trawl start location and depth, and associated catches for individual trawls conducted by these vessels. Landed catch associated with trips reported on TCEPR and TCER forms is reported at the end of a trip on the Catch Landing Return (CLR).

The Quota Management System (QMS) totals are collected from fishing permit holders on a monthly basis (Monthly Harvest Return, MHR) and are subjected to a different regime of storage and checking.

2.1 Data processing

Three separate catch and effort data sets were generated from the original data extract:

i. A STA 7 fishery characterisation data set, 1989/90–2012/13;
ii. An inshore STA 7 bottom trawl CPUE data set aggregated by vessel fishing day (format equivalent to the CELR format), 1989/90–2012/13; and
iii. An inshore STA 7 bottom trawl CPUE data set in TCER format, 2007/08–2012/13.

2.1.1 Fishery characterisation data set

The STA 7 characterisation data set included all fishing trips that landed STA 7 and the associated fishing effort from within the statistical areas that approximate the fishstock area (Statistical Areas 017, 023–039, and 701–705). The initial set of STA 7 landed catch records was screened to retain the records that represented the final destination of the STA 7 catch (destination codes L, A, C, E, and O). This resulted in a 2.5% reduction in the total STA 7 landed catch included in the landings data set (Table 1). Most of the reduction was attributable to the removal of records that represented the transfer of STA 7 catch to another vessel (transhipment, destination code T) or retention on board the vessel (destination code R).

Table 1: Total STA 7 landed catch included in the fishery characterisation data set at each step of the catch grooming process.

Criterion	STA 7 landed catch (t)	Percent of total landed catch
All landing records	22 903.7	100.0%
Destination codes (L, A, C, E, O)	22 340.8	97.5%
Exclude landed catch outliers	21 958.8	95.9%
Associated effort records	20 797.6	90.8%
Conversion factor correction	22 940.1	

Potential landed catch outliers were examined by comparing the landed catch from a trip with the aggregated estimated catches from a trip. In most cases, the ratio of the trip landed catch to the estimated catch approximated 1.0 indicating a good correspondence between the landed catch and estimated catch (Figure 1). There was a smaller proportion of trips with a ratio of about 2.0. These records are likely to correspond to the reporting of estimated catches in terms of processed weight. Most stargazer catches are processed at sea to the dressed V-cut (DVC) state with a conversion factor of 2.15.

Potentially erroneous landed catch records were identified based on the ratio of the trip landed catch to the aggregated estimated catch; i.e. where the ratio exceeded a factor of 4.0 and landed catches exceeded 1000 kg. A total of 255 trips (of a total of 23 197 trips) met these criteria and the landed catches for these trips were further examined by comparing the landed catch with the corresponding processed catch weight multiplied by the conversion factor of the associated state code. A subset of those trips (86 of 255 trips) had catch values derived from the processed catch data that were considerably lower than the landed catch. For these trips, the landed catches were corrected using the green weight equivalent of the processed catches. This resulted in a reduction in the total STA 7 catch included in the data set, primarily due to the correction of the catch data from three large landings (Table 1).

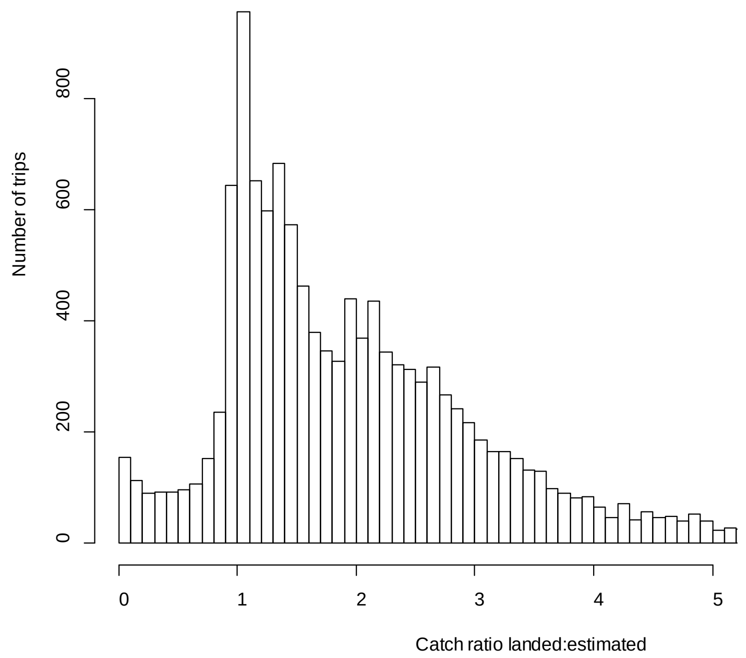

Figure 1: Ratio of the STA 7 landed catch and the sum of stargazer estimated catches from individual fishing trips.

Prior to 2007/08, most (80–90%) of the STA 7 landed catch was associated with fishing effort recorded in the CELR format. Since 2007/08, most of the catch has continued to be reported by the inshore trawl fleet and, consequently, the reporting of STA 7 catch has been associated with the TCER reporting form (Figure 2). Approximately 10–20% of the annual STA 7 landed catch has been associated with the larger trawl vessels reporting fishing effort data using the TCEPR form.

Catch and effort data from the qualifying fishing trips were aggregated in a manner that approximates the daily aggregate format of the CELR following the approach of Langley (2014). The approach aggregates method specific fishing effort (number of trawls and hours fished) for each fishing vessel and fishing day. The resulting records are assigned a statistical area and target species based on the predominant statistical area and declared target species from the day of fishing. The estimated species catches are also aggregated for the vessel fishing day and the aggregate catches are ranked based on species catch weight. The five largest species estimated catches are retained, replicating the recording of the top five species estimated catches from the CELR. The estimated catches of the remainder of the species (non top five) are not included in the subsequent analysis.

This aggregation approach reduces the potential for the catch and effort data set to be influenced by the changes in reporting formats, especially from CELR to TCER. Given the high proportion of the landed catch reported in the CELR format prior to 2007/08 it was considered important to maintain a consistent reporting format in the subsequent years. The aggregation of the catch and effort data means that the additional detail associated with the trawl based reporting from the TCER and TCEPR forms is not included within the main characterisation data set. Nonetheless, these data were included in a number of supplementary analyses, and the TCER data were utilised to characterise the more recent operation of the stargazer inshore trawl fishery.

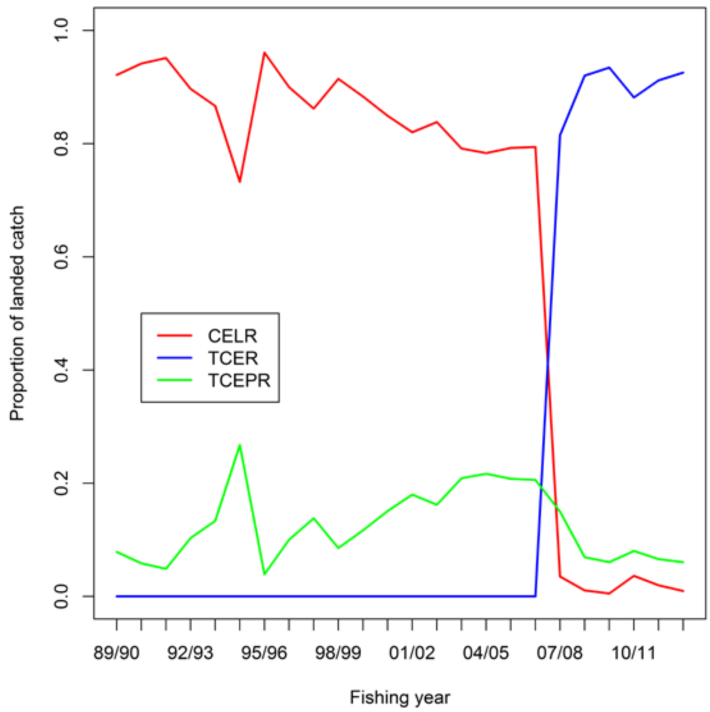

Figure 2: Annual proportion of the total STA 7 landed catch associated with the statutory catch and effort reporting forms.

A total of 23 099 trips (from 23 197 trips) with a landed catch of STA 7 were successfully linked to the aggregated fishing effort records. However, the number of trips was reduced by the exclusion of fishing effort records in statistical areas outside of STA 7, fishing methods records that would not be expected to catch STA 7 (e.g. surface longline and troll) and/or target species that are unlikely to be associated with stargazer (e.g. ORH, SSO, and BOE) (21 460 trips retained). There were also fishing effort records that were missing the data fields required to generate the aggregated effort records. The reduction in the number of fishing trips included in the final data set resulted in a small reduction in the overall quantity of STA 7 landed catch (Table 1).

For 1990/91–1995/96, the landed catch data set represented approximately 77–85% of the total annual STA 7 catch reported in the MPI Plenary document (Figure 3). The reason for this discrepancy is not known, however, it was also apparent in the STA 5 fishery (Langley & Bentley 2014). Over the subsequent years, there was an increased proportion of the total STA 7 catch included within the landed data set, steadily increasing to about 96–98% in 2008/09–2012/13.

The estimated catches of stargazer represented about 60–70% of the landed catch for 1992/93–2006/07 (Figure 3). Since 2007/08, the estimated catches have represented about 70% of the landed catch and the higher level of reporting of estimated catch is likely to be attributable to the introduction of the TCER reporting form for the inshore trawl fleet. The under estimation of the stargazer catches appears to be partly attributable to the recording of some estimated catches as processed weight rather than unprocessed (green) weight.

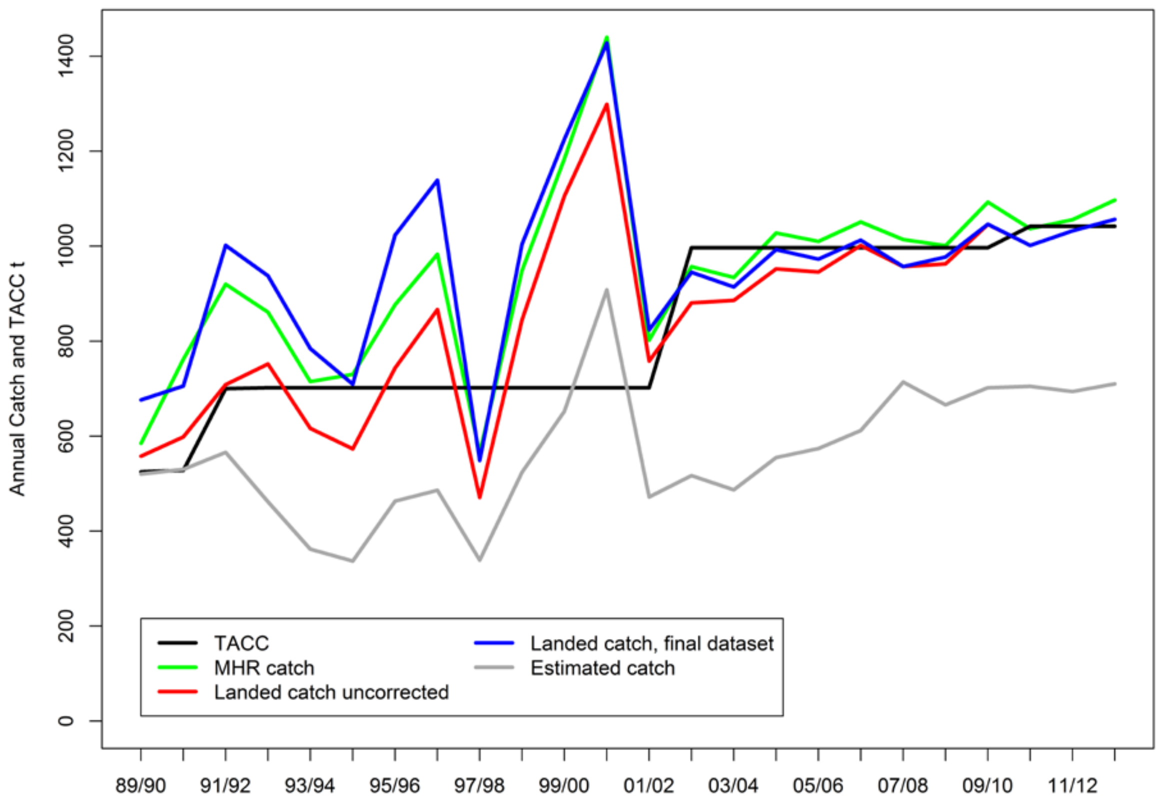

Figure 3: Comparison of total annual STA 7 landed catches (t) by fishing year from vessel trip landing returns and the total reported landings (t) to the QMS (MHR). Also shown are the landed catch totals (t) which remain after the dataset has been prepared for the characterisation analysis (final data set) and the estimated catch from trips retained in the characterisation dataset.

Primary processing of stargazer generally occurs at-sea, typically removing the head and viscera. A conversion factor is applied to the weight of the processed catch to determine the equivalent green weight of the landed catch. Most of the STA 7 catch has been landed in HGU (head-and-gutted), DRE (dressed cut) and DVC (dressed-v cut) processed states. The definition of these processed states primarily differs based on the type of cut used to sever the head from the body. Over the study period, there was a transition in the processing of stargazer initially from HGU to DRE and then to DVC. Since the early 2000s, the stargazer catch has almost exclusively been processed at sea to the DVC state (Figure 4).

During the study period, there were a number of changes to the conversion factors applied to the main stargazer processed states (Table 2). The landed catches of stargazer from individual fishing trips were corrected to account for these changes. Individual fishing trips almost exclusively landed stargazer in one processed state. The corrected landed green weight of stargazer for individual trips was calculated by multiplying the reported landed green weight by the ratio of the current (2012/13) DVC conversion factor to the conversion factor that was applicable at the date of landing (CF $Year_{2012/13}/Year_{Landing}$). Fish processed in the HGU and DRE state were assumed to have actually been processed to the DVC state (Table 2).

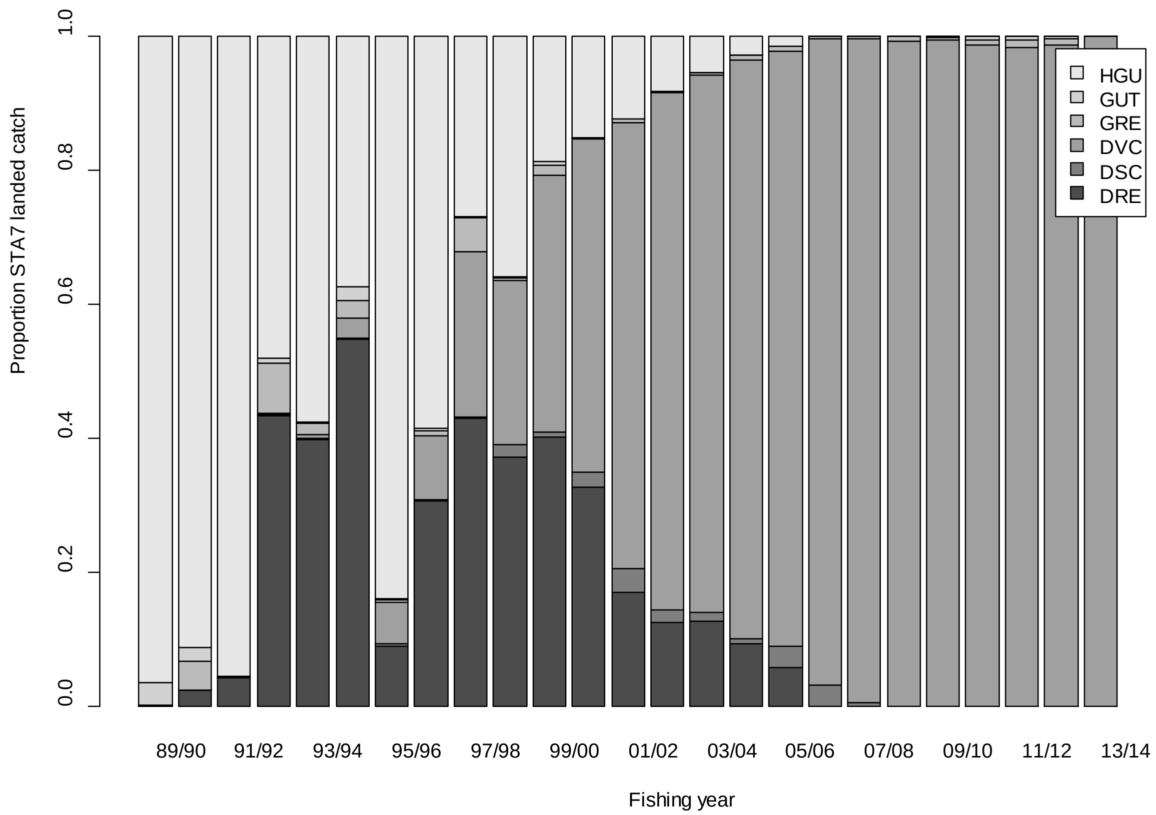

Figure 4: Proportion of annual stargazer landings (reported green weight) by process state code for the core vessel, target fleet.

Table 2: Gazetted conversion factors for the main processed states used for stargazer (from Manning 2008 and Fisheries (Conversion Factors) Notice 2011 (No. F607)) and the correction factor applied to the corresponding STA 7 landed green weight data.

State code	Start date	End date	Conversion factor	Correction
HGU	1 Oct 1986	30 Sept 1991	1.80	2.15/1.80
HGU	1 Oct 1991	current	1.50	2.15/1.50
DRE	1 Oct 1990	30 Sept 1996	2.00	2.15/2.00
DVC	1 Oct 1991	30 Sept 1996	2.00	2.15/2.00
DVC	1 Oct 1996	30 Sept 1999	2.05	2.15/2.05
DVC	1 Oct 1999	current	2.15	-

Cumulatively, the correction for the changes in the conversion factors resulted in an increase (17–37%) in the annual landed catches of stargazer from 1989/90 to 1996/97 (Figure 3).

The landed catches of STA 7 from each fishing trip were apportioned to the aggregate fishing effort records following the approach developed by Starr (2007). For fishing trips that recorded at least one top five estimated catch of stargazer, the STA 7 landed catch was allocated to the individual fishing effort records in proportion to the individual estimated catches. For fishing trips with no associated top five estimated catches, the landed catch was assigned to the daily fishing records in proportion to the number of trawls per day.

2.1.2 Daily aggregated trawl CPUE data set

The WCSI inshore bottom trawl fishery, targeting the suite of species barracouta, tarakihi, stargazer, red cod and blue warehou, accounts for most of the catch from STA 7. This fishery was identified from the fishery characterisation as the primary candidate fishery for the development of CPUE indices. The fishery is limited to inshore trawl vessels (less than 43 m) and all catch and effort data were recorded in either CELR format (1989/90– 2007/08) or TCER format (2007/08–2012/13).

The initial CPUE data set included all daily aggregated catch and effort records for fishing trips that targeted one of the suite of species (BAR, TAR, STA, RCO or WAR) off the west coast of the South Island (Statistical Areas 033, 034 or 035). The catch and effort data were configured following the approach described for the fishery characterisation data set (Section 2.1.1). The approach aggregated the TCER fishing effort records in a manner that closely approximates the CELR data and, thereby, minimises the potential biases in the CPUE analysis that might be introduced due to changes in reporting (Langley 2014).

2.1.3 Individual trawl CPUE data set

Since 2007/08, the WCSI inshore trawl fishery has exclusively reported catch and effort data using the TCER form. This form records the details of individual trawls including start and end time, target species, trawl speed, and the location and bottom depth at the start of a trawl. The estimated catch of up to eight species is also recorded for each trawl.

The individual trawl records enable a more thorough analysis of the recent catch and effort data from the target trawl fishery. The initial data set retained all the available TCER fishing effort records from fishing trips that conducted at least one trawl targeting the suite of inshore species (BAR, TAR, STA, RCO or WAR) off the west coast of the South Island (Statistical Areas 033, 034 or 035) regardless of whether or not stargazer was caught (i.e. including fishing trips with no landed catch of STA 7). The landed catch of STA 7 from these fishing trips was apportioned amongst the corresponding effort records in proportion to the estimated catch of stargazer from the individual trawls.

3 RESULTS

3.1 Characterisation of the bottom trawl fishery

Stargazer in STA 7 is caught almost entirely by bottom trawl with the method accounting for at least 99% of the annual catch. This component of the catch was predominantly taken by trawls targeting barracouta, tarakihi and, to a lesser extent stargazer (Figure 5 and Table 3). During 1989/90–2012/13, there was considerable variability in the distribution of stargazer catch amongst the main target species. The barracouta target trawls accounted for about 70% of the annual STA 7 catch during 1994/95–2001/02, while in subsequent years a higher proportion of the STA 7 catch was taken by the tarakihi target trawls (about 40–45% in 2008/09–2012/13) (Figure 5 and Table 3). The proportion of STA 7 catch taken by trawls targeting stargazer and red cod was also higher during the latter period (STA target 10–20% and RCO target 5–20% during 2002/03–2012/13).

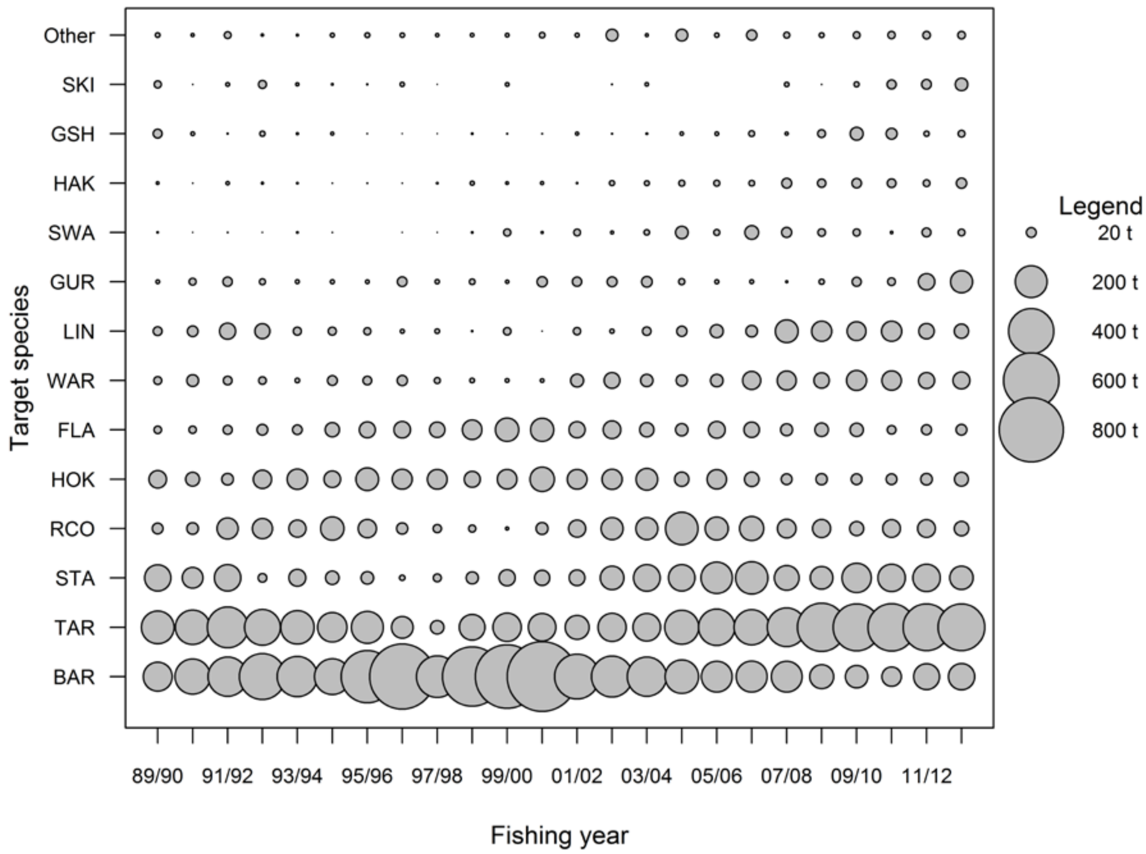

Figure 5: Landed catch of stargazer by target species and fishing year for the 13 target species that accounted for most of the total stargazer catch. Maximum total catch is 945 t.

Table 3: Distribution of stargazer bottom trawl catch (t) by target species and fishing year for STA 7.

Fishing	Target species (t)										
year	BAR	TAR	STA	RCO	HOK	FLA	WAR	LIN	GUR	SWA	Other
89/90	164.8	210.5	136.7	24.1	61.3	11.7	13.0	16.5	3.2	0.7	33.9
90/91	243.3	233.3	85.2	26.8	38.4	11.6	28.2	22.9	10.4	0.0	5.7
91/92	303.0	325.8	139.4	88.2	26.7	16.7	15.9	52.6	17.4	0.2	15.8
92/93	412.6	252.6	15.7	80.6	66.9	23.7	11.9	44.8	7.5	0.0	21.2
93/94	317.5	221.2	56.8	58.3	82.9	19.2	4.9	13.7	3.5	0.8	5.4
94/95	252.4	172.6	36.2	108.2	55.0	40.5	19.8	13.9	3.6	0.1	7.3
95/96	534.4	201.5	31.9	66.8	102.1	51.2	15.9	10.5	3.2	0.0	5.8
96/97	826.3	92.7	6.6	25.4	80.0	55.3	21.3	3.7	19.1	0.0	8.6
97/98	340.0	36.4	13.2	14.2	77.8	47.3	7.6	4.9	4.2	0.0	3.3
98/99	686.2	129.9	30.0	10.7	50.8	76.3	4.9	0.7	6.9	0.8	7.3
99/00	789.4	159.0	52.5	2.3	76.5	109.1	3.5	11.6	2.5	10.5	8.3
00/01	945.1	150.1	45.9	28.9	117.3	106.3	3.0	0.0	21.1	1.2	9.2
01/02	392.3	113.5	49.7	57.9	78.5	52.4	33.8	11.3	17.6	9.9	6.9
02/03	328.9	157.6	110.4	96.9	80.7	61.8	49.3	4.0	19.7	2.0	33.9
03/04	303.2	151.3	140.3	97.5	94.2	41.2	31.2	14.8	23.0	6.5	11.0
04/05	221.4	228.2	137.5	208.6	41.2	30.8	25.3	21.3	8.1	31.4	38.8
05/06	187.8	260.7	195.8	105.5	74.6	56.0	31.9	34.5	3.8	7.6	14.8
06/07	189.8	243.4	206.7	116.4	41.5	47.0	65.0	27.2	3.4	37.4	34.9
07/08	187.3	295.1	121.8	69.6	23.7	29.1	71.5	102.7	1.1	20.8	34.3
08/09	114.1	456.8	101.0	64.6	25.8	36.9	47.3	81.2	5.7	11.7	32.2
09/10	100.2	431.8	170.7	39.4	24.0	35.5	78.7	71.0	16.7	10.6	67.3
10/11	74.8	439.0	147.6	62.2	24.1	15.9	74.4	81.0	12.2	1.5	68.9
11/12	131.8	427.5	147.7	62.2	27.3	20.8	51.1	47.4	54.0	16.5	46.0
12/13	136.4	427.1	108.7	42.3	38.2	23.9	57.5	40.6	97.3	9.8	74.7

The data collected from TCER and TCEPR forms during 2007/08–2012/13 were used to characterise the depth distribution of the STA 7 catch. The catch was dominated by the inshore trawl fishery targeting tarakihi (TAR), stargazer (STA), barracouta (BAR) and blue warehou (WAR) in the 50–200 m depth range (Figure 6). Most of the remainder of the catch was taken by the ling (LIN) target trawl fishery operating in the 200–400 m depth range and the red cod (RCO) trawl fishery (20–150 m).

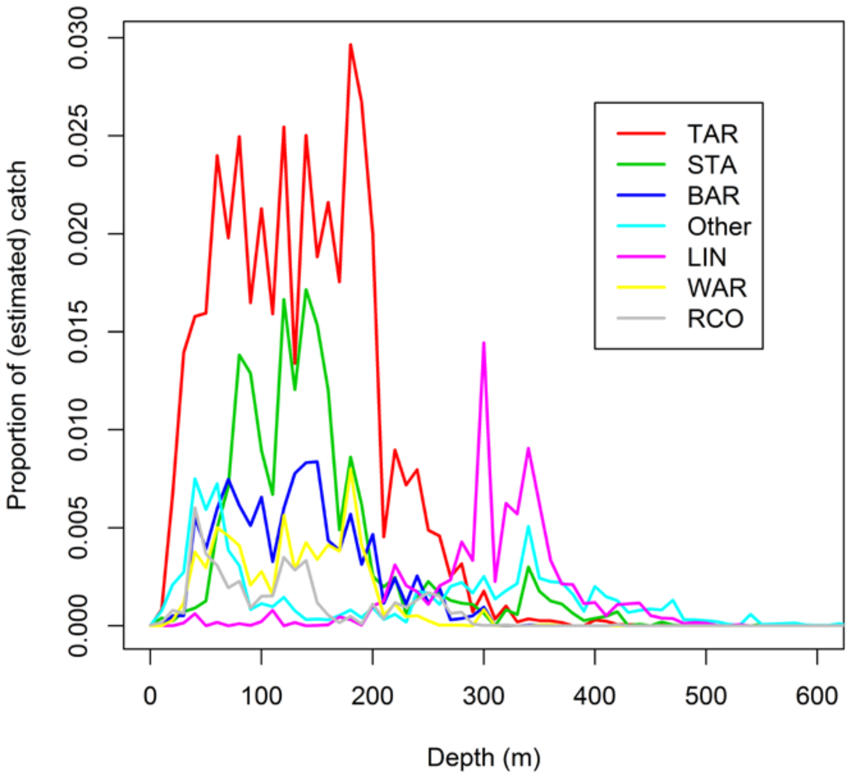

Figure 6: Proportional depth distribution of stargazer estimated catch by bottom depth (10 metre depth intervals) and target species from 2007/08 to 2012/13 for the main bottom trawl target species (TCEPR or TCER records, all years combined).

The bottom trawl catches of STA 7 were predominantly taken off the WCSI in Statistical Areas 034 and 033 and, to a lesser extent 035 (Figure 7 and Figure 8). A smaller catch was also taken in Clifford and Cloudy Bays (Statistical Area 017) and minor catches were taken in Tasman and Golden Bays (038) (Figure 8).

There was no strong seasonal distribution in the catch of stargazer, although catches tended to be lower during May–June and higher in November (Figure 9).

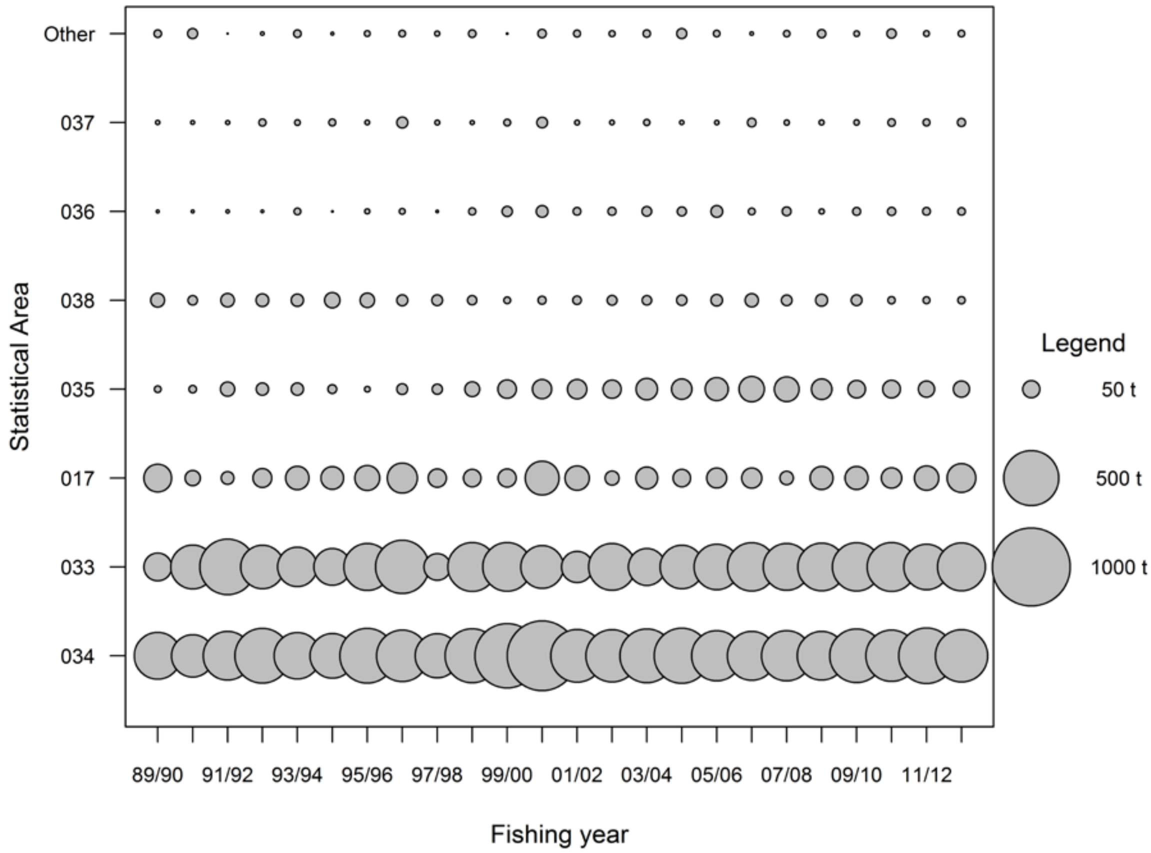

Figure 7: Annual distribution of bottom trawl stargazer catch by statistical area. The area of the circle is proportional to the catch. The maximum catch is 801 t.

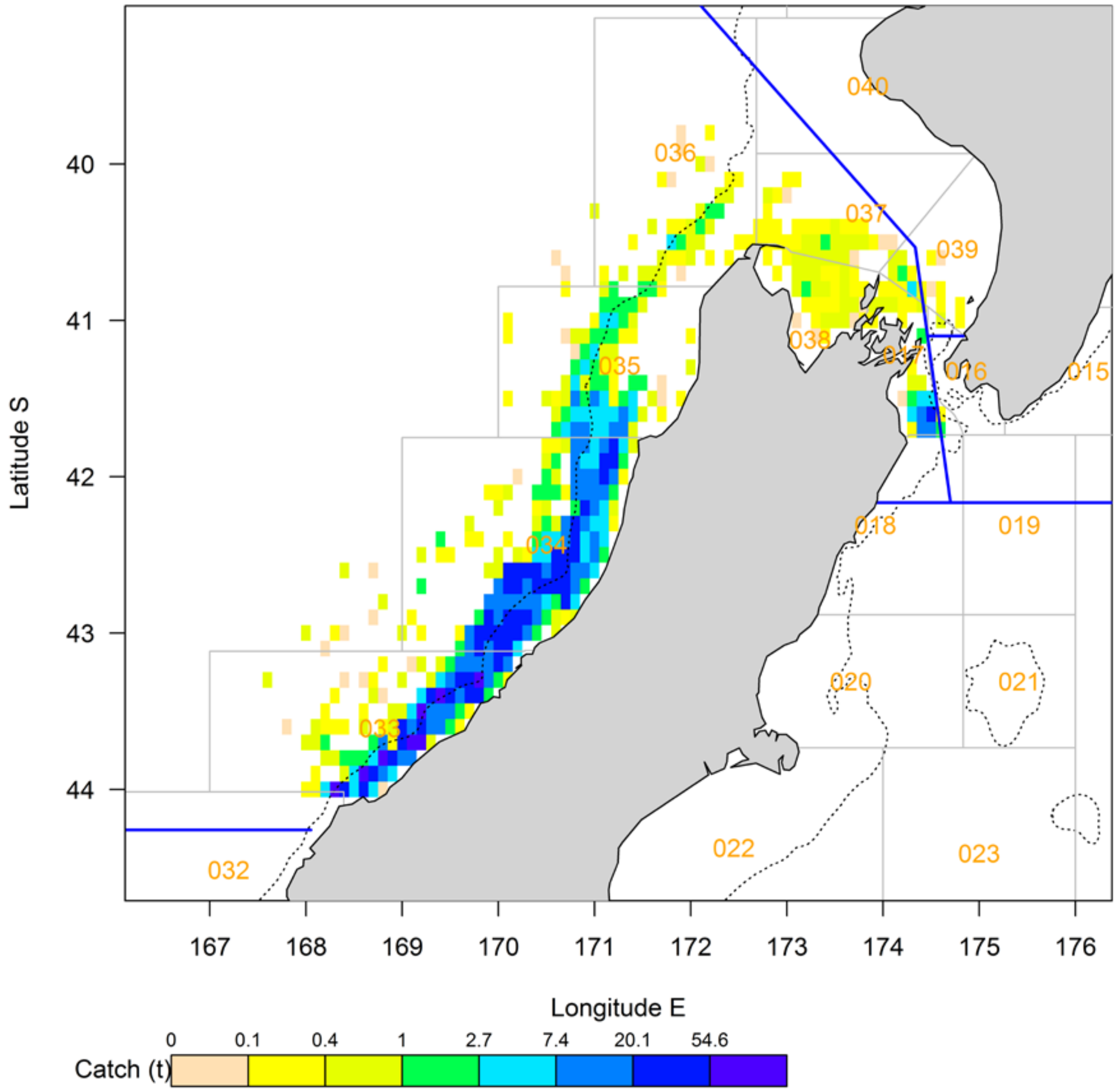

Figure 8: Spatial distribution of stargazer estimated catches from fishing trips catching STA 7 aggregated for 2007/08–2012/13 fishing years (derived from TCER and TCEPR records). The catch data are aggregated by 0.1 lat/long spatial cells. The blue lines represent the boundaries of the STA 7 fishstock area. The dashed line represents the 200 m depth contour.

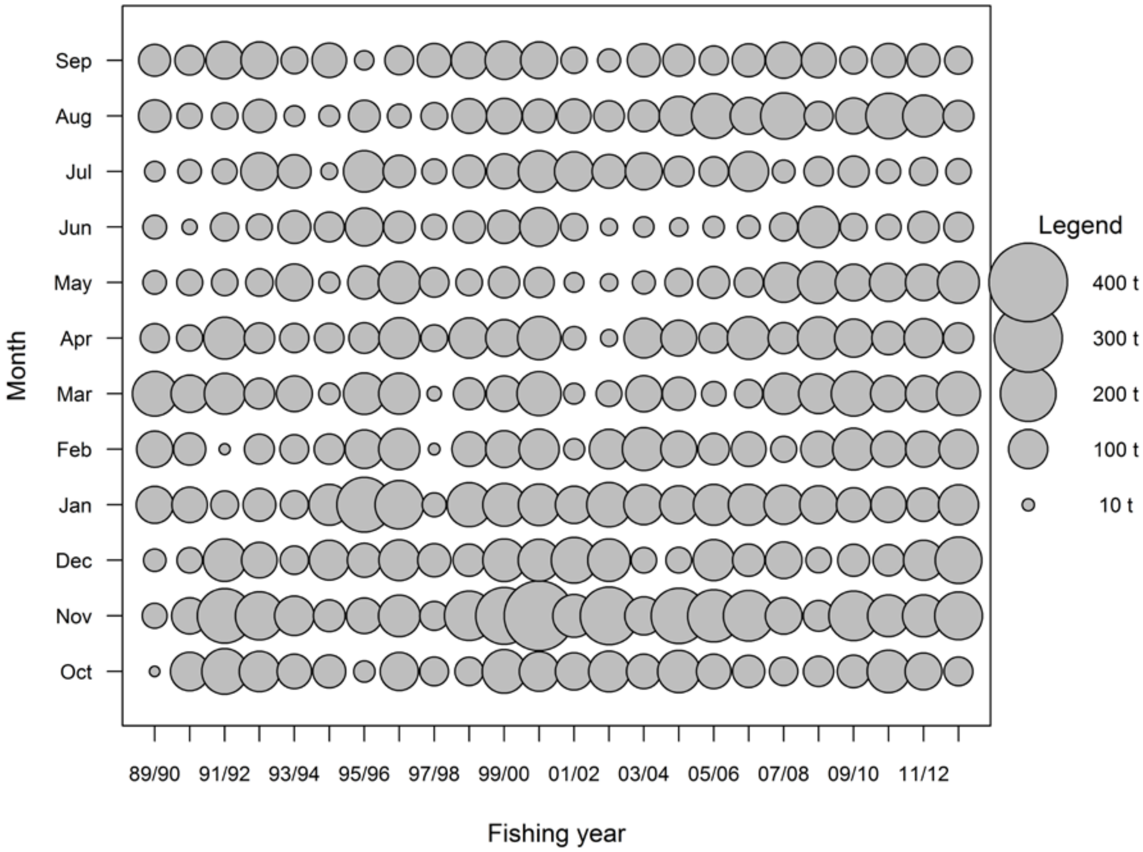

Figure 9: The monthly distribution of trawl stargazer catches in STA 7 by fishing year. Circle areas are proportional to the catch (maximum catch 315 t).

Based on the characterisation of the entire STA 7 fishery, the WCSI inshore trawl fishery was identified as the main fishery component within STA 7. The fishery was defined based on the fishing area (Statistical Areas 033, 034 and 035) and a suite of target species: barracouta, tarakihi, stargazer, red cod and blue warehou. These target species were selected as the fishing effort accounted for most of the stargazer catch and/or the target fisheries operate over the main depth range of stargazer catch. Fishing vessels operating in the WCSI inshore fishery may routinely target more than one of the suite of species during an individual fishing trip. Catch and effort data from vessels larger than 43 m in overall length were excluded from the data set.

The spatial domain of the WCSI inshore trawl fishery encompasses the distribution of most of the catch from the entire STA 7 fishery (Figure 10). The spatial distribution of the stargazer catch remained relatively constant from 2007/08 to 2012/13.

The inshore trawl fleet was comprised of about 20–25 vessels each year during 1989/90 to 2012/13. Nine of those vessels operated in the fishery for at least 20 years during that period (Figure 11). One of those vessels (5713) consistently accounted for at least 10% of the annual stargazer catch from the inshore fishery during 1995/96–2012/13.

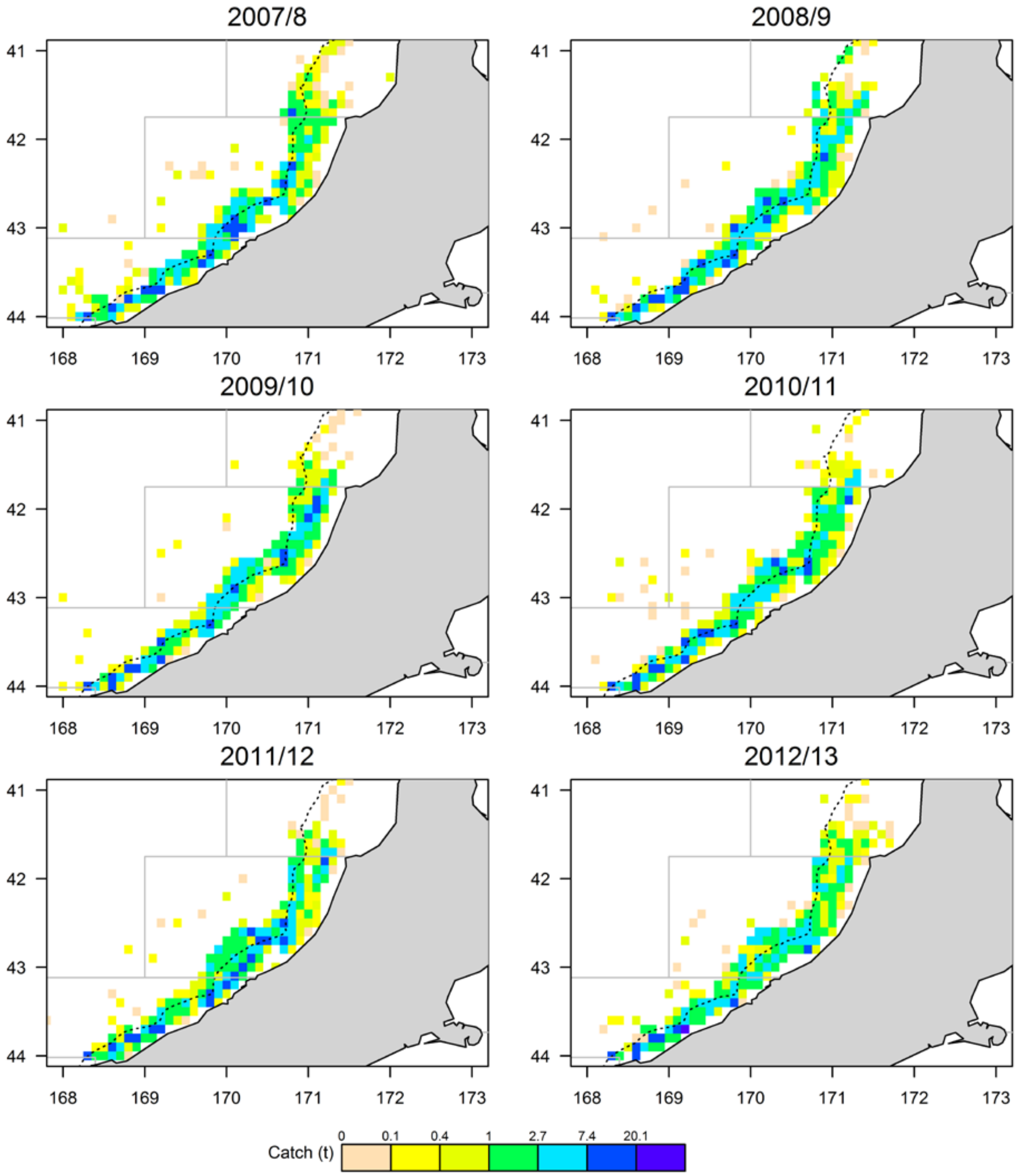

Figure 10: Spatial distribution of stargazer estimated catches from STA 7 bottom trawls targeting STA, TAR, BAR, RCO, or WAR by fishing year from 2007/08 to 2012/13 (derived from TCER records). The catch data are aggregated by 0.1 lat/long spatial cells. The dashed line represents the 200 m depth contour.

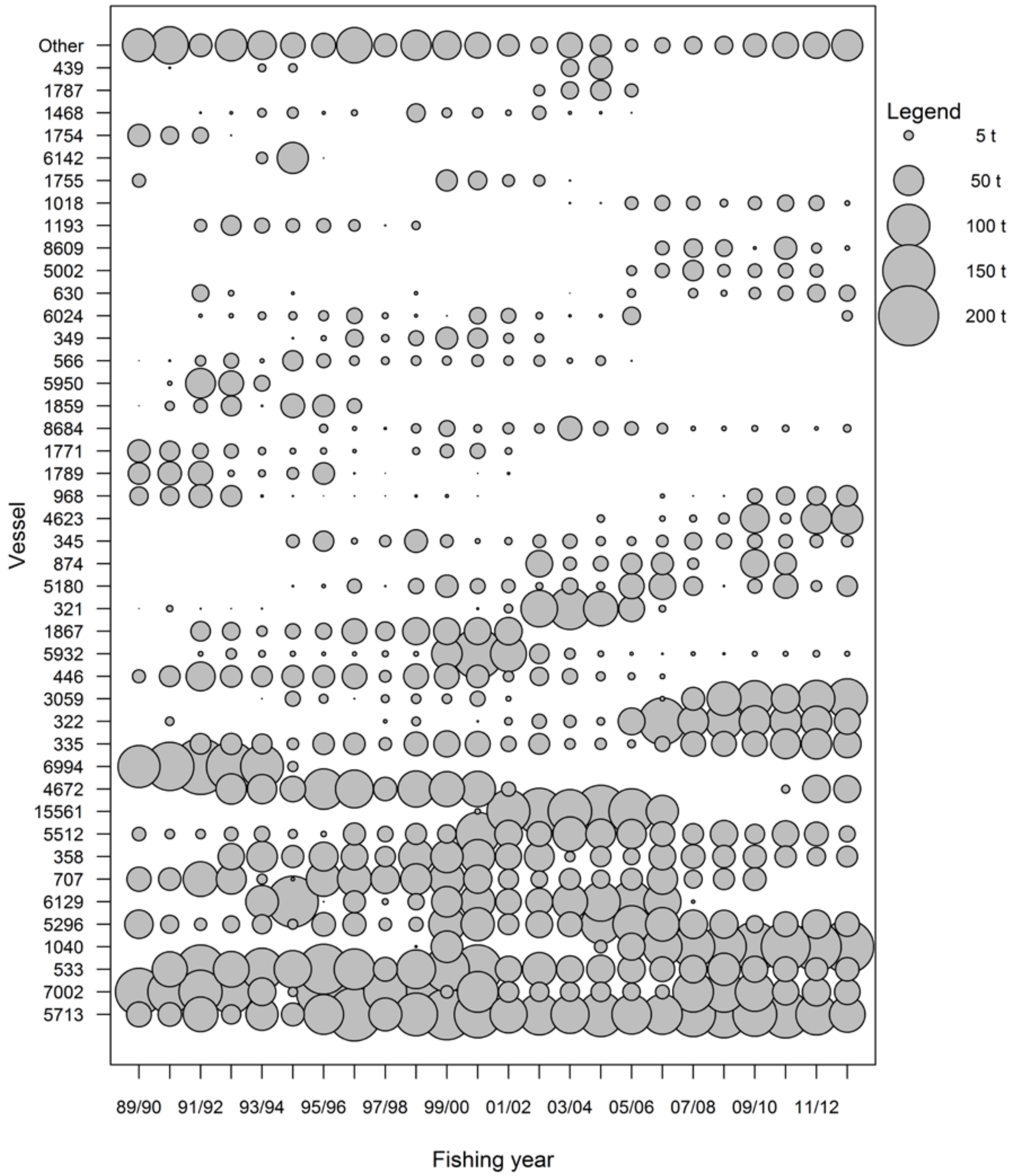

Figure 11: The fleet distribution of inshore bottom trawl stargazer catches in STA 7 by fishing year for individual vessels accounting for at least 5% of the total catch. Circle areas are proportional to the catch (maximum 211 t).

For individual fishing trips included within the defined WCSI inshore trawl fishery, the proportion of fishing effort (trawls) assigned to the five most frequently recorded target species was determined (Figure 12). Barracouta and tarakihi were the most common target species and the proportion of effort targeted at either species varied considerably, in inverse proportion, over the time period. Barracouta was the dominant target species during 1995/96–2003/04, while negligible targeting of tarakihi was reported during that period. Since 2005/06, tarakihi was increasingly targeted while barracouta target effort diminished. There was limited fishing effort reported as directly targeting stargazer. Fishing effort targeting a range of other species increased from 2008/09 (Figure 13). The other species primarily include blue warehou, ling, red gurnard and hoki.

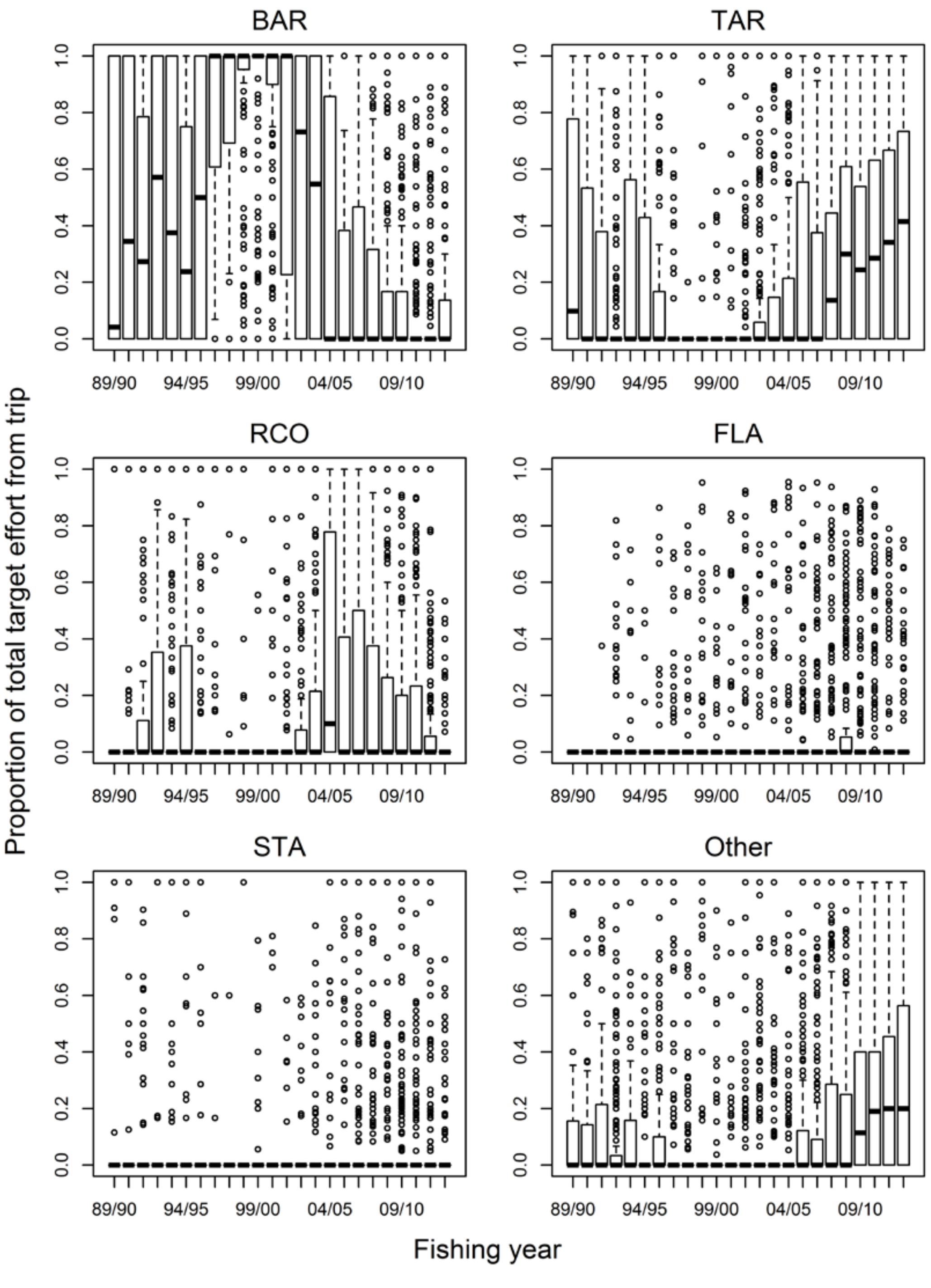

Figure 12: Boxplots of the proportion of trawls by selected target species (panel) from individual fishing trips that conducted target STA 7 bottom trawls, by fishing year (fishery characterisation data set). The fleet is limited to inshore vessels that targeted BAR, TAR, STA, RCO and/or WAR within Statistical Areas 033, 034 or 035.

The species composition of the total landed catch from the defined inshore trawl fishing trips was dominated by the specified target species; i.e. barracouta, stargazer, red cod, tarakihi and blue warehou (Figure 13), although the relative species composition of the landed catch varied over the time period. The proportion of stargazer and red cod in the landed catch tended to vary inversely, with higher proportions of stargazer in the landed catch in 1989/90 and 1998/99–2000/01 and, correspondingly, lower proportions of red cod. Since 2004/05, the proportion of red cod in the landed catch declined, while there was an increase in cumulative catch of a range of minor species included in the "Other" category (Figure 13). Most of the recent increase in the catch in the "Other" category relates to an increase in the catch of hoki.

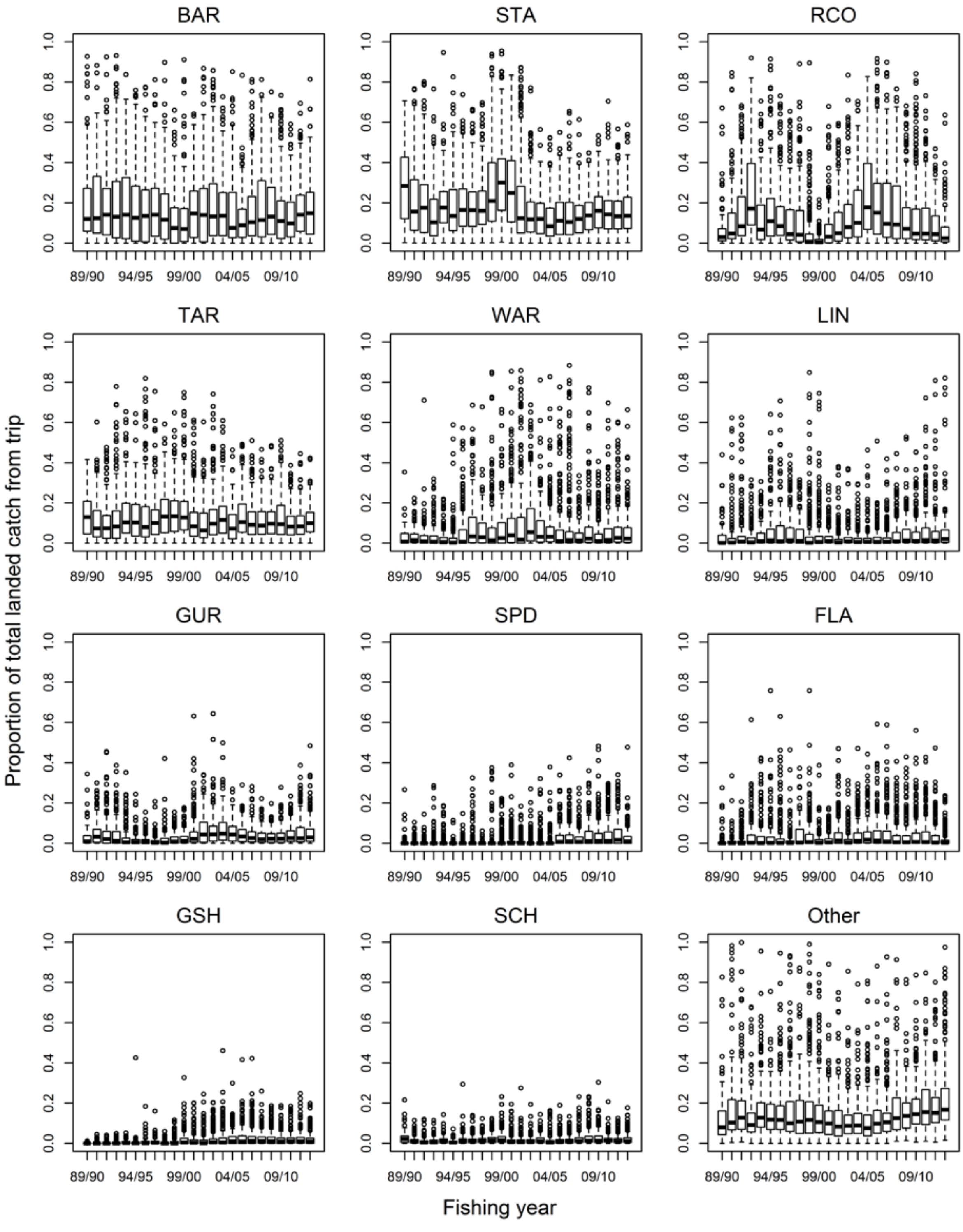

Figure 13: Boxplots of the proportion of the landed catch of individual species from individual fishing trips that conducted target STA 7 bottom trawls, by fishing year. 'Other' represents the aggregate catches of the species not included in the top eleven individual species reported. The fleet is limited to inshore vessels that targeted BAR, TAR, STA, RCO and/or WAR within Statistical Areas 033, 034 or 035. STA landed catches were not corrected for changes in conversion factor.

The TCER catch and effort records provide individual trawl location and fishing depth for the WCSI inshore trawl fishery. The records from trawls targeting the suite of inshore species (BAR, TAR, STA, WAR and RCO) within Statistical Areas 033, 034 and 035 during 2007/08–2012/13 were used to conduct a detailed characterisation of the recent fishing activity. The data set was limited to a fleet of 19 vessels with each vessel conducting at least 30 trawls per annum in at least three of the six years. This data set is equivalent to the data set used in the TCER CPUE analysis (see Section 3.2.3).

During 2007/08–2012/13, the monthly unstandardized trawl catch rates of stargazer from the WCSI inshore fishery fluctuated, with higher catch rates generally occurring during November–April and lower catch rates during May–September (Figure 14). Fishing depth varied considerably among months (Figure 15); trawl effort tended to occur in shallower water (less than 80 m) during November–January and deeper water (greater than 120 m) during June–September, although the seasonal trend in fishing depth varied among years. There is a weak negative correlation between unstandardized stargazer catch rates and fishing depth (corr. coef = -0.288).

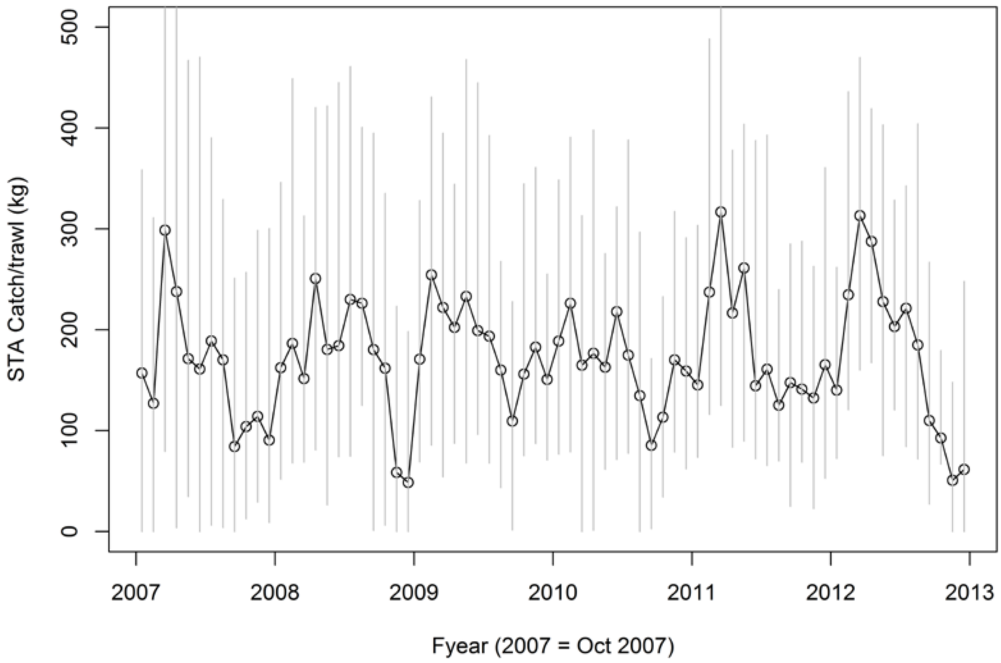

Figure 14: Monthly unstandardised stargazer catch rates (kg per trawl) from the WCSI inshore trawl fishery (TCER core vessel data set) from October 2007 to September 2013. The points represent the median monthly catch rate and the vertical lines represent the interquartile range.

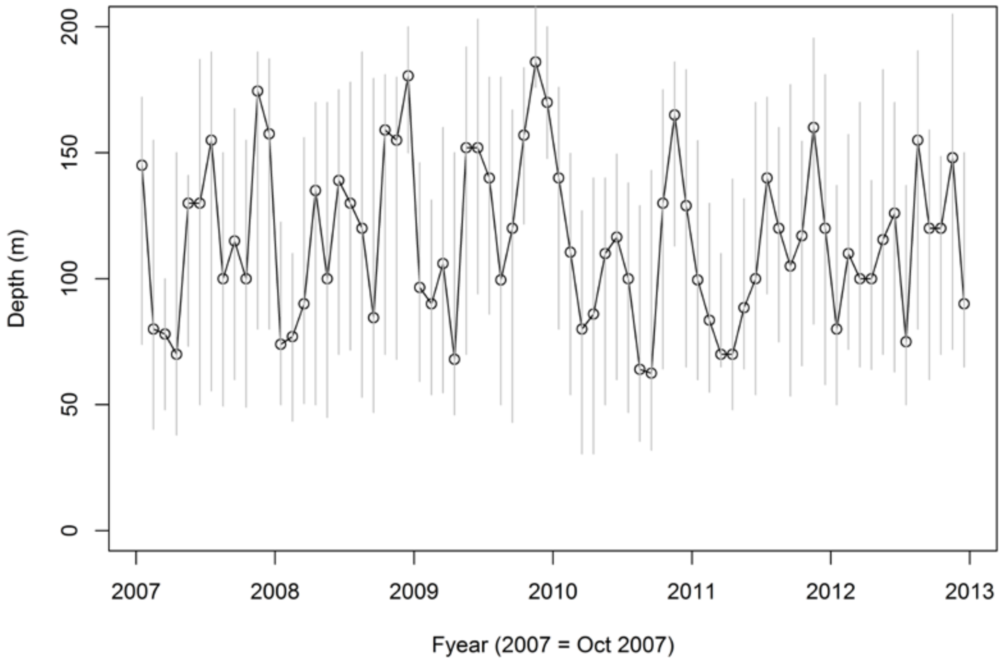

Figure 15: Median and interquartile range of the trawl fishing depth by month for the WCSI inshore trawl fishery (TCER core vessel data set) from October 2007 to September 2013. The points represent the median depth and the vertical lines represent the interquartile range.

Catch rates of stargazer from the trawl fishery indicate that stargazer are distributed throughout Statistical Areas 033 and 034 and in the southern area of Statistical Area 035. Nevertheless, the spatial variability in stargazer catch rates indicate that there are localised areas of higher relative abundance of stargazer, primarily between Greymouth and Cape Foulwind, off Whatoroa, and off Jackson Bay (Figure 16).

For the 2007/08-2012/13 period, the distribution of trawl effort was examined relative to the overall spatial variation in stargazer catch rates (Figure 16 and Figure 17). The median catch rate of stargazer in each 0.2 degree cell of latitude and longitude was determined for all years combined. The 0.2 degree spatial resolution was chosen as it approximates the average distance of an individual trawl (about 12 n.mile). The data set included fishing activity within a total of 93 cells, although most (95%) of the fishing effort occurred within 53 of the cells. Each cell received a relative ranking based on the median catch rate (1 = lowest, 93 = highest). The ranking was then standardised to a maximum rank of 1.0 (0 = lowest, 1 = highest). The relative ranking assigned to the individual cells was also compared amongst years and amongst months. There was no indication of strong annual or seasonal variability in the relative distribution of stargazer. The global data set was therefore used as the basis for the final spatial ranking of the latitude/longitude cells.

The final spatial ranking was used to determine the extent to which fishing activity was directed towards stargazer. The stargazer target metric was derived by firstly determining the frequency of trawls in each 0.2 degree cell for the variable of interest (e.g. year or year/month), and then determining the median (and interquartile range) spatial ranking associated with the fishing effort records for each variable attribute.

The target metric was initially determined for each vessel/fishing year combination. The resulting values are correlated with the median stargazer catch rate for each vessel/fishing year (Figure 18). An index of less than 0.5 corresponds to a low overall catch rate of stargazer indicating that most of the trawls were conducted in the areas of lower stargazer abundance. There is a considerable increase in stargazer catch rates associated with an increasing spatial target index from 0.5 to 0.75 consistent with an increase in fishing effort in the locations where stargazer are more abundant (Figure 18). The relationship between the target metric and stargazer catch rates was weaker for values greater than 0.8 with two vessel/year combinations yielding lower stargazer catch rates than would be expected from the high spatial target ranking. Nonetheless, the overall relationship indicates that the spatial distribution of trawl effort is a reasonably good predictor for stargazer catch rate and that the spatial metric is likely to be informative regarding the degree of stargazer target fishing activity.

The stargazer target metric was then determined by fishing year/month for the entire fleet (all vessels combined) (Figure 19). The target index tended to increase during 2007/08 and 2009/10, declined considerably in early 2010/11 and fluctuated about the longer term average level during 2011/12 and 2012/13. There is no indication of a persistent seasonal trend in the degree of target fishing activity over the study period (Figure 19).

The target index was also derived for the individual vessels in the fleet (all years combined) (Figure 20). There is considerable variability in the spatial operation of the main (core) vessels in the WCSI inshore trawl fleet with five vessels conducting a greater proportion of their fishing activity within the areas of higher stargazer catch rates. One vessel has a considerably lower spatial target index than the remainder of the fleet.

A comparison of the spatial target index derived for each declared target species (all years and vessels combined) reveals that trawls for which STA was the declared target species tended to occur in the areas of higher stargazer catch rate (Figure 21). Conversely, trawls targeting RCO were in the areas of lower stargazer catch rate. Trawls declared to have targeted BAR, TAR and WAR tended to have occurred in areas of moderate stargazer relative abundance (Figure 21). These results indicate that target species is being reasonably well reported by the fishing fleet, and that stargazer target fishing behaviour is closely associated with fishing location.

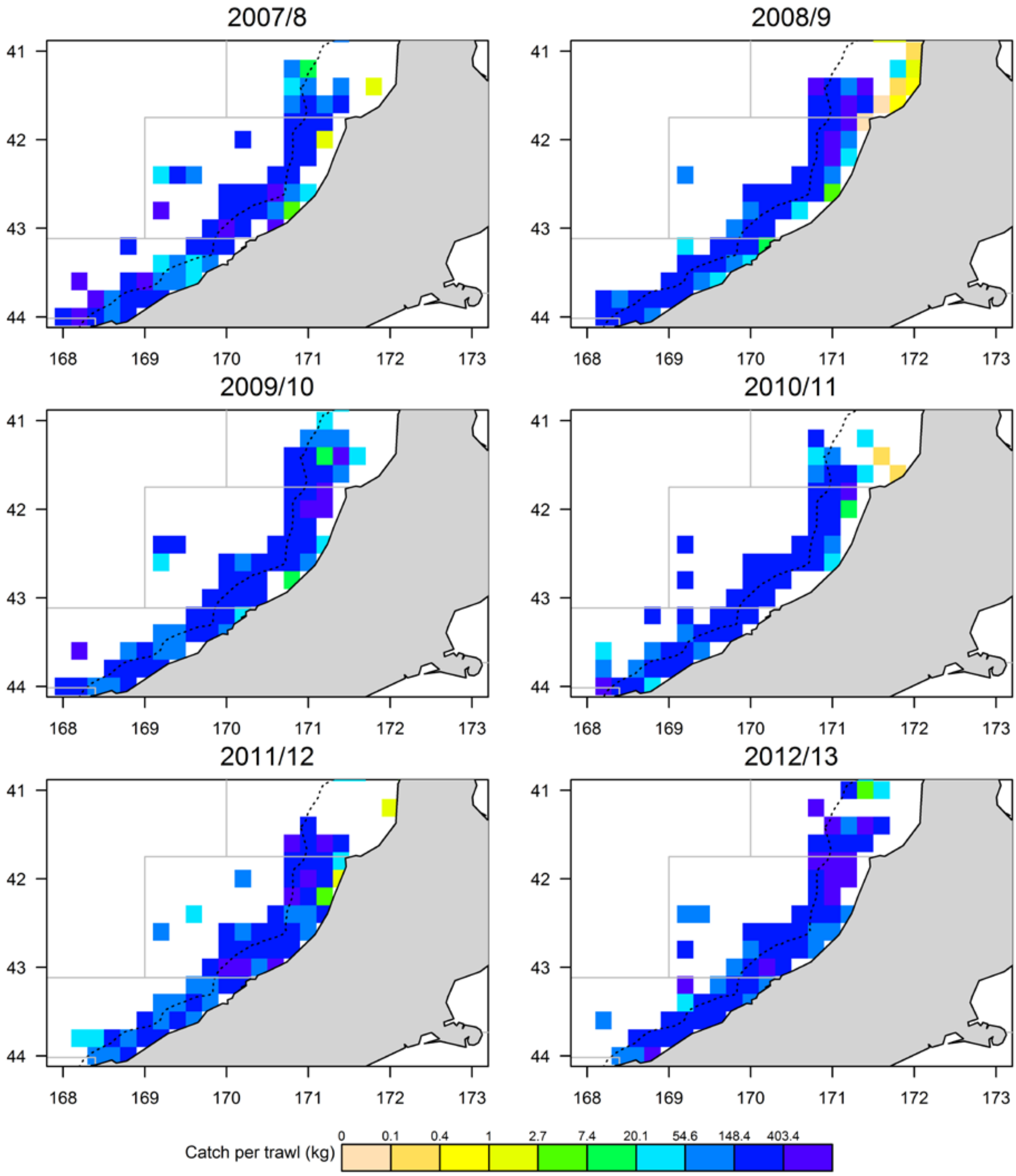

Figure 16: Annual median catch rate of stargazer (kg per trawl) by 0.2 degree latitude/longitude cell from the WCSI inshore trawl fishery (TCER core vessel data set), 2007/08 to 2012/13.

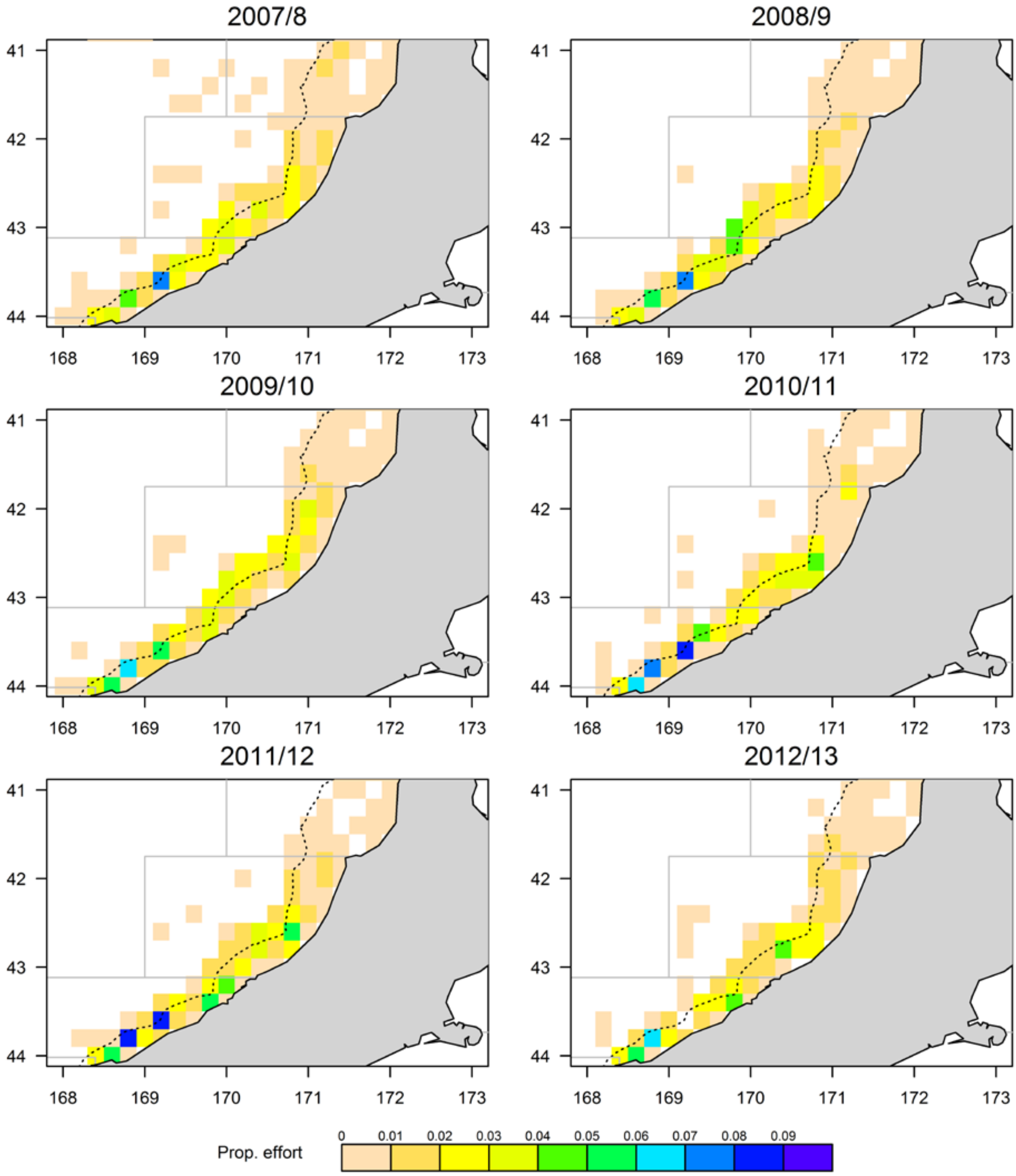

Figure 17: Annual proportional distribution of trawl effort by 0.2 degree latitude/longitude cell from the WCSI inshore trawl fishery (TCER core vessel data set), 2007/08 to 2012/13.

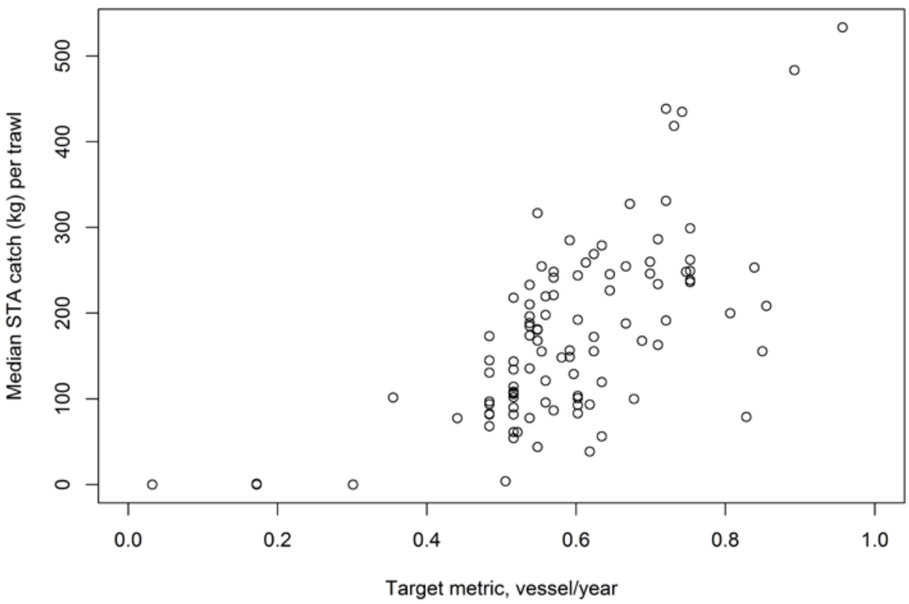

Figure 18: A comparison of the spatially based target metric derived for stargazer for each vessel/fishing year combination and the corresponding median catch rate of stargazer for the WCSI inshore trawl fishery, 2007/08 to 2012/13. See text for a description of the target metric.

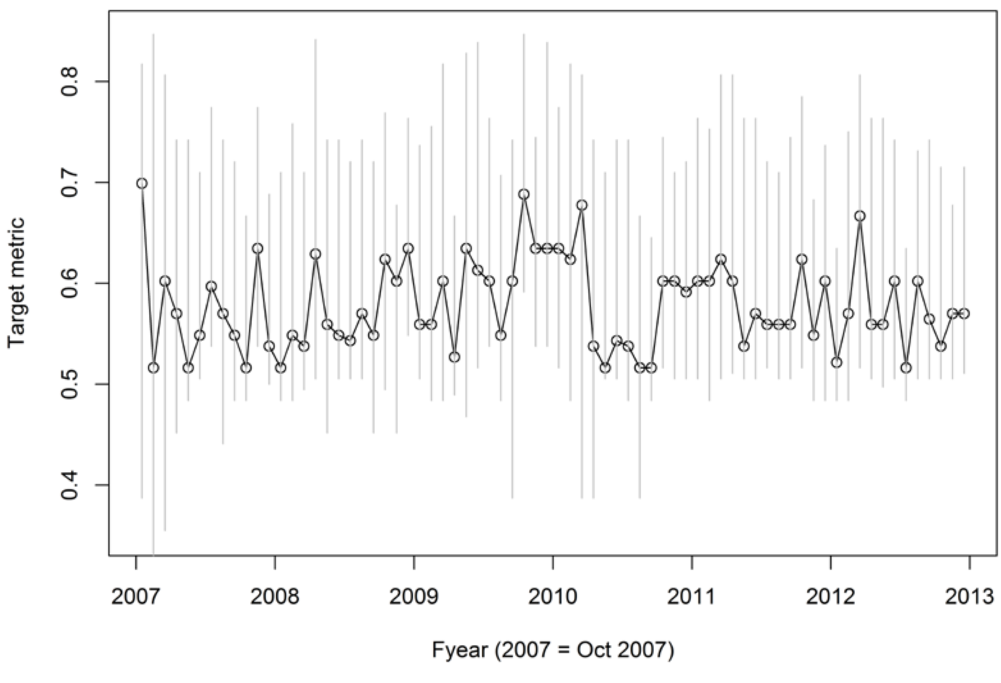

Figure 19: Monthly indices of the spatial targeting of stargazer by the WCSI inshore trawl fishery (TCER core vessel data set) from October 2007 to September 2013. The points represent the median target index and the vertical lines represent the interquartile range (see text for details).

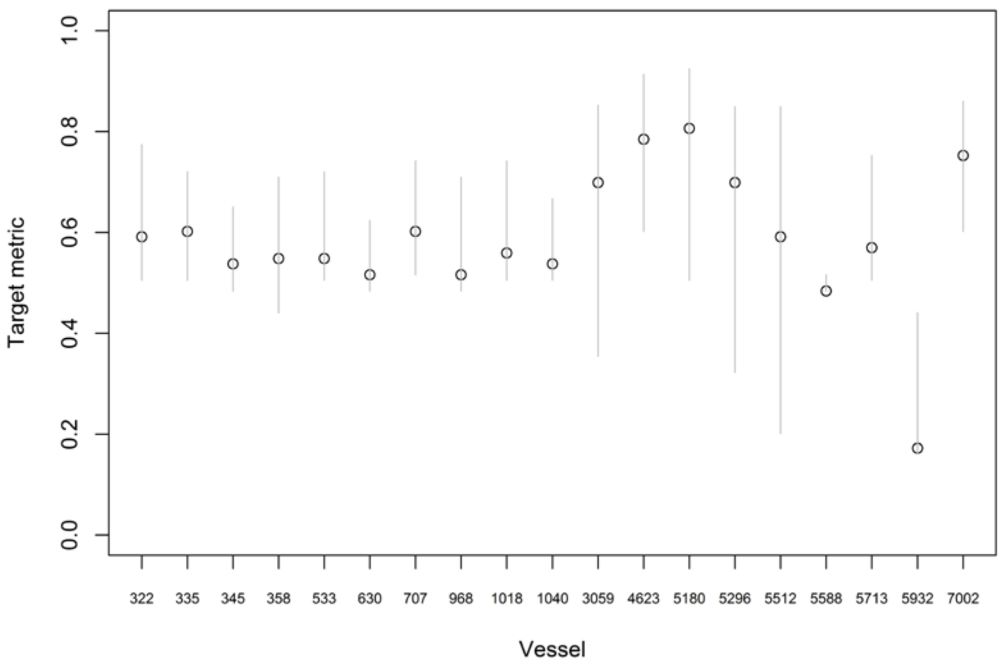

Figure 20: Individual vessel indices of the spatial targeting of stargazer by the WCSI inshore trawl fishery (TCER core vessel data set) from October 2007 to September 2013. The points represent the median target index and the vertical lines represent the interquartile range (see text for details).

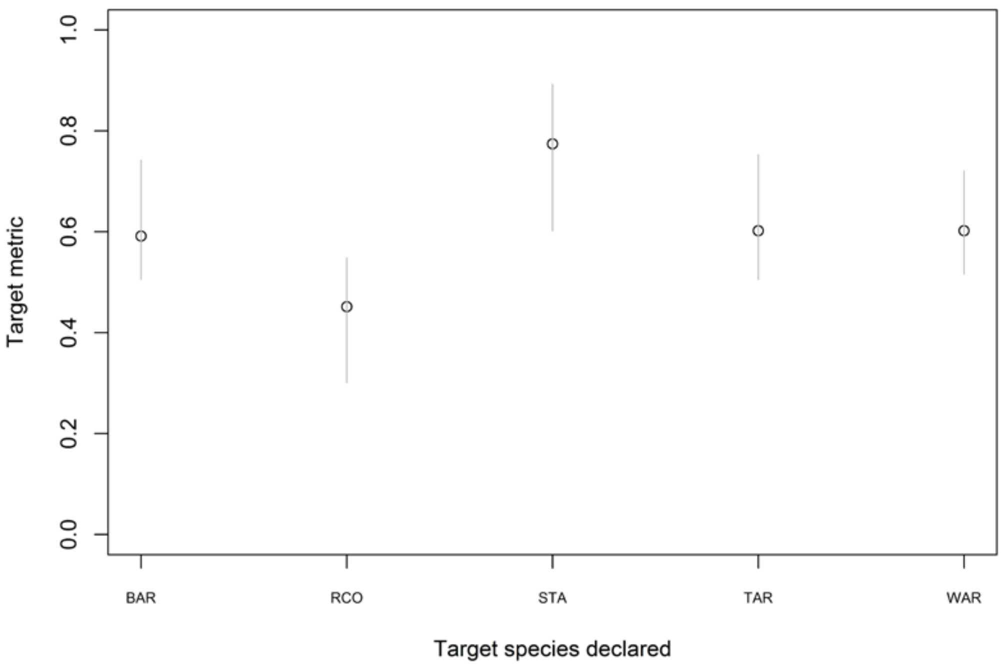

Figure 21: Individual indices of the spatial targeting of stargazer determined by declared target species for the WCSI inshore trawl fishery (TCER core vessel data set) from October 2007 to September 2013. The points represent the median target index and the vertical lines represent the interquartile range (see text for details).

3.2 CPUE Analyses

CPUE models were developed using a Generalised Linear Modelling (GLM) approach. Separate analyses were conducted for the two CPUE data sets: the daily aggregated CPUE data from 1989/90–2012/13 and the individual trawl based data (TCER format) from 2007/08–2012/13.

3.2.1 Daily aggregated CPUE data set

This CPUE analysis was based on the daily aggregated catch and effort data for the inshore bottom trawl fishery targeting BAR, TAR, WAR, STA or RCO within Statistical Areas 033, 034 and 035. Catch and effort records were included regardless of whether or not there was an associated reported catch of stargazer (i.e. a landed catch of STA 7). The data set excluded vessels larger than 43 m. The fishery accounted for 60–80% of the STA 7 landed catch since 1989/1990 (Figure 22). Most of the remainder of the catch was associated with fishing effort targeting a range of other species, most notably red gurnard, flatfish, ling and hoki (Table 3).

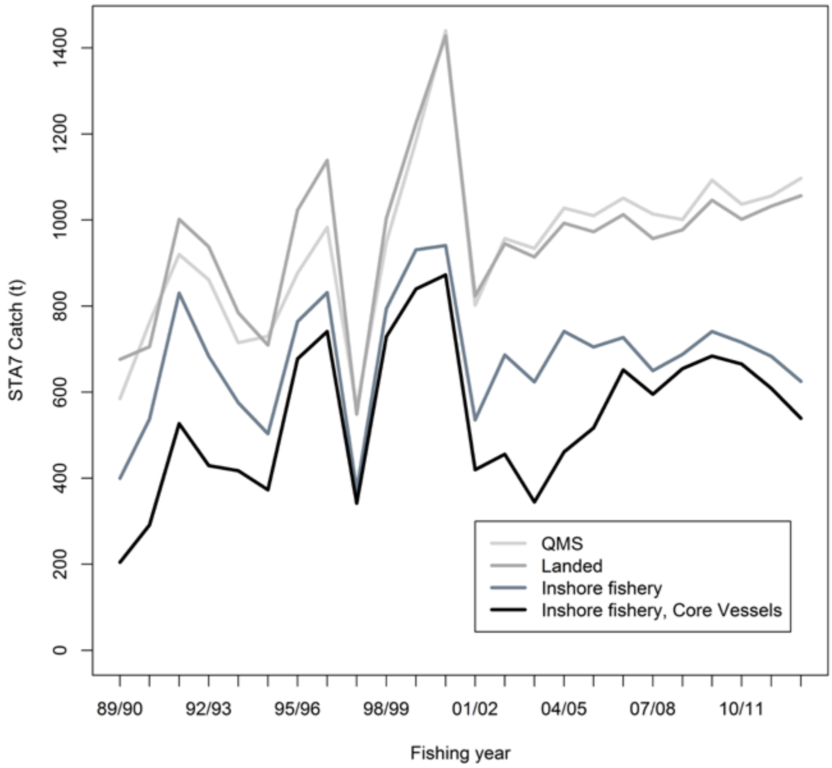

Figure 22: A comparison of the annual STA 7 catch included in various subsets of the final catch and effort data set: the catch included in the final characterisation data set (Landed), the subset of the catch taken by the defined inshore trawl fishery and the catch taken by the defined core fleet. The total reported QMS catch is also presented.

A core fishing fleet was identified that accounted for at least 80% of the total stargazer catch from the target fishery (from 1989/90 to 2012/13). The continuity criteria were defined as those vessels completing a minimum of 5 trips in a minimum of 6 years (Figure 23). The criteria resulted in the selection of 27 unique vessels which accounted for 5 676 of the 7 378 individual fishing trips within the defined inshore trawl fishery. Four of these vessels had operated in the fishery for at least 20 years (Figure 24). The core fleet accounted for 50–90% of the total annual stargazer catch from the defined inshore fishery (Figure 22).

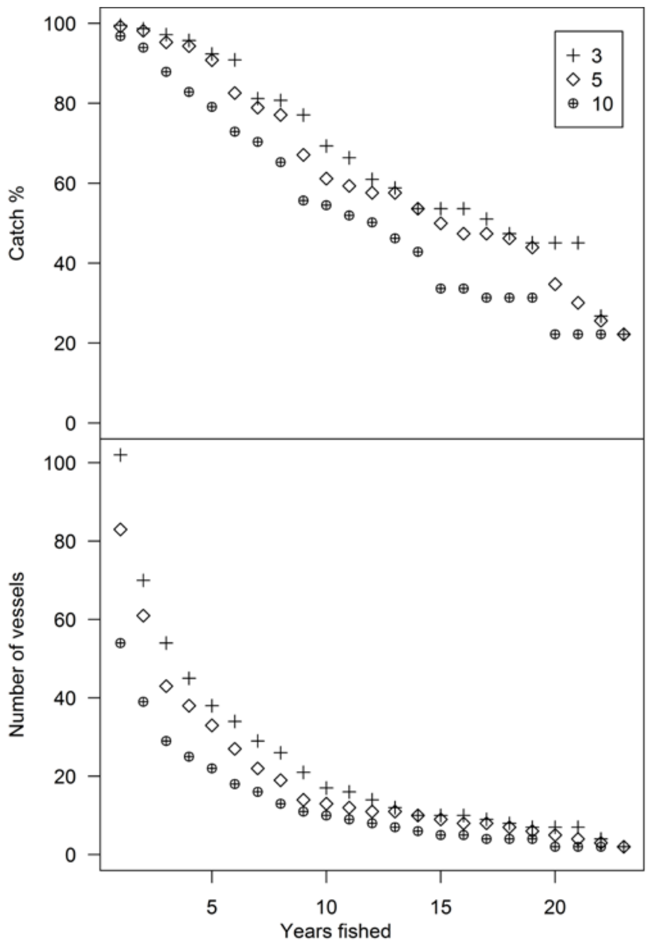

Figure 23: The percentage of the inshore trawl stargazer catch (top panel) and the number of fishing vessels included in the data set including individual vessels participating in the fishery for a minimum number of years (years fished) where yearly participation is defined as a minimum of three, five or 10 fishing trips.

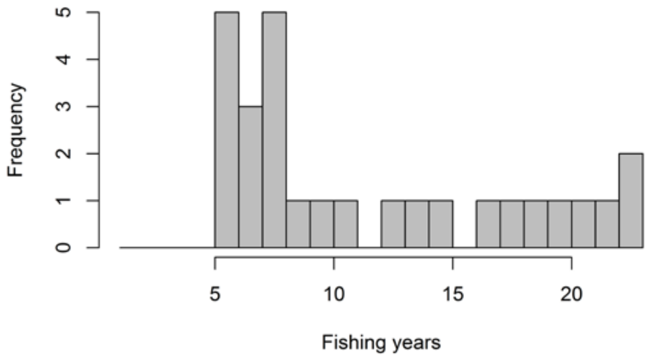

Figure 24: Histogram of the number of years each of the core vessels participated in the target fishery during 1989/90–2012/13.

The fishing effort included within the CPUE data set was aggregated by vessel fishing day; i.e., the number of trawls and cumulative duration of trawling per vessel day. Broad range limits were applied to the effort variables and a small number (fewer than 1%) of the records with variables outside the data range were excluded from the final data set (Table 4).

Table 4: The variables included in the CPUE data set aggregated in a format consistent with the CELR records.

Variable	Definition	Data type	Range
Vessel	Fishing vessel category	Categoric (24)	
FishingYear	Fishing year	Categoric (24)	
Month	Month	Categoric (12)	1–12
StatArea	Main statistical area fished in fishing day	Categoric (3)	033, 034, 035
TargetSpecies	Main species targeted in fishing day	Categoric (5)	BAR,TAR,WAR,STA, RCO
NumTrawl	Number of trawls conducted	Continuous	1–7
Duration	Total duration of trawling (hrs)	Continuous	1–24
STAcatch	STA catch (kg) (corrected for changes in conversion factors)	Continuous	< 10 000 kg

For the inshore trawl fishery the number of trawls conducted during a fishing day remained relatively constant throughout the study period, while there was a general increase in the total daily trawl duration over the time period (Figure 25). Most of the target fishing effort occurred within Statistical Areas 033 and 034 with the proportion of fishing effort in the former area steadily increasing since the early 2000s (Figure 26).

The CPUE data set included a considerable proportion (12–33%) of records with no stargazer catch. There was a lower proportion of nil catch records in 1999/2000–2000/01 and 2009/10–2012/13 (Table 5).

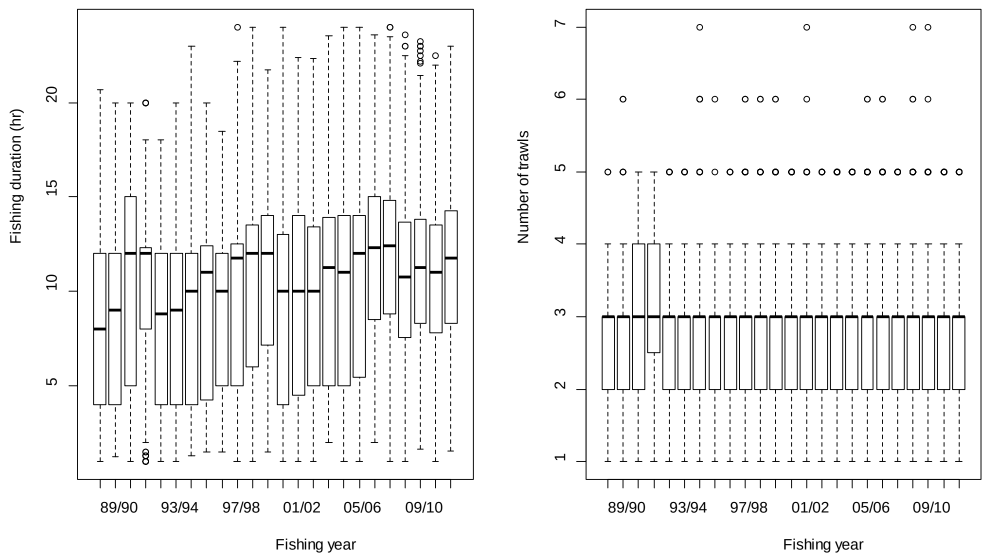

Figure 25: Boxplots of the main fishing effort variables included in the final core vessel CPUE data set.

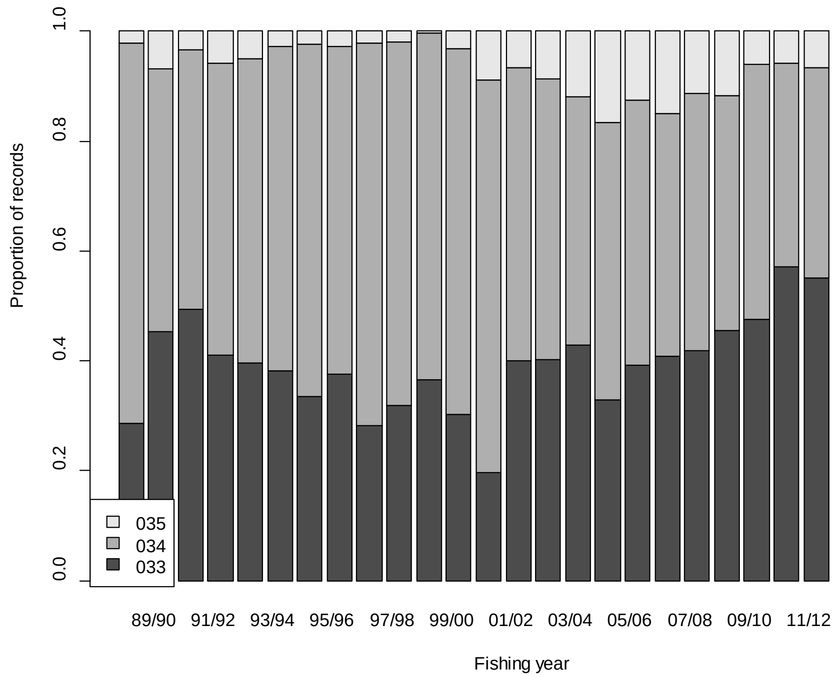

Figure 26: Proportional distribution of CPUE data records by statistical area and fishing year.

The dimensions of the trawl net (gear width and headline height) were also available for each fishing record (either CELR or TCER format). For most of the vessels in the core vessel data set, the recorded trawl gear width and headline height were relatively constant throughout the data period. There was also no reported use of twin rig fishing gear in the WCSI fishery as was evident in the STA 5 target trawl fishery (Langley & Bentley 2014). Trawling speed was not recorded on the CELR reporting forms and, consequently, is not available prior to 2007/08.

Table 5: Summary of catch and effort (effort strata) included in the final core vessel data set (including zero species catch records). The annual catches are reported catches corrected for changes in conversion factor. The percentage of fishing days with no associated stargazer catch area also presented.

Fishing year	No. of records	No. of vessel	No of trips	Catch (t)	No. of trawls	Fishing duration (hrs)	Percent zero catch
1989/90	404	9	87	230.2	1 015	3 260	23.0
1990/91	587	13	141	329.0	1 627	5 063	20.8
1991/92	865	16	241	570.7	2 477	8 938	24.2
1992/93	971	18	279	455.5	2 873	9 979	34.1
1993/94	610	17	195	422.0	1 643	5 164	28.5
1994/95	651	17	194	412.5	1 814	5 548	32.7
1995/96	903	20	279	730.3	2 552	8 060	26.0
1996/97	1 005	17	261	751.2	2 793	9 738	25.4
1997/98	576	15	193	340.5	1 529	5 288	31.8
1998/99	1 011	20	320	735.6	2 829	10 004	25.8
1999/00	950	18	269	887.6	2 655	9 954	12.5
2000/01	1 009	18	284	878.7	2 901	10 729	15.4
2001/02	784	19	242	420.6	2 237	7 410	25.5
2002/03	741	17	211	454.3	2 113	7 127	20.9
2003/04	662	16	178	344.6	1 835	6 441	30.5
2004/05	766	16	191	459.3	2 161	7 814	21.7
2005/06	873	18	221	522.4	2 504	9 119	32.1
2006/07	1 152	17	295	659.8	3 352	12 135	30.8
2007/08	934	16	257	595.0	2 576	11 083	26.6
2008/09	989	16	247	656.3	2 725	11 855	19.2
2009/10	1 035	18	308	683.9	2 771	11 079	15.1
2010/11	1 023	18	289	665.7	2 825	11 446	17.7
2011/12	906	17	265	609.2	2 378	9 787	16.8
2012/13	766	14	240	537.6	2 047	8 736	16.4

3.2.2 CPUE models, daily aggregated data set

A preliminary CPUE model of the stargazer positive (non zero) catch records was configured to determine the most appropriate statistical distribution for the data set. The five alternative distributions were assessed based on the Akaike Information Criterion (AIC) and the degree of conformance of the model residuals to a normal distribution. The Weibull distribution was selected as the most suitable distribution based on these criteria, although the deviation in the distribution of the standardised residuals for the Weibull distribution was somewhat lower than expected from a normal distribution indicating a degree of nonconformity with the underlying statistical assumptions (Figure 26). Nonetheless, the diagnostics indicated that the performance of the Weibull distribution was superior to the other statistical distributions considered and the Weibull distribution was adopted for the final CPUE model (Figure 26).

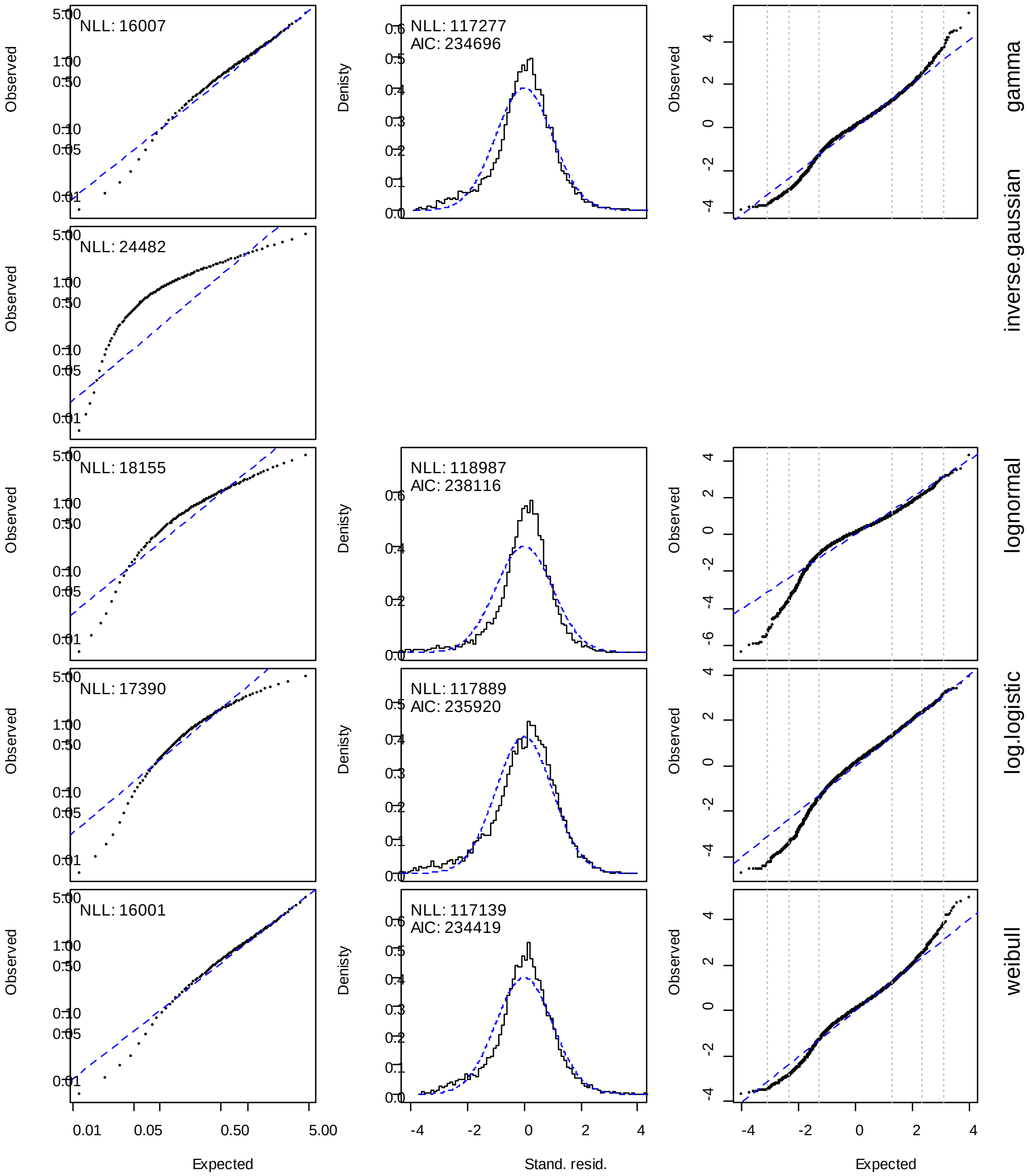

Figure 27: Diagnostics for alternative assumptions regarding the statistical distribution of the response variable for the positive catch CPUE model. Left: quantile-quantile plot of observed response values(centred (by mean) and scaled (by standard deviation) in log space) versus a maximum likelihood fit of the distribution to those values; Middle: standardised residuals from a generalised linear model fitted using the formula catch ~ fyear + month + stat_area + target_species + vessel + poly(log(num), 3) 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). A missing panel indicates that the fit failed to converge. NLL = negative log-likelihood; AIC = Akaike Information Criterion.

A step-wise fitting procedure was implemented to construct the final positive catch CPUE model. The dependent variable was the natural logarithm of the (non zero) catch of stargazer (in kilogrammes) and the variable was assumed to have a Weibull distribution with an estimated scale parameter. The potential explanatory variables included the categoric variables *Vessel*, *FishingYear*, *Month*, *TargetSpecies* and *StatArea*, and the continuous variables the natural logarithm of *NumTrawl* and the natural logarithm of *Duration*. The continuous variables were parameterised using a third order polynomial function. The categoric variable *FishingYear* was included in the initial model and subsequent variables were included in the model based on the improvement in the AIC. Additional variables were included in the model until the improvement in the Nagelkerke pseudo-R^2 was less than 1%.

The final Weibull (positive catch) CPUE model included the predictor variables *FishingYear*, *Vessel*, log *NumTrawl*, *TargetSpecies*, *StatArea*, *Month* and log *Duration* (Table 6). Overall, the model explained 28.4% of the variation in the positive catch of stargazer (Nagelkerke pseudo-R^2), while the *FishingYear* variable accounted for a small proportion of the variation (1.6%). The scale parameter of the Weibull distribution was estimated as 0.869.

The distribution of the CPUE model residuals deviates from the assumption of normality, particularly at the lower range (Figure 28). The low residual values were predominantly for low catch records (less than 20 kg). Most (90%) of these low catch records were not allocated to the effort data based on recorded estimated catches as no estimated catches of stargazer were recorded for these trips. Hence, the reliability of the catches associated with these effort records may be low. However, overall only 12.3% of the total positive catch records were allocated in this manner and there was no indication of a temporal trend in the method of catch allocation that could influence the resulting annual indices.

Table 6: Summary of stepwise selection of variables in the positive catch CPUE model. 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 (% Improvement)
FishingYear	23	-119534	239117	1.6 *
Vessel	26	-118381	236865	13.7 *
poly(log(*NumTrawl*), 3)	3	-117829	235766	5.9 *
TargetSpecies	4	-117443	235003	3.9 *
StatArea	2	-117256	234633	1.8 *
Month	11	-117139	234419	1.2 *
poly(log(*Duration*), 3)	3	-117091	234330	1.6 *

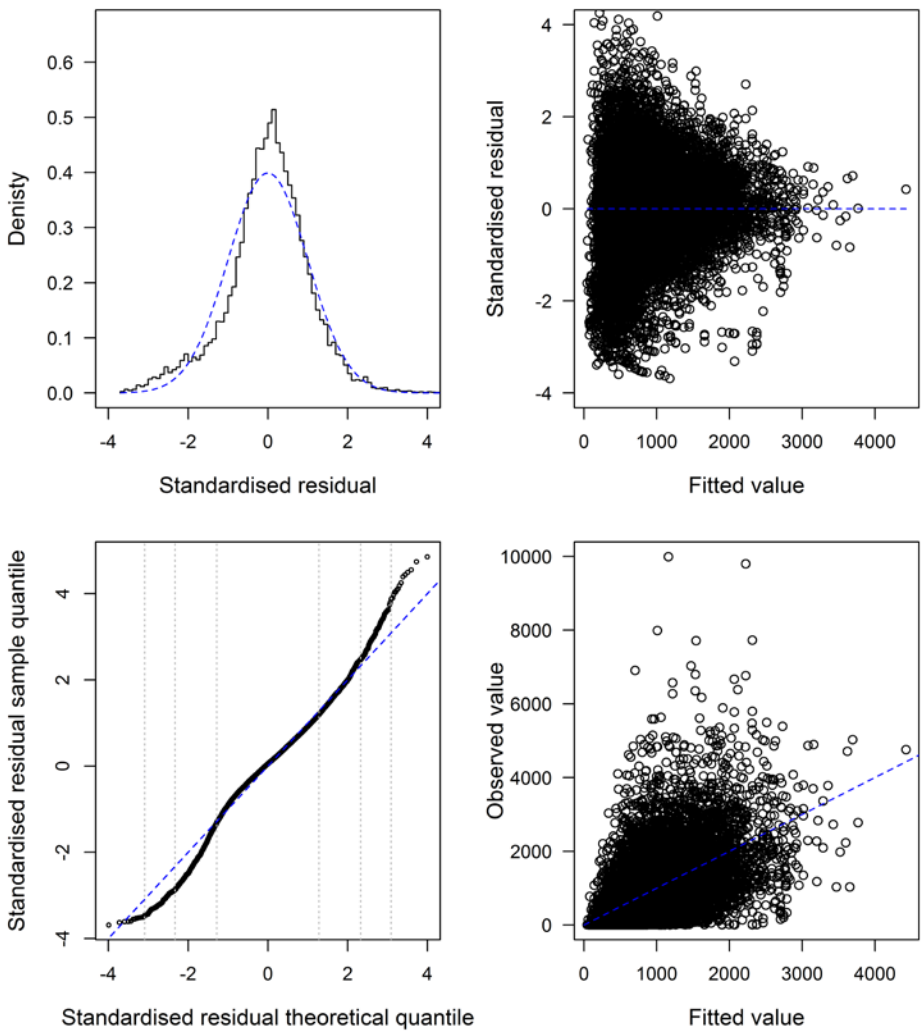

Figure 28: Residual diagnostics for the final model derived from daily aggregated data set. Top left: histogram of standardised residuals compared to standard normal distribution. Bottom left: quantile-quantile plot of standardised residuals. Top right: fitted values versus standardised residuals. Bottom right: observed values versus fitted values.

The annual indices derived from the Weibull CPUE model were relatively high during 1991/92–2000/01, declined considerably in 2001/02 and remained at the lower level for the remainder of the period (Figure 29). The sharp decline in the CPUE indices was also evident in the unstandardized catch rate; however, since 2006/07 the unstandardized CPUE has steadily increased (Figure 22). Most of the difference between the standardised and unstandardized CPUE indices during the latter period is attributed to the influence of the fleet configuration (vessel effects) and, to a lesser extent, the declared target species (Figure 30).

Influence plots (Bentley et al. 2011) for the individual model variables are presented in Appendix 1. The influence attributable to the *Vessel* variable from 2002/03 onwards is due to an increase in the proportion of the fishing effort records from vessels with a higher overall catch rate of stargazer (Figure A1). Since 2002/03, there was also a higher proportion of the effort targeting tarakihi and, to a lesser extent stargazer (Figure A3).

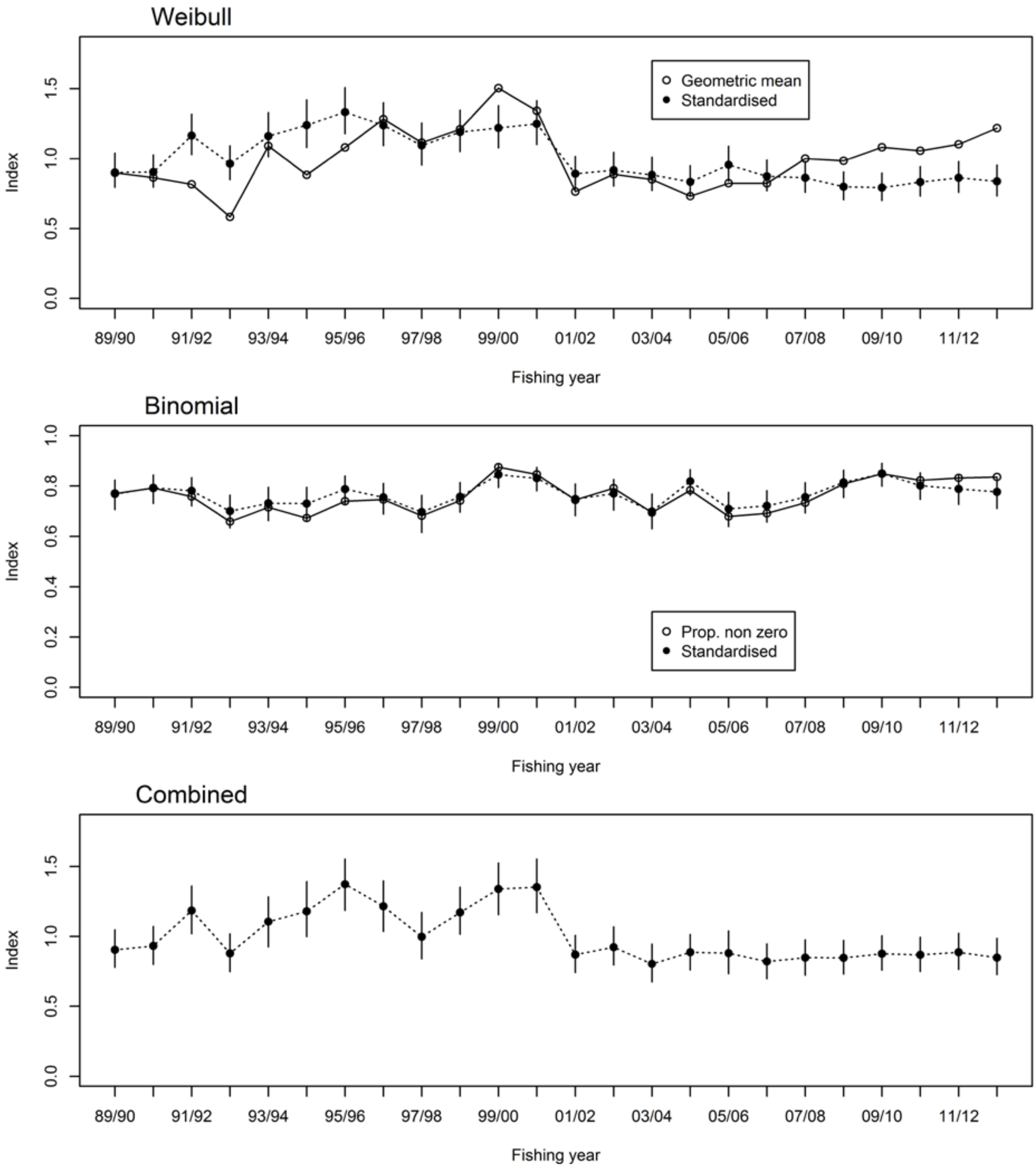

Figure 29: A comparison of the standardised CPUE indices and the geometric mean of the annual catch per day (unstandardised) (top panel), a comparison of the binomial indices and the annual proportion of positive catch records in the data set (middle panel) and the combined index (bottom panel) . The error bars represent the 95% confidence intervals associated with each index.

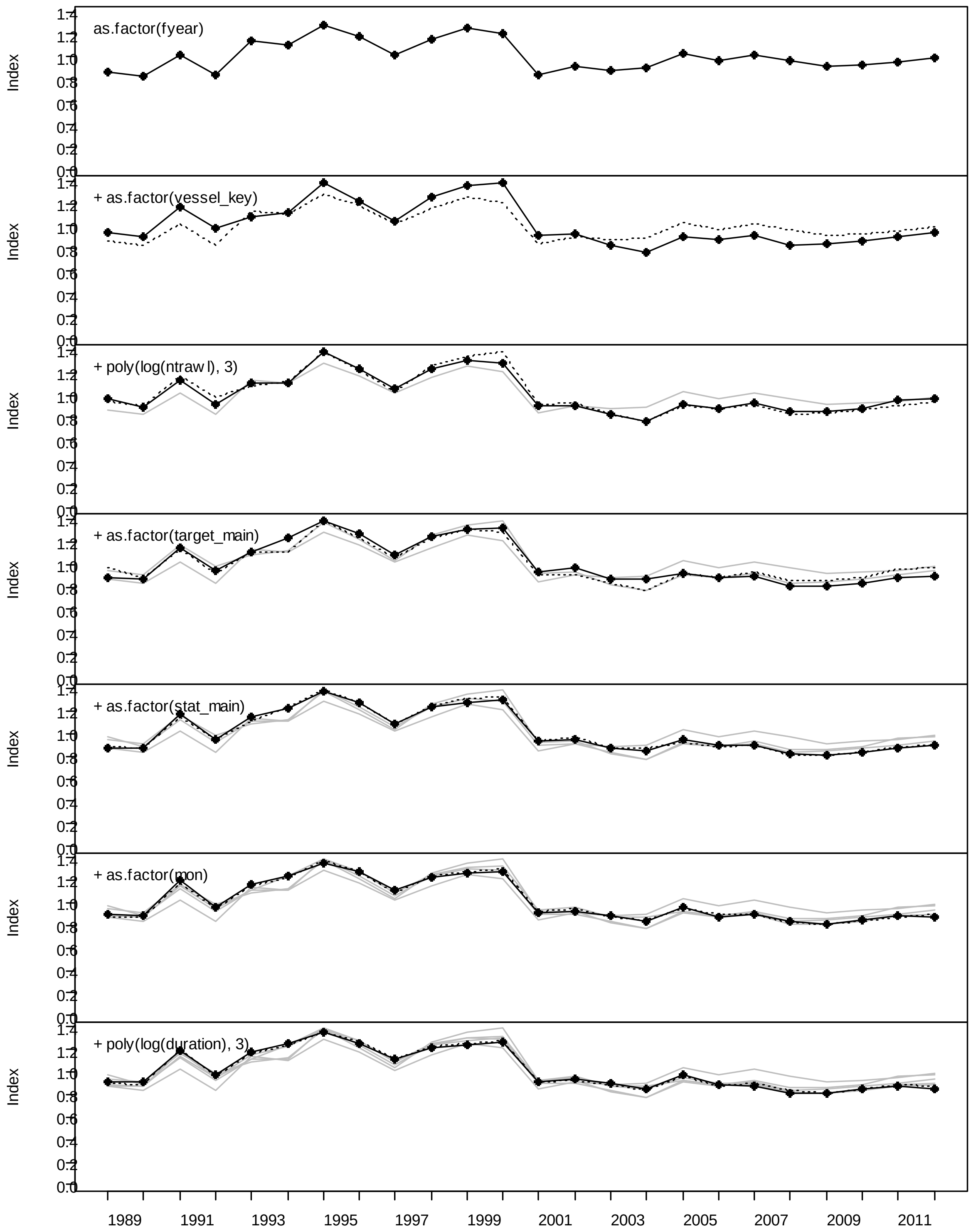

Figure 30: The change in the annual coefficients with the step-wise inclusion of each of the significant variables in the Weibull CPUE model (from top to bottom panel). The solid line and points represent the annual coefficients at each stage. The fishing year is denoted by the calendar year at the beginning of the fishing year (e.g. 1989 denotes the 1989/90 fishing year).

The Weibull CPUE model was further evaluated by investigating potential interactions between key variables and fishing year. Three separate models were reconfigured to include interactions between fishing year and statistical area, target species or fishing vessel. The fishing year:statistical area interactions indicated that the CPUE trends were relatively comparable between the two main fishing areas (Statistical Areas 033 and 034) (Figure 31), while indices derived from Statistical Area 035 were considerably more variable.

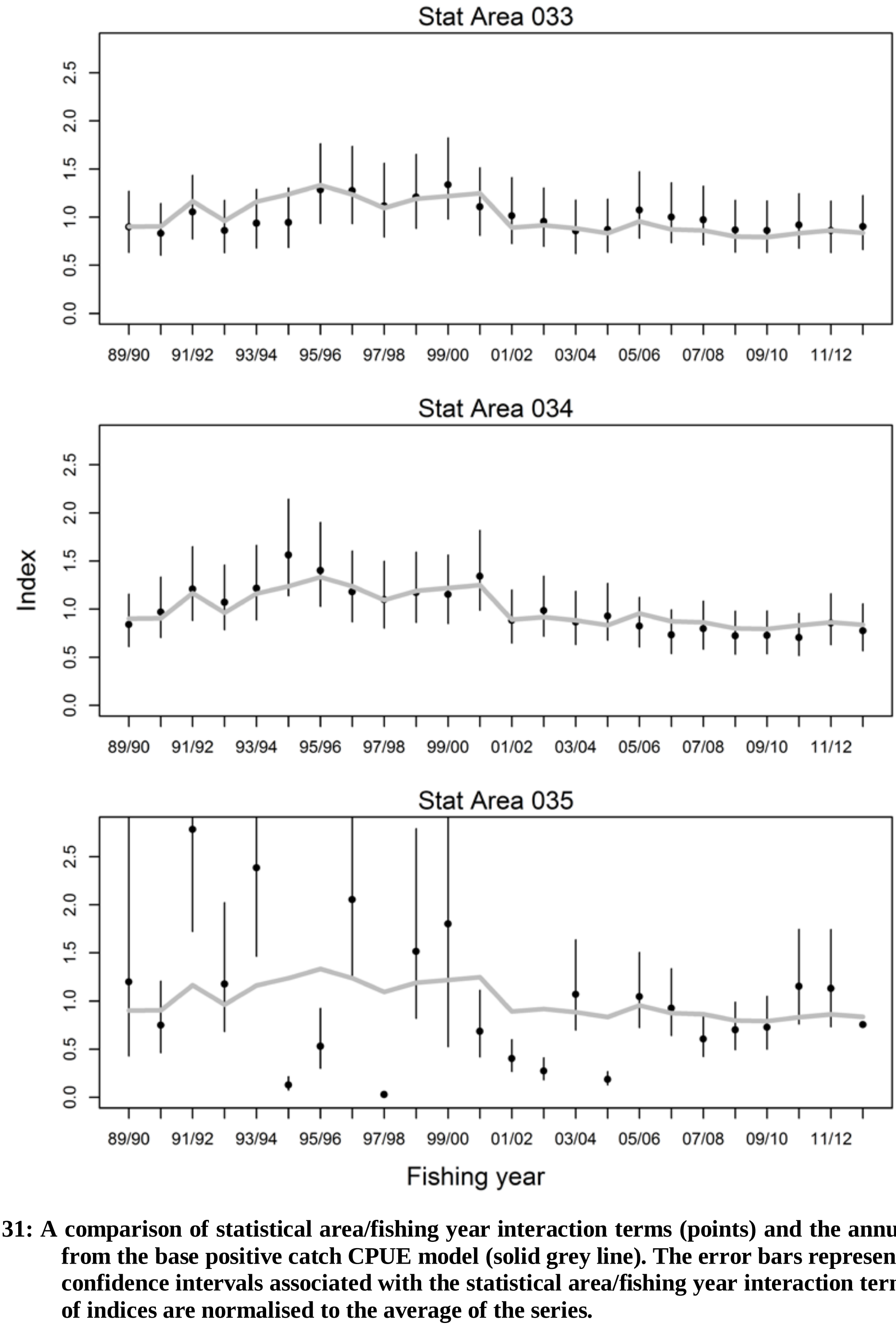

Figure 31: A comparison of statistical area/fishing year interaction terms (points) and the annual indices from the base positive catch CPUE model (solid grey line). The error bars represent the 95% confidence intervals associated with the statistical area/fishing year interaction term. All sets of indices are normalised to the average of the series.

The base CPUE indices are comparable for the two main target species, namely barracouta and tarakihi (Figure 32). For the other target species (STA, RCO and WAR), the target species/fishing year interaction terms deviate considerably from the base indices in the years prior to 2001/02. This may indicate inter-annual differences in the spatial operation of the individual target fisheries during this period. In the more recent years, the target species indices tend to be more consistent with the base index, although the red cod target indices have increased from 2010/11 (Figure 32).

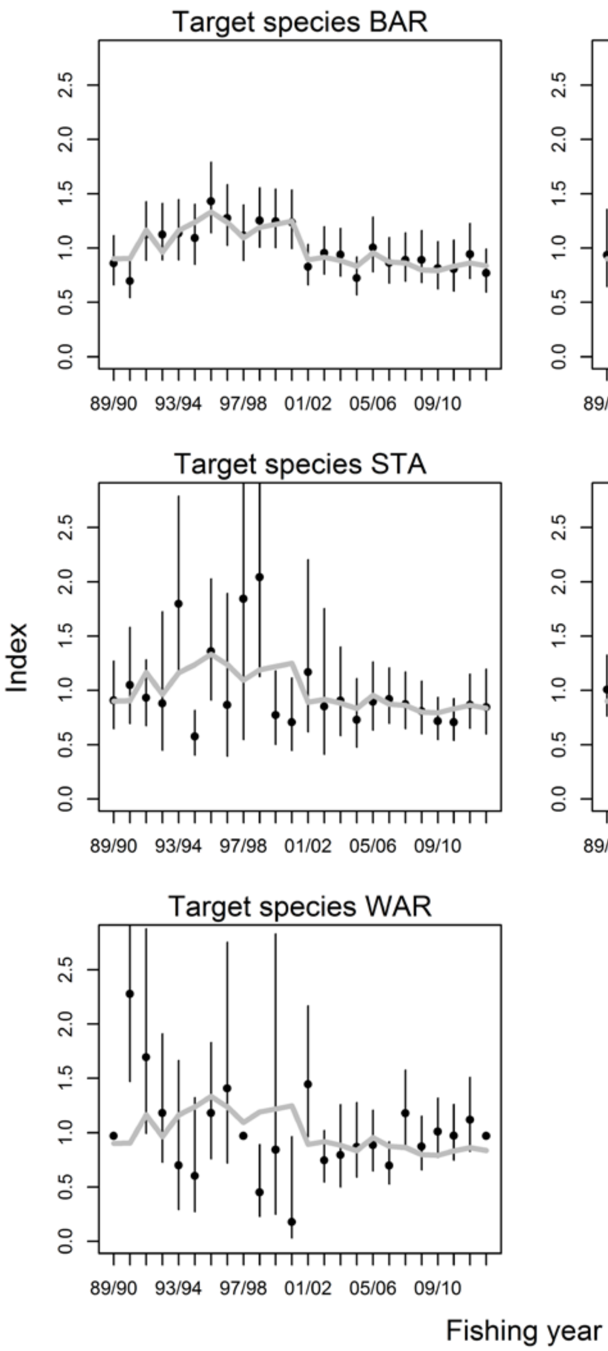

Figure 32: A comparison of target species/fishing year interaction terms (points) and the annual indices from the base positive catch CPUE model (solid grey line). The error bars represent the 95% confidence intervals associated with the target species /fishing year interaction term. All sets of indices are normalised to the average of the series.

The fishing vessel/fishing year interaction terms reveal that there are considerable differences in the CPUE trends amongst the vessels within the core fleet (see Appendix 2). Nonetheless, most of the vessels that operated in the fishery for at least 15 years (esp. vessels 335, 345, 358, 446, 533, and 702) have CPUE trends broadly consistent with the base CPUE indices; i.e. higher indices during the 1990s, a sharp drop around 2000/01 and lower indices for the remainder of the period.

The presence/absence of stargazer catch in each fishing day was modelled using a GLM approach and assuming a binomial error structure. The range of potential explanatory variables was evaluated in a forward step-wise fitting procedure based on an initial model that included *FishingYear* only. The final model also included the categoric variables *TargetSpecies, StatArea, Vessel* and *Month* (Table 7).

The resulting annual indices derived from the binomial model were comparable to the unstandardized annual proportion of positive catch records (Figure 29).The indices fluctuated over the study period with slightly higher indices during 1989/90–1991/92, 1999/2000–2000/01 and 2008/09–2010/11 (Appendix 4).

Table 7: Summary of stepwise selection of variables in the binomial presence/absence CPUE model. 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 (% Improvement)
FishingYear	23	-10796.2	21640.3	3.3 *
TargetSpecies	4	-9894.7	19845.5	12.6 *
StatArea	2	-9707.0	19474.0	2.5 *
Vessel	26	-9506.2	19124.5	2.6
Month	11	-9418.4	18970.7	1.1 *
poly(log(*Duration*), 3)	3	-9355.3	18850.7	0.8
poly(log(*NumTrawl*), 3)	3	-9345.6	18837.3	0.1

The positive catch (Weibull) and binomial indices were multiplied together to derive combined indices following the approach of Stefansson (1996). The confidence intervals associated with the combined indices were determined using a bootstrapping approach. The resulting combined indices were very similar to the Weibull positive catch CPUE indices (Figure 29, Appendix 4).

3.2.3 CPUE models, TCER trawl data set

A supplementary CPUE analysis was conducted using the TCER catch and effort records from the WCSI inshore trawl fishery from 2007/08–2012/13. The definition of the TCER data set was comparable to the daily aggregated data set. Fishing effort records were limited to bottom trawls targeting barracouta, tarakihi, blue warehou, red cod or stargazer within Statistical Areas 033, 034 and 035. Landed catches of stargazer (STA 7) were apportioned to individual fishing records based on the associated estimated catches (stargazer in the top eight species reported per trawl).

The data set was limited to fishing records in depths shallower than 300 m. The catch and effort records were assigned to 0.2 degree latitude/longitude cells based on location at the start of the trawl. Trawl records from latitude/longitude cells with a small number of records (less than 11 trawls) were assumed to be erroneous locations and/or at the periphery of the distribution of the fishery and were excluded from the data set. Coarse range checks were applied to key data variables: trawl duration (1–8 hours), trawl speed (1–4 knots) and stargazer trawl catch (less than 2 500 kg).

The final TCER data set included a core set of vessels that conducted a minimum of 30 trawls per annum in at least three of the six years. The data set included 14 695 fishing records and accounted for about 55–65% of the annual stargazer catch. Approximately 15% of all qualifying trawls had no associated stargazer catch (Table 8).

Table 8: Summary of catch and effort records included in the TCER data set (including zero species catch records). The percentage of trawls with no associated catch of stargazer is also presented.

Fishing year	No. of records	No. of vessels	No of trips	Catch (t)	No. of trawls	Fishing duration (hrs)	Percent zero catch
2007/08	2 378	17	257	591.5	2 378	10 212	23.2
2008/09	2 649	17	252	652.1	2 649	11 454	17.6
2009/10	2 703	19	305	674.6	2 703	10 745	13.6
2010/11	2 698	17	296	606.6	2 698	10 899	17.4
2011/12	2 278	18	275	586.1	2 278	9 416	12.1
2012/13	1 989	15	238	498.4	1 989	8 337	12.9

Over the six years of data, there was a change in the latitudinal distribution of the fishing effort, with a reduction of fishing effort in the central region of the fishery (around 43-43.5° S) and a corresponding increase in fishing effort further south (Figure 33). There was also an increase in the relative proportion of annual trawl effort conducted within the 50–100 m depth range. Trawl duration remained relatively constant over the time period and trawls typically commenced at relatively distinct time intervals during the fishing day (Figure 33).

An examination of the trawl gear variables (headline height and trawl net width) for the individual core vessels revealed no appreciable difference in trawl gear configuration over the time period. Therefore, any difference in the dimensions of the fishing gear among individual vessels would be aliased by the overall vessel effect and, consequently, the gear variables were not included in the CPUE data modelling.

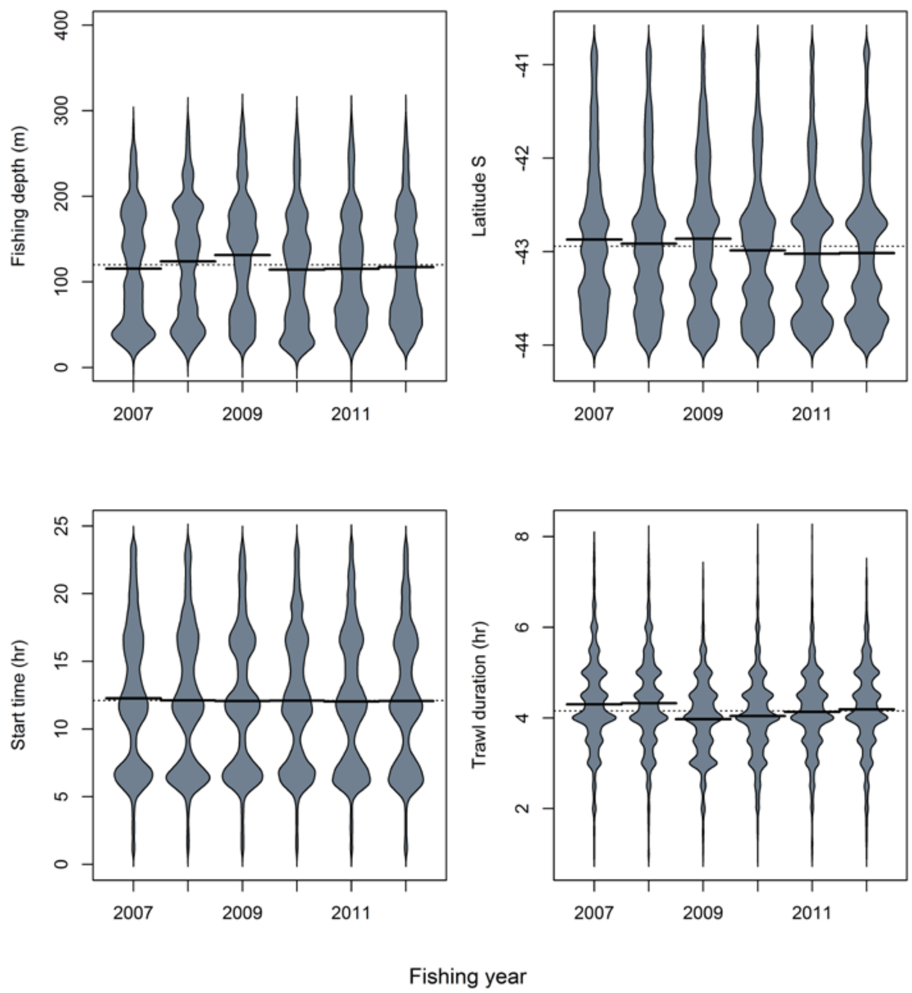

Figure 33: Beanplots of the annual distribution of selected variables in the TCER data set. The dashed horizontal line represents the global average and the black lines represent the annual average. The fishing year is denoted by the calendar year at the beginning of the fishing year (e.g. 2007 denotes the 2007/08 fishing year).

Generalised linear models were developed to model the positive (non zero) catch of stargazer and the presence/absence of stargazer in the catch. The presence/absence of stargazer in the trawl catch was modelled with the assumption of a binomial distribution, while a range of alternative distributional assumptions were evaluated for modelling the positive catch component, including lognormal, Weibull, gamma and log logistic. All models were configured using a step-wise fitting procedure that included variables based on the improvement in the AIC. *Fishing year* was included in the model at the first step and subsequent iterations selected from the categoric variables *location* (0.2 degree latitude/longitude cell, n=77), *vessel* (n=19), and *month* (n=12) and the linear variables *bottom depth*, *start time*, *trawl speed* and natural logarithm of *trawl duration*. The linear variables were included in the model with a third order polynomial functional form. From the range of preliminary positive catch model options, the Weibull distribution was selected based on the AIC and a comparison of the distribution of the residuals from the respective models.

Target species (BAR, WAR, TAR, RCO or STA) was not included as a potential explanatory variable in the formulation of the final TCER models. It is considered that target species is likely to be strongly correlated with other key variables included in the CPUE models, specifically fishing location and fishing depth and, potentially, fishing season. The declaration of target species is also likely to differ amongst vessels and may vary annually depending on the availability of the individual species. Nonetheless, the sensitivity of the CPUE indices to the inclusion of the *target species* categoric variable was examined for the final CPUE models. The annual indices derived from both the positive catch and presence/absence CPUE models were virtually identical regardless of whether or not *target species* was included.

The final positive catch CPUE model included the variables *FishingYear, Location, Vessel*, the natural logarithm of *TrawlDuration, Month, BottomDepth* and *TrawlSpeed* (Table 9). Overall, the final model accounted for 31.2% of the variation in the natural logarithm of catch per trawl (Nagelkerke pseudo-R^2). The fit to the individual observations are generally consistent with the Weibull distributional assumptions (Figure 34).

The inclusion of the individual variables in the model have a minor influence on the annual indices (Figure A5) and the final annual indices are very similar to the unstandardized, geometric mean. The annual indices are relatively constant for the six year period (Figure 35 and Appendix 4).

Table 9: Summary of positive catch model for the TCER data set. Independent variables are listed in the order of acceptance to the model. AIC: Akaike Information Criterion; *: Term included in final model. Fishing year was forced as the first variable.

Term	DF	Log likelihood	AIC	Nagelkerke pseudo-R^2 (% Improvement)	
FishingYear	5	-81 209	162 433	0.4	*
Location	76	-79 964	160 095	18.4	*
Vessel	18	-79 344	158 890	7.9	*
poly(log(*TrawlDuration*), 3)	3	-79 154	158 517	2.2	*
Month	11	-79 066	158 362	1.0	*
poly(*BottomDepth*, 3)	3	-78 970	158 176	1.1	*
poly(*TrawlSpeed*,3)	3	-78 955	158 153	0.2	*

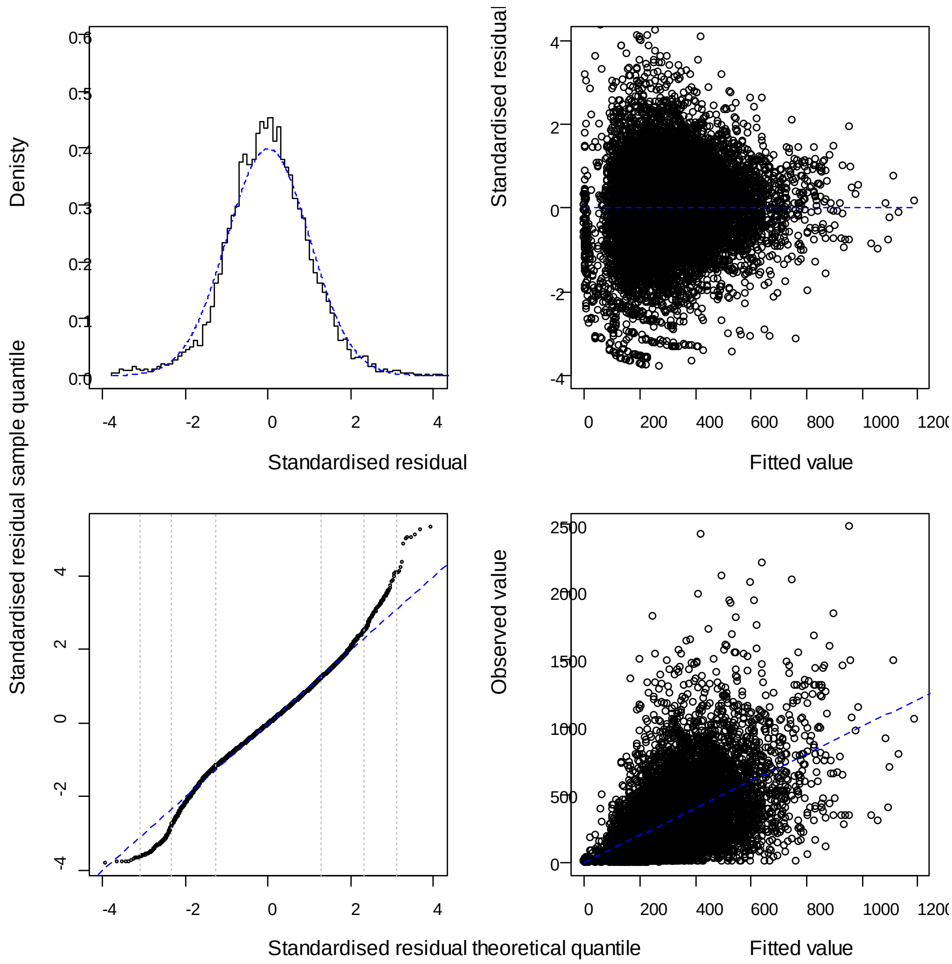

Figure 34: Diagnostics for the TCER positive catch Weibull CPUE model. Top left: histogram of standardised residuals compared to standard normal distribution. Bottom left: quantile-quantile plot of standardised residuals. Top right: fitted values versus standardised residuals. Bottom right: observed values versus fitted values.

The binomial CPUE model of the presence/absence of stargazer catch included the variables *FishingYear*, *Location*, *BottomDepth*, *Month Vessel*, the natural logarithm of *TrawlDuration*, and *StartTime* (Table 10). A high proportion of the explained variation was attributable to the fishing location. The resulting annual indices are virtually identical to the annual proportion of non zero catch records from the fishery and do not indicate a change in the probability of catching stargazer over the period.

The Weibull and binomial CPUE indices were combined to derive a composite set of *combined* CPUE indices. The resulting indices increase slightly over the six years with most of the increase attributable to the small increase in the binomial indices (Figure 35 and Appendix 4).

Table 10: Summary of the stargazer presence/absence CPUE model for the TCER data set. Independent variables are listed in the order of acceptance to the model. AIC: Akaike Information Criterion; *: Term included in final model. Fishing year was forced as the first variable.

Term	DF	Log likelihood	AIC	Nagelkerke pseudo-R^2 (% Improvement)	
FishingYear	5	-6354.0	12720.0	1.7	*
Location	76	-5065.1	10294.1	27.4	*
poly(*BottomDepth*, 3)	3	-4709.4	9588.7	6.7	*
Month	11	-4604.2	9400.4	1.9	*
Vessel	18	-4521.8	9271.7	1.5	*
poly(log(*TrawlDuration*), 3)	3	-4490.1	9214.2	0.6	*
poly(*StartTime*,3)	3	-4473.2	9186.4	0.3	*

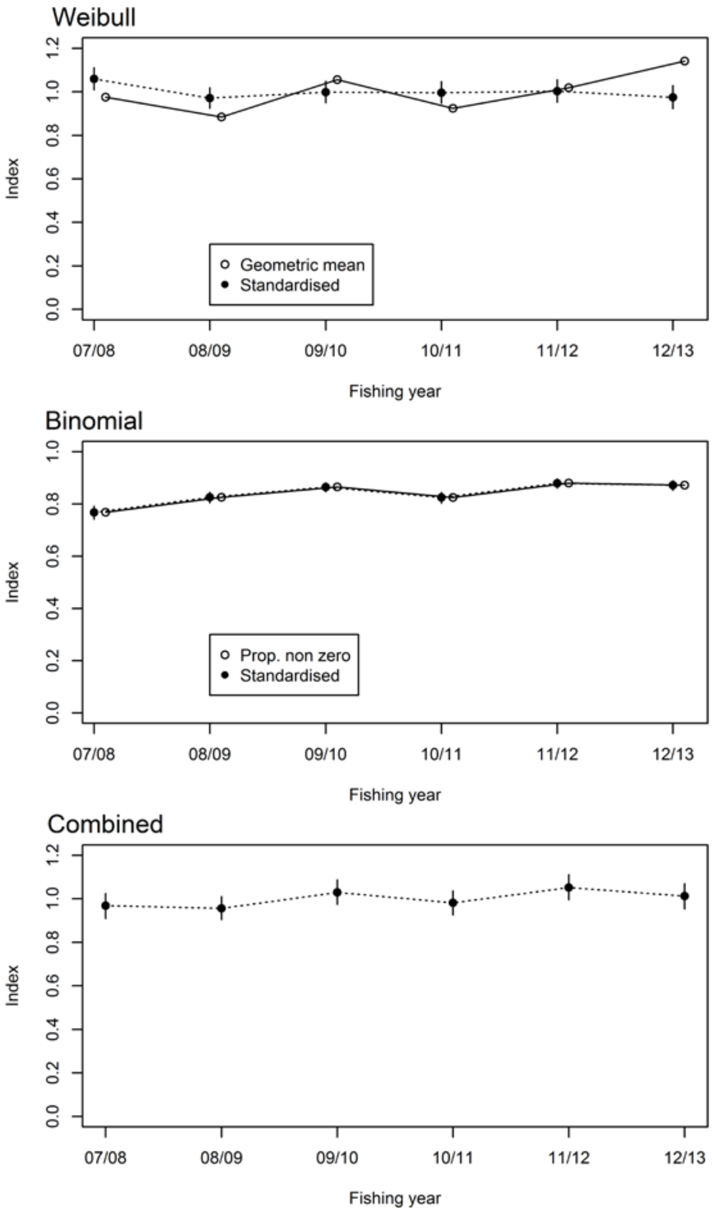

Figure 35: A comparison of the standardised TCER CPUE indices and the geometric mean of the annual catch per trawl (unstandardised) (top panel), a comparison of the binomial indices and the annual proportion of positive catch records in the data set (middle panel) and the combined index (bottom panel) . The error bars represent the 95% confidence intervals associated with each index.

4 DISCUSSION

The annual indices derived from the trawl based CPUE data set are generally consistent with the daily aggregated CPUE indices for the corresponding period (2007/08–2012/13) (Figure 36). Both sets of indices are relatively constant during the period. The trawl survey relative abundance estimates were also relatively similar from the three surveys conducted during that period. However, over the longer term the trawl survey biomass estimates appear to be inconsistent with the trend in the daily aggregated CPUE indices, particularly since the late 1990s (Figure 37). The trawl survey biomass estimates declined considerably from 1997 to 2003 and subsequently recovered. The decline in the trawl survey biomass during the late 1990s coincides with the relatively large catches taken from the fishery at about that time (peak catches occurred in 1999/2000 and 2000/01).

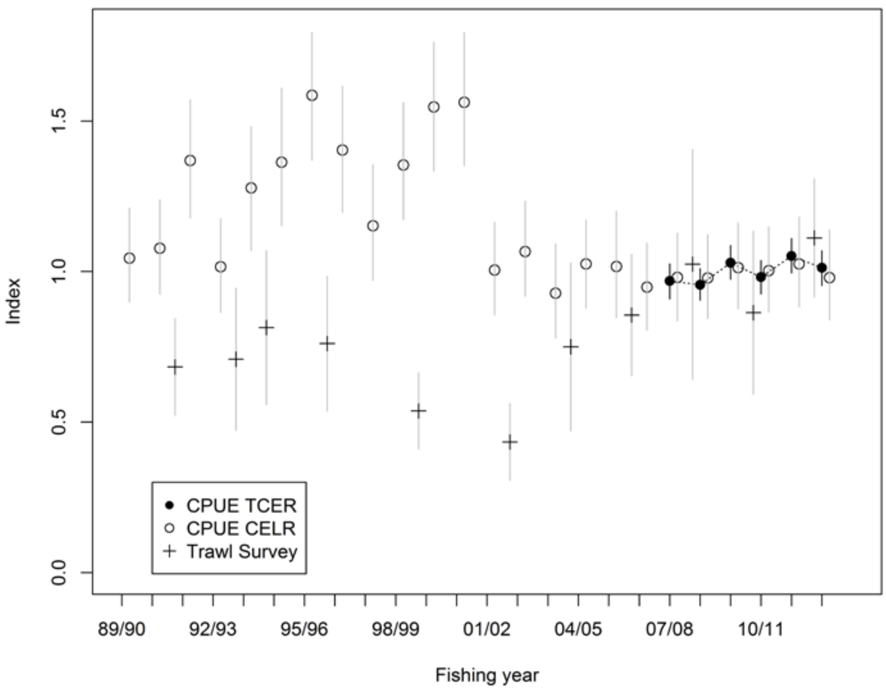

Figure 36: A comparison of annual indices from the CELR CPUE model, CPUE indices from the TCER model and the WCSI trawl survey stargazer biomass estimates. The error bars represent the 95% confidence intervals. All indices are normalised to the average of the 2007/08-2012/13 fishing years.

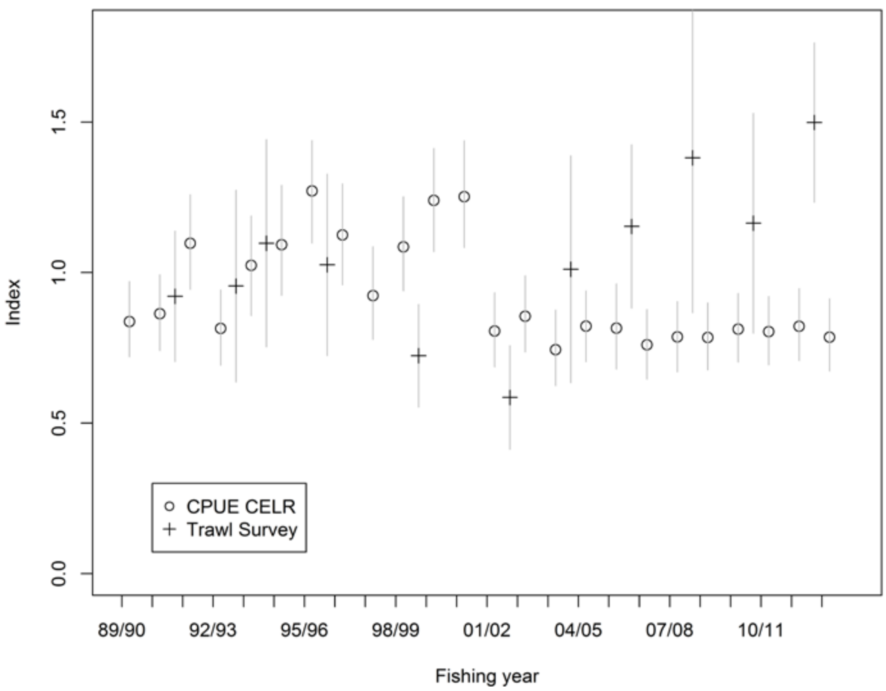

Figure 37: A comparison of annual indices from the CELR CPUE model and the WCSI trawl survey stargazer biomass estimates. The error bars represent the 95% confidence intervals. All indices are normalised to the average of the 1989/90-1996/97 fishing years.

In contrast, the CPUE indices remained high during 1998/99–2000/01 and then declined sharply in 2001/02 (Figure 37). Further, the CPUE indices have remained relatively constant throughout the subsequent years and do not indicate shown any indication of the increase in stock abundance evident from the trawl survey biomass estimates.

The conflicting trends between the trawl survey and CPUE indices were evident in the STA 7 stock assessment (Manning 2008) and could not be accounted for by any differences in the age composition between the component of the stock vulnerable to the trawl survey and commercial fishery. The trawl survey is considered to provide a reliable index of the abundance of stargazer in the WCSI fishery (Stevenson & Hanchet 2000). The trawl survey encompasses the area and depth range of the main STA 7 fishery and the relative abundance of stargazer amongst trawl survey area strata is consistent with the spatial distribution of the stargazer catch.

The discrepancy in the trends between the trawl survey indices and CPUE indices indicates that the CPUE indices are probably influenced by factors that are not directly related to stock abundance. CPUE indices were maintained at a high level during the late 1990s while trawl survey abundance indices declined. This may indicate an increase in the degree of targeting of stargazer during the period. The spatial variability in the distribution of stargazer catch rates indicates that areas of higher stargazer abundance can be targeted by the WCSI fishery. Detailed fishing location data were not available from the fishery until 2007/08 and therefore it is not possible to examine trends in the spatial distribution of fishing activity from the earlier period.

Nonetheless, the species catch composition data from the fishery does provide some suggestion that targeting practices may have changed during the late 1990s. During this period, there was a marked change in the ratio of stargazer to red cod in the landed catches from the WCSI inshore trawl fishery. The relative proportion of stargazer in the combined catch increased considerably from 1995/96 to 1999/2000 (Figure 38). The relative distributions of the two species differ considerably in the WCSI fishery with red cod more abundant in shallower waters (less than 50 m) while stargazer is more abundant in areas deeper than 80 m and abundance is generally lower in shallower waters. Therefore, the observed change in the species composition could be, at least partly, the result of a shift in the spatial distribution of fishing effort. There are also likely to be fluctuations in the abundance of red cod that may influence the relative catch composition during the period.

The magnitude of the decline (about 30%) in stargazer CPUE from 2000/01 to 2001/02 does not seem consistent with the stock dynamics of STA 7; i.e. relatively low variability in annual recruitment, moderate natural mortality and a reasonable number of vulnerable age classes (Manning 2008). The sharp decline in CPUE may relate to a shift in fishing effort from the areas of higher stargazer abundance in preference for other species (possibly barracouta, see Figure 13) at that time. The decline in CPUE of stargazer in 2001/02 has been linked to a decline in the demand for stargazer in the key Asian markets at that time. This followed the decline in the annual catch in 1997/98 that has been attributed to a decline in the demand for stargazer immediately following the Asian Financial Crisis.

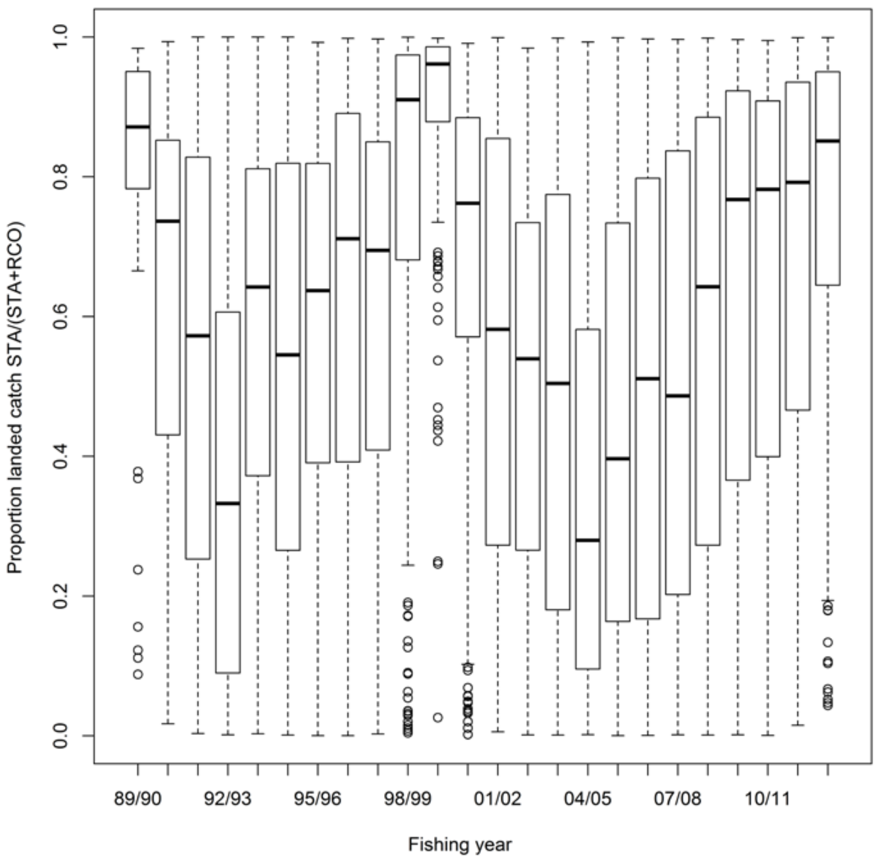

Figure 38: Boxplots of the proportion of stargazer in the combined landed catch of stargazer and red cod from fishing trips included within the daily aggregated core vessel data set.

Since 2002/03 the trawl survey biomass indices have increased considerably (by about 100%), while the daily aggregated CPUE indices remained relatively stable or only slightly increased. Annual catches of STA 7 have been at the level of the TACC since about 2002/03 (MPI 2014) and, therefore, the recent CPUE indices are possibly being constrained by the TACC. The trawl based TCER data provide some indication that the distribution of fishing effort has changed in more recent years, although the CPUE standardisation procedure did not indicate a strong (declining) trend in the relative efficiency of the trawl effort over the six year period.

5 MANAGEMENT IMPLICATIONS

The SINS WG (18 March 2015) reviewed the CPUE analysis and reiterated the previous conclusions that the daily aggregated CPUE indices do not represent a reliable abundance index for STA 7. The SINS WG concluded that the individual trawl based CPUE indices may, in the longer term, provide a reliable index of stock abundance for STA 7. The reliability of the CPUE indices will be evaluated based on a comparison with the stargazer biomass estimates derived from the ongoing time series of WCSI trawl surveys. It is anticipated that a minimum of 10 years of CPUE indices and trawl survey biomass estimates from five biennial surveys would be required to assess the comparability of the two sets of indices. A more definitive evaluation would be possible if there was significant contrast in the abundance indices during the evaluation period.

The stock assessment of STA 7 was conducted based on data complete up to the 2004/05 fishing year. Since then, the results are available from a further five WCSI trawl surveys (including the 2015 trawl survey) and the assessment could be updated to include these data and the other recent data from the fishery (principally annual catches).

6 ACKNOWLEDGMENTS

The project was funded by Southern Inshore Fisheries Management Company Limited. The catch and effort data sets were provided by the Data Management Team of the Ministry for Primary Industries. The CPUE analyses utilised software packages developed by Nokome Bentley (Trophia Limited). Members of the SINS Working Group provided a useful review of the analyses.

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APPENDIX 1. INFLUENCE PLOTS FOR THE MAIN VARIABLES INCLUDED IN THE FINAL DAILY AGGREGATED WEIBULL CPUE MODEL

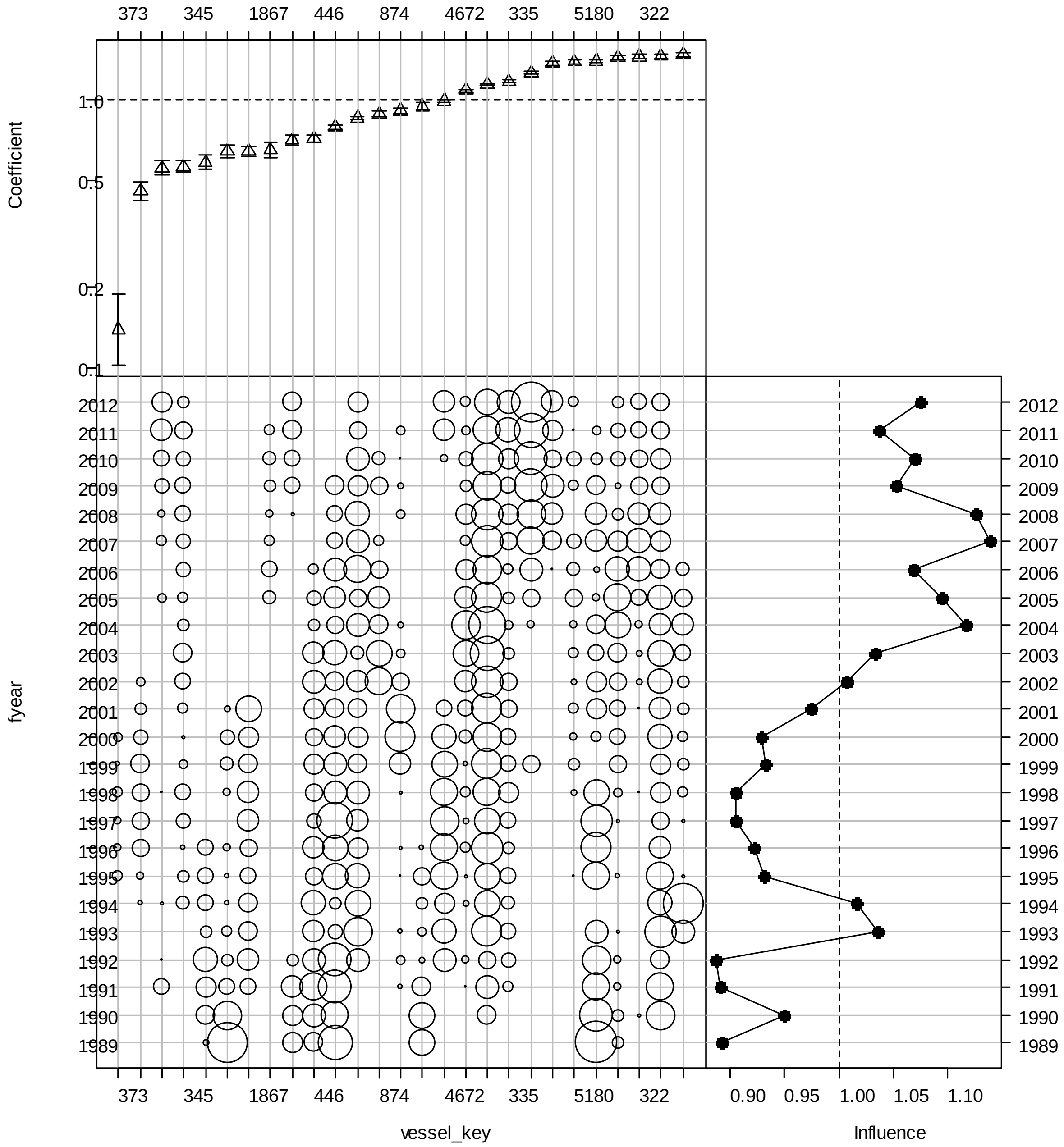

Figure A1: Coefficient-distribution-influence plot for *vessel*.

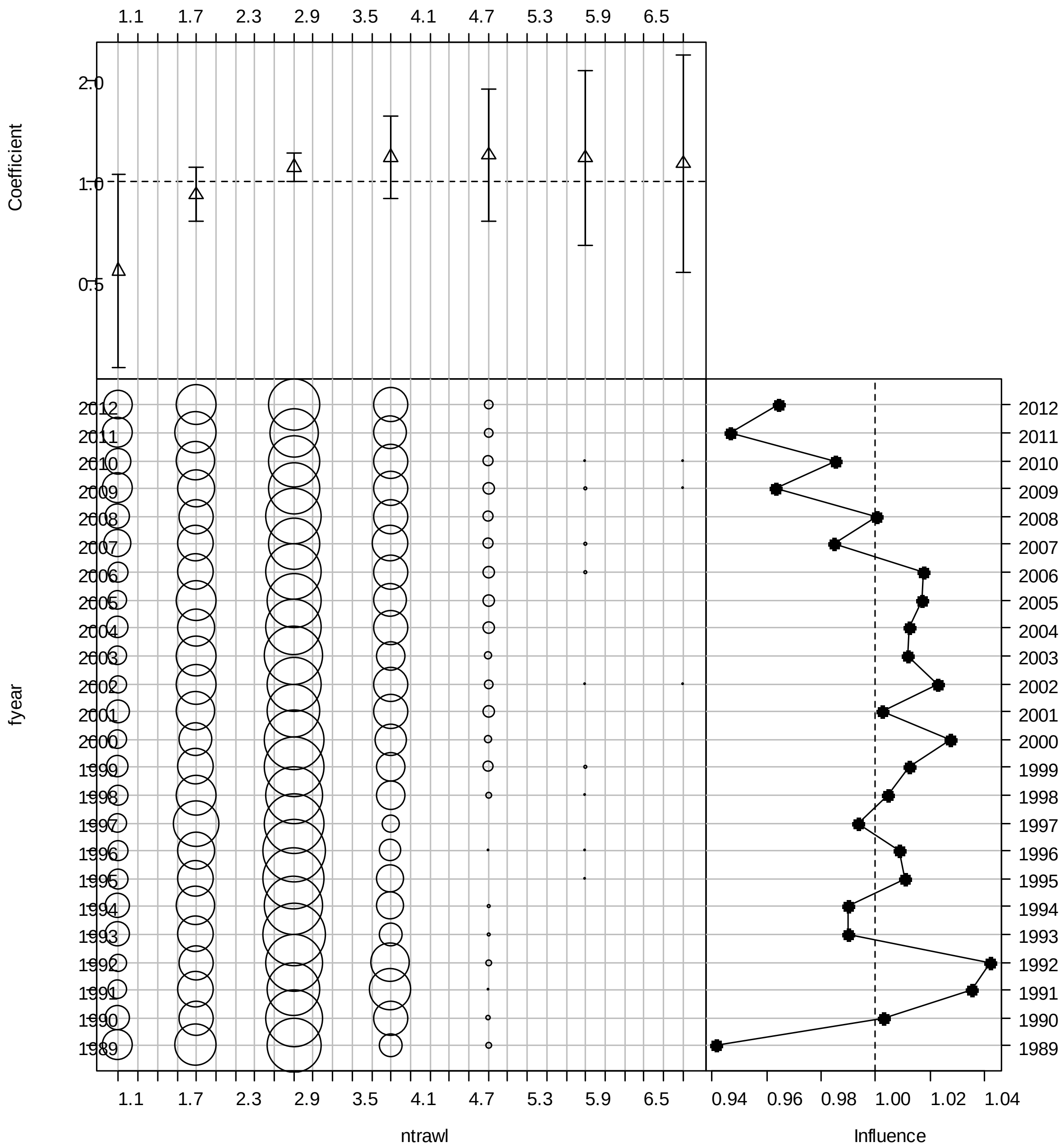

Figure A2: Coefficient-distribution-influence plot for number of trawls (*NumTrawl*).

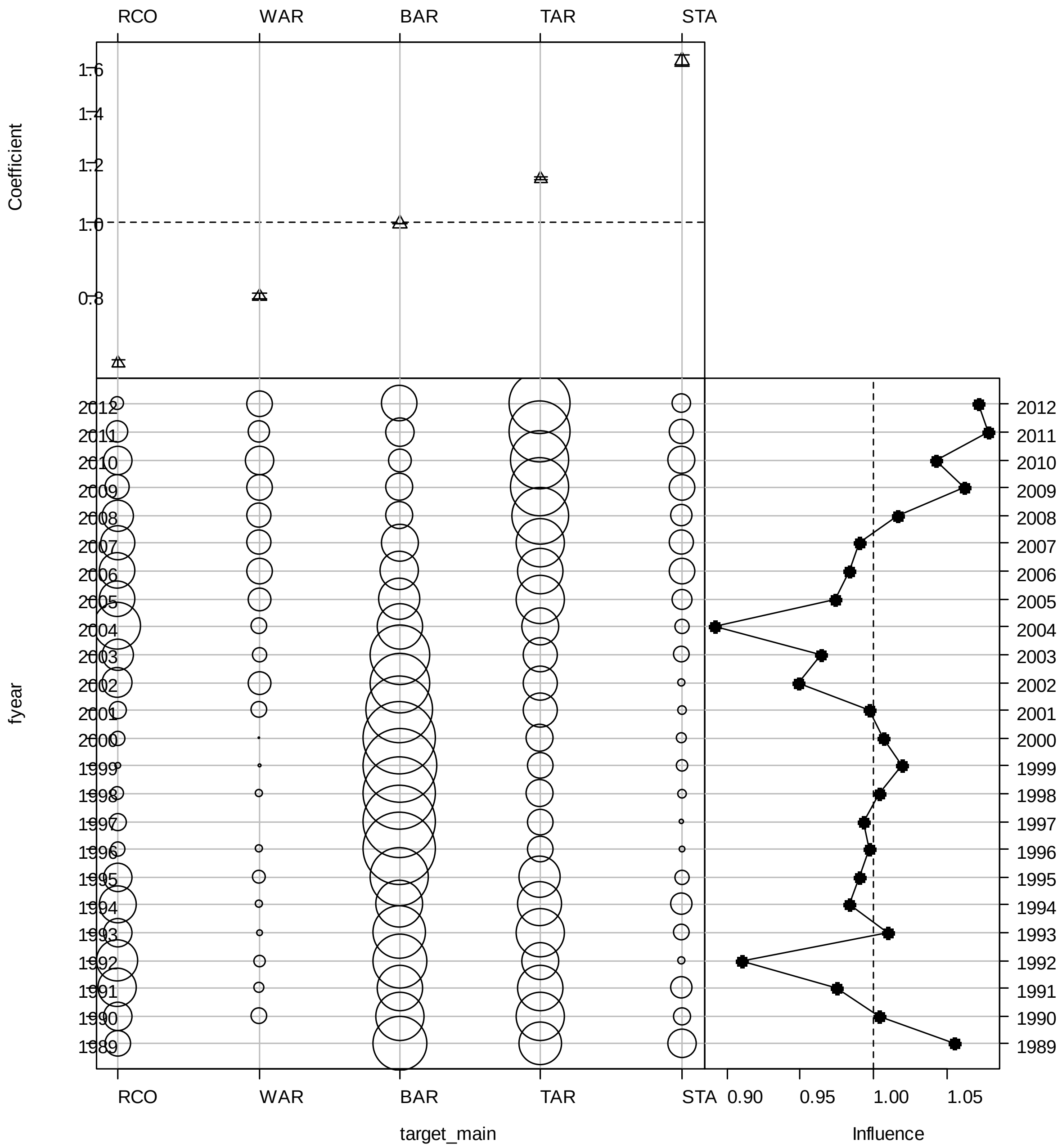

Figure A3: Coefficient-distribution-influence plot for *TargetSpecies*.

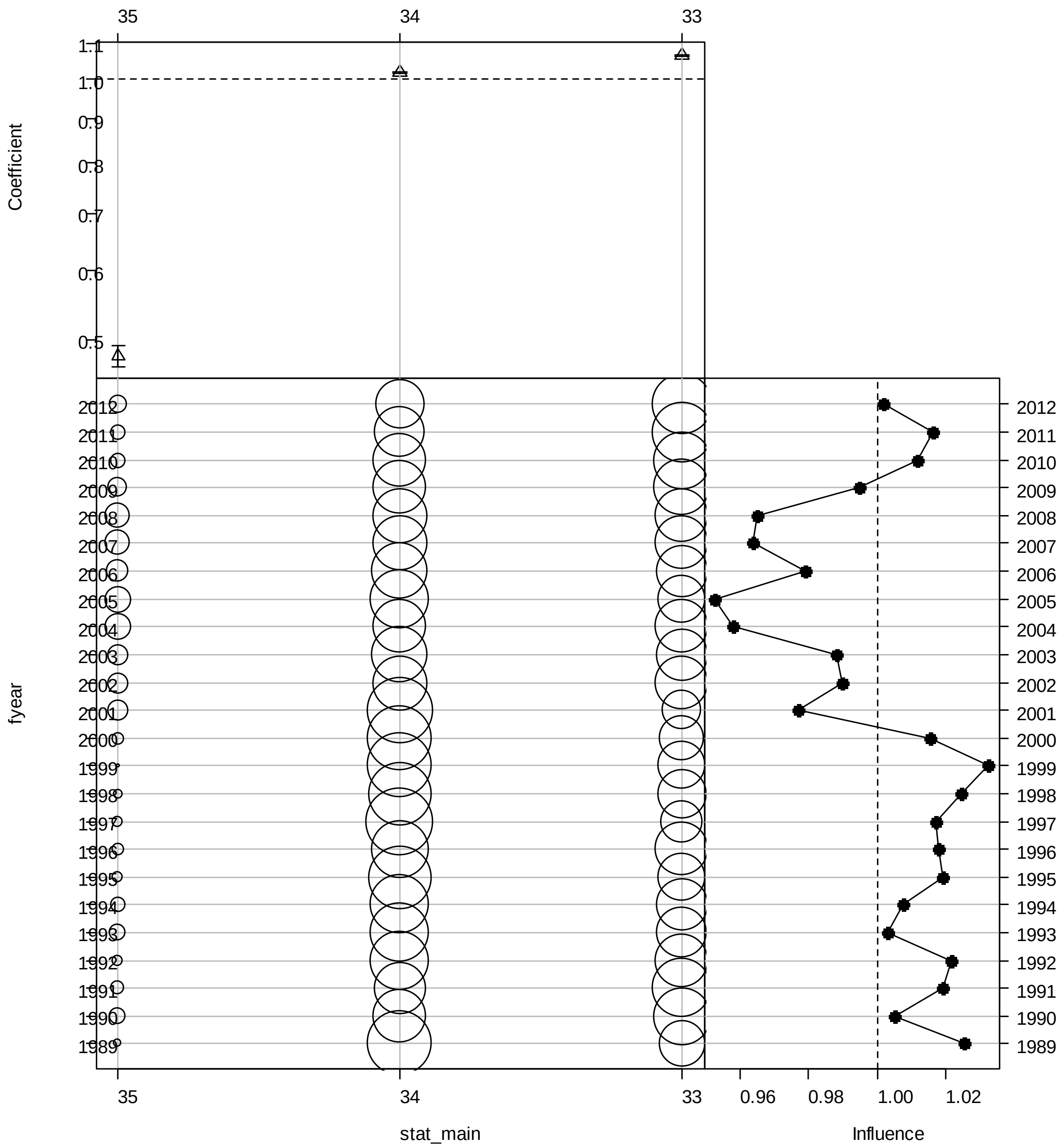

Figure A4: Coefficient-distribution-influence plot for *StatArea*.

APPENDIX 2. AN EXAMINATION OF THE INTERACTION BETWEEN FISHING VESSEL AND FISHING YEAR FOR THE FINAL DAILY AGGREGATED WEIBULL CPUE MODEL

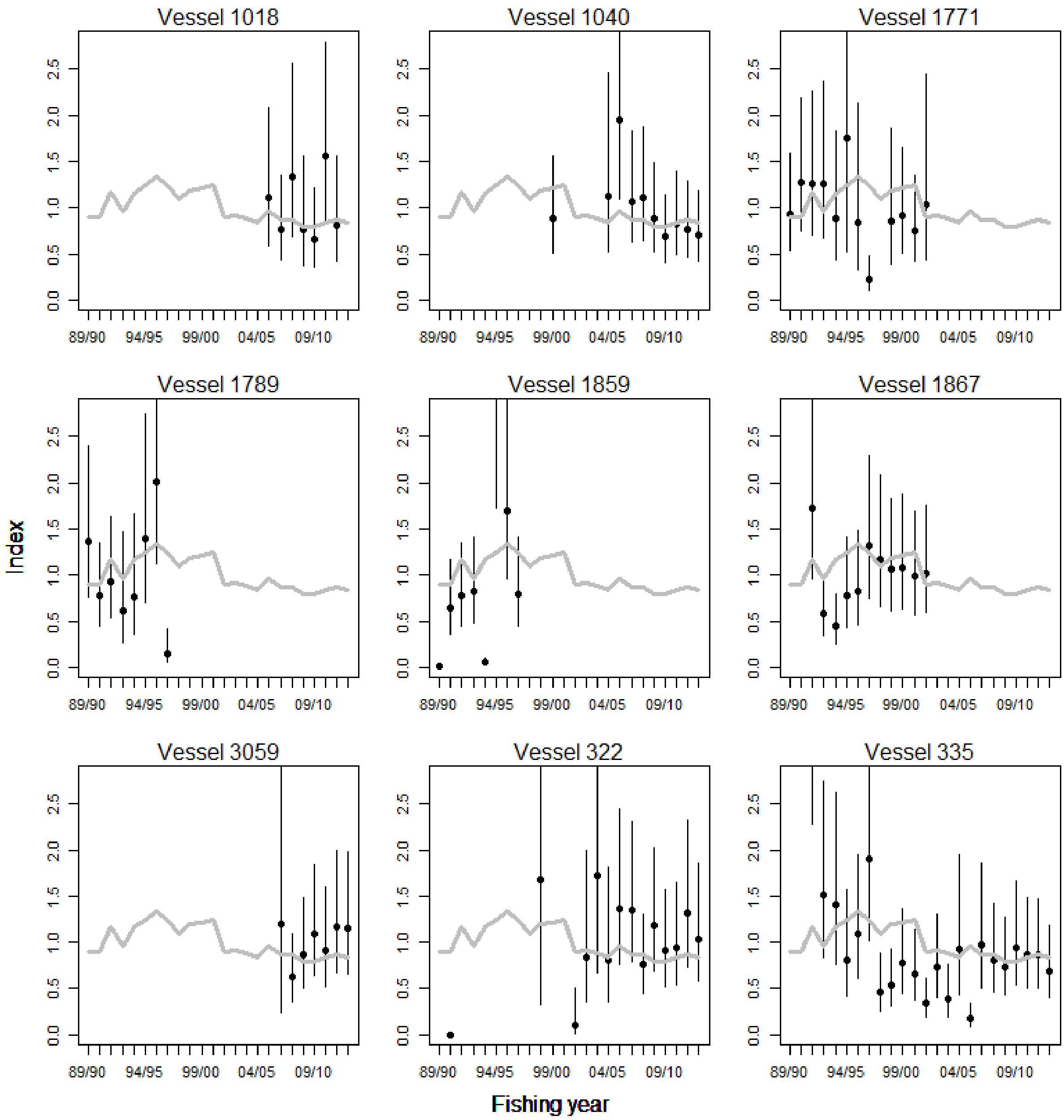

Figure A5: A comparison of fishing vessel/fishing year interaction terms (points) and the annual indices from the base positive catch CPUE model (solid grey line). The error bars represent the 95% confidence intervals associated with the fishing vessel/fishing year interaction term. All sets of indices are normalised to the average of the series.

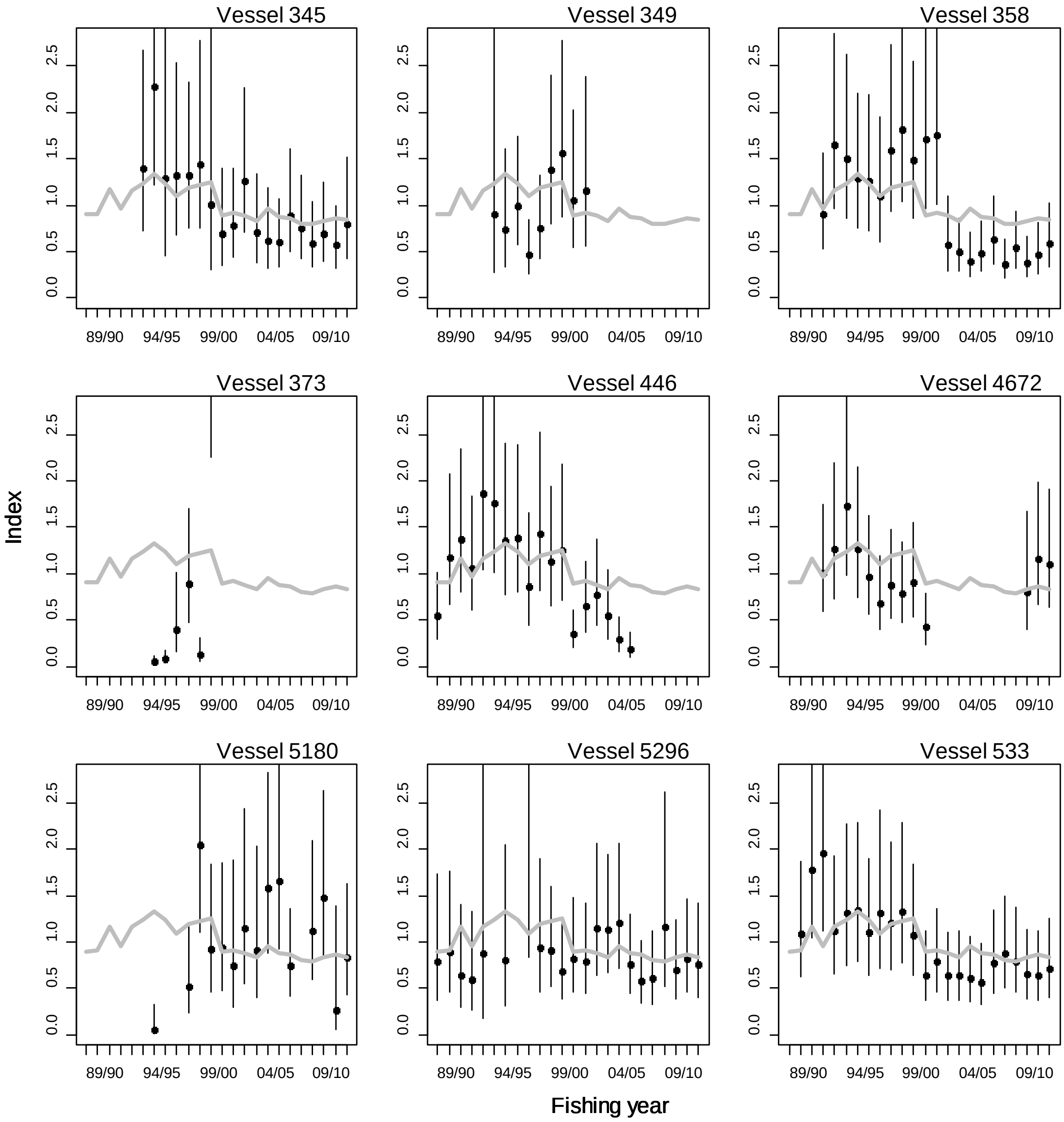

Figure A5: continued.

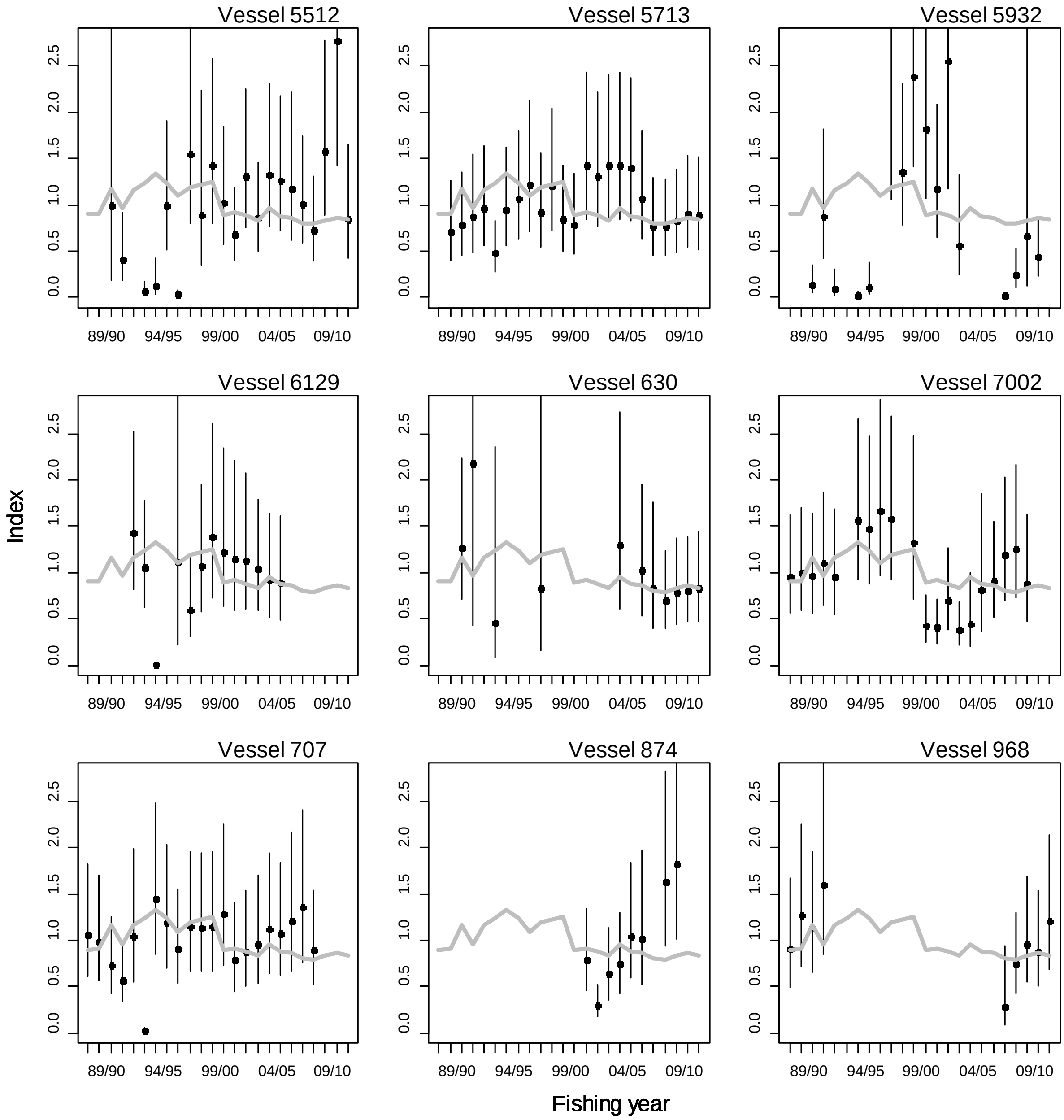

Figure A5: continued.

APPENDIX 3. DIAGNOSTIC PLOTS FOR THE VARIABLES INCLUDED IN THE FINAL TRAWL BASED CPUE MODEL

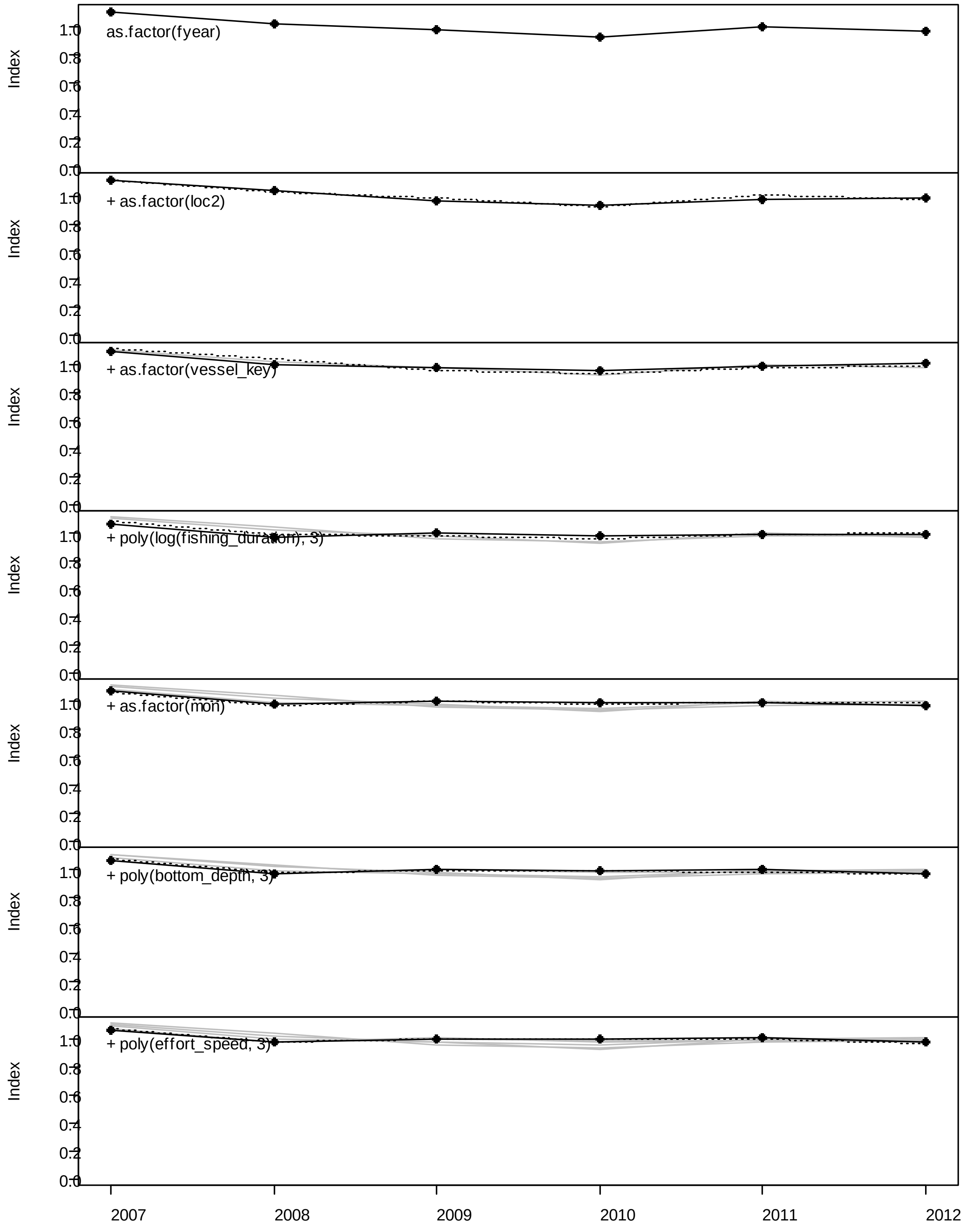

Figure A6: The change in the annual coefficients with the step-wise inclusion of each of the significant variables in the final trawl based CPUE model (from top to bottom panel). The solid line and points represent the annual coefficients at each stage. The fishing year is denoted by the calendar year at the beginning of the fishing year (e.g. 1989 denotes the 1989/90 fishing year).

APPENDIX 4. TABULATED CPUE INDICES

Table A1: Annual CPUE indices and the lower (LCI) and upper (UCI) bounds of the 95% confidence intervals from the final daily aggregated CPUE models.

Fishing	Weibull			Binomial			Combined		
year	Index	LCI	UCI	Index	LCI	UCI	Index	LCI	UCI
89/90	0.902	0.795	1.040	1.001	0.920	1.073	0.904	0.778	1.048
90/91	0.904	0.796	1.027	1.032	0.952	1.099	0.932	0.800	1.072
91/92	1.165	1.029	1.319	1.017	0.940	1.085	1.185	1.020	1.360
92/93	0.963	0.850	1.091	0.913	0.825	0.995	0.879	0.748	1.018
93/94	1.162	1.015	1.330	0.952	0.863	1.035	1.106	0.926	1.283
94/95	1.238	1.080	1.420	0.951	0.860	1.035	1.180	0.998	1.393
95/96	1.333	1.178	1.508	1.025	0.948	1.095	1.373	1.186	1.553
96/97	1.238	1.093	1.401	0.983	0.897	1.055	1.215	1.036	1.398
97/98	1.095	0.954	1.256	0.908	0.801	0.993	0.997	0.841	1.173
98/99	1.190	1.051	1.348	0.987	0.907	1.060	1.172	1.015	1.352
99/00	1.219	1.077	1.380	1.101	1.034	1.159	1.339	1.155	1.525
00/01	1.249	1.102	1.415	1.082	1.017	1.138	1.352	1.170	1.553
01/02	0.892	0.783	1.017	0.975	0.889	1.052	0.870	0.742	1.008
02/03	0.917	0.805	1.045	1.002	0.917	1.076	0.923	0.795	1.068
03/04	0.884	0.772	1.011	0.910	0.821	1.001	0.804	0.675	0.946
04/05	0.833	0.731	0.950	1.067	0.994	1.127	0.888	0.760	1.014
05/06	0.956	0.839	1.089	0.924	0.832	1.009	0.880	0.734	1.039
06/07	0.874	0.770	0.991	0.939	0.855	1.017	0.821	0.698	0.947
07/08	0.863	0.760	0.980	0.985	0.903	1.059	0.849	0.724	0.976
08/09	0.799	0.705	0.905	1.061	0.982	1.124	0.847	0.731	0.971
09/10	0.793	0.700	0.898	1.106	1.041	1.160	0.877	0.759	1.005
10/11	0.832	0.733	0.944	1.044	0.973	1.110	0.868	0.749	0.994
11/12	0.863	0.760	0.980	1.026	0.947	1.098	0.888	0.764	1.023
12/13	0.837	0.735	0.954	1.011	0.926	1.082	0.848	0.727	0.986

Table A2: Annual CPUE indices and the lower (LCI) and upper (UCI) bounds of the 95% confidence intervals from the trawl based CPUE models.

Fishing	Weibull			Binomial			Combined		
year	Index	LCI	UCI	Index	LCI	UCI	Index	LCI	UCI
07/08	1.059	1.009	1.111	0.915	0.884	0.944	0.969	0.909	1.025
08/09	0.971	0.925	1.019	0.984	0.959	1.007	0.956	0.905	1.010
09/10	0.998	0.950	1.048	1.030	1.009	1.050	1.029	0.975	1.087
10/11	0.996	0.948	1.047	0.983	0.957	1.006	0.982	0.926	1.037
11/12	1.002	0.952	1.055	1.048	1.026	1.068	1.052	0.995	1.110
12/13	0.974	0.923	1.028	1.039	1.016	1.059	1.013	0.954	1.069