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Fisheries characterisation and catch-per-unit-effort analyses FLA 2

New Zealand Fisheries Assessment Report 2018/04

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The fisheries taking flatfish in Quota Management Area (QMA) FLA 2 are described from 1989–90 to 2015–16 based on compulsory reported commercial catch and effort data held by the Ministry for Primary Industries (MPI). FLA 2 comprises the lower half of the North Island from Cape Runaway on the east coast round to the southern point of Nuhuhakari Bay on the west coast. The vast majority of the commercial FLA 2 fishery is captured within the Hawkes Bay bottom trawl fishery, but a small set net fishery also occurs in Wellington. The FLA 2 fishery has declined since the mid 1990s with the catches between 150 –250 tonnes in the last 5 years, compared to the 726 ton TACC. The fishery is spatially discrete with catch and effort concentrated within Hawke Bay between Cape Kidnappers and Waipatiki. The FLA 2 fishery catches a range of flatfish species, the dominant species reported are New Zealand sole and sand flounder.

This study reanalyses the FLA 2 bottom trawl CPUE index, to include data to the end of the 2015–16 fishing years. This analysis also forms indices of abundance for sand flounder and New Zealand sole from 2007–08 to 2015–16, where reporting quality was deemed sufficient. The CPUE indices were derived using a delta-lognormal approach that incorporated Generalised Linear Models of the occurrence of flatfish in the trawl catch (binomial model) and the magnitude of positive flatfish catches (Gamma model). The all species CPUE index is the accepted index for monitoring abundance in FLA 2. The CPUE index shows cyclic fluctuations in abundance with no apparent long term trend and cycles generally between 5 –8 years. Since the last assessment the CPUE indices showed a decline from 2013 to 2015 followed by a rapid increase in 2016. The CPUE indices for New Zealand sole and sand flounder provide an index of abundance that is consistent with the trends of the aggregate FLA fishery.

1. INTRODUCTION

The FLA 2 fishery primarily operates within shallow inshore waters of Hawke Bay. The catch consists of a suite of flatfish species (FLA, BFL, BLF, BRI, ESO, FLO, GFL, LSO, SFL, SOL, TUR, WIT, YBF), although, the most consistent species reported in the estimated catches is New Zealand sole (ESO). FLA 2 is primarily caught in an inshore target trawl fishery, although some by-catch occurs in the BT-Mix and BT-TAR target fisheries in the deeper waters of Hawke Bay.

A primary question is whether the FLA 2 fishery can be effectively monitored using indices based on individual species. The FLA 1 and FLA 3 fisheries are both monitored using indices of abundance based on their dominant species. FLA 3 also uses an all species index (Ministry for Primary Industries 2016). The dominant flatfish species in the FLA 2 fishery are New Zealand sole (ESO) and sand flounder (SFL) (Kendrick & Bentley 2014, Beentjes 2003).

The FLA 2 TACC is currently 726 tonnes, set in 1990-91. Since 1999-00 catches have been between 150 and 300 tonnes. The abundance of flatfish (all species) has been monitored using standardised Catch-Per-Unit-Effort (CPUE) indices derived from the trawl fishery (Kendrick & Bentley 2014).

2. METHODS

2.1 Dataset

Statutory catch, effort and landings data for FLA 2 from the beginning of the 1990 fishing year (1 October 1989), to the end of the 2016 fishing year (30 September 2016) were sourced from the Ministry for Primary Industries' `warehou` database. The characterisation dataset captured all fishing effort in FMA 2 that had the potential to capture flatfish species (inshore trawls in Statistical Areas 011:016) regardless of whether flatfish was captured. The CPUE dataset was restricted to only the target flatfish fishery.

2.2 Data Grooming

Data were groomed within Trident's `kahawai` database which implements grooming methods described by Starr (2007) using code adapted from the Groomer package (Bentley 2012). The grooming process implements error checks on both the landings and effort datasets.

Missing values in three effort records were corrected using values from records on the corresponding forms, matched on the DCF (form) key. DCF correction was used for Catch Effort Landing Return (CELR) forms for the fields: primary method, target species and start stats area code.

Grooming of effort data then used the logic described by Starr (2007) to correct likely erroneous or missing values in the reported target species, Statistical Area, primary method, date, time, position and units of effort.

Grooming of landings also followed logic described by Starr (2007) to correct likely erroneous or missing values in the reported date, destination type, state code, and conversion factor, and to remove duplicate landings.

Table 1: Summary of the fishing effort grooming that resulted in dropped effort; Code, description of grooming and frequency

Code	Description	Frequency
FELLS	Coordinate outside of Statistical Area	2 014
FETSW	Target species invalid	156

Table 1 shows a summary of the effort records that were removed due to changes from the data grooming process, further records were removed due to missing values. Figure 1 shows the break up of landings removed from the data due to data grooming. The majority of the data were removed by check LADTH, this represents landing records where the catch was not landed and corresponds to destination types of 'P' (Holding receptacle in the water), 'Q' (Holding receptacle on land), or 'R' (Retained on board). Earlier in the time series some data was removed by the check LADUP, this identifies duplicate landings (Figure 1). The amount of data removed as a consequence of data grooming was a trivial component of the overall catches.

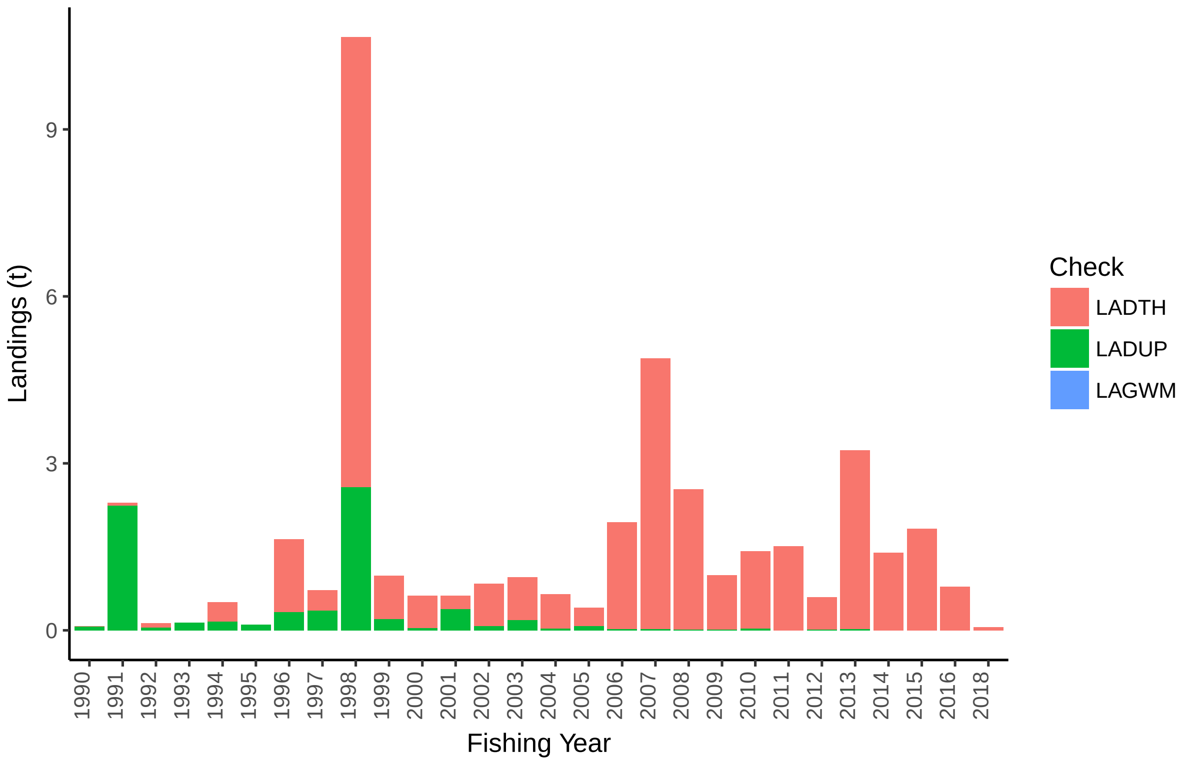

Figure 1: The flatfish landings data removed from the FLA 2 CPUE analysis dataset, the bar colour indicates the grooming checks contributing to the removals.

There is a good correspondence between reported landings and the QMR/MHR returns (Figure 2).

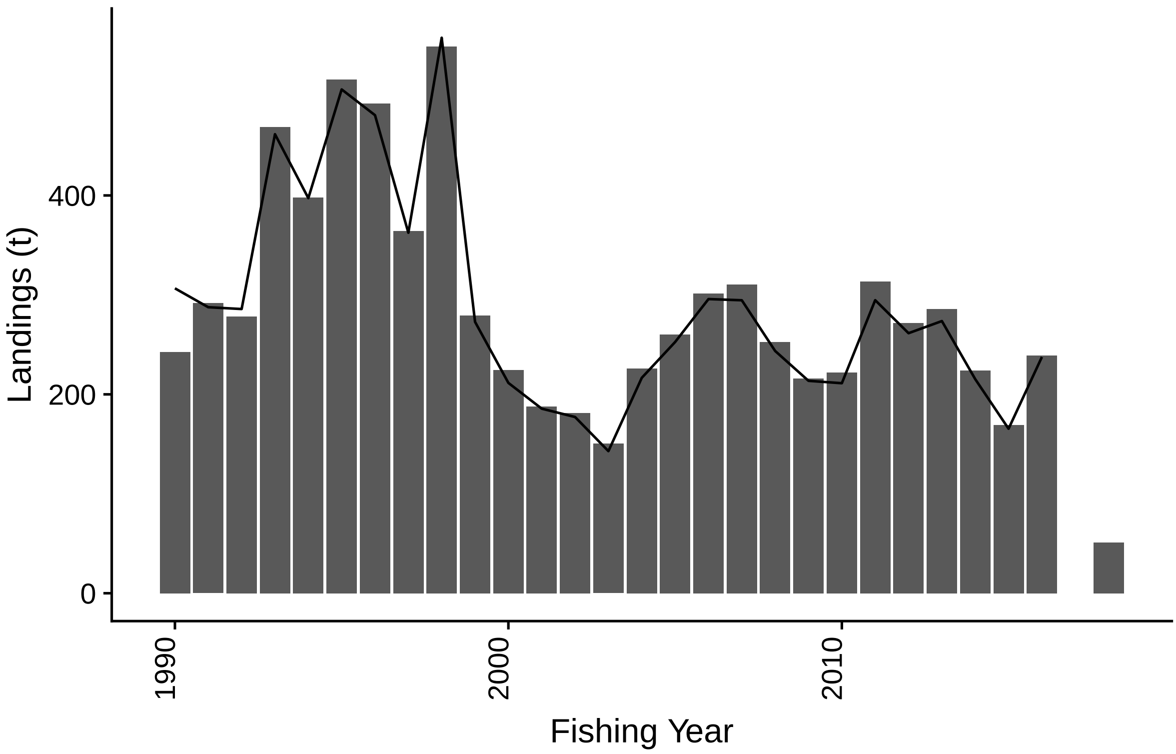

Figure 2: A comparison between the groomed FLA 2 annual landed catch (bars), the combination of Quota Management Returns (QMR, 1990 –2001) and Monthly Harvest Returns (MHR, 2002 –2015) (black).

2.3 Data description

The data sets were configured to generate three separate data sets for the fishery characterisation and CPUE analyses. The fishery characterisation was conducted using the individual effort records for all fishing methods. Landed catches of the species of interest were allocated to the fishing event records following the methodology of Starr (2007); i.e. landed catches were predominantly allocated in proportion to the estimated catches associated with the fishing effort records. Flatfish is always landed as the generic species code FLA with no individual species recorded in the landed catch. When landings are allocated to fishing effort all individual species estimated catches are summed to derive the scaled FLA landing.

For the bottom trawl fishing method, catch and effort data were recorded in CELR format prior to 2007–08 and in the TCER format in subsequent years (Figure 3). Two separate CPUE data sets were configured based on the two main data formats: 1) an aggregated data set configured to approximate the format of the CELR format data including data from 1989–90 to 2015–16 and 2) a trawl event based data set that retains the detail of the TCER data format from 2007–08 to 2015–16. For the event based data set, the landed catch from each fishing trip was allocated amongst the trawl records from the respective fishing trips in proportion to the estimated catches of the species (Starr 2007).

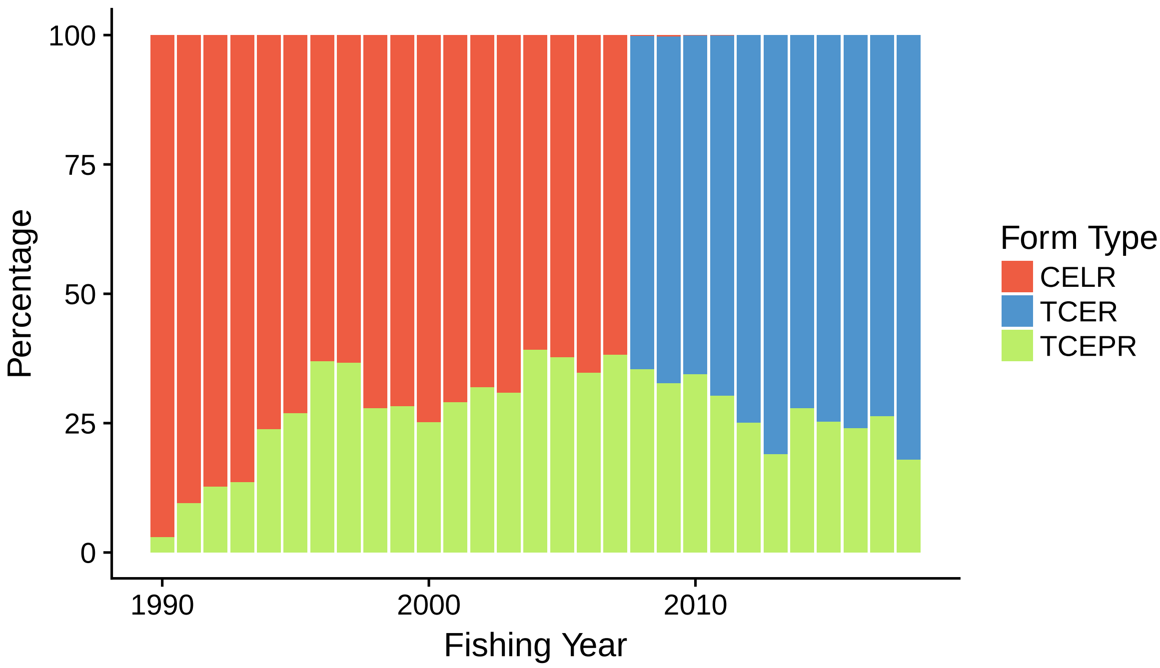

Figure 3: The reporting form types in the FLA 2 fishery from 1990 to 2016 fishing years, TCER forms were introduced for vessels > 6m in 2008.

The configuration of the aggregated CPUE data set summarised effort records for each vessel fishing day following the approach of Langley (2014). For each fishing day, the following variables were derived: the number of trawls, total fishing duration (hours), the predominant target species and the predominant Statistical Area where fishing occurred. The estimated catches of all species were also determined for each fishing day. For comparability with the CELR data format, only the estimated catch of the five main species (by catch magnitude) were retained in the final aggregated data set. In the first instance, the landed catches of the species of interest from individual trips were allocated amongst the associated aggregated event records in proportion to the (daily aggregated) estimated catch of the species. In the absence of the species being included within the daily aggregated estimated catch, the landed catch was allocated in proportion to the fishing effort (number of trawls) within the fishing trip.

For the individual flatfish species analyses allocated catch was scaled to the proportion to the estimated catch reported for the focal species.

2.4 Data filtering for CPUE analyses

Records were excluded from the CPUE data set if the reported fishing duration was less than 1 hour or greater than the 99.5th percentile. Landings were excluded if they were exceeded the 99th percentile and the estimated catch differed significantly from the reported landing.

2.5 Model selection

2.5.1 CPUE models

A Generalised Linear Model (GLM) approach was used to model the occurrence (presence/absence) of positive flatfish catch and the magnitude of positive flatfish catches. The dependent variable of the catch magnitude CPUE models was the natural logarithm of catch. For the positive catch CPUE models, a Gamma error structure was adopted following an evaluation of alternative distributions (Log logistic, lognormal, Gamma). The presence/absence of flatfish catch was modelled based on a binomial distribution. The final (combined) indices were determined from the product of the positive catch CPUE indices and the binomial indices following the approach of Stefansson (1996).

The model terms offered to vessel-day models are evident in Table 2 and the model terms offered to the tow resolution models in Table 3. Fishing year (fyear) was forced into all CPUE models. Models were selected by forward stepwise selection of additional model terms was based on Akaike's Information Criterion (AIC) with predictors retained if they increased the deviance explained by at least 1%.

The influence of predictors in the various CPUE models was investigated using methods provided in the R package `influ` (Bentley et al. 2011).

Table 2: The variables offered to the Binomial and Gamma vessel-day resolution FLA 2 CPUE model for model selection. ** Area was removed from model selection due to a large shift in dominant statistical area after the introduction of TCER forms in 2008.

Variable	Definition	Data type	Range
Fishing Year	Fishing year	Categorical (27)	1990:2016
Vessel	Fishing vessel	Categorical (47)	
Month	Month	Categorical (12)	Jan-Dec
Area	Statistical Area	Categorical (2)	013, 014 **
Duration	Natural logarithm of trawl duration (hours)	Continuous	ln(1:24)
Effort	Number of trawls in the vessel-day	Continuous	1-6

Table 3: The variables offered to the Binomial and Gamma TCER resolution FLA 2 CPUE model for model selection.

Variable	Definition	Data type	Range
Fishing Year	Fishing year	Categorical (9)	2008:2016
Vessel	Fishing vessel	Categorical (24)	
Month	Month	Categorical (12)	Jan-Dec
Area	Statistical Area	Categorical (2)	013, 014
Area * Month	Area month interaction	Categorical (24)	
Duration	Duration of fishing effort for the day (hours)	Continuous	ln(1-6)
Effort	Number of trawls in the day	Continuous	1-6
Latitude	Absolute start latitude for the trawl	Continuous	37.45–40.915
Longitude	Reported start longitude for the trawl	Continuous	176.2–178.73
Speed	Speed of the trawl (knots)	Continuous	1.9–4
Distance	Distance trawled (N. miles)	Continuous	2–14
Trawl width	Wingspread of the trawl gear (m)	Continuous	5–40
Trawl height	Headline height of trawl gear (m)	Continuous	0.5–15
Depth	Depth of the bottom (m)	Continuous	1–100

3. CHARACTERISING THE COMMERCIAL FISHERIES IN FLA 2

The FLA 2 fishery is primarily a bottom trawl fishery, with a consistent small set net fishery catching some flatfish in the southern Statistical Areas of FMA 2 (Figure 4). Flatfish catches have declined considerably since 1997 with catches less then 250 tonnes since the 2000 fishing year. There has been a corresponding decline in fishing effort (Figure 5A).

Within the FLA 2 bottom trawl fishery there is inconsistent reporting of individual flatfish species as target species (Figure 5), as a consequence, all flatfish target species have been adjusted to FLA. The FLA 2 bottom trawl fishery is dominated by a flatfish target fishery but low levels of flatfish by-catch occur in the substantially larger FMA2 mixed species bottom trawl fishery, which targets gurnard, snapper and trevally, as well as, the bottom trawl tarakihi fishery (Figure 6, Figure 7). The relative importance of each of these fisheries to overall FLA landings is evident in Figure 7, BT-FLA contributes the majority of the catch throughout the time series, although the BT-FLA landings have declined substantially since 1999. The contribution of the BT-Mix fishery to the total FLA 2 landings has been consistent through the time series, although, its relative importance has increased since 1999 (Figure 7).

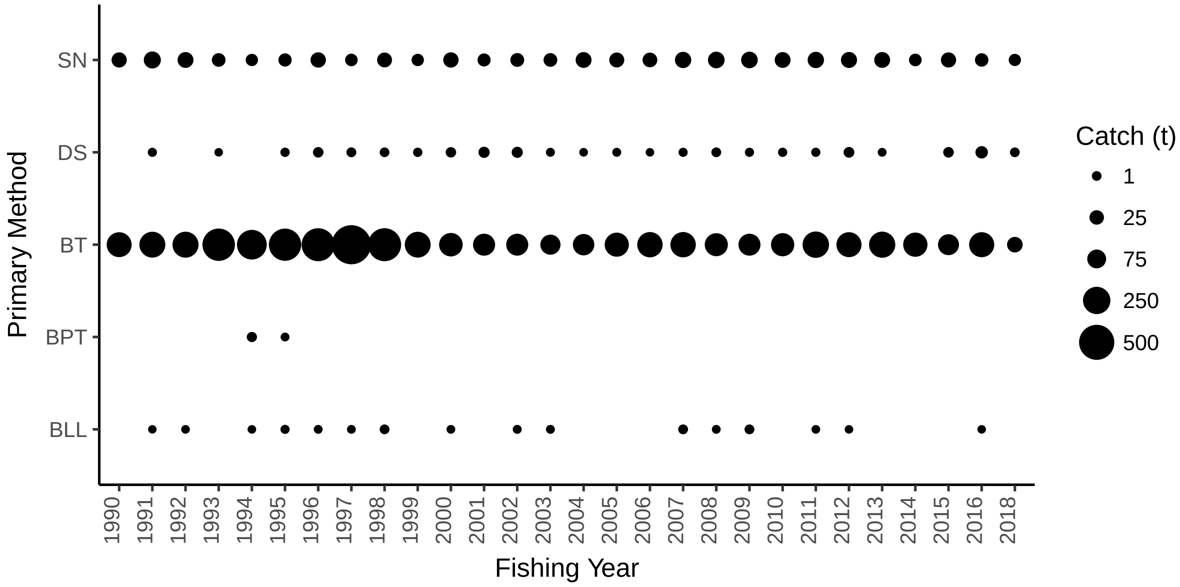

Figure 4: The flatfish catch in the FLA 2 fishery by primary method from the 1990 to the 2016 fishing year.

The FLA 2 fishery is spatially discrete, with the flatfish target fishery operating in inshore waters around the port of Napier, as well as on the western side of Mahia Peninsula (Figure 8). The BT-Mix fishery accumulates a high proportion of the FLA 2 TACC, this is distributed sparsely around the FMA but higher concentrations (more then one tonne between 2008 and 2016) are evident within Hawke Bay and Poverty Bay. The BT-TAR fishery operates in generally deeper waters off Poverty Bay and East Cape (Figure 8).

Fishing effort in the flatfish target fishery is dominated by Statistical Areas 013 and 014, with sporadic effort in other areas (Figure 9). The fishing effort is spread homogenously across the fishing year (Figure 9), this pattern is consistent throughout the time series (Figure 10).

The majority of FLA 2 catch from the flatfish target fishery was taken between Waipatiki and Cape Kidnappers (Figure 11). The CPUE from the target fishery was greater closer to Cape Kidnappers but the highest CPUE was generated by the Mahia Peninsula fishery (Figure 12).

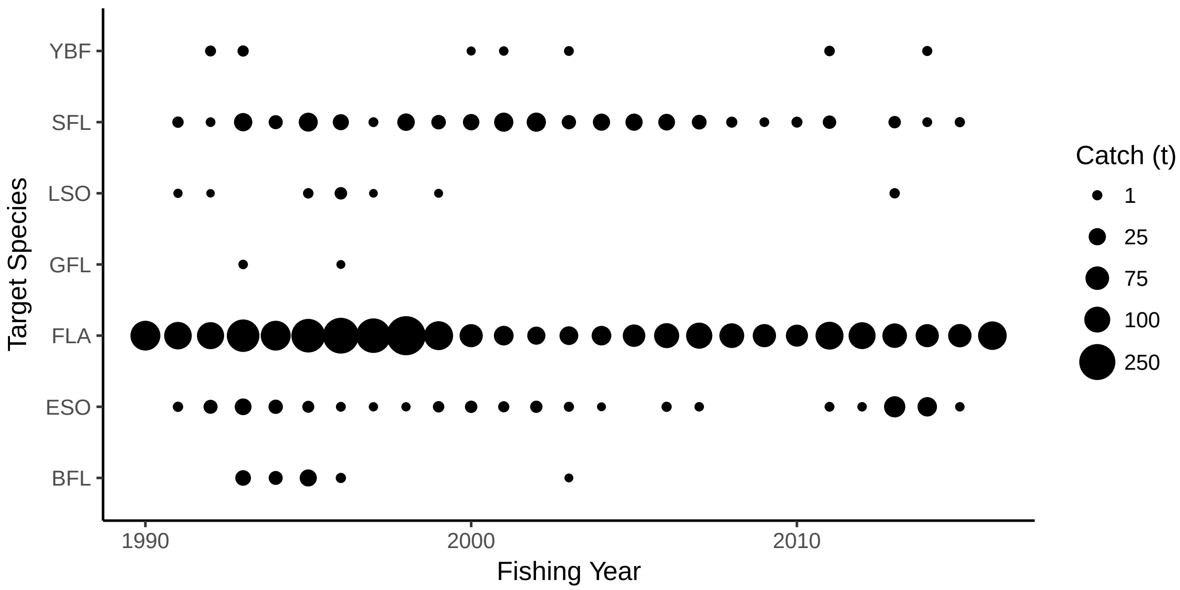

Figure 5: Reporting of individual flatfish species as the target species in FLA 2 from the 1990 to the 2016 fishing year.

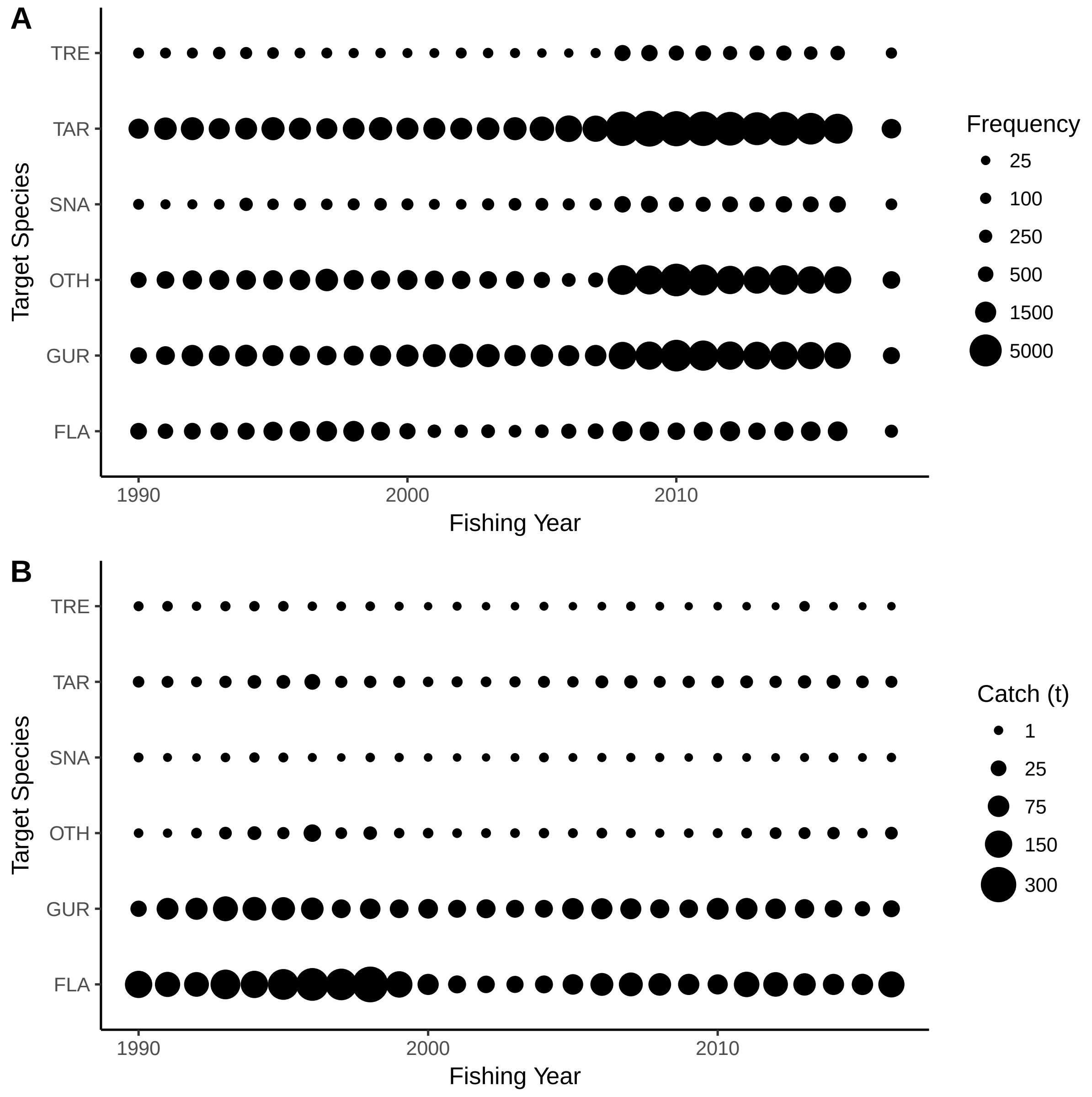

Figure 6: The breakdown of reported target species by effort (A) and flatfish catch (B) in the FLA 2 bottom trawl fishery, all flatfish targets have been recorded as FLA.

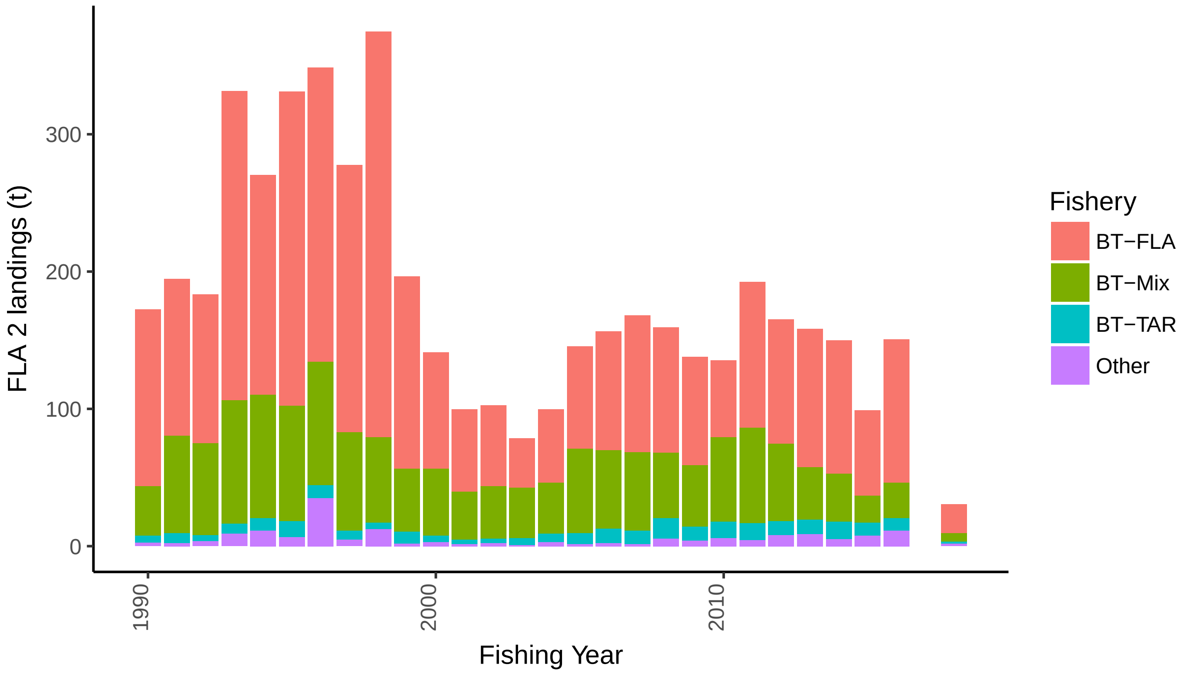

Figure 7: The breakdown of FLA 2 landings between the main inshore fisheries operating in FMA2.

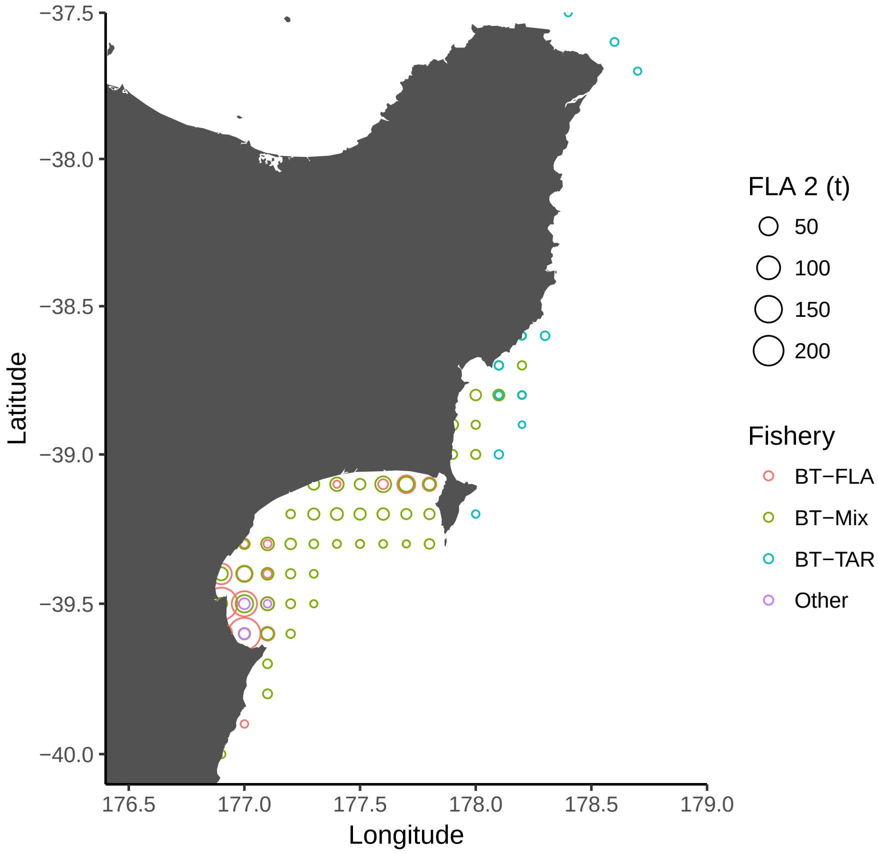

Figure 8: The spatial distribution of the fisheries within FLA 2. Only TCER data was used due to the availability of trawl starting positions, FLA catches have been filtered to be greater then 1 tonne in each 0.1 x 0.1 degree latitude longitude bin from the 2008 to the 2016 fishing year.

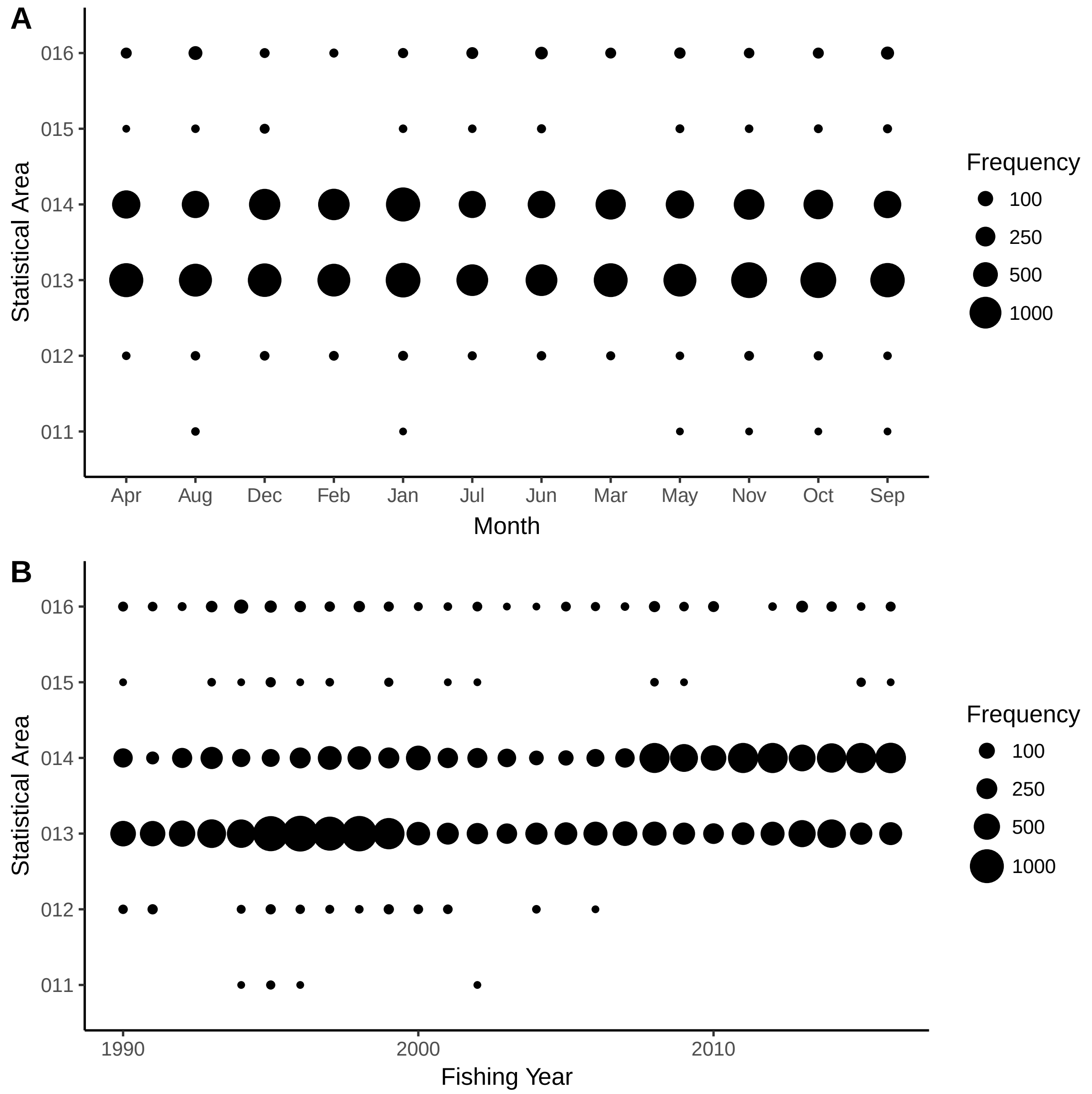

Figure 9: The seasonal (A) and annual (B) patterns in fishing effort within the Statistical Areas of the FLA 2 target bottom trawl fishery from the 1990 to the 2016 fishing year.

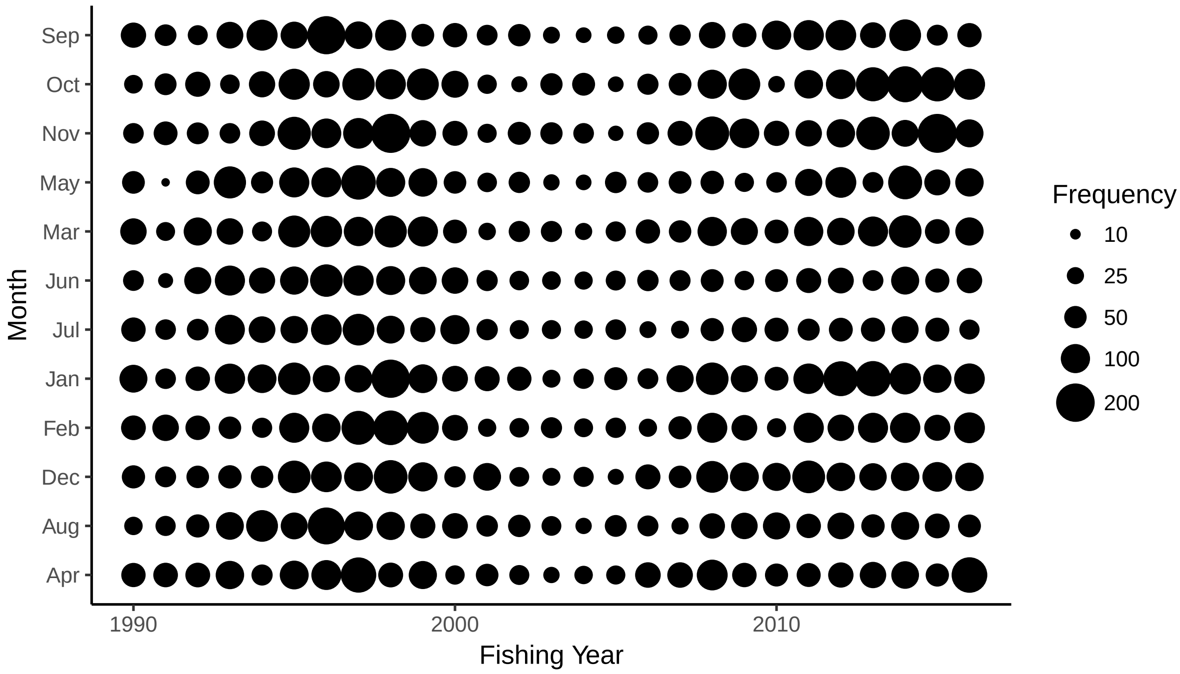

Figure 10: The temporal distribution of annual effort in the FLA 2 target bottom trawl fishery from the 1990 to the 2016 fishing year.

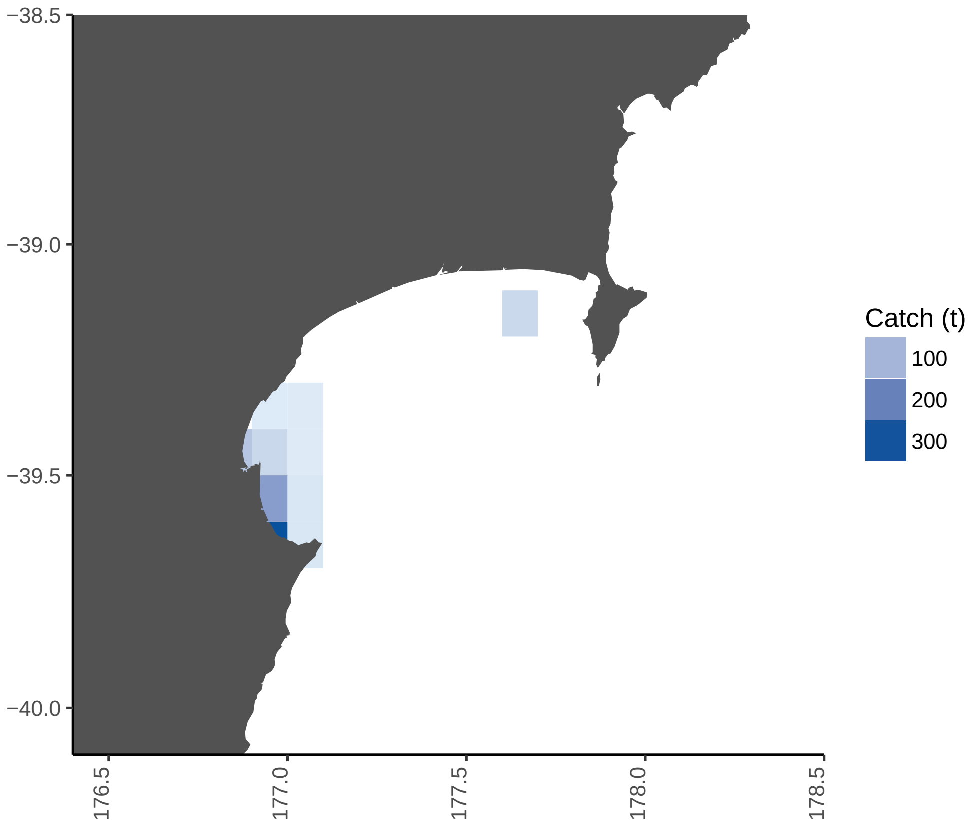

Figure 11: The spatial distribution of catch within FLA 2, based on TCER data. Catches are aggregated to 0.1° x 0.1° cells, and only cells with at least 20 records between the 2008 and 2016 fishing years are displayed.

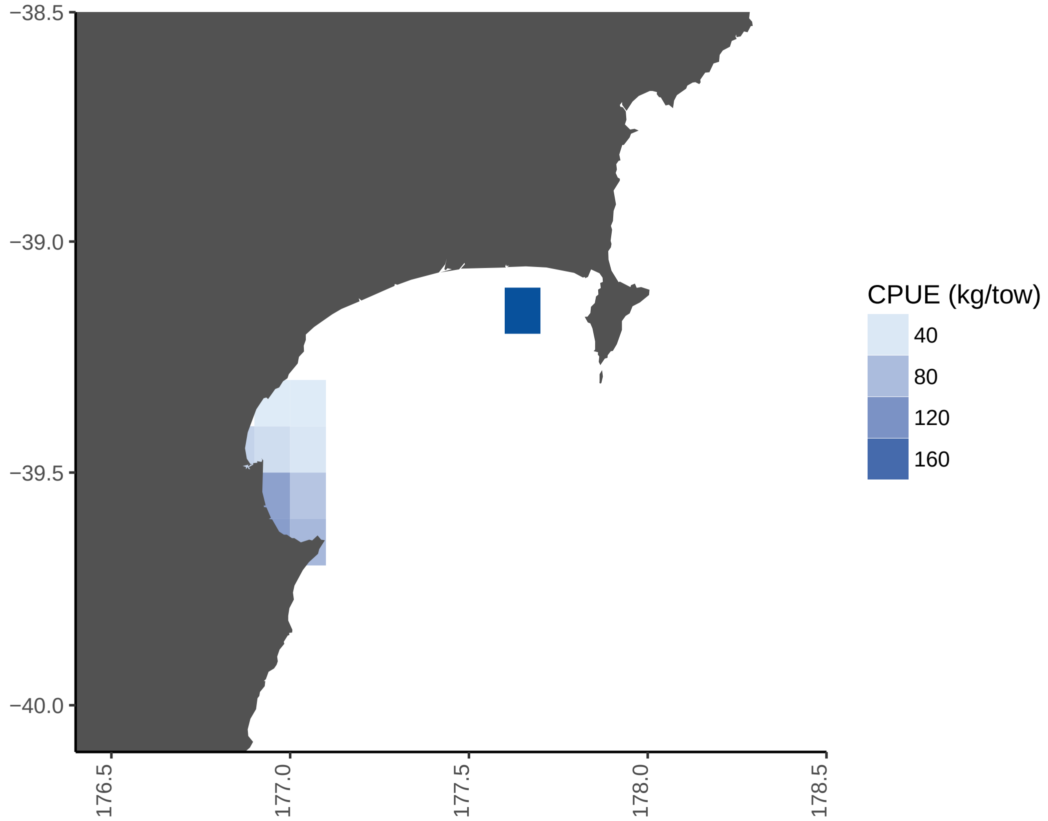

Figure 12: The spatial distribution of CPUE within FLA 2, based on TCER data. Catches are aggregated to 0.1° x 0.1° cells, and only cells with at least 20 records between the 2008 and 2016 fishing years are displayed.

3.1 Flatfish species reporting in FLA 2

As flatfish are landed as FLA and estimated catches have been inconsistently reported at the species level the management of FLA 2 has historically focused on CPUE analysis of all flatfish species collectively. Holistic management is undesirable as it may be appropriate for some flatfish species, whilst equally inappropriate not for others. This section explores the quality of FLA 2 data at a species level to try to provide some indices of abundance for individual FLA 2 species.

Some data restrictions were applied to this analysis, in an effort to remove noise from caused by non-core participants in the FLA 2 fleet. The restrictions made the dataset akin to the probable data for CPUE analysis: the data was restricted to the FLA 2 target bottom trawl fishery, within Statistical Areas 011 to 016.

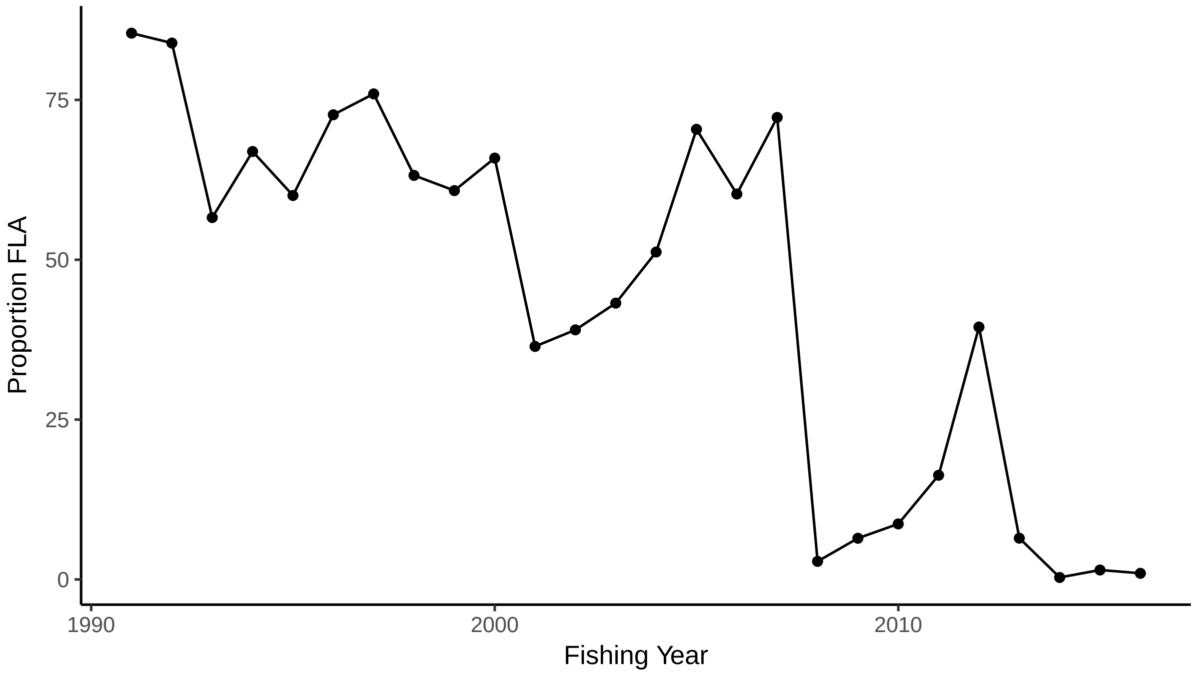

Figure 13: The percentage of the estimated catch recorded as FLA. ***note: TCER forms were introduced in the 2008 fishing year.***

The proportion of the estimated catch reported as FLA has declined steadily since 1990 (Figure 13). The introduction of TCER forms in the 2008 fishing year led to the largest increase in species reporting. There is a slight anomaly as reporting of FLA increased between 2010 and 2012 (Figure 13), this was driven by a vessel increasing its FLA catch from 2009 but not reporting individual flatfish species until 2012.

There has been inconsistent reporting of individual flatfish species through the FLA 2 time series, New Zealand sole (ESO) and sand flounder (SFL) have been reported since 1991, however, the catches estimated have varied considerably (Table 4). Since 2008 the reporting of turbot (TUR), lemon sole (LSO) and yellow belly flounder (YBF) catches has increased (Table 4). Table 5 demonstrates that the reporting of individual flatfish species is minimal outside of Statistical Areas 013 and 014.

Starr et al. (in prep) utilise the metric of 'splitter trips' for analysis in FLA 3. A splitter trip is defined as: a trip where FLA was not recorded in the estimated catch i.e. only individual flatfish species codes were recorded for the estimated flatfish catch. The splitter catch shows a similar trend to Figure 13, with the majority of the FLA catch represented by splitter trips from 2008 and a dip in split catch from 2009 to 2012 (Table 6).

Table 4: The estimated catch in tonnes for each flatfish species code from the 1990 fishing year to the 2016 fishing year for Statistical Areas 013 –014.

Year	BFL	ESO	FLA	FLO	GFL	LSO	SFL	TUR	YBF	OTH
1991	0.0	6.0	95.3	0.0	0.0	0.0	8.6	0.1	0.6	0.1
1992	0.0	10.8	99.3	0.0	0.0	1.1	4.1	0.9	2.2	0.0
1993	13.2	49.0	116.2	0.0	0.3	1.4	31.0	1.0	2.1	0.1
1994	7.3	18.5	93.9	0.0	0.0	1.7	13.8	0.3	1.0	0.0
1995	15.6	31.5	136.1	0.0	0.0	3.7	33.6	1.5	0.8	2.5
1996	3.7	29.4	161.7	0.0	1.6	4.4	17.2	1.7	0.5	6.9
1997	0.0	30.3	147.1	0.1	3.2	3.3	5.6	1.5	2.7	1.5
1998	0.0	61.3	182.1	0.0	7.9	2.1	26.6	2.8	6.7	0.7
1999	0.0	25.6	77.6	0.0	7.7	0.9	10.7	2.3	2.7	1.9
2000	0.0	12.0	53.9	0.0	0.5	0.2	12.9	0.6	1.8	0.3
2001	0.0	15.3	24.8	0.0	1.0	0.3	22.7	0.4	3.7	0.1
2002	0.0	15.6	20.8	0.0	0.0	0.0	18.6	0.6	1.9	0.0
2003	0.0	8.5	17.1	0.1	0.0	0.1	7.9	0.8	5.2	0.0
2004	0.0	7.4	29.2	0.0	0.0	0.0	20.3	0.3	0.2	0.0
2005	0.0	7.3	55.0	0.0	0.0	0.0	16.1	0.1	0.0	0.0
2006	0.0	14.4	59.2	0.0	0.0	0.0	22.8	0.3	2.1	0.0
2007	0.0	9.9	75.2	0.0	0.0	0.0	15.7	0.6	2.9	0.0
2008	0.0	26.0	1.8	0.1	8.4	1.0	20.2	3.1	20.2	0.2
2009	0.1	17.3	3.5	0.0	0.0	0.0	25.9	1.6	11.3	0.2
2010	0.0	19.8	4.5	0.0	0.0	0.3	16.5	1.6	9.1	0.4
2011	0.0	46.2	17.8	0.0	0.0	0.9	30.9	1.0	12.4	0.2
2012	0.0	36.3	39.8	0.0	0.0	0.7	13.4	1.5	8.9	0.3
2013	0.1	70.3	8.4	0.3	0.0	1.0	28.5	3.5	13.1	0.0
2014	0.1	52.4	0.3	0.4	0.0	0.6	21.4	3.6	16.5	0.4
2015	0.0	23.1	0.8	0.0	0.0	4.3	17.6	2.8	11.3	0.1
2016	0.1	32.0	1.0	0.4	0.0	15.2	37.5	1.7	14.7	0.0

Table 5: The estimated catch in tonnes for each flatfish species code for Statistical Areas 011, 012, 015 and 016.

Year	ESO	FLA	FLO	GFL	LSO	SFL	TUR	YBF	OTH
1991	0.0	6.2	0.0	0.0	0.4	1.4	0.0	0.2	0.0
1992	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1993	0.0	11.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1994	8.9	16.2	0.0	0.0	2.0	0.8	0.1	0.0	0.0
1995	7.4	8.2	0.0	0.0	1.2	0.8	0.0	0.0	0.0
1996	3.5	6.6	0.0	0.0	1.0	0.3	0.1	0.0	0.1
1997	0.1	1.3	0.0	0.0	0.2	0.1	0.0	0.0	0.0
1998	0.0	2.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1999	0.8	1.3	0.1	0.0	0.0	0.1	0.0	0.0	0.1
2000	0.2	0.6	0.0	0.0	0.0	0.1	0.0	0.0	0.2
2001	0.1	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.1
2002	0.0	2.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2003	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2004	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2005	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2006	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2007	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2008	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2009	0.4	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2010	0.9	0.2	0.0	0.0	0.2	0.7	0.3	0.0	0.0
2012	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
2013	1.5	0.1	0.0	0.0	3.2	1.0	0.5	0.0	0.0
2014	0.4	0.0	0.0	0.0	0.3	0.3	0.1	0.0	0.0
2015	0.3	0.0	0.0	0.0	0.2	0.3	0.0	0.0	0.0
2016	0.1	0.0	0.0	0.0	0.5	0.1	0.4	0.0	0.0

Table 6: Summary of estimated catches of the top three flatfish species for the data restricted to splitter trips: where FLA was not recorded in the estimated catch. Vessels = the number of vessel that split, Split = the total split weight for all species, Total = sum of flatfish estimated catch.

Year	ESO	SFL	YBF	Vessels	Split	Total	% Split
1991	6.0	10.0	0.8	6	17.5	190.7	9.2
1992	10.2	4.1	2.2	10	18.2	186.0	9.8
1993	45.9	30.9	1.7	13	93.9	326.3	28.8
1994	26.7	14.6	1.0	19	53.6	258.1	20.8
1995	38.6	34.2	0.8	16	94.3	323.2	29.2
1996	31.5	16.6	0.5	15	60.8	300.8	20.2
1997	30.1	5.5	2.7	14	47.3	237.2	19.9
1998	61.1	26.6	6.7	10	107.8	348.0	31.0
1999	25.0	10.8	2.7	13	49.8	167.6	29.7
2000	10.6	11.5	1.8	6	25.3	125.8	20.1
2001	14.1	22.8	3.7	10	42.3	98.6	42.9
2002	15.4	18.1	1.9	6	36.1	96.8	37.3
2003	8.5	7.9	5.2	7	22.6	68.2	33.2
2004	7.2	19.2	0.1	8	26.8	88.4	30.4
2005	7.0	15.8		4	22.9	133.0	17.2
2006	13.7	22.6	2.1	5	38.7	153.7	25.2
2007	9.7	15.6	2.7	7	28.7	157.8	18.2
2008	26.0	20.2	20.2	9	78.9	121.2	65.1
2009	17.6	24.6	11.2	9	55.2	98.1	56.2
2010	20.4	16.8	9.1	7	48.3	114.7	42.1
2011	46.1	30.8	12.4	7	91.4	173.1	52.8
2012	30.2	13.4	8.9	7	54.8	159.4	34.4
2013	67.7	29.5	13.1	12	118.7	172.3	68.9
2014	52.8	21.7	16.5	11	96.5	132.2	73.0
2015	23.4	17.8	11.2	11	59.9	79.6	75.2
2016	32.1	37.6	14.8	11	102.8	137.7	74.7

3.1.1 TCER fleet reporting

Only the TCER data were considered for individual species analysis due to the majority of the catch not being split until 2008 (Figure 13, Table 6). Generally, once vessels started reporting flatfish species compositions they continued to do so, although, there are some exceptions (Figure 14). Vessels in the FLA 2 fleet tend to reported similar species compositions, with New Zealand sole and sand flounder the dominant species (Figure 14).

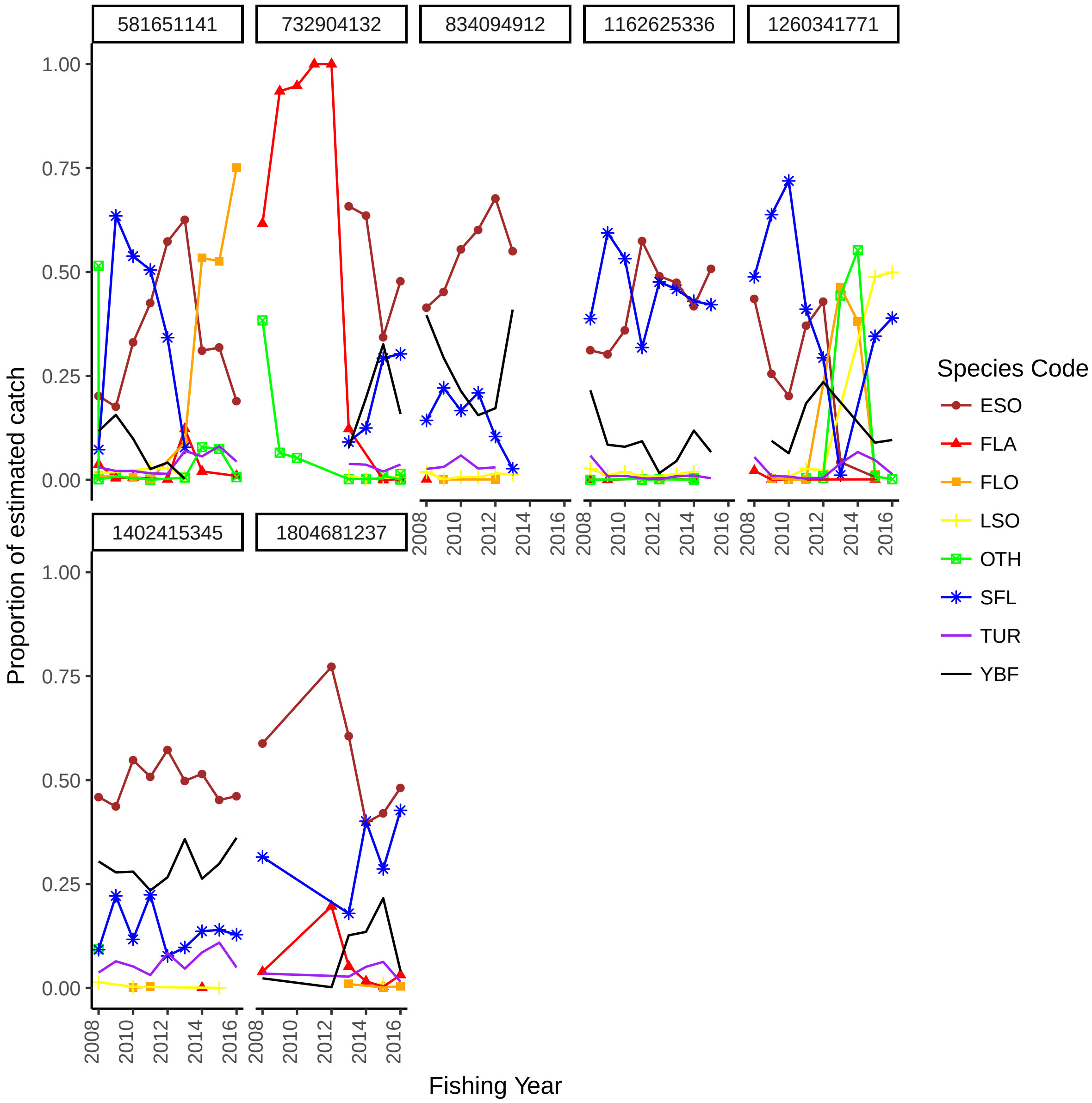

Figure 14: Summary of reported estimated catch by species from for core vessels (5 trips per year for 7 years) in the FLA 2 fishery. The less prominent species codes (BFL, BRI, FLO, GFL, SOL, WIT) have been aggregated to other (OTH).

All flatfish species appear to be captured at depths between 5 and 50 m, with proportions peaking at 15m (Figure 15). Figure 15B shows there is no clear distinction between the capture depths of the four most frequently reported species in FLA 2. However the relative proportions of species varies accros the depth range with YBF more concentrated in the 10–15 m depth band and SFL more common in the 25–35 m band. The relative distribution of fishing effort by each vessel could influence the species mix of the catch (Figure 15B).

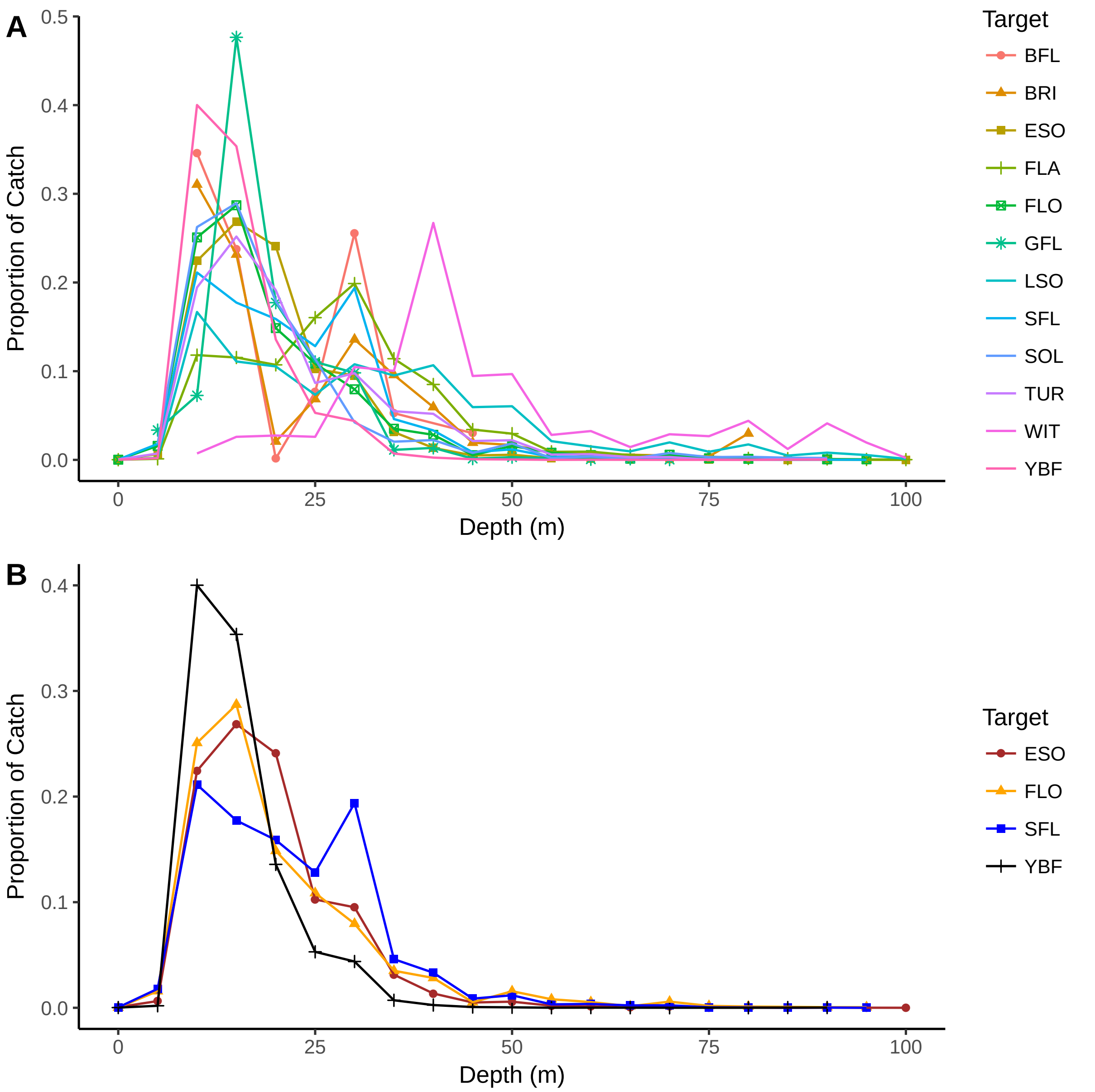

Figure 15: The proportion of estimated catch by species, for all species (A) and the main FLA 2 species (B), in each five metre depth bin, estimated catches were aggregated from the 2008 to the 2016 fishing years.

3.2 Fisheries for CPUE analyses

Prior to 2008, vessels reported individual flatfish species compositions inconsistently (Figure 14), the proportion of the estimated catch represented by splitter trips fluctuated annually between 10 - 40% (Table 6). After the introduction of TCER forms in 2008 the proportion of trips represented by splitter trips has increased to about 60% (Table 6), consequently, individual species analysis is only appropriate since 2008. The two dominant species in the FLA 2 fishery are New Zealand sole and sand flounder, therefore the FLA 2 CPUE indices will comprise of TCER indices for these species, as well as a FLA 2 index from 1990 to 2016 (Table 7).

Table 7: The fisheries defined for CPUE analysis.

Fishery	Target Species	Form	Years	Aggregation
BT	FLA	TCER, TCEPR, CELR	1990:2016	vessel-date
BT ESO	FLA	TCEPR, TCER	2008:2016	None
BT SFL	FLA	TCEPR, TCER	2008:2016	None

3.3 FLA 2 Statistical Area reporting

In Figure 16 there is a major shift in 2008 between the majority of the FLA target fleet operating in Statistical Area 013 to the fleet operating in Statistical Area 014. FLA 2 fishing effort straddles the boundary between Statistical Area 013 and 014 (Figure 17). The shift between dominant Statistical Area occurred in 2008 with the introduction of TCER forms and is likely to be indicative of misreporting of Statistical Area on CELR forms. As a consequence, area was removed as a potential predictor from both flatfish occurrence and CPUE indices which use the whole series of data from the 1990 to 2016 fishing year. The sand flounder and New Zealand sole analyses have area included as a potential predictor, as it was reported consistently between the 2008 and the 2016 fishing years.

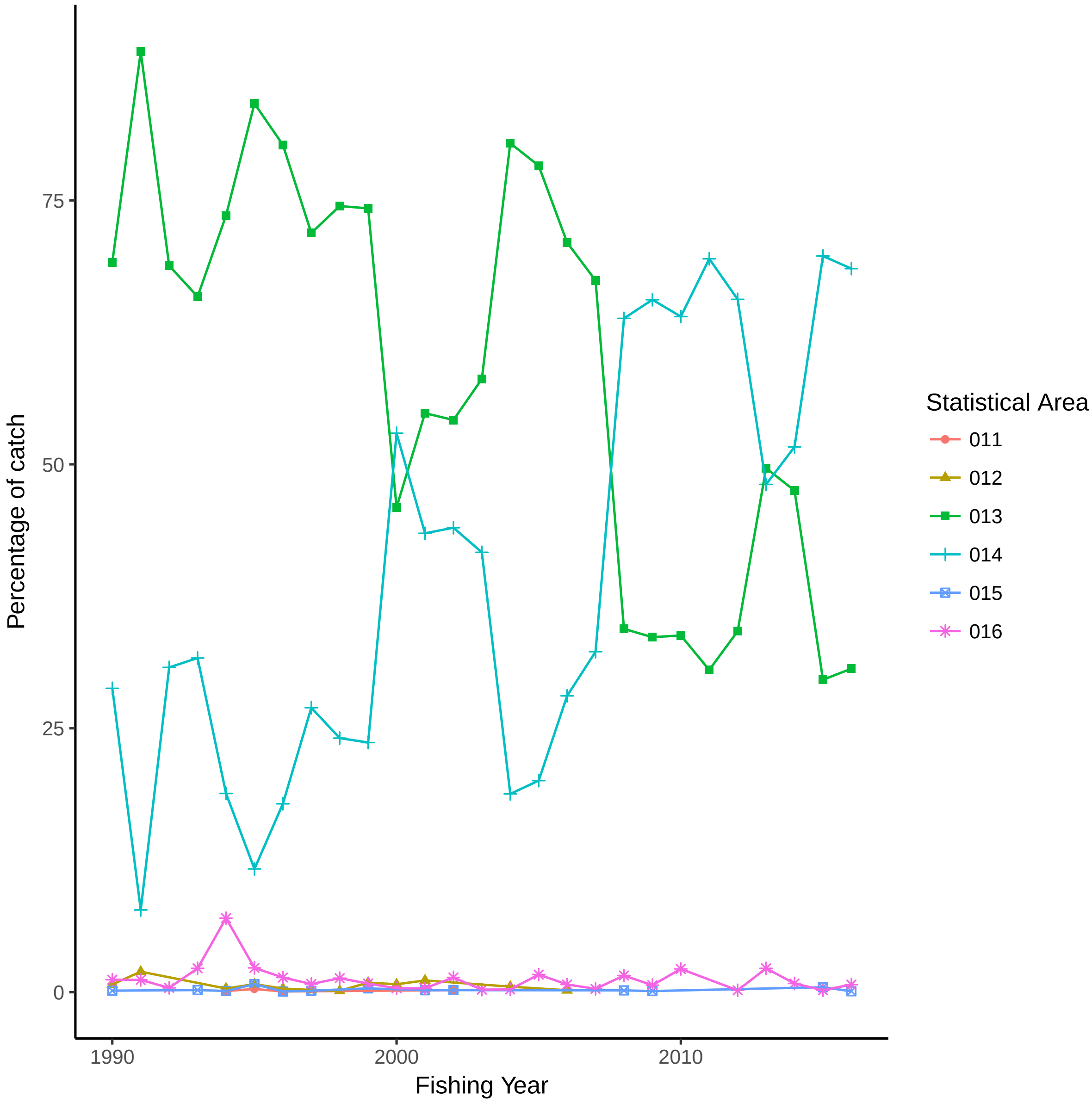

Figure 16: The annual percentage of fishing effort in each Statistical Area of FLA 2.

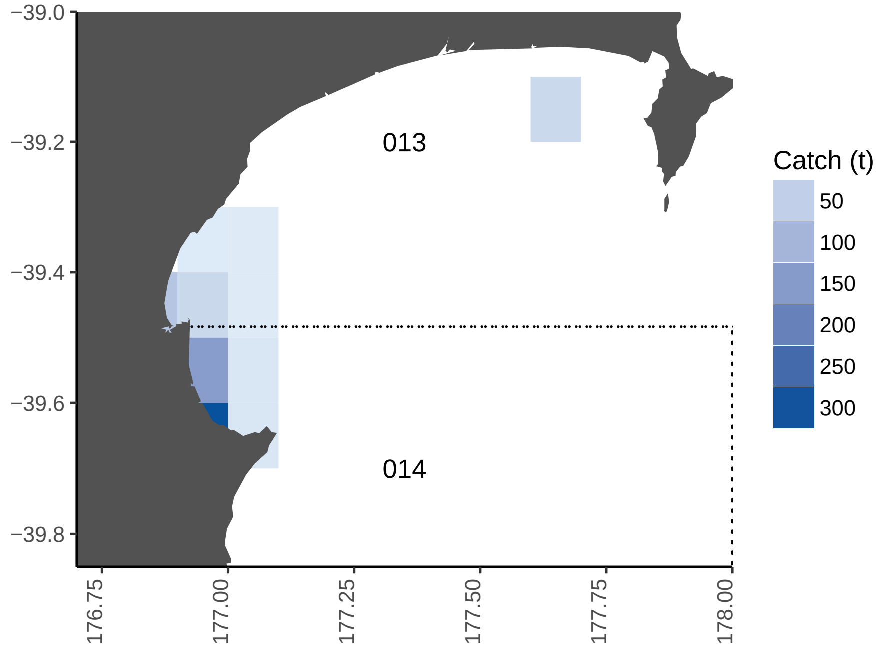

Figure 17: The spatial distribution of catch within FLA 2, based on TCER data. Catches are aggregated to 0.1° ×0.1° cells, and only cells with at least 20 records between the 2008 and 2016 fishing years are displayed.

4. FLA 2 CPUE ANALYSIS

4.1 Aggregation

The number of fishing events within each stratum for alternate “roll ups” of the data are evident in Figure 18B. Most approaches aggregate the data to two fishing events per stratum. The percentage of events, trips and strata with positive catch in the FLA target fishery is nearly 100% (Figure 18).

The vessel-date aggregation recommended by Langley (2014), is used to dervive the aggregated dataset from 1990 to 2016.

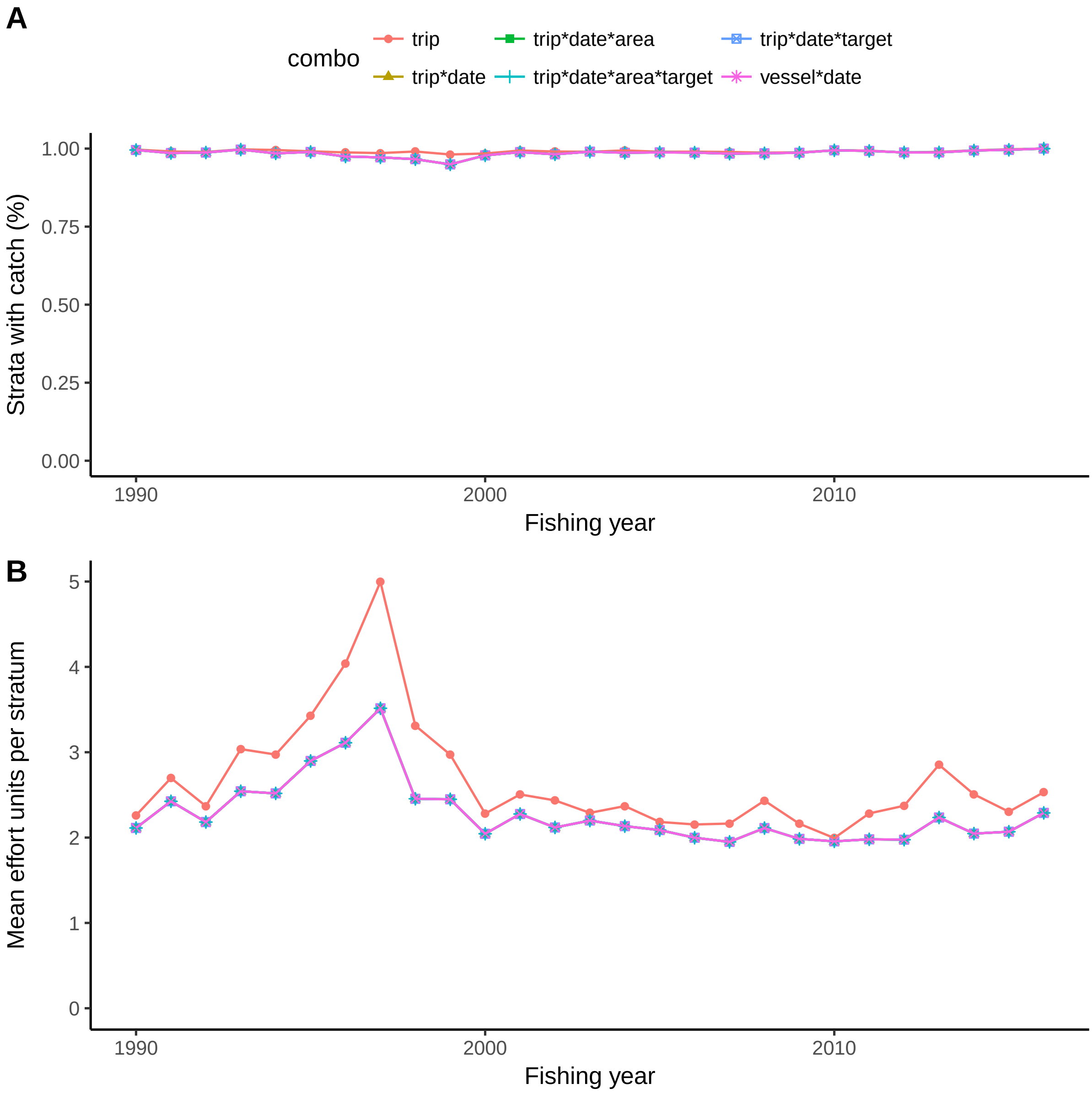

Figure 18: Summaries of effort and catch by fishing year with alternate strata aggregations. A shows the percentage of strata with positive catch, whereas B shows the mean number of effort units (i.e tows or shots) per stratum.

4.2 Fishery definition and trends

The FLA 2 target bottom trawl fishery (FLA 2) is defined as:

- Form type in (CEL, TCP, TCE)
- Primary method: bottom trawl (BT)
- Target flatfish species (FLA, BFL, BLF, BRI, ESO, FLO, GFL, LSO, SFL, SOL, TUR, WIT, YBF)
- Fishing effort conducted within Statistical Areas 013 and 014
- Fishing effort conducted between 1 Oct 1989 and 30 Sept 2016

The FLA 2 fleet size is contracting, the number of vessels operating in the fishery since 2010 is around a third of the number participating in the 1990s (Table 8). The percentage of trips and events that caught flatfish has remained constant at nearly 100%.

Table 8: Summary of data by fishing year after the FLA 2 vessel-day bottom trawl fishery definition has been applied. Events represent a row in the effort dataset, trips caught represents the number of trips which reported catching FLA and events caught represents the percentage of days with positive catch.

Fishing year	Vessels	Trips	Records	Effort (num)	Effort (hrs)	Catch (t)	Trips caught	Days caught
1990	16	615	662	1 390	4 159	147.1	99.7	99.5
1991	21	436	501	1 176	3 366	116.1	99.1	98.6
1992	24	654	728	1 549	5 008	126.5	99.2	99.0
1993	27	793	948	2 408	7 262	251.8	99.8	99.7
1994	26	659	793	1 959	5 643	149.0	99.7	98.6
1995	28	1 018	1 248	3 489	9 935	256.4	99.1	98.9
1996	26	1 060	1 400	4 281	10 415	259.6	98.8	97.5
1997	27	973	1 400	4 861	9 836	224.8	98.6	97.8
1998	21	1 068	1 485	3 537	10 875	335.4	99.2	96.7
1999	24	847	1 067	2 517	7 294	150.7	98.5	95.3
2000	17	701	788	1 599	5 143	95.1	98.6	98.0
2001	18	477	528	1 195	3 765	80.7	99.6	99.0
2002	16	427	492	1 040	3 278	70.0	99.1	98.2
2003	11	390	406	893	2 716	47.0	99.0	99.0
2004	15	336	375	796	2 600	65.0	99.4	98.7
2005	8	393	412	858	2 723	88.0	99.0	98.8
2006	10	501	540	1 079	3 213	112.6	99.0	98.7
2007	13	554	620	1 199	3 543	115.8	98.9	98.4
2008	9	460	1 117	1 119	3 326	89.7	98.7	98.5
2009	12	414	895	895	2 787	71.9	98.8	98.7
2010	6	356	710	710	2 030	60.2	99.4	99.5
2011	10	463	1 057	1 057	3 282	134.7	99.3	99.2
2012	10	472	1 120	1 120	3 512	112.1	98.7	98.8
2013	9	380	1 084	1 084	3 207	140.6	99.0	98.8
2014	8	525	1 316	1 316	4 002	110.2	99.4	99.4
2015	9	459	1 057	1 057	3 154	73.1	99.8	99.6
2016	8	435	3 925	1 101	3 185	133.9	100.0	100.0

The flatfish species level information has been ignored for this full dataset catch-per-unit-effort analysis, that is, all flatfish species codes in the landings, estimated catch, effort and monthly harvest returns were re-coded to FLA.

4.3 Data filtering

Records were dropped if fishing duration was less then 1 hour, as this fleet is composed of inshore day vessels the maximum duration was restricted to 18 hours.

4.4 Core Vessel Selection

Appropriate criteria for selecting the core fleet were vessels operating in the FLA 2 fishery for 7 years, with at least 5 trips per year (Figure 19). Applying these criteria resulted in a core fleet of 15 vessels, which contributed 73.32% of the FLA 2 catch.

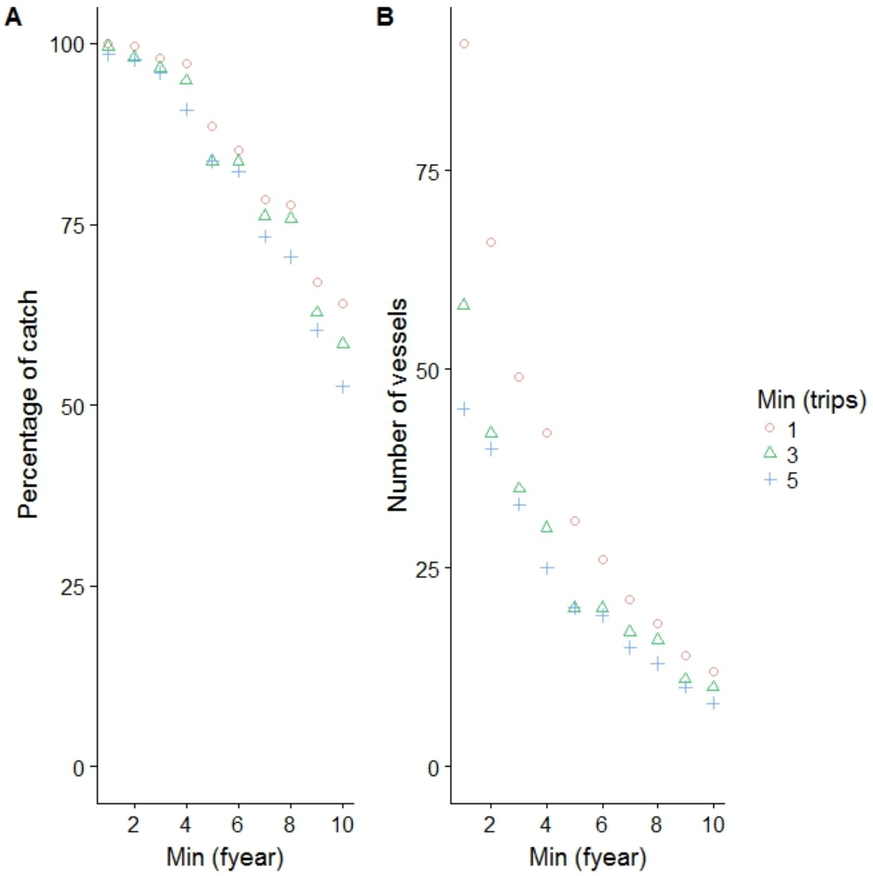

Figure 19: Examination of parameters for defining core vessels. The left panel indicates how the percentage of catch represented by core vessels changes with alternative criteria. The right panel indicates how the number of vessels changes with alternative criteria.

There has been a large turnover in the FLA 2 fleet from 1990 to 2016, only two vessels operated in the fishery throughout the series (Figure 20). The raw catch magnitude is variable but has generally fluctuated around 70 kg per unit effort, which was consistent between the core and overall fleets (Figure 21).

A summary of the data used for FLA 2 CPUE analysis after filtering and restriction to the core fleet is provided in Table 9.

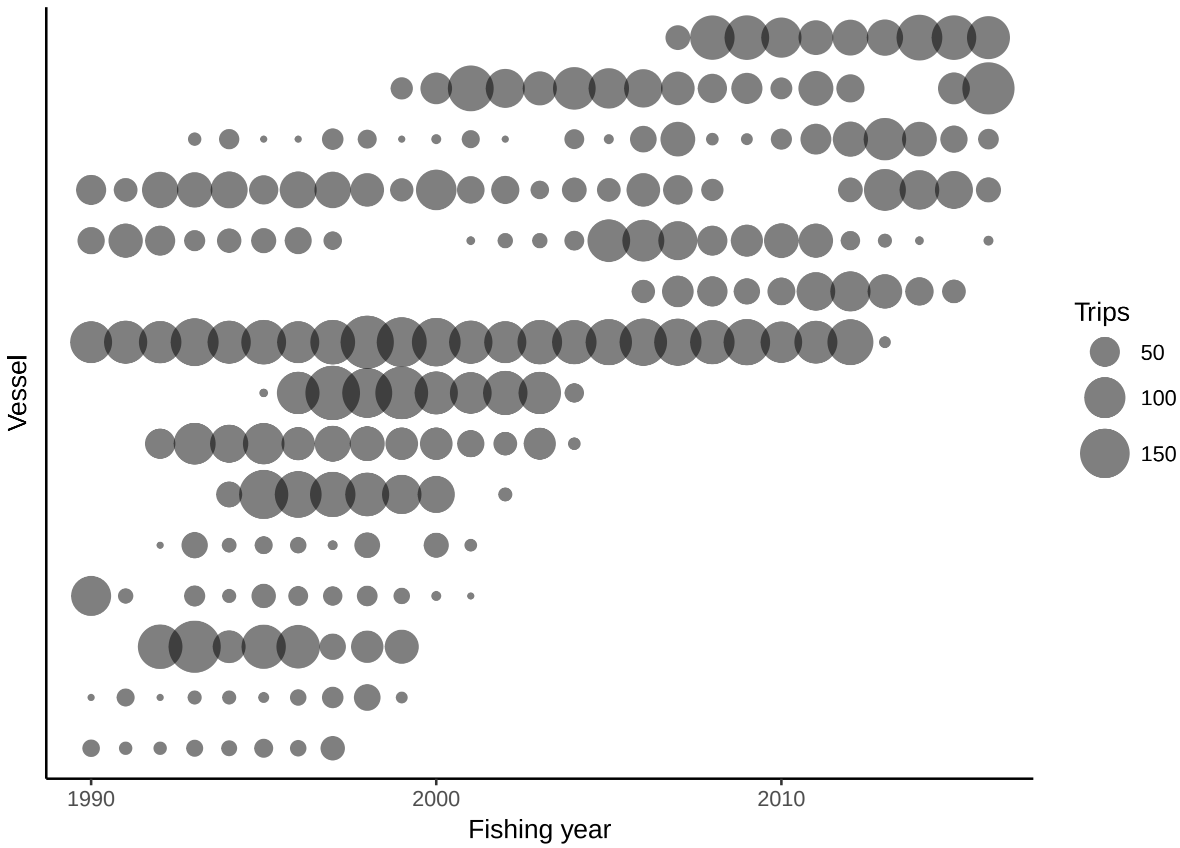

Figure 20: Number of trips by fishing year for FLA 2 vessel-day core vessels. The area of circles is proportional to the number of trips for a vessel in a fishing year.

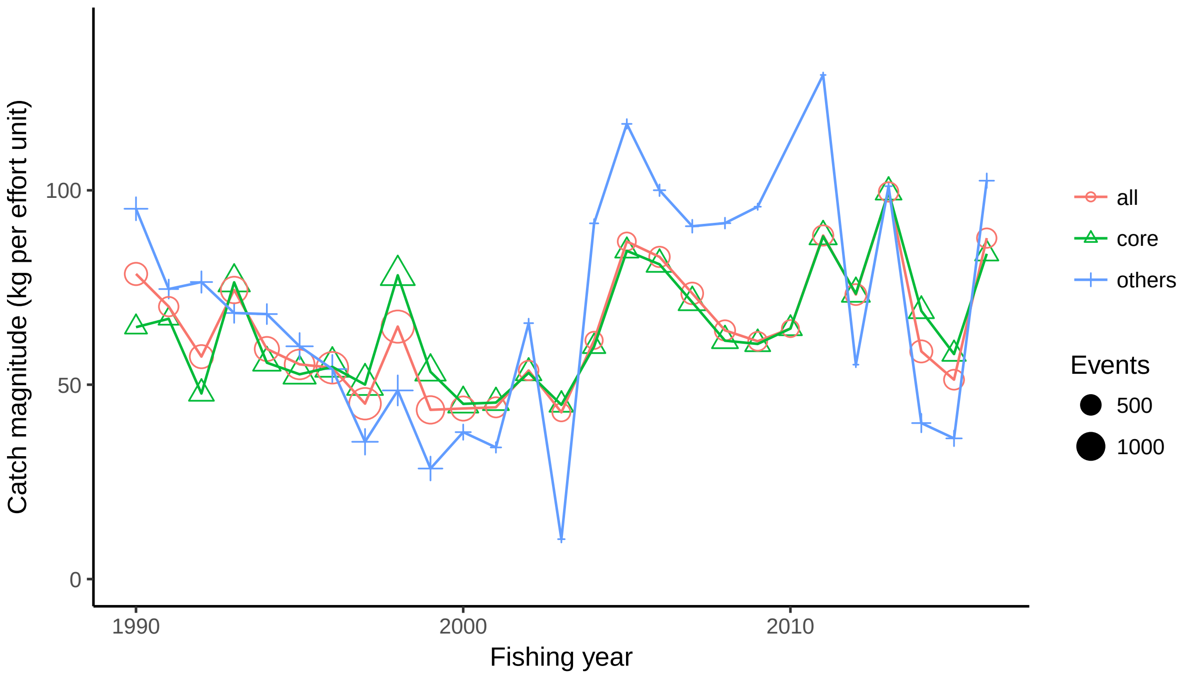

Figure 21: The unstandardised CPUE (geometric mean of catch divided by effort, where catch was positive) for all vessels and core vessels.

Table 9: Summary of core FLA 2 vessel-day dataset by fishing year after the core fleet definition (5 trips/yr for 7 years) was applied. Records represent a row in the effort dataset, whereas effort number is the sum of the reported trawls. Trips caught and days caught represent the percentage of trips and days which reported catching FLA.

Fishing Year	Vessels	Trips	Records	Effort (num)	Effort (hrs)	Catch (t)	Trips caught	Days caught
1990	6	305	333	727	2 130	68.0	99.3	99.1
1991	6	239	291	667	1 790	62.3	100.0	100.0
1992	8	413	451	979	2 931	62.3	99.8	99.5
1993	10	591	720	1 921	5 783	199.0	100.0	99.9
1994	11	461	541	1 376	3 947	96.3	99.8	98.9
1995	12	643	767	2 057	6 359	153.4	98.9	99.0
1996	12	702	868	2 114	6 122	155.1	99.0	98.1
1997	12	733	958	3 626	6 577	150.9	99.7	98.7
1998	10	746	865	1 883	5 960	194.4	99.9	99.9
1999	10	619	674	1 478	4 141	98.0	98.7	98.4
2000	9	592	655	1 324	4 163	78.5	99.3	99.1
2001	9	447	478	1 075	3 267	69.0	99.8	99.4
2002	8	405	459	962	2 967	63.5	99.5	99.6
2003	6	378	392	861	2 631	46.3	99.5	99.5
2004	7	320	347	729	2 336	56.8	100.0	100.0
2005	5	366	373	767	2 359	75.6	99.7	99.7
2006	6	457	475	935	2 728	97.0	99.8	99.8
2007	7	497	533	1 025	2 921	95.9	99.2	99.1
2008	7	421	997	999	2 913	78.1	98.6	98.3
2009	6	408	857	857	2 662	66.7	98.8	98.9
2010	6	356	710	710	2 030	60.2	99.4	99.5
2011	6	458	1 042	1 042	3 231	132.6	99.6	99.4
2012	7	466	1 105	1 105	3 465	111.1	98.7	98.8
2013	6	372	1 038	1 038	3 028	134.7	98.9	98.7
2014	5	333	890	890	2 643	86.2	100.0	99.8
2015	5	330	779	779	2 332	60.6	99.7	99.5
2016	5	334	2 900	873	2 522	95.9	100.0	100.0

4.5 Occurrence

Occurrence of positive catch was modelled using a binomial generalised linear model (GLM) with a logistic link function. The full set of terms offered to the stepwise selection algorithm was:
$\sim fyear + vessel + poly(log(duration), 3) + target + area * month + area + month + poly(width, 3) + poly(height, 3)$

The final model after stepwise selection (Table 10) was:
$\sim fyear + vessel + area * month + poly(log(duration), 3)$

Table 10: Summary of stepwise selection for FLA 2 vessel-day occurrence of positive catch. Model terms are listed in the order of acceptance to the model. AIC: Akaike Information Criterion; *: Term included in final model.

Step	Df	AIC	%dev.expl	add%dev.expl	Included
fyear	25	2 331	6.7	6.7	*
+ vessel	19	2 031	20.6	13.9	*
+ month	11	2 005	22.5	2.0	*
+ poly(log(duration), 3)	3	1 990	23.4	0.9	*

Most of the records in the FLA 2 aggregated data have positive catch (Figure 22). The NINS WG has accepted the FLA 2 CPUE index with indices derived from the positive catch component only (Ministry for Primary Industries 2016).

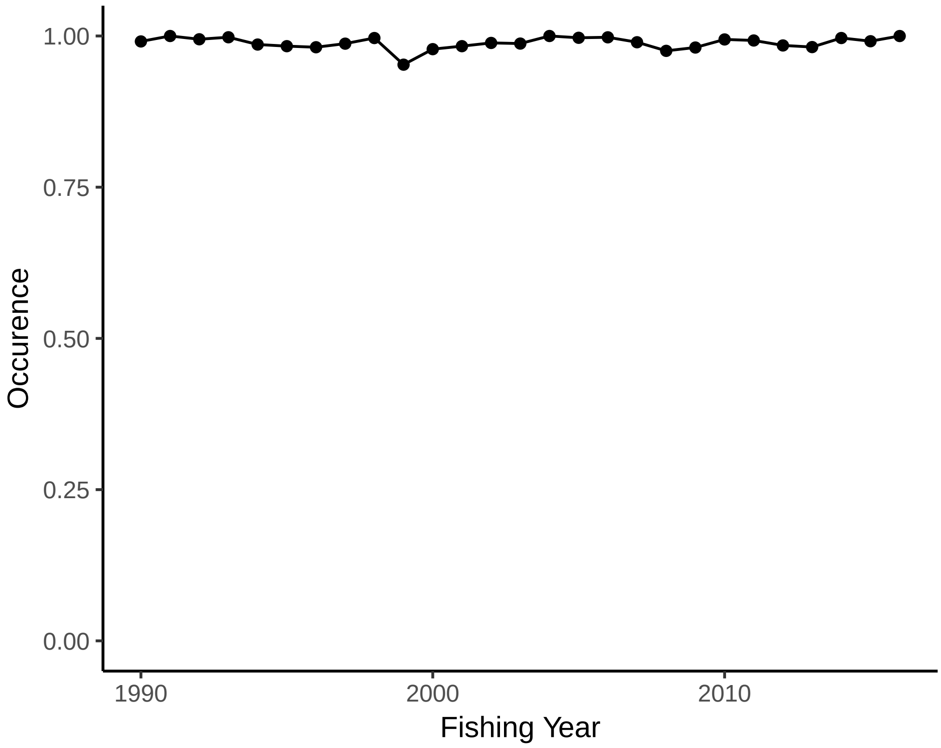

Figure 22: The occurrence of positive catch indices for the FLA2 vessel-day fishery. Fishing years are labelled by the latter calendar year e.g. 1990 = 1989/90

4.6 Positive Catch

The magnitude of non-zero catches were modelled using a Gamma distribution. In this analysis a Gamma distribution also had the lowest AIC and was selected as the most appropriate error structure for the final model.

The full set of model terms offered to the stepwise selection algorithm was:
$\sim fyear + vessel + poly(log(duration), 3) + month + poly(width, 3) + poly(height, 3)$

The final model after stepwise selection (Table 11) was:
$\sim fyear + poly(log(duration), 3) + month + vessel$

Table 11: Summary of stepwise selection for FLA 2 vessel-day magnitude of positive catch. Model terms are listed in the order of acceptance to the model. AIC: Akaike Information Criterion; *: Term included in final model.

Step	Df	AIC	%dev.expl	add%dev.expl	Included
fyear	25	198 522	5.6	5.6	*
+ poly(log(duration), 3)	3	194 332	25.3	19.7	*
+ month	11	193 378	29.4	4.0	*
+ vessel	19	192 590	32.6	3.2	*

4.6.1 Diagnostics

The model residuals indicate small and large FLA 2 catches are poorly predicted by the model (Figure 23). The distribution of the residuals is considerably tighter than predicted from the Gamma distribution.

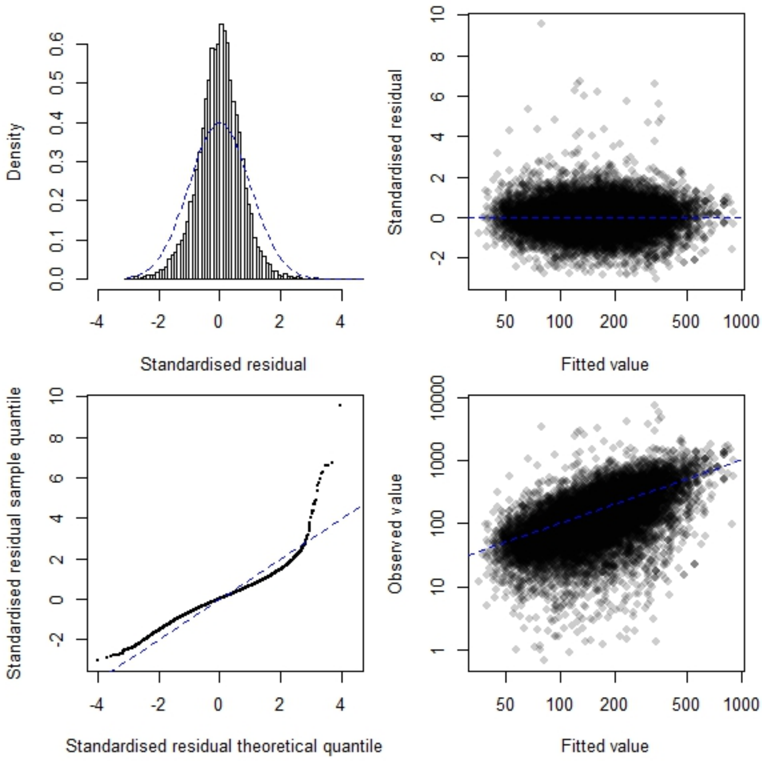

Figure 23: The diagnostic plots for the FLA 2 vessel-day Gamma general linear model fit. top left: Standardised residuals from the accepted generalised linear model fit; top right: The standardised residuals versus the fitted values; bottom left: Quantile-quantile plot of observed response versus likelihood of the distribution of these values; bottom right: Obversed values vs fitted values.

4.6.2 Influence of model terms

The effect of standardisation on the CPUE indices is small, although the 1993 peak in the unstandardised indices is moderated (Figure 24).

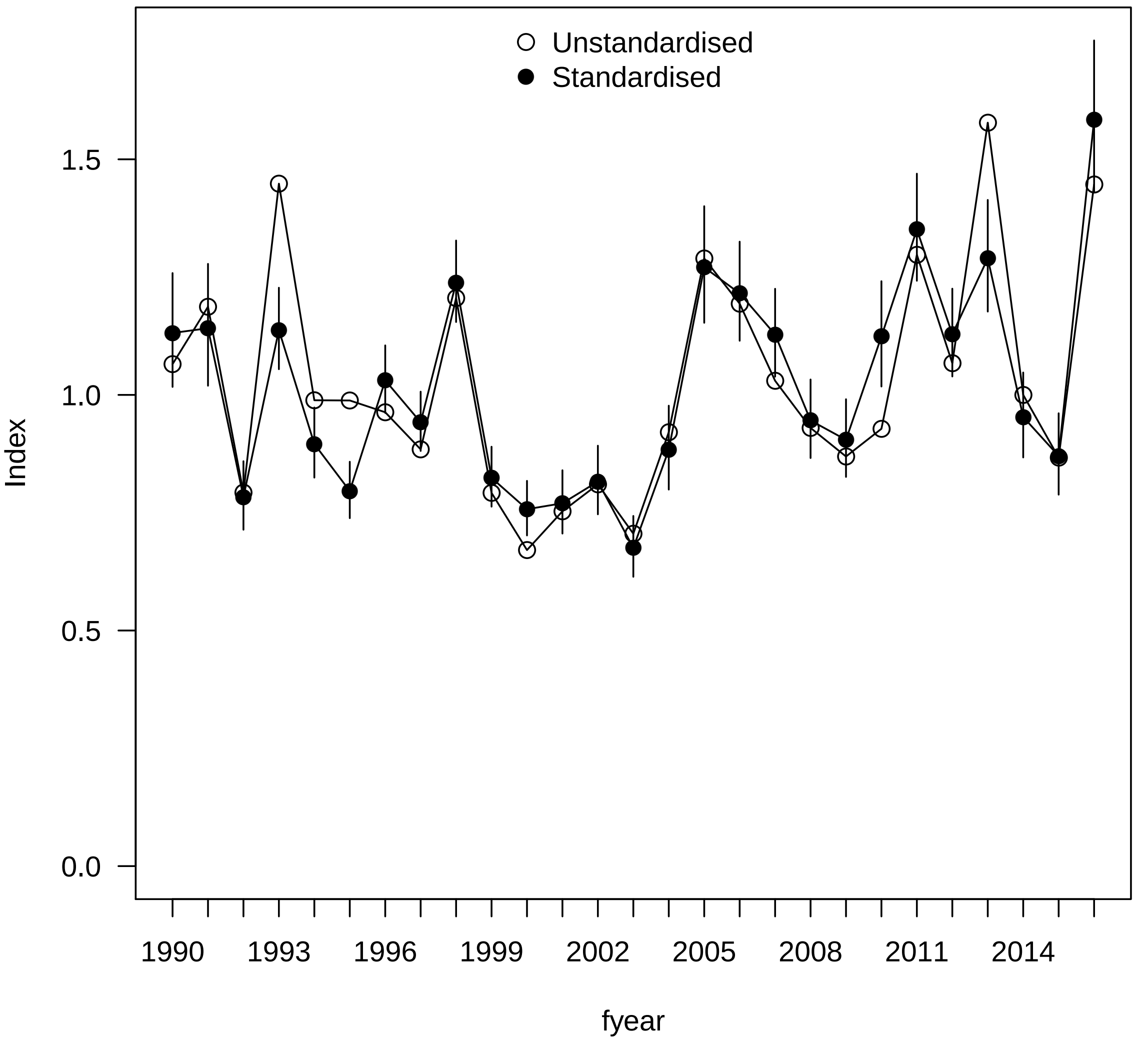

Figure 24: A comparison of the standardised CPUE indices and unstandardised indices of the FLA 2 vessel-day model. The unstandardised index is based on the geometric mean of the catch per strata and is not adjusted for effort.

The addition of duration, month and vessel had small localised annual influences on the CPUE indices (Figure 25). The major variation is due to interannual variation in catch rates (Figure 25).

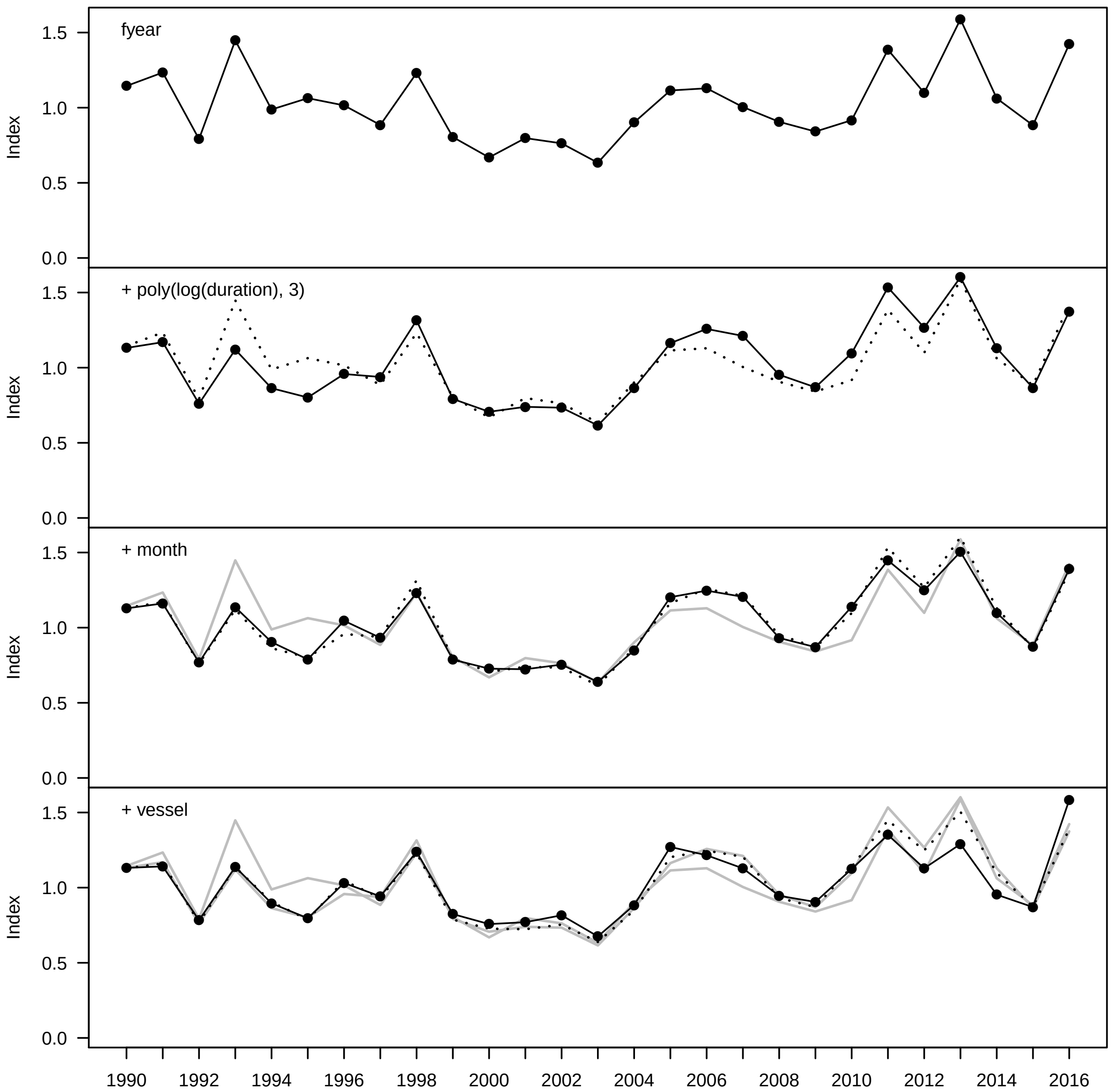

Figure 25: Changes in CPUE indices as each term is successively added to the FLA 2 vessel-day model. The indices are normalised to an overall geometric mean of 1.

The majority of the aggregated fishing effort is between 3–8 hours in duration (Figure 26). Between 1992 and 1996 fishing durations were the longest in the series, in 2006 and 2007 there was a drop in fishing duration from which point duration has gradually increased (Figure 26).

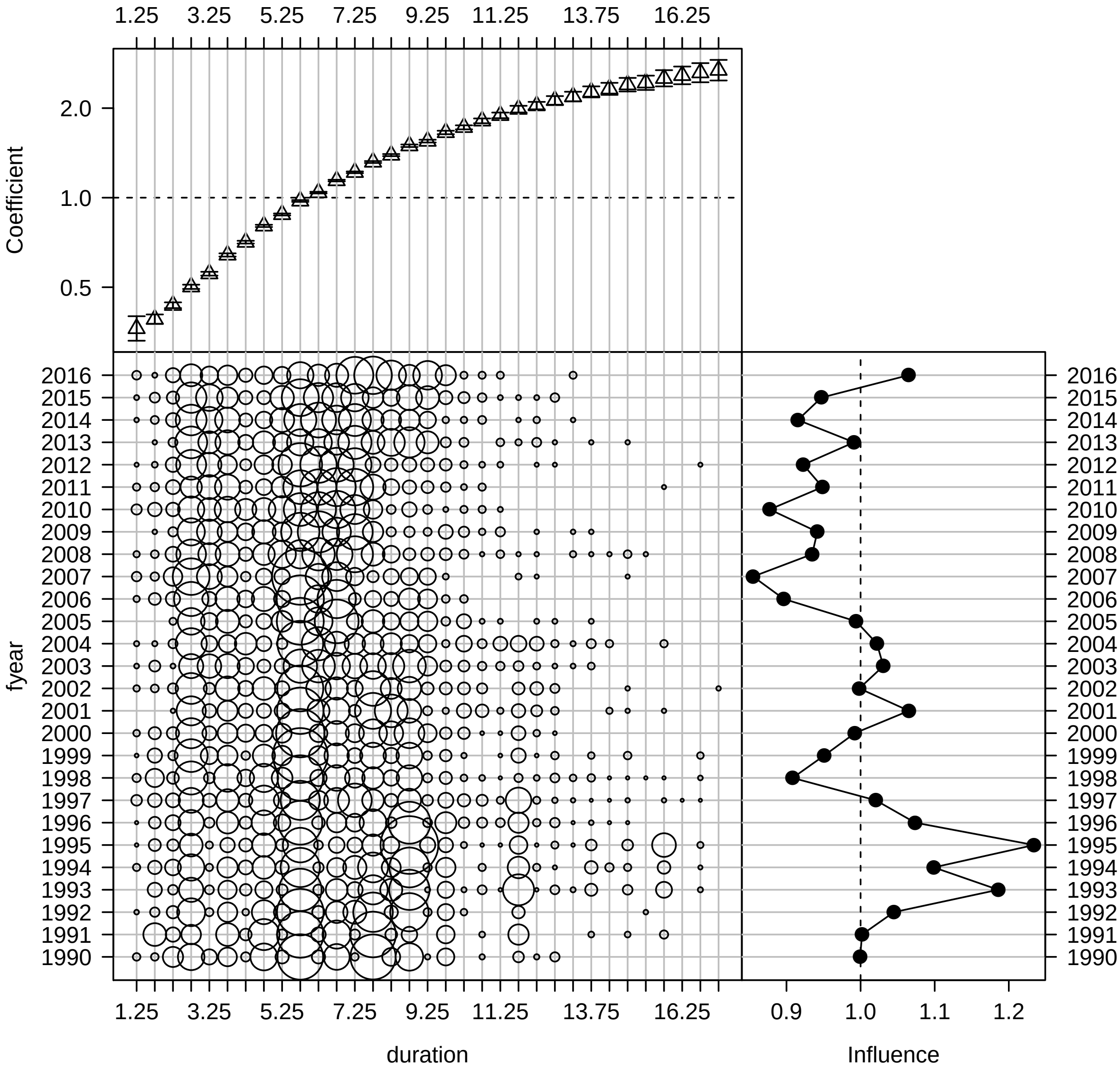

Figure 26: FLA 2 vessel-day coefficient-distribution-influence plot for fishing duration.

The CDI plot for month shows that there were higher coefficients for summer months, October - February (Figure 27). There was no consistent temporal variation in fishing activity throughout the year (Figure 27).

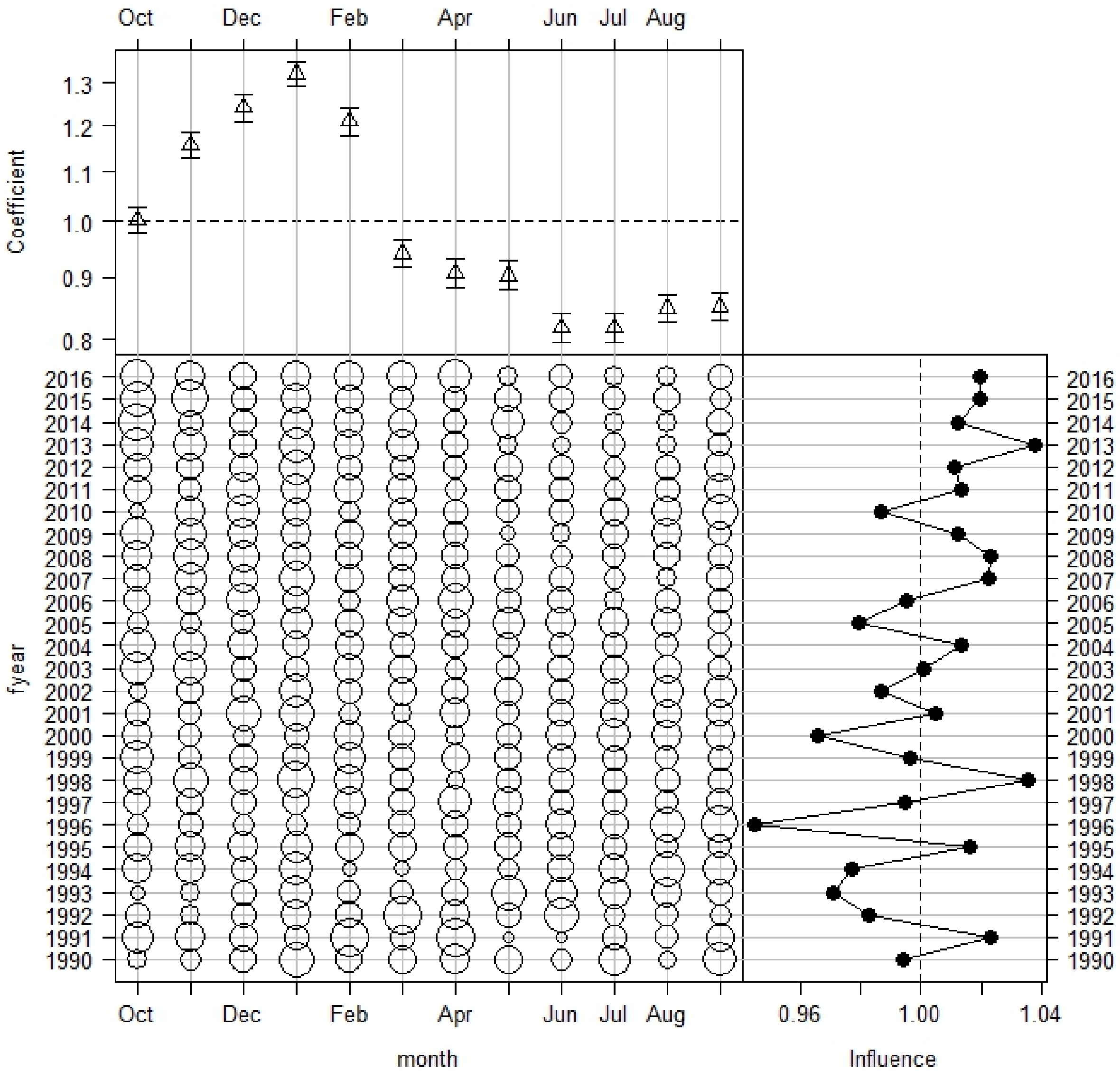

Figure 27: FLA 2 vessel-day coefficient-distribution-influence plot for month.

There are a range of vessel coefficients across the FLA 2 fleet, as the fleet is small the influence of vessel is dictated by individual participants, especially since 2010 (Figure 28).

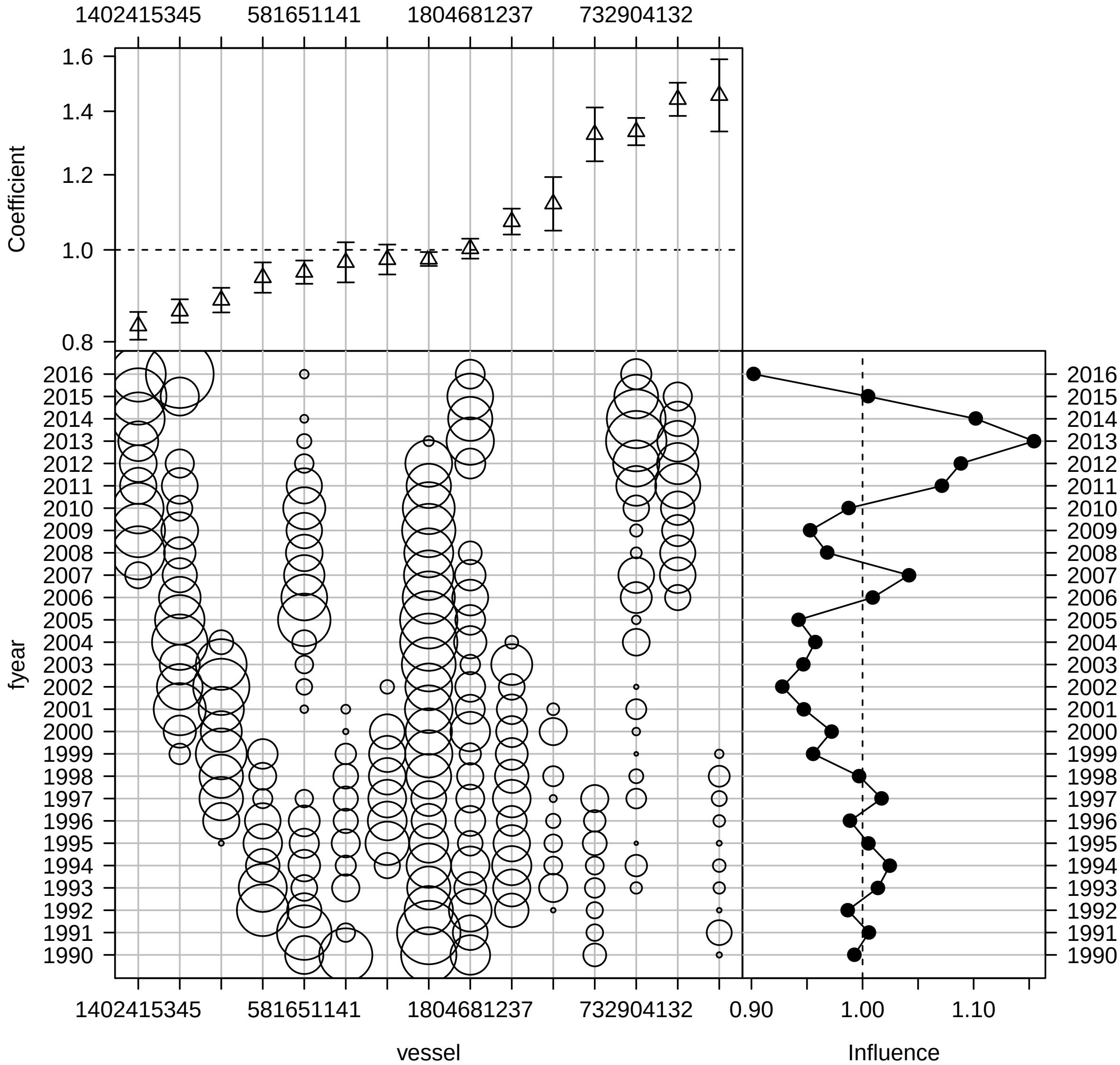

Figure 28: FLA 2 vessel-day coefficient-distribution-influence plot for vessel.

5. NEW ZEALAND SOLE

The New Zealand sole bottom trawl fishery (ESO 2) is defined as:

- Primary method: bottom trawl (BT)
- Target species flatfish species (FLA, BFL, BLF, BRI, ESO, FLO, GFL, LSO, SFL, SOL, TUR, WIT, YBF)
- Fishing effort conducted within Statistical Areas 013 and 014
- Fishing effort conducted between 1 Oct 2008 and 30 Sept 2016

The ESO 2 fishery has a small fleet size with about 90% of effort reporting ESO in the estimated catch (Table 12).

Table 12: Summary of data by fishing year after the ESO 2 fishery definition has been applied. Events represent a row in the effort dataset, trips caught represents the number of trips which reported catching ESO and events caught represents the percentage of days with positive catch.

Fishing Year	Vessels	Trips	Records	Effort (num)	Effort (hrs)	Catch (t)	Trips caught	Days caught
2008	12	481	1 119	1 121	3 334	29.2	92.5	92.2
2009	13	435	894	894	2 786	20.4	89.9	88.8
2010	7	367	709	709	2 031	23.1	89.7	88.1
2011	10	481	1 057	1 057	3 279	53.7	85.7	80.4
2012	10	484	1 119	1 119	3 506	38.6	80.6	72.4
2013	10	396	1 079	1 079	3 189	80.2	92.7	92.2
2014	9	541	1 317	1 317	4 009	58.9	96.3	96.3
2015	10	469	1 047	1 047	3 133	27.5	85.1	85.9
2016	8	445	3 864	1 094	3 152	35.9	59.5	60.9

5.1 Data filtering

Records were dropped if fishing duration was less than 1 hour, or alternatively if the fishing duration was greater then 6 hours (99.5% percentile). Landings were assessed for accuracy if they exceeded 342 kg (99.5% percentile); of the 40 records affected, 10 were removed due to large (order of magnitude) differences between estimated and allocated catch.

5.2 Core vessel selection

The core fleet has been restricted to vessels that consistently reported individual flatfish species codes (Figure 29). This resulted in a core fleet of 6 vessels which contributed to 61.92% of the New Zealand sole catch.

A summary of the data used for CPUE analysis after filtering and restriction to the core fleet is provided in Table 13.

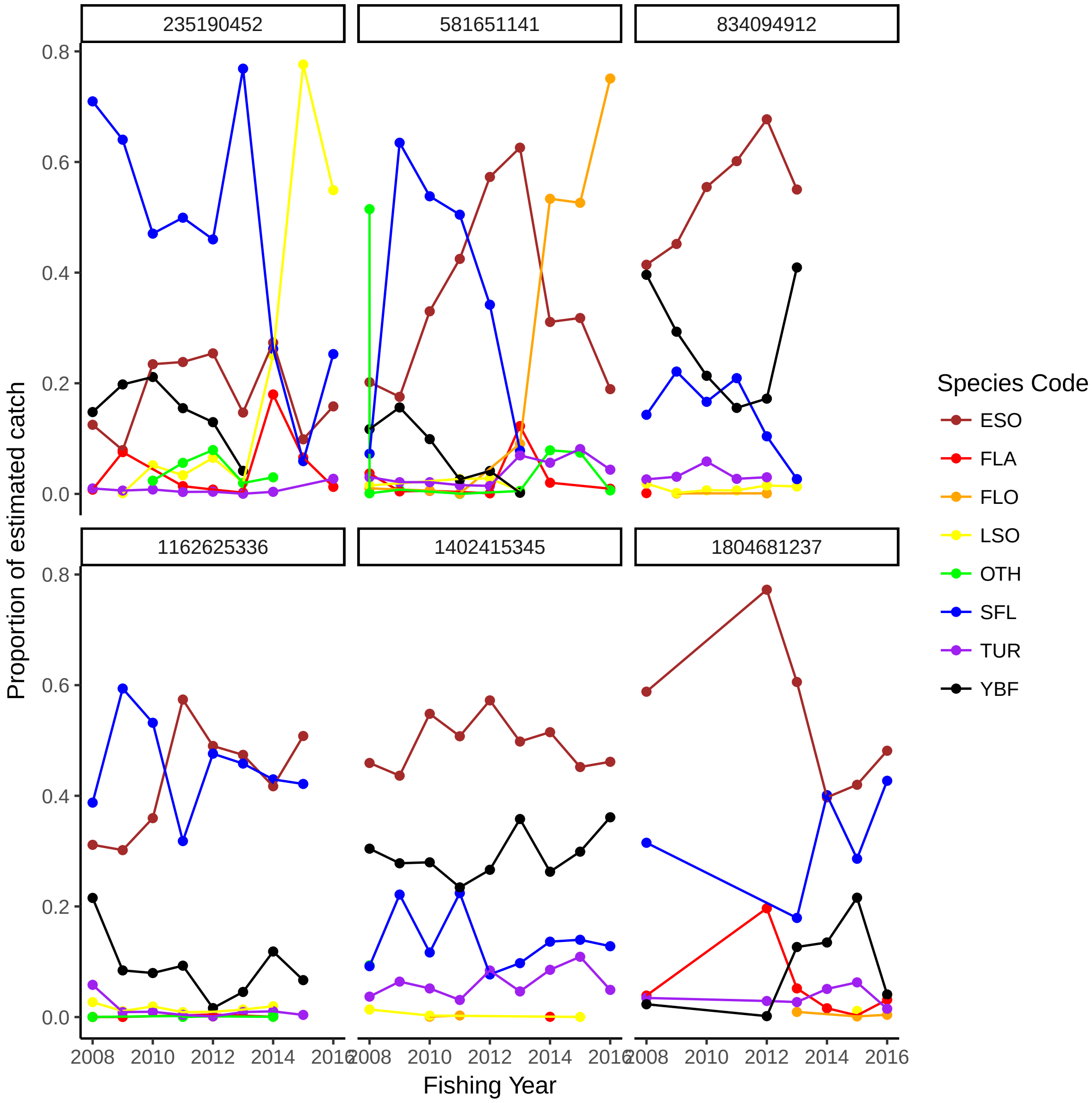

Figure 29: The reported flatfish species compositions from 2008 to 2016, for the core ESO 2 fleet. The less common species codes (BFL, BRI, FLO, GFL, SOL, WIT) have been aggregated to other (OTH).

Table 13: Summary of core dataset by fishing year after the core fleet definition was applied. Records represent a row in the effort dataset, whereas effort number is the sum of the reported trawls. Trips caught and days caught represent the percentage of trips and days which reported catching ESO.

Fishing year	Vessels	Trips	Records	Effort (num)	Effort (hrs)	Catch (t)	Trips caught	Days caught
2008	6	384	913	913	2 669	25.6	93.5	92.9
2009	5	366	721	721	2 176	16.4	91.0	91.0
2010	4	318	618	618	1 739	22.2	95.9	95.4
2011	4	348	724	724	2 210	46.4	97.7	97.6
2012	5	358	745	745	2 231	33.1	96.9	96.9
2013	6	281	602	602	1 769	34.6	96.4	95.9
2014	4	271	561	561	1 619	19.8	96.7	96.3
2015	3	233	478	478	1 380	17.3	98.3	98.4
2016	3	146	918	339	894	15.7	99.3	99.3

5.3 Occurrence

Occurrence of positive catch was modelled using a binomial GLM with a logistic link function. The full set of terms offered to the stepwise selection algorithm was:
$\sim fyear + vessel + poly(log(duration), 3) + target + poly(bottom, 3) + month + poly(width, 3) + poly(height, 3) + poly(lon, 3) + poly(abs(lat), 3)$

The final model after stepwise selection (Table 14) was:
$\sim fyear + vessel + month + poly(log(bottom), 3) + month + area$

Table 14: Summary of stepwise selection for ESO occurrence of positive catch. Model terms are listed in the order of acceptance to the model. AIC: Akaike Information Criterion; *: Term included in final model.

Step	Df	AIC	%dev.expl	add%dev.expl	Included
fyear	7	3 390	23.3	23.3	*
+ vessel	9	2 287	48.8	25.5	*
+ month	11	2 267	49.7	1.0	*
+ poly(abs(lat), 3)	3	2 246	50.4	0.6	*
+ poly(lon, 3)	3	2 236	50.7	0.4	
+ poly(bottom, 3)	3	2 231	51.0	0.2	

The occurrence of New Zealand sole has increased from about 90% to about 95% through the series (Figure 30).

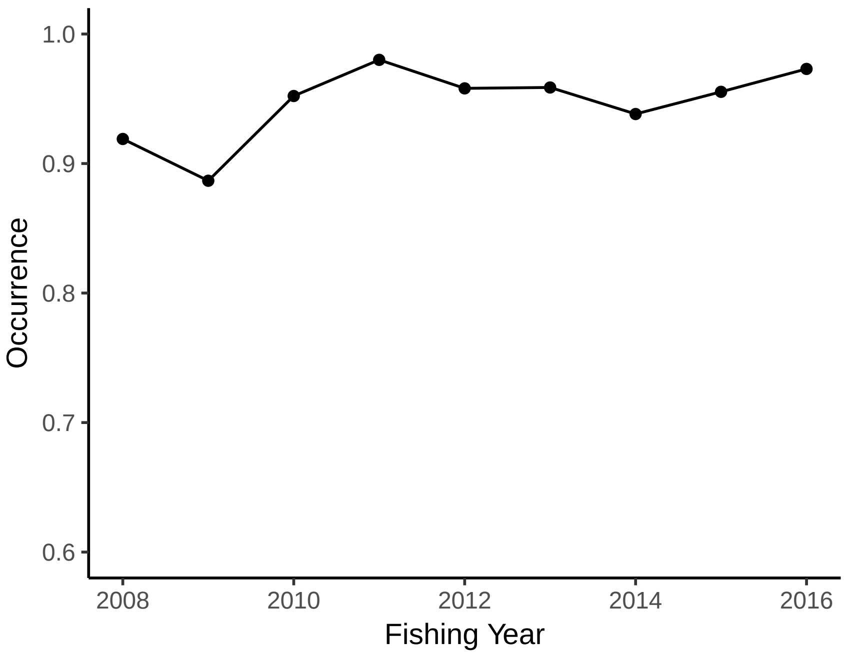

Figure 30: The occurrence of positive catch indices for the New Zealand Sole fishery.

5.4 Positive catch

Non-zero catches were modelled by Kendrick & Bentley (2014) using a Gamma distribution, in this analysis a Gamma distribution also had the lowest AIC and was selected as the most appropriate error structure for the final model.

The full set of terms offered for model selection was:

$\sim fyear + vessel + area * month + poly(log(duration), 3) + area + month + poly(height, 3) + poly(width, 3) + poly(depth, 3) + poly(speed, 3) + poly(distance, 3) + poly(abs(lat), 3)$

the final model selected was:
$\sim fyear + vessel + poly(lon, 3) + month$

This model explained 26.9% model deviance (Table 15), width was removed from the model selection because it was having an illogical coefficient effect and appeared to be confounded with the vessel effect.

Table 15: Summary of stepwise selection for ESO 2 magnitude of positive catch. Model terms are listed in the order of acceptance to the model. AIC: Akaike Information Criterion; *: Term included in final model.

Step	Df	AIC	%dev.expl	add%dev.expl	Included
fyear	7	49 593	12.2	12.2	*
+ vessel	8	48 784	23.7	11.6	*
+ poly(lon, 3)	3	48 654	25.5	1.8	*
+ month	11	48 562	26.9	1.5	*
+ poly(width, 3)	3	48 493	27.9	0.9	
+ poly(log(duration), 3)	3	48 484	28.1	0.2	
+ poly(height, 3)	3	48 479	28.2	0.1	
+ poly(bottom, 3)	3	48 474	28.3	0.1	

5.4.1 Diagnostics

The distribution of the residuals is tighter than predicted from the Gamma distribution, with the model deviating from the expected distribution outside of 2 standard deviations (Figure 31).

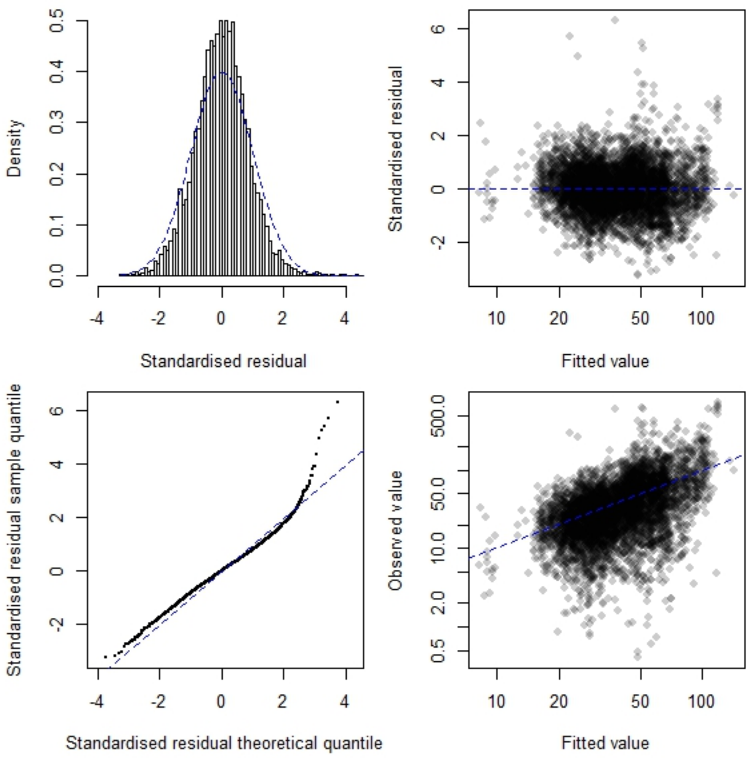

Figure 31: The diagnostic plots for the ESO Gamma general linear model fit. top left: Standardised residuals from the accepted generalised linear model fit; top right: The standardised residuals versus the fitted values; bottom left: Quantile-quantile plot of observed response versus likelihood of the distribution of these values; bottom right: Obversed values vs fitted values.

5.4.2 Influence of model terms

The standardisation process has had minimal influence on the ESO CPUE indices (Figure 32).

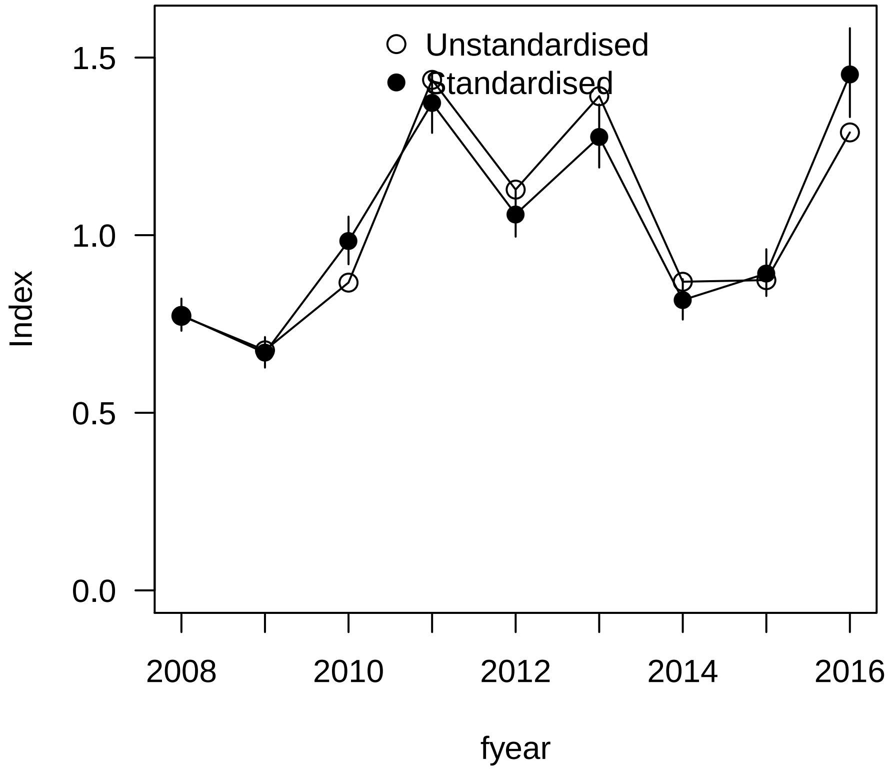

Figure 32: A comparison of the standardised CPUE indices and unstandardised indices of the model. The unstandardised index is based on the geometric mean of the catch per strata and is not adjusted for effort.

The addition of the vessel variable reduced CPUE indices from 2011 to 2014 and increased indices in 2016 (Figure 33). The addition of month and longitude had subtle changes on the ESO 2 CPUE indices (Figure 33).

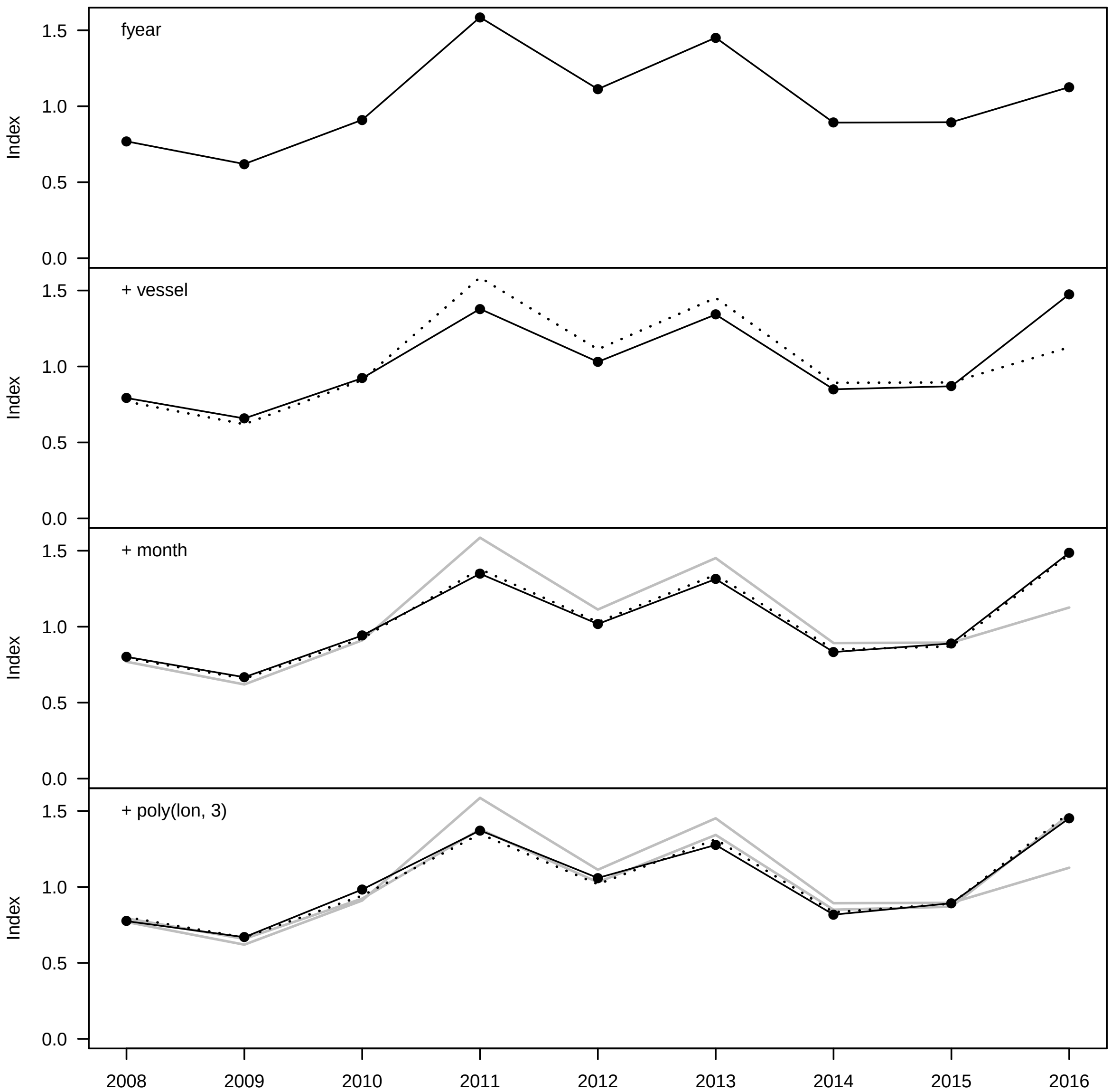

Figure 33: Changes in CPUE indices as each term is successively added to the ESO 2 model. The indices are normalised to an overall geometric mean of 1.

The coefficient distribution of influence (CDI) plot for vessel showed that the influence is subject to large catches from single vessels as a consequence of the small fleet (Figure 34).

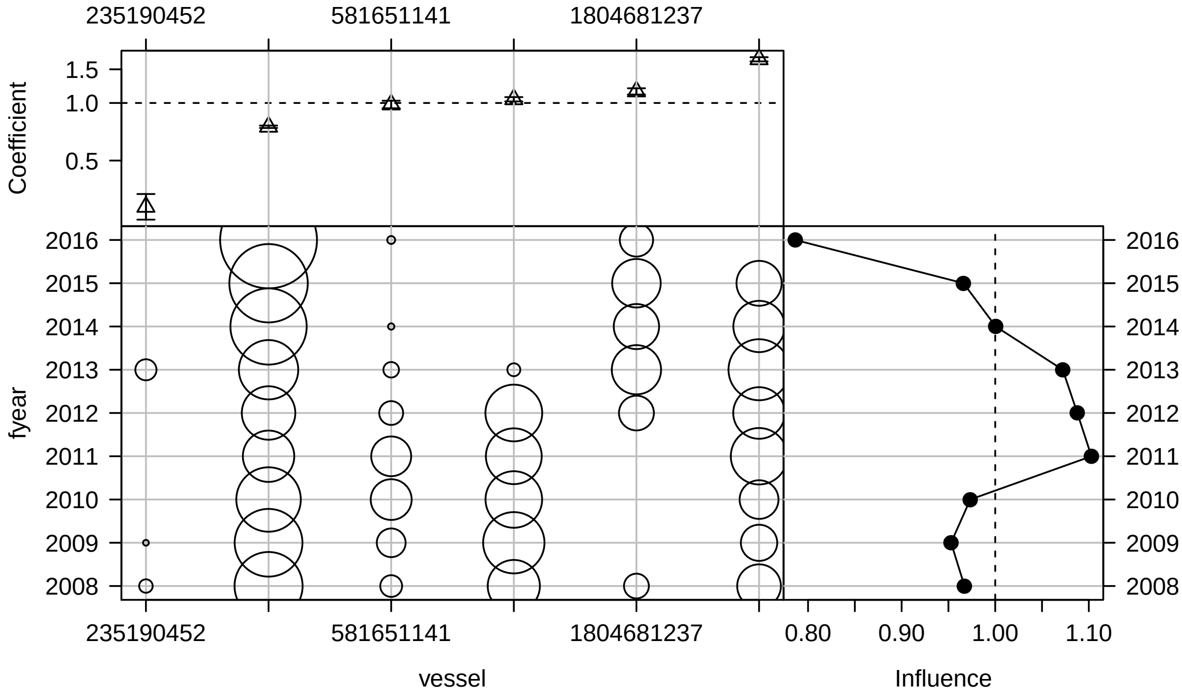

Figure 34: ESO 2 coefficient-distribution-influence plot for vessel.

Longitude had higher coefficients at longitudes around the Port of Napier and the fishery inside of Mahia Peninsula which is targeted infrequently (Figure 35).

There appears to be no temporal pattern in ESO 2 fishing effort; month coefficients were highest in the summer months and lowest in June-August (Figure 36).

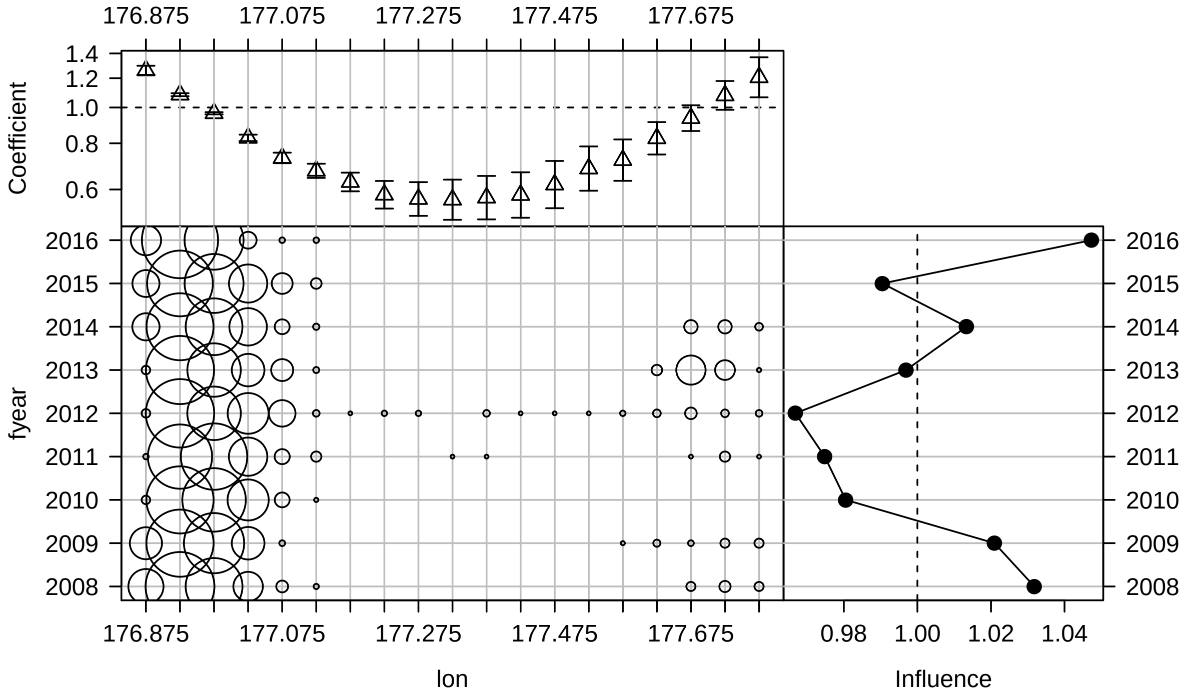

Figure 35: ESO 2 coefficient-distribution-influence plot for longitude.

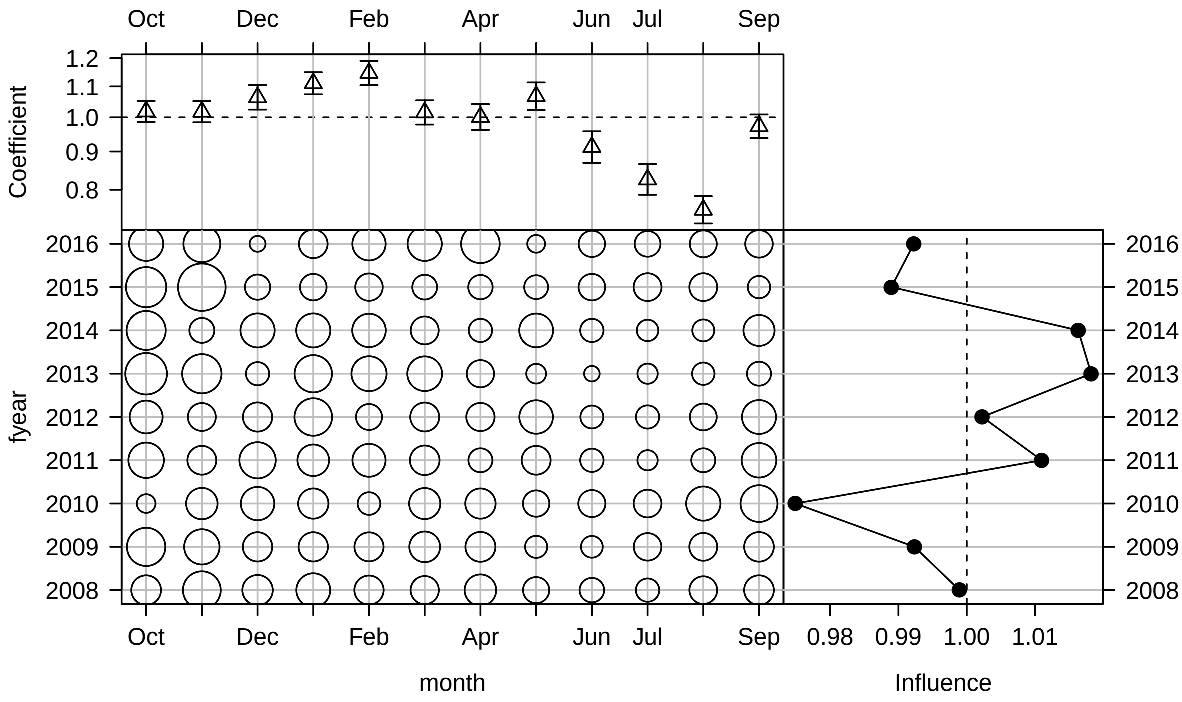

Figure 36: ESO 2 coefficient-distribution-influence plot for month.

5.5 CPUE indices

The New Zealand sole catch probability has gradually increased through the series from about 90% to 95% (Figure 37). The CPUE indices showed inter-annual variation but generally increased through the series, consequently the combined indices show a similar pattern to the CPUE indices' inter-annual variation and a generally increasing index (Figure 37).

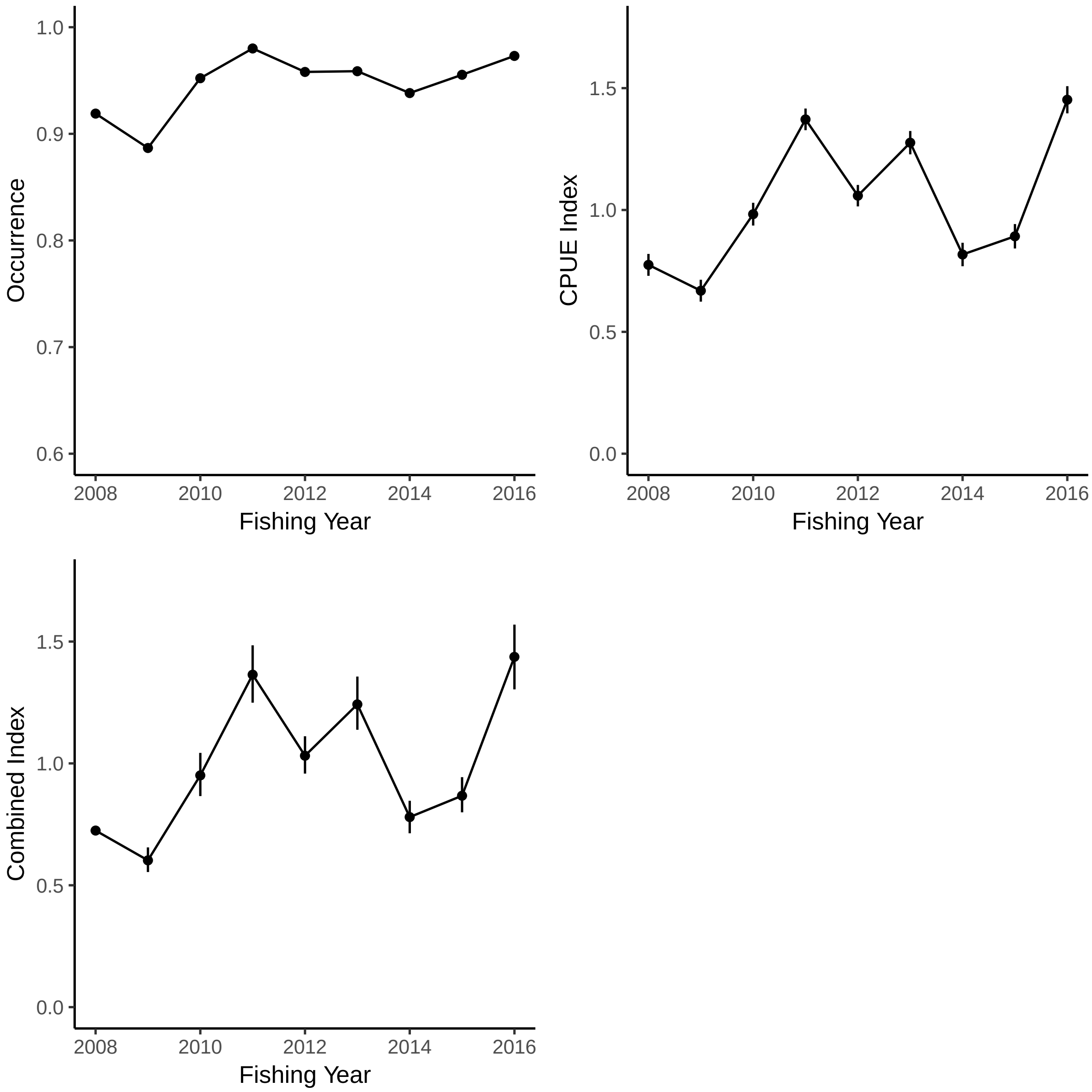

Figure 37: The New Zealand sole indices: occurrence (proportion of records with catches; top), CPUE indices (magnitude of catches; middle) and combined (occurrence x magnitude normalised; bottom) from 2008 to 2016.

6. SAND FLOUNDER

The sand flounder bottom trawl fishery (SFL 2) is defined as:

- Primary method: bottom trawl (BT)
- Target species flatfish species (FLA, BFL, BLF, BRI, ESO, FLO, GFL, LSO, SFL, SOL, TUR, WIT, YBF)
- Fishing effort conducted within Statistical Areas 013 and 014
- Fishing effort conducted between 1 Oct 2008 and 30 Sept 2016

The sand flounder bottom trawl fishery has a small fleet size with about 60% of effort reporting SFL in the estimated catch (Table 16).

Table 16: Summary of data by fishing year after the sand flounder bottom trawl fishery definition has been applied. Events represent a row in the effort dataset, trips caught represents the number of trips which reported catching SFL and events caught represents the percentage of days with positive catch.

Fishing Year	Vessels	Trips	Records	Effort (num)	Effort (hrs)	Catch (t)	Trips caught	Days caught
2008	12	481	1 119	1 121	3 334	18.4	59.7	57.8
2009	13	435	894	894	2 786	25.5	64.1	64.2
2010	7	367	709	709	2 031	17.0	63.2	61.7
2011	10	481	1 056	1 056	3 275	34.1	66.3	62.7
2012	10	485	1 121	1 121	3 512	14.8	44.5	38.4
2013	10	396	1 079	1 079	3 189	27.5	66.9	68.1
2014	9	541	1 317	1 317	4 009	25.5	68.2	69.2
2015	10	469	1 047	1 047	3 133	16.2	66.5	66.9
2016	8	445	3 864	1 094	3 152	24.7	49.2	51.0

6.1 Data filtering

Records were dropped if fishing duration was less then 1 hour, or greater then 6 hours (99.5% percentile). Landings were excluded if they were improbably high. Landings were assessed for accuracy if they exceeded 366 kg (99.5% percentile); of the 26 records affected, 2 were removed due to the large difference between estimated and allocated catch.

6.2 Core vessel selection

The core fleet has been restricted to vessels that consistently reported individual flatfish species codes, the sand flounder core fleet is the same as the New Zealand sole core fleet (Figure 29). This resulted in a core fleet of 6 vessels which contributed 63.9% of the sand flounder catch.

Table 17 summarises the SFL 2 TCER dataset for the core fleet.

Table 17: Summary of core dataset by fishing year after the core fleet definition was applied. Records represent a row in the effort dataset, whereas effort number is the sum of the reported trawls. Trips caught and days caught represent the percentage of trips and days which reported catching SFL.

Fishing year	Vessels	Trips	Records	Effort (num)	Effort (hrs)	Catch (t)	Trips caught	Days caught
2008	6	384	913	913	2 669	12.3	53.9	51.7
2009	5	366	721	721	2 176	15.1	63.4	63.7
2010	4	318	618	618	1 739	13.9	65.7	64.9
2011	4	348	723	723	2 206	26.6	75.0	75.7
2012	5	359	747	747	2 237	11.3	50.7	48.2
2013	6	281	602	602	1 769	21.1	61.2	60.2
2014	4	271	561	561	1 619	15.1	62.7	63.7
2015	3	233	478	478	1 380	9.9	66.1	65.6
2016	3	146	918	339	894	5.8	73.3	73.4

6.3 Occurrence

Occurrence of positive catch was modelled using a binomial GLM with a logistic link function. The full set of terms offered to the stepwise selection algorithm was:
$\sim fyear + vessel + month + poly(log(duration), 3) + poly(bottom, 3) + month + poly(width, 3) + poly(height, 3) + poly(lon, 3) + poly(abs(lat), 3)$

The final model after stepwise selection (Table 18) was:
$\sim fyear + vessel + poly(abs(lab), 3) + poly(bottom, 3) + poly(width, 3) + month$

Table 18: Summary of stepwise selection for SFL occurrence of positive catch. Model terms are listed in the order of acceptance to the model. AIC: Akaike Information Criterion; *: Term included in final model.

Step	Df	AIC	%dev.expl	add%dev.expl	Included
fyear	7	8 054	3.9	3.9	*
+ vessel	9	7 319	12.9	9.0	*
+ poly(abs(lab), 3)	3	6 886	18.20	5.2	*
+ poly(bottom, 3)	3	6 743	20.00	1.8	*
+ poly(width, 3)	3	6 688	20.7	0.7	*
+ month	11	6 650	21.4	0.7	*
+ poly(log(height), 3)	3	6 622	21.8	0.4	
+ poly(log(lon), 3)	3	6 613	22.0	0.2	

The positive catch indices have shown a very gradual increase through the series from about 50% to 55% (Figure 38).

6.4 Positive Catch

The magnitude of non-zero catch were modelled by Kendrick & Bentley (2014) using a Gamma ditribution, in this analysis a Gamma distrbution also had the lowest AIC and was selected as the most appropriate error structure for the final model. The full set of terms offered for model selection was:
$\sim fyear + vessel + poly(log(duration), 3) + month + poly(height, 3)) + poly(width, 3)) + poly(depth, 3)) + poly(speed, 3)) + poly(distance, 3)) + poly(abs(lat), 3)$

The final model after stepwise selection (Table 19) was:
$\sim fyear + vessel + month + poly(lon, 3) + poly(width, 3)$

Table 19: Summary of stepwise selection for SFL 2 magnitude of positive catch. Model terms are listed in the order of acceptance to the model. AIC: Akaike Information Criterion; *: Term included in final model.

Step	Df	AIC	%dev.expl	add%dev.expl	Included
fyear	7	29 982	5.3	5.3	*
+ vessel	8	28 512	36.8	31.5	*
+ poly(log(abs(lat)), 3)	3	28 094	43.8	7.1	*
+ month	11	27 977	46.0	2.2	*
+ poly(log(width), 3)	3	27 937	46.7	0.7	
+ poly(log(height), 3)	3	27 918	47.1	0.4	
+ poly(log(duration), 3)	3	27 913	47.2	0.2	
+ area	1	27 911	47.3	0.1	
+ area:month	11	27 861	48.4	1.1	
+ poly(log(lon), 3)	3	27 858	48.5	0.1	
+ poly(log(bottom), 3)	3	27 852	48.7	0.2	

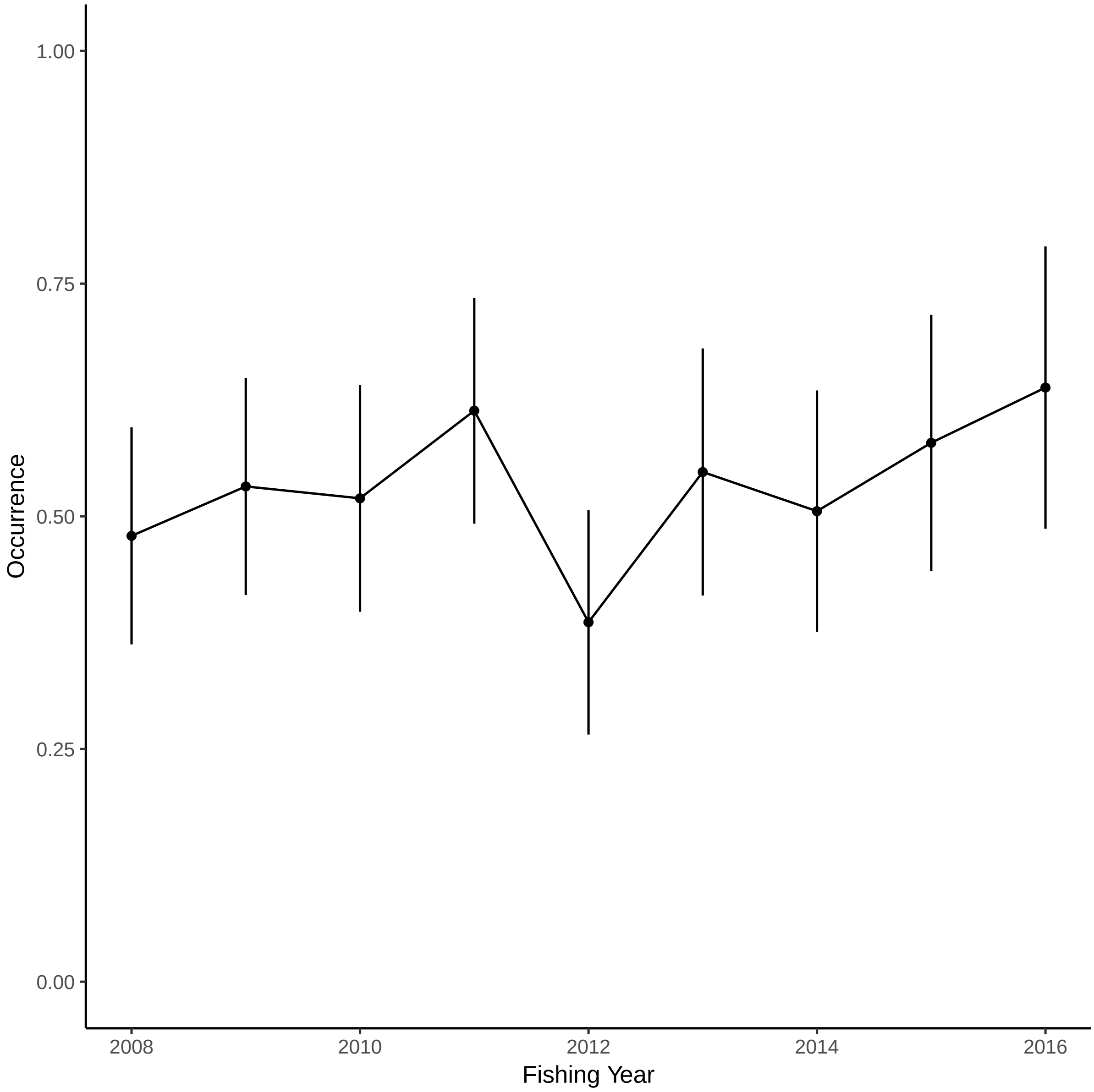

Figure 38: The occurrence of positive catch indices for the sand flounder fishery.

6.4.1 Diagnostics

The distribution of the residuals is tighter than predicted from the Gamma distribution, with the model deviating from the expected distribution outside of two standard deviations (Figure 39).

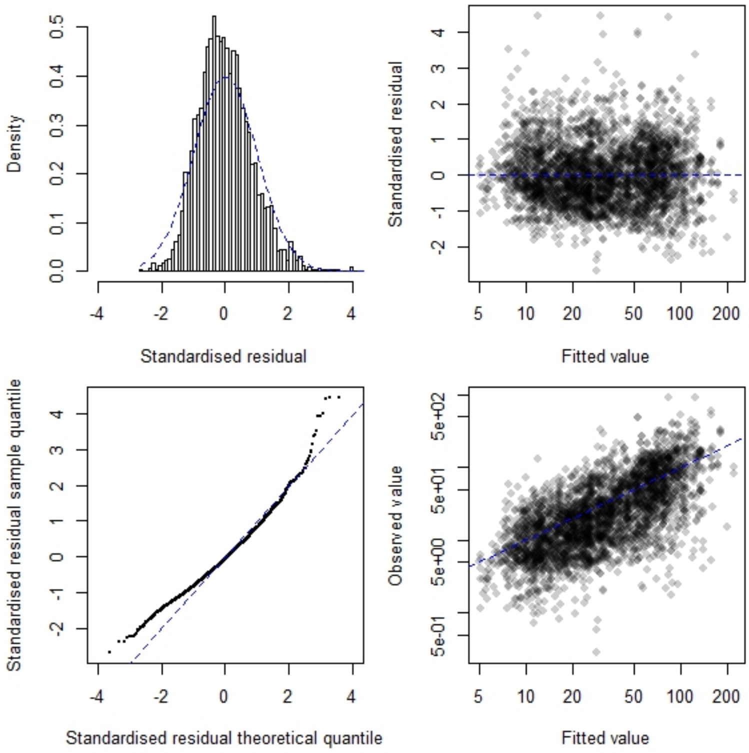

Figure 39: The diagnostic plots for the SFL Gamma general linear model fit. top left: Standardised residuals from the accepted generalised linear model fit; top right: The standardised residuals versus the fitted values; bottom left: Quantile-quantile plot of observed response versus likelihood of the distribution of these values; bottom right: Obversed values vs fitted values.

6.4.2 Influence of model terms

The unstandardised indices increased between 2008 and 2011, the indices flattened despite a 2012 dip then declined from 2014 to 2016 (Figure 40). In contrast, the standardised indices fluctuated around the series mean but displayed a large increase in 2016 (Figure 40).

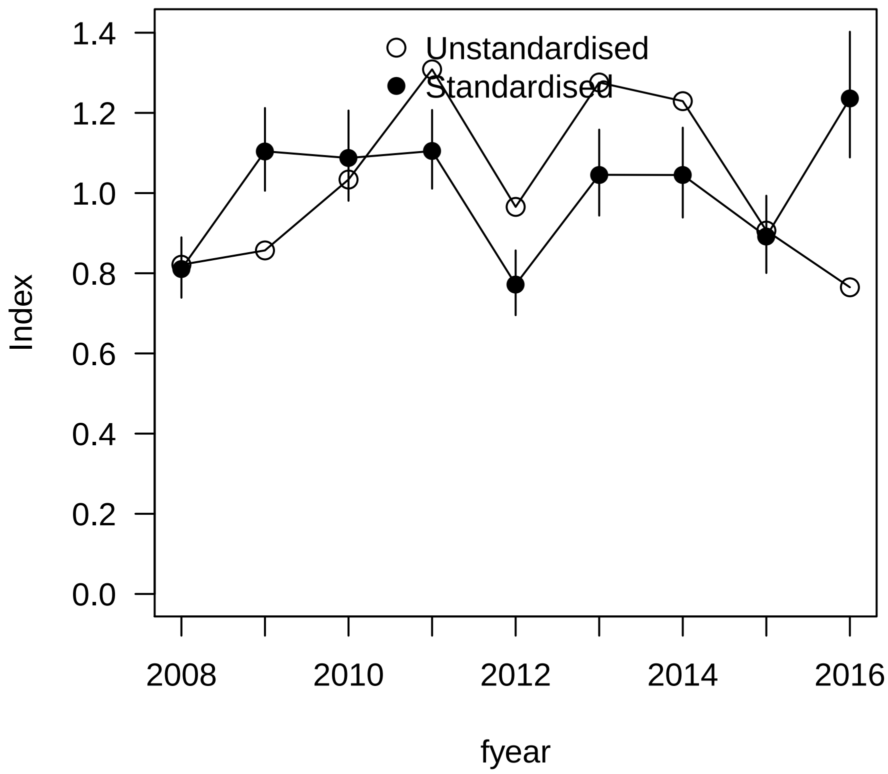

Figure 40: A comparison of the standardised CPUE indices and unstandardised indices of the model. The unstandardised index is based on the geometric mean of the catch per strata and is not adjusted for effort.

The addition of vessel had the major influence on the SFL 2 CPUE indices, it reduced the CPUE indices between 2010 and 2014 and then increased the 2016 index (Figure 41). The addition of latitude and month made relatively minor changes to the CPUE indices (Figure 41).

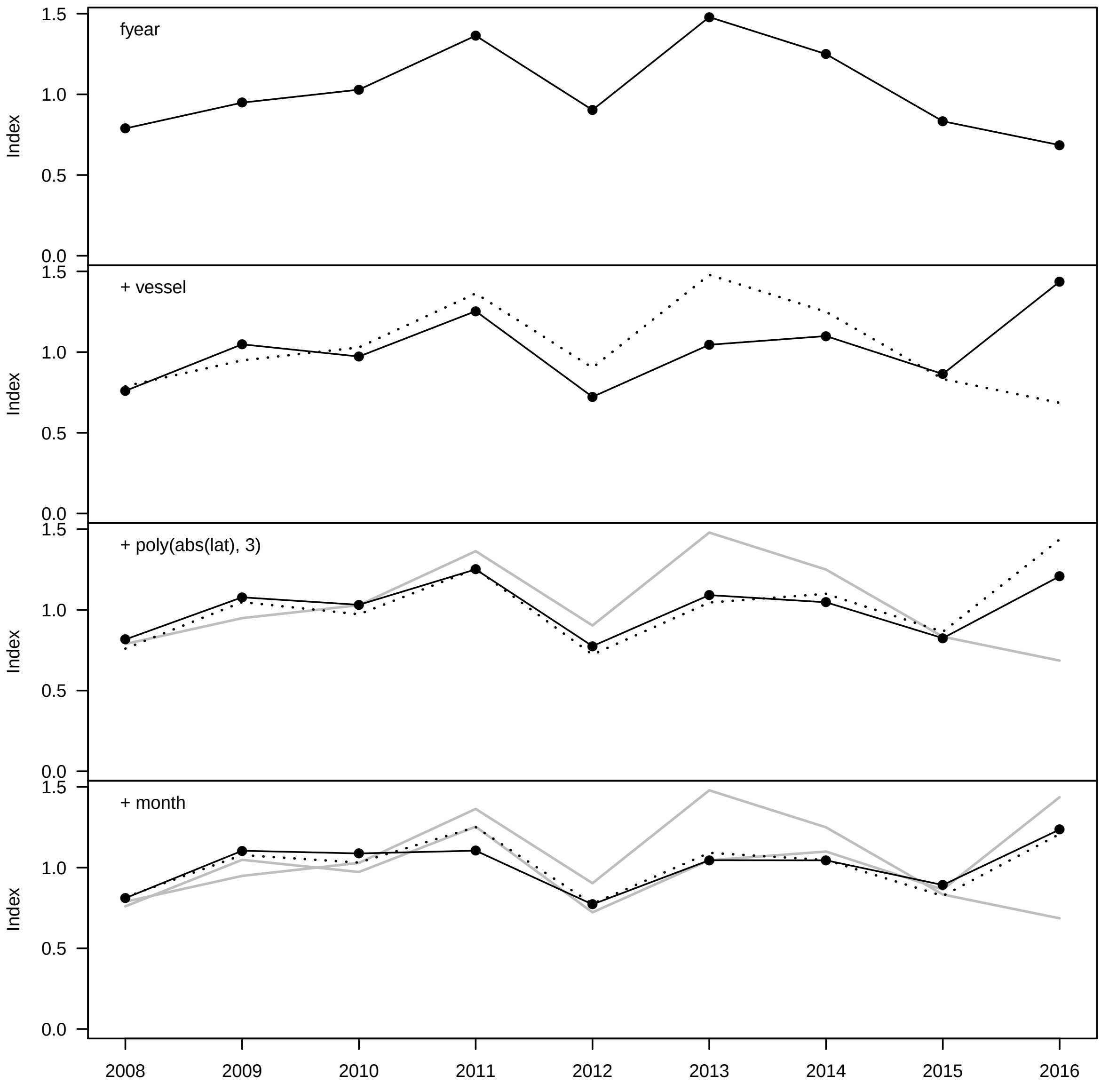

Figure 41: Changes in CPUE indices as each term is successively added to the SFL 2 model. The indices are normalised to an overall geometric mean of 1.

The SFL 2 fleet is small, consequently the relative SFL catch of the participating vessels influences the CPUE indices (Figure 42). The 2016 maxima is a consequence of the catch being dominated by the vessel with the lowest coefficient (Figure 42).

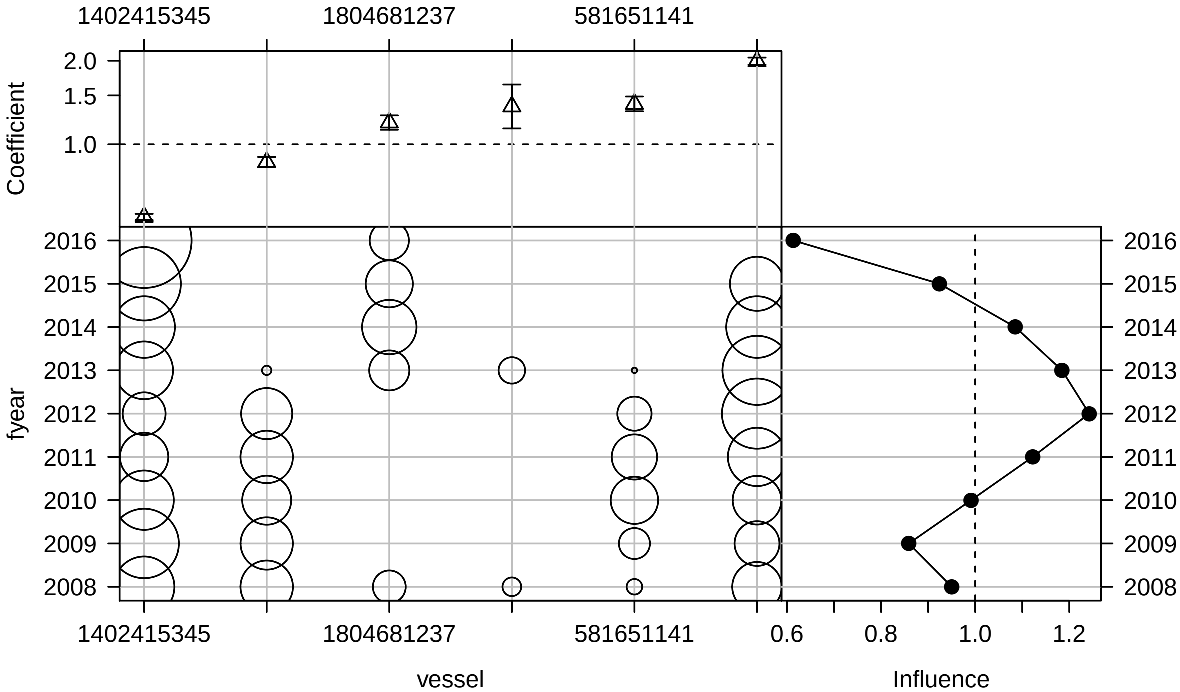

Figure 42: SFL 2 coefficient-distribution-influence plot for vessel.

The majority of fishing effort is conducted between Cape Kidnappers and Waipatiki, with coefficients highest at the southern latitudes (Figure 43). There also areas of high coefficients further north around Mahia Peninsula (Figure 43). The fishery operates in consistent areas through the series with the Mahia fishery fished infrequently (Figure 43).

There is no consistent temporal pattern in the fishing effort throughout the fishing year (Figure 44). The month coefficients are generally higher for summer months relative to winter months (Figure 44).

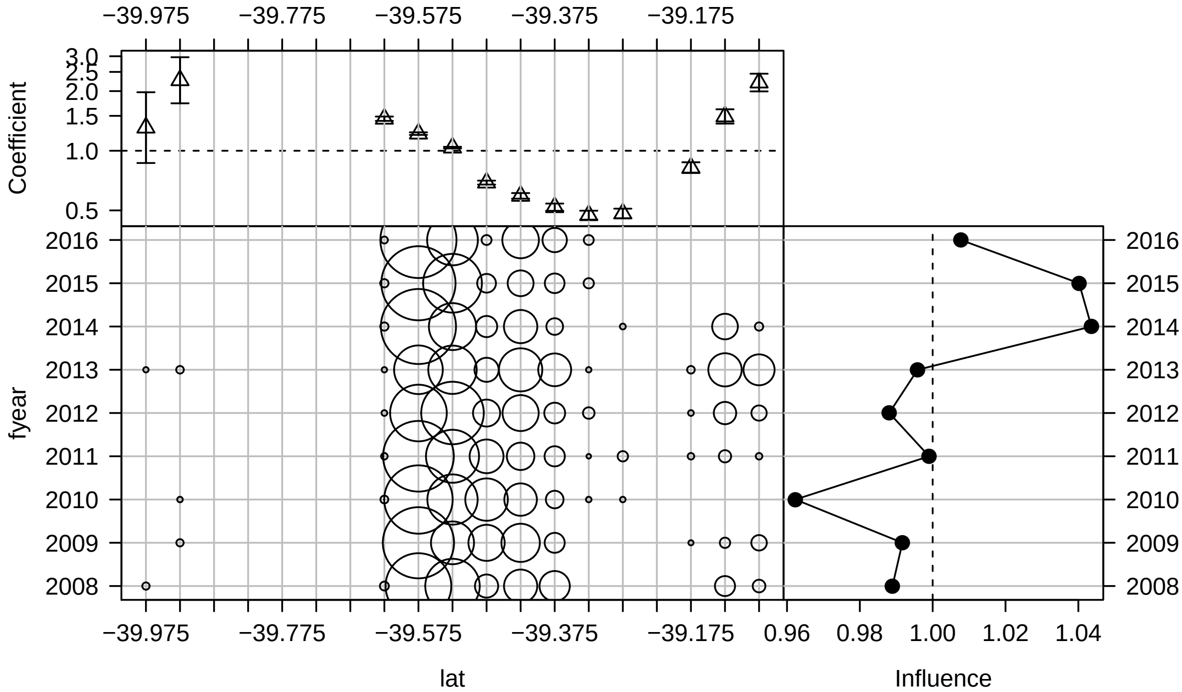

Figure 43: SFL 2 coefficient-distribution-influence plot for tow starting latitude.

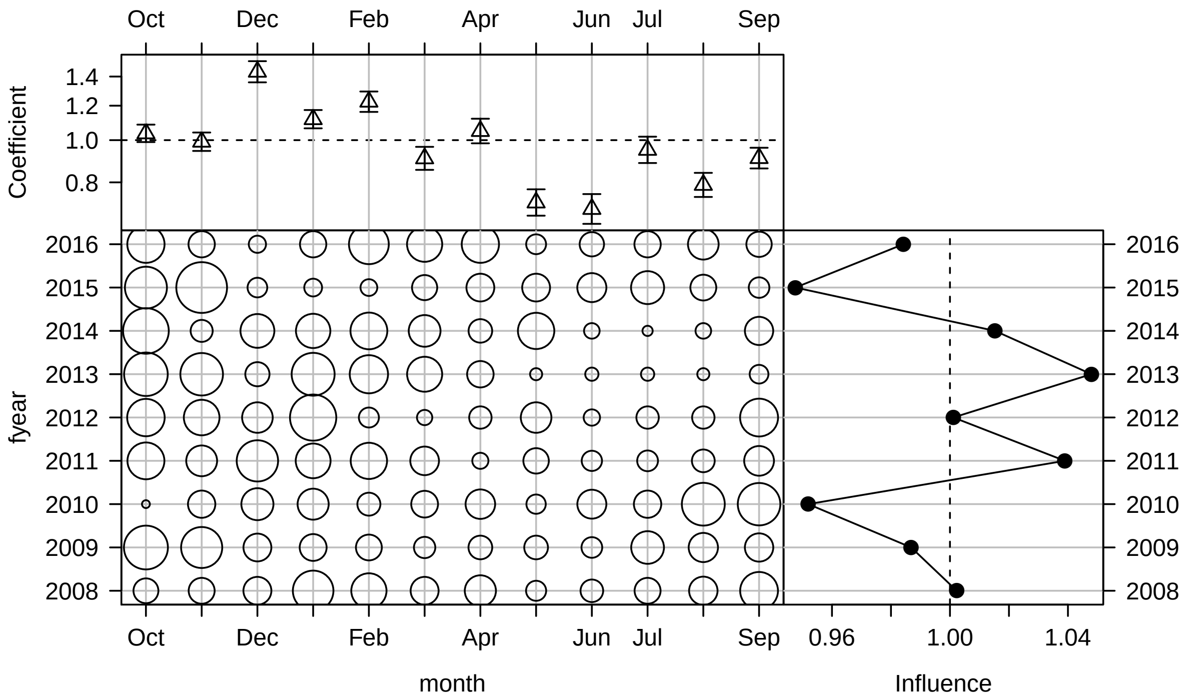

Figure 44: SFL 2 coefficient-distribution-influence plot for month.

6.5 CPUE indices

The sand flounder catch probability has increased through the time series from a catch rate of 50% to 60% (Figure 45). The CPUE indices have fluctuated around a geometric mean of one, with a drop in 2012 (Figure 45). The combined indices show a gradual increase through the time-series, with the exception of a trough in 2012 (Figure 45).

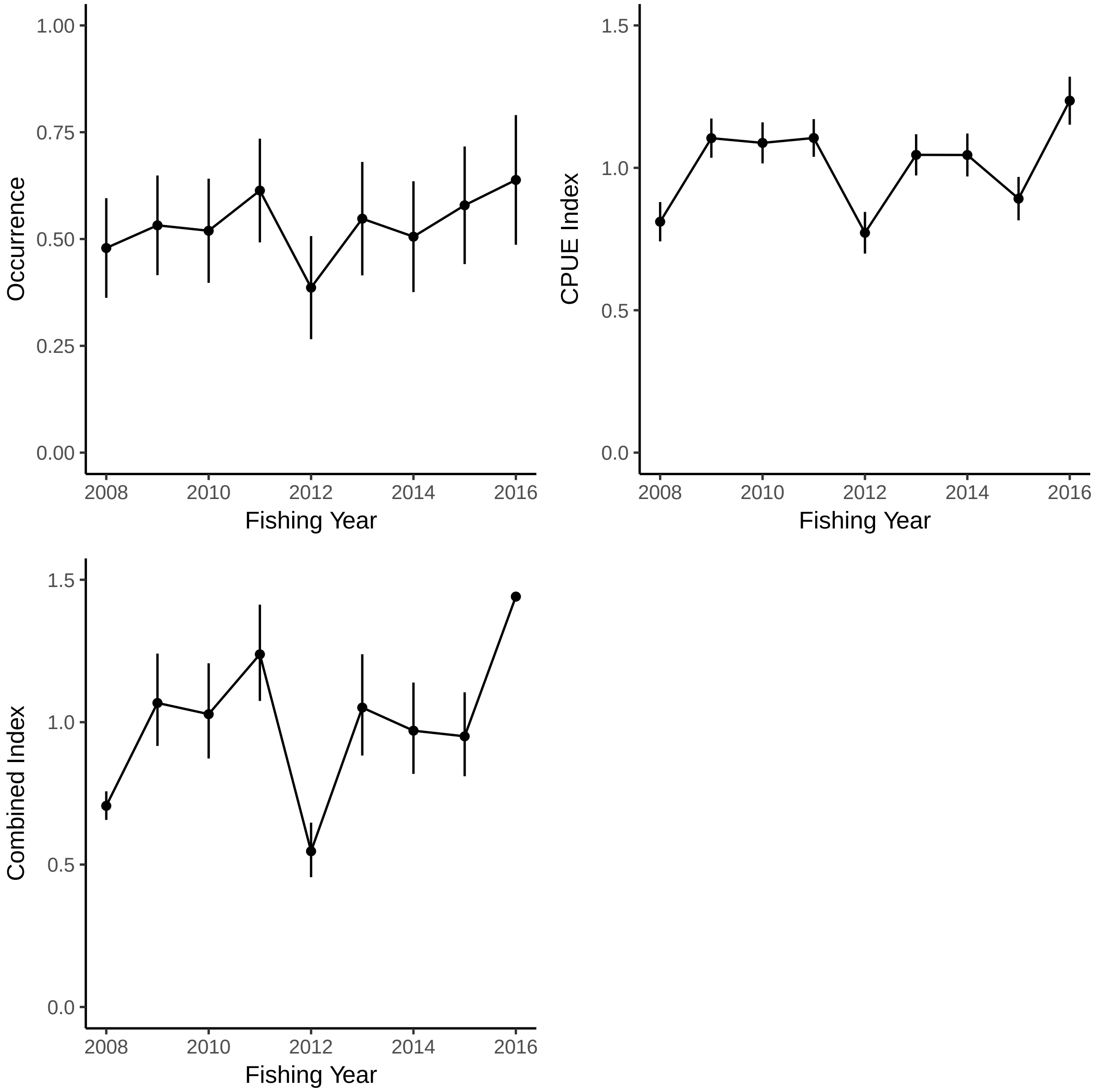

Figure 45: The sand flounder indices: occurrence (proportion of records with catches; top), CPUE indices (magnitude of catches; middle) and combined (occurrence x magnitude normalised; bottom) from 2008 to 2016.

7. DISCUSSION

7.1 CPUE indices

The FLA 2 CPUE indices show cyclic fluctuations in abundance with 5 –8 year cycles (Figure 46). Since the last assessment the CPUE indices showed a decline from 2013 to 2015 followed by a rapid increase in 2016 (Figure 46). The current CPUE indices differ from those of Kendrick & Bentley (2014) between 2009 and 2013, this was attributed to the inclusion of Statistical Area as an explanatory area in the previous analysis.

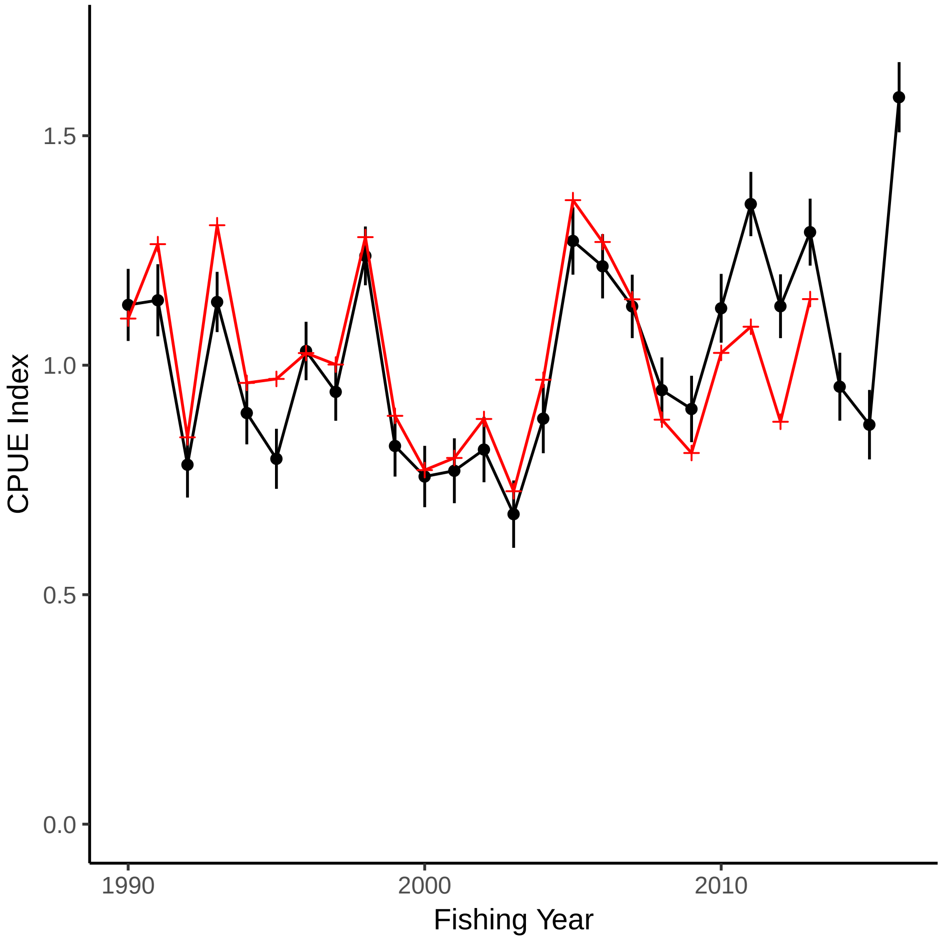

Figure 46: The CPUE indices for the FLA 2 vessel-day bottom trawl fishery (black) compared to the indices from Kendrick & Bentley (2014) (red).

The CPUE indices for New Zealand sole show an increasing trajectory between 2009 and 2011, a gradual drop between 2012 and 2014, then an increase to 2016 (Figure 47). The sand flounder CPUE indices generally follow the same trajectory as New Zealand sole, staying relatively flat between 2003 and 2015 with the exception of a large drop in 2012 then an increase in 2016 (Figure 47).

The New Zealand sole, sand flounder and flatfish indices are comparable from 2008 to 2016 (Figure 48). The flatfish and New Zealand sole indices are closely aligned; this is unsuprising given the dominance of New Zealand sole in catch from the FLA 2 fishery (Figure 48).

The flatfish fleet has reduced in size over the time period examined. The introduction of TCER forms in 2008 led to an increase in reporting resolution and stimulated the majority of the fleet toward reporting individual flatfish species in the estimated catch. This was not adopted homogenously and as a consequence there is a small dataset available for forming abundance indices for the two main species in FLA 2 fishery New Zealand sole and sand flounder. The indices themselves are heavily influenced by

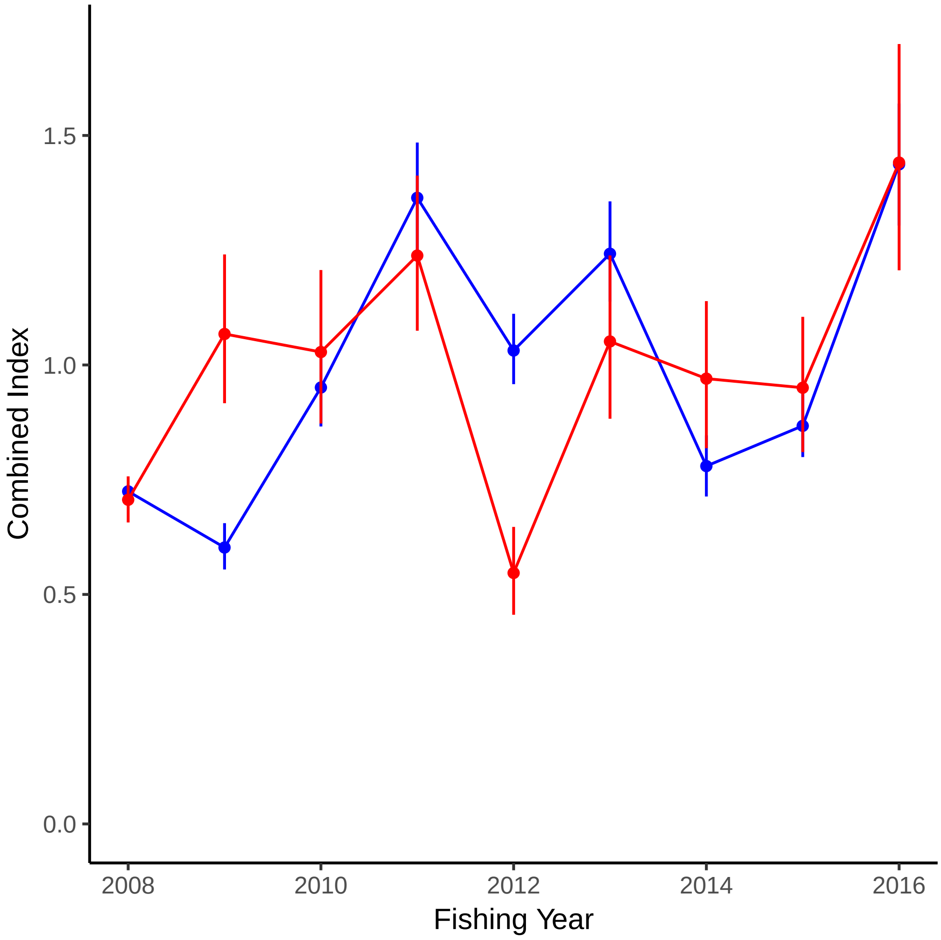

Figure 47: The combined indices for the New Zealand sole (blue) and sand flounder (red) bottom trawl fisheries

the catch of individual vessels, this is especially apparent in the 2016 fishing year.

The species composition of the estimated catch varies considerably between vessels. Given the spatially discrete nature of the fishery, the level of variation is somewhat surprising and comparison with other information such as LFR records may be helpful.

The CPUE indices for New Zealand sole and sand flounder provide an index of abundance that is consistent with the trends of the aggregate FLA fishery. There is potential to form an index for yellowbelly flounder but other species in the FLA 2 fishery are infrequently reported and consequently have insufficient data. The CPUE indices for the two main species and the composite indices increased from 2008 to 2012 then declined from 2013 to 2015 and all three indices increased substantially in the 2016 fishing year.

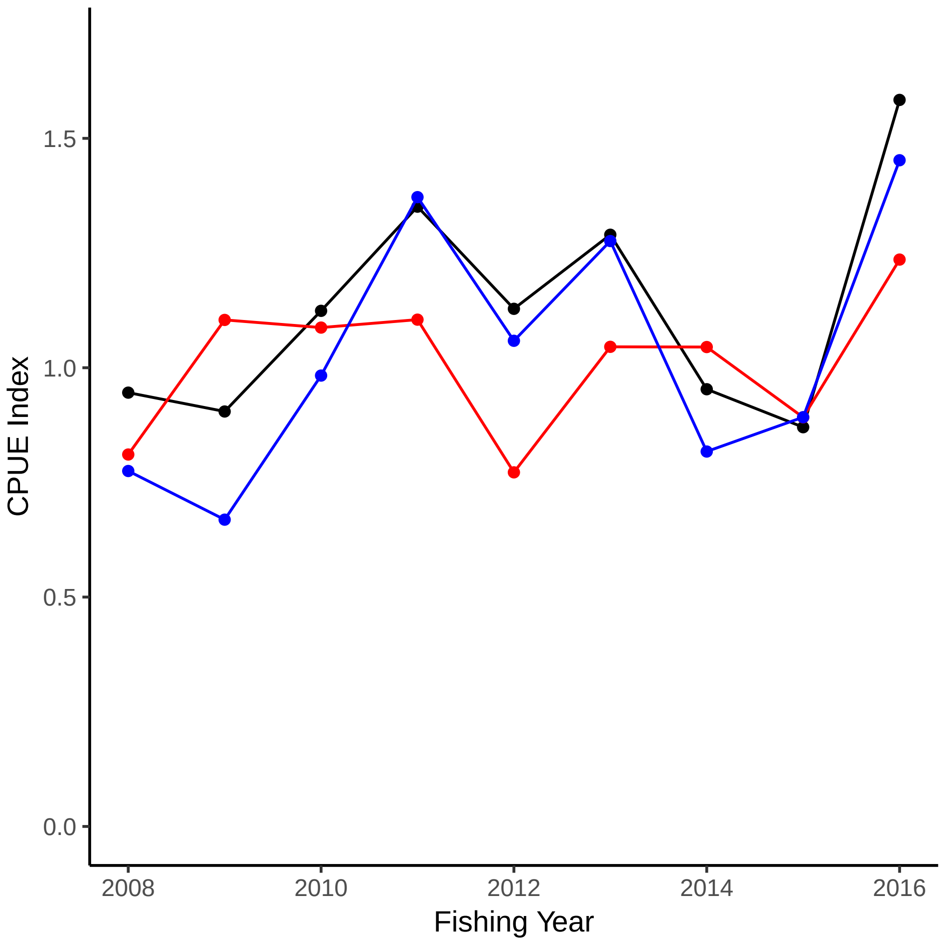

Figure 48: Comparison between the CPUE indices for the vessel-day aggregated FLA 2 target fishery (black), the New Zealand sole fishery (red) and the sand flounder fishery (blue) from the 2008 to 2016 fishing year.

7.2 Management Implications

The NINS WG has accepted the BT-FLA CPUE index with indices derived from the positive catch component only (Ministry for Primary Industries 2016). The BMSY proxy is the mean of the CPUE indices from 1989–90 to 2009–10; since the last assessment CPUE indices stayed at the 2013 level then declined slightly in 2014–15 before rapidly increasing in 2015/16. This analysis produced individual indices for Sand flounder and New Zealand sole, these indices followed similar trajectories to the FLA indices, although combined indices are required at the species level to incorporate the occurrence of positive catch (ESO/SFL). These additional indices provide reassurance that that the current monitoring of CPUE aggregated by species is probably sufficient to monitor the two main species.

7.3 Acknowledgements

This study was funded by Fisheries Inshore New Zealand and the project was conducted by Trident Systems LP. Members of the Northern Inshore Fishery Assessment Working Group reviewed the analysis. Software developed by Nokome Bentley was utilised for the presentation of CPUE model diagnostics.

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9. APPENDICES

9.1 Appendix 1 Tabulated CPUE indices

Table 20: Annual FLA 2 vessel day CPUE indices and the lower (LCI) and upper (UCI) bounds of the 95 percent confidence intervals.

Fishing Year	Index	LCI	UCI
1990	1.131	1.053	1.210
1991	1.141	1.063	1.220
1992	0.783	0.712	0.855
1993	1.138	1.072	1.203
1994	0.896	0.828	0.964
1995	0.796	0.731	0.861
1996	1.031	0.967	1.095
1997	0.942	0.879	1.005
1998	1.238	1.174	1.302
1999	0.824	0.757	0.891
2000	0.757	0.691	0.824
2001	0.770	0.699	0.841
2002	0.816	0.745	0.887
2003	0.675	0.602	0.749
2004	0.884	0.808	0.959
2005	1.271	1.197	1.344
2006	1.216	1.145	1.286
2007	1.128	1.059	1.197
2008	0.946	0.874	1.017
2009	0.905	0.832	0.977
2010	1.124	1.049	1.199
2011	1.351	1.281	1.421
2012	1.128	1.059	1.198
2013	1.290	1.217	1.363
2014	0.953	0.879	1.027
2015	0.870	0.795	0.946
2016	1.584	1.507	1.660

Table 21: Annual FLA 2 sand flounder TCER CPUE indices and the lower (LCI) and upper (UCI) bounds of the 95 percent confidence intervals.

Fishing Year	Combined Index	LCI	UCI	Binomial Index	LCI	UCI	CPUE index	LCI	UCI
2008	0.706	0.657	0.757	0.479	0.362	0.596	0.811	0.742	0.880
2009	1.068	0.917	1.241	0.532	0.415	0.649	1.104	1.035	1.173
2010	1.028	0.872	1.207	0.519	0.397	0.641	1.088	1.015	1.160
2011	1.238	1.075	1.413	0.614	0.492	0.735	1.105	1.039	1.171
2012	0.547	0.456	0.647	0.386	0.266	0.507	0.772	0.699	0.845
2013	1.051	0.883	1.239	0.548	0.415	0.680	1.046	0.973	1.118
2014	0.970	0.818	1.139	0.506	0.376	0.635	1.045	0.970	1.120
2015	0.950	0.810	1.105	0.579	0.441	0.717	0.892	0.816	0.968
2016	1.441	1.206	1.699	0.638	0.487	0.790	1.236	1.152	1.320

Table 22: Annual FLA 2 New Zealand sole TCER CPUE indices and the lower (LCI) and upper (UCI) bounds of the 95 percent confidence intervals.

Fishing Year	Combined Index	LCI	UCI	Binomial Index	LCI	UCI	CPUE index	LCI	UCI
2008	0.725	0.710	0.739	0.919	0.728	1.110	0.775	0.730	0.820
2009	0.602	0.554	0.655	0.887	0.696	1.077	0.669	0.624	0.714
2010	0.951	0.866	1.043	0.952	0.717	1.187	0.983	0.936	1.030
2011	1.364	1.249	1.485	0.980	0.713	1.248	1.372	1.327	1.416
2012	1.031	0.958	1.111	0.958	0.729	1.188	1.059	1.015	1.103
2013	1.242	1.138	1.356	0.959	0.722	1.196	1.276	1.228	1.324
2014	0.780	0.713	0.847	0.938	0.695	1.181	0.817	0.769	0.866
2015	0.867	0.799	0.944	0.955	0.650	1.261	0.892	0.842	0.942
2016	1.437	1.304	1.569	0.973	0.494	1.453	1.452	1.397	1.508