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Characterisation and catch-per-unit-effort analyses for FMA 2 trevally (TRE 2) up to 2016–17

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EXECUTIVE SUMMARY

Schofield, M.I. [1]; Langley, A.D. [2]; Middleton, D.A.J.[1] (2022). Characterisation and catch-per-unit-effort analyses for FMA 2 trevally (TRE 2) up to 2016–17.

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The fisheries taking trevally (*Pseudocaranx dentex*, TRE) in Quota Management Area (QMA) TRE 2 are described from 1989–90 to 2016–17 based on statutory commercial catch and effort data held by Fisheries New Zealand. TRE 2 comprises waters off the eastern and southern North Island from Cape Runaway south around to Mana Island off the west coast. Trevally is caught as by-catch throughout TRE 2. However, the majority of the TRE 2 catch is taken by the mixed-species (red gurnard, snapper, trevally and tarakihi) bottom trawl fishery within Hawke Bay and Poverty Bay. Over the period examined, the annual TRE 2 catch fluctuated between 187 and 417 tonnes, regularly exceeding the 241 tonne Total Allowable Commercial Catch. TRE 2 is thought to be part of TRE 1 biological stock in the Bay of Plenty with large changes in catch and abundance in TRE 2 attributed to the movement of fish into and out of this QMA.

This study examines TRE 2 relative abundance using a TRE 2 bottom trawl catch-per-unit-effort (CPUE) index, including data to the end of the 2016–17 fishing year. The CPUE indices were derived using a delta approach that incorporated Generalised Linear Models of the occurrence of trevally in the trawl catch (binomial model) and the magnitude of positive trevally catches (Weibull model). The CPUE index shows large fluctuations in abundance between 1989–90 and 2007–08. Since the last analysis (with data to 2009–10) the CPUE indices have been relatively stable, with an increasing trend from 2008–09 to 2016–17. This increase is corroborated by a tow-based series using data collected on Trawl Catch Effort Returns from 1 October 2007.

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1. INTRODUCTION

Trevally (*Pseudocaranx dentex*, TRE) is a common coastal species that occurs around the North Island and the top of the South Island. Trevally is an important commercial species with 3810 tonnes of the 3933 tonne Total Allowable Commercial Catch (TACC) caught in the in the 2016–17 fishing year, mainly by bottom trawl and purse seine methods.

The spatial extent of the TRE 2 Quota Management Area (QMA) is equivalent to Fishery Management Area (FMA) 2, commonly known as 'Area 2'. Within TRE 2 trevally are harvested primarily by trawling, with a moderate contribution from the inshore set net fishery. The Area 2 trawl fleet operates between Cape Runnaway and Palliser Bay, with the majority of catch and effort centered in the inshore waters of Hawke Bay. Previous analysis of TRE 2 (Bentley & Kendrick 2015) identified two distinct TRE 2 fisheries: a mixed trawl fishery, which targets red gurnard (*Chelidonichthys kumu*, GUR), snapper (*Chrysophrys auratus*, SNA) and trevally, and a tarakihi (*(Nemadactylus macropterus*, TAR) target bottom trawl fishery. Catch-per-unit-effort (CPUE) indices were previously derived for each fishery using a Generalised Linear Model (GLM) approach (Bentley & Kendrick 2015).

The last analysis of TRE 2 (Bentley & Kendrick 2015) led the Ministry for Primary Industries (MPI) Northern Inshore Working Group to conclude that trevally in TRE 2 are probably part of the TRE 1 biological stock in the Bay of Plenty (Ministry for Primary Industries 2017). The variable CPUE indices evident for TRE 2 are thought to be due to the abundance in TRE 2 fluctuating due to the movement of fish into and out of this QMA. A stock assessment of TRE 1 was attempted in 2015 (McKenzie et al. 2016); this analysis found evidence of two biological stocks in TRE 1: an East Northland and a Bay of Plenty Stock. McKenzie et al. (2016) recommended that catch sampling be undertaken in TRE 2 in the future to determine the degree of stock separation between the TRE 1 and 2 quota management areas (QMAs) and that stock assessments for TRE 2 be done in the future in conjunction with TRE 1.

The most recent analysis of TRE 2 reported in the MPI (now Fisheries New Zealand) plenary document included data to 2009–10 (Ministry for Primary Industries 2017). This report updates the fisheries characterisation and CPUE indices to 2016–17. This project was funded by Fisheries Inshore New Zealand and conducted by Trident Systems.

Throughout this report fishing years refer to a 12 month period spanning 1 October to 30 September. The year quoted refers to the second calendar year of the fishing year. For example, the 1990 fishing year refers to fishing activity undertaken between 1 October 1989 to 30 September 1990.

2. METHODS

Statutory catch, effort and landings data for TRE 2 from the beginning of the 1990 fishing year (1 October 1989) to the end of the 2017 fishing year (30 September 2017) were sourced from the Ministry for Primary Industries `warehou` database. The dataset captured all fishing effort in FMA 2 that had potential to capture trevally (inshore trawls in Statistical Areas 011–016), regardless of whether trevally was captured.

2.1 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 29 effort records were corrected using values from records on the corresponding forms, matched on the form key. This approach was used for Catch Effort Landing Return (CELR) forms for the fields: primary method, target species and Statistical Area.

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. Effort records removed due to changes from the data grooming process are summarised in Table 1, further records were removed due to missing values.

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, conversion factor, and to remove duplicate landings. A small number of landings were removed during grooming by rule LADTH, which identifies landing records where the catch was not landed (destination types of P (Holding receptacle in the water), Q (Holding receptacle on land), or R (Retained on board)). The total landed catch by fishing year removed through this grooming process is plotted in Figure 1.

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

Table 1: Fishing effort grooming resulting in dropped effort records.

Code	Description	Number of records
FEMEM	Effort field missing	328
FEPMM	Primary method missing	66
FETSW	Target species invalid	204

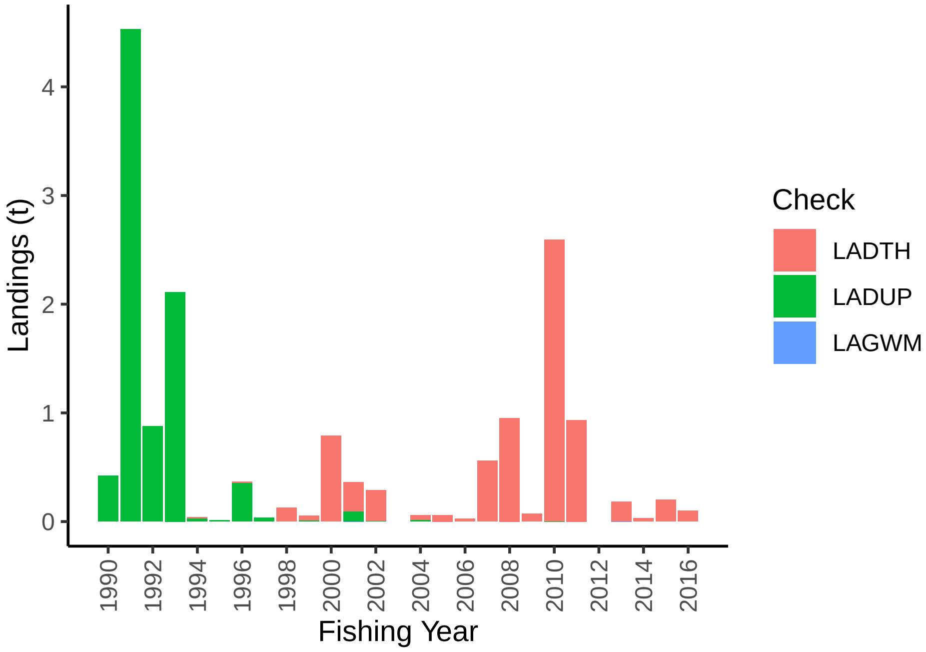

Figure 1: The trevally landings data removed from the TRE 2 CPUE analysis dataset, the bar colour indicates the grooming checks contributing to the removals.

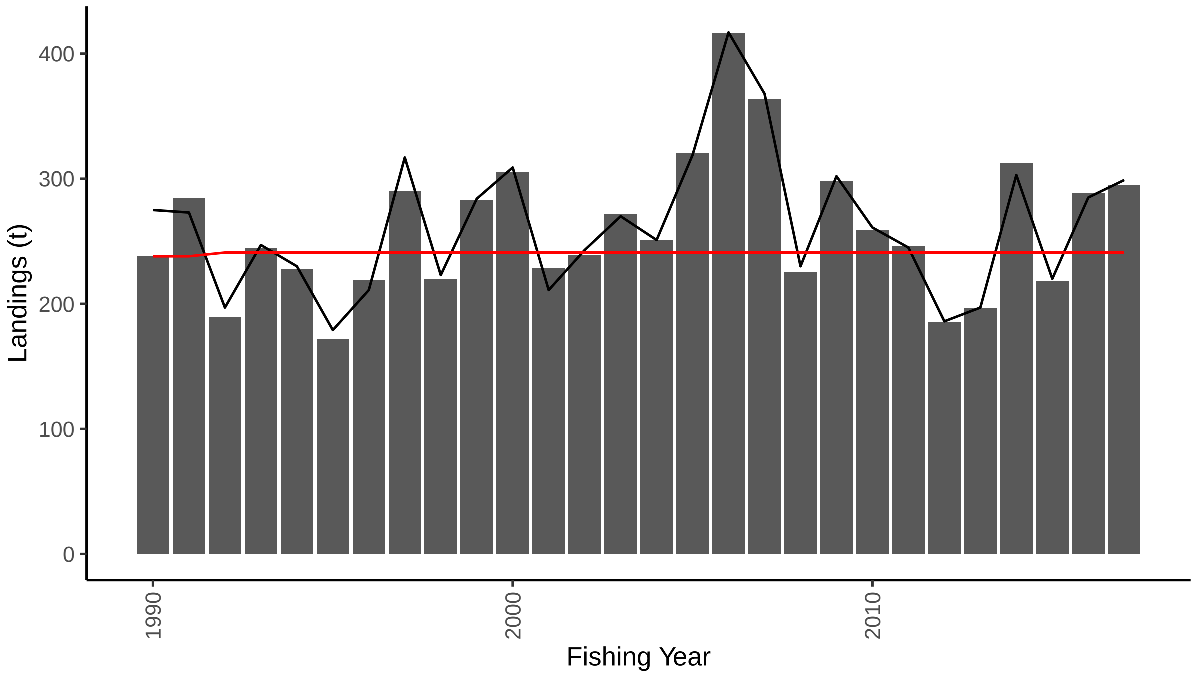

Figure 2: A comparison between the groomed TRE 2 annual landed catch (bars), Quota Management Returns (QMR, 1990–2001) and Month Harvest Returns (MHR, 2002–2015) (black line) and Total Allowable Commercial Catch (TACC, red line).

2.2 Analysis data sets

The data 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, regardless of whether trevally was captured. Landed catches of trevally 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, but when there were no landed catches they were apportioned according to effort.

For the bottom trawl fishing method, catch and effort data were generally recorded using CELR or Trawl Catch Effort and Processing Return (TCEPR) forms prior to 2008 and primarily on the Trawl Catch Effort Return (TCER) in subsequent years (Figure 3). Two separate CPUE data sets were configured based on the two main data formats: an aggregated data set configured to approximate the format of the CELR data which includes data from 1990 to 2017, and a trawl event-based data set that retains the detail of the TCER and TCEPR data formats from 2008 to 2017. 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 (following Starr 2007).

The configuration of the aggregated CPUE data set summarised effort records for each vessel fishing day followed 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.

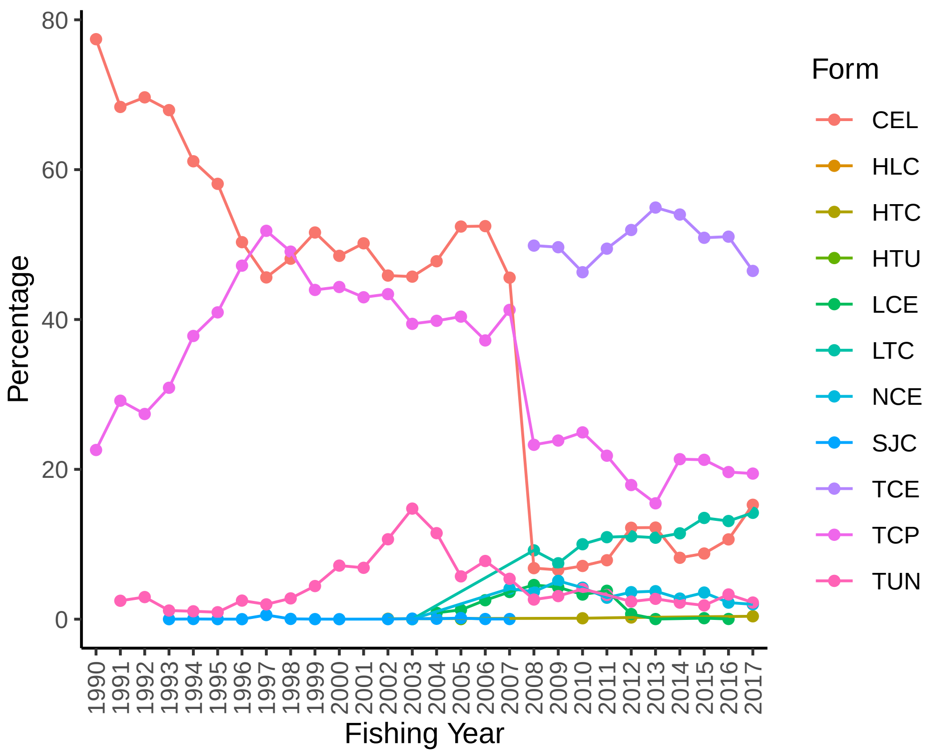

Figure 3: The reporting form types for events that landed TRE 2 from the 1990 to the 2017 fishing year. TCER forms were introduced for trawl vessels > 6m in the 2008 fishing year. Form type abbreviations are: CEL = Catch Effort Landing Return, HLC = High Seas Lining Catch Effort Return, HTC = High Seas Trawl Catch Effort Return, HTU = High Seas Tuna Lining Catch Effort Return, LCE = Lining Catch Effort Return, LTC = Lining Trip Catch Effort Return, NCE = Netting Catch Effort Landing Return, SJC = Squid Jigging Catch Effort Return, TCE = Trawl Catch Effort Return, TCP = Trawl Catch Effort and Processing Return, TUN = Tuna Lining Catch Effort Return.

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.

2.3 CPUE methods

2.3.1 Data filtering for CPUE analyses

When carrying out CPUE analyses, records were dropped if the fishing duration was less than 1 hour or if the daily aggregated effort was greater than 18 hours. For the tow-resolution data set, records were dropped if the duration exceeded 8 hours. Landings were excluded if they exceeded the 99th percentile and if the reported estimated catch differed significantly from the landed catch.

2.3.2 CPUE models

A Generalised Linear Model (GLM) approach was used to model the occurrence (presence/absence) of trevally catch and the magnitude of positive trevally catches. The dependent variable of the catch magnitude CPUE models was the natural logarithm of catch. For the positive catch CPUE models, a Weibull error structure was adopted following an evaluation of alternative distributions (lognormal, gamma). The presence/absence of trevally 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 listed 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` of Bentley et al. (2012).

Table 2: The variables offered to the binomial and Weibull vessel-day resolution TRE 2 CPUE model for model selection.

Variable	Definition	Data type	Range
fyear	Fishing year	Categorical (28)	1990–2017
vessel	Fishing vessel	Categorical (47)	
month	Month	Categorical (12)	Jan–Dec
area	Statistical Area	Categorical (6)	011–016
area * month	Area and month combination	Categorical (72)	
duration	Natural logarithm of trawl duration (hours)	Continuous	ln(1:24)
effort	Number of trawls in the vessel-day	Continuous	1–6
target	Most frequent target species for the vessel-day	Categorical (4)	TRE, SNA, GUR, TAR

Table 3: The variables offered to the binomial and Weibull TCER resolution TRE 2 CPUE model for model selection.

Variable	Definition	Data type	Range
fyear	Fishing year	Categorical (10)	2008:2017
vessel	Fishing vessel	Categorical (24)	
month	Month	Categorical (12)	Jan–Dec
area	Statistical Area	Categorical (6)	011–016
area * month	Area month combination	Categorical (72)	
duration	Duration of fishing effort for the day (hours)	Continuous	ln(1–6)
effort	Number of trawls in the day	Continuous	1–10
target	Most frequent target species for the vessel-day	Categorical (4)	TRE, SNA, GUR, TAR
latitude	Absolute start latitude for the trawl	Continuous	37.45° S–40.915° S
longitude	Reported start longitude for the trawl	Continuous	176.2° E–178.73° E
speed	Speed of the trawl (knots)	Continuous	1.9–4
distance	Distance trawled (N. miles)	Continuous	2–14
width	Wingspread of the trawl gear (m)	Continuous	5–40
height	Headline height of trawl gear (m)	Continuous	0.5–15
depth	Depth of the bottom (m)	Continuous	1–150

3. CHARACTERISATION OF THE TRE 2 FISHERY

TRE 2 is primarily a bottom trawl fishery, although a small set net fishery operated throughout the series (Figure 4). There were sporadic TRE 2 catches from purse seine and Danish seine fisheries (Figure 4).

Statistical Areas 013 and 014 produced the largest TRE 2 catches throughout the series (Figure 5). Other areas consistently generated smaller catches, although Statistical Areas 015 and 016 sporadically produced larger catches (Figure 5).

TRE 2 catches occurred whilst targeting a range of species, although gurnard and tarakihi targeting captured the most trevally (Figure 6). Trevally was a common target species in the TRE 2 fishery early in the series but has become less prevalent since the turn of the century (Figure 6).

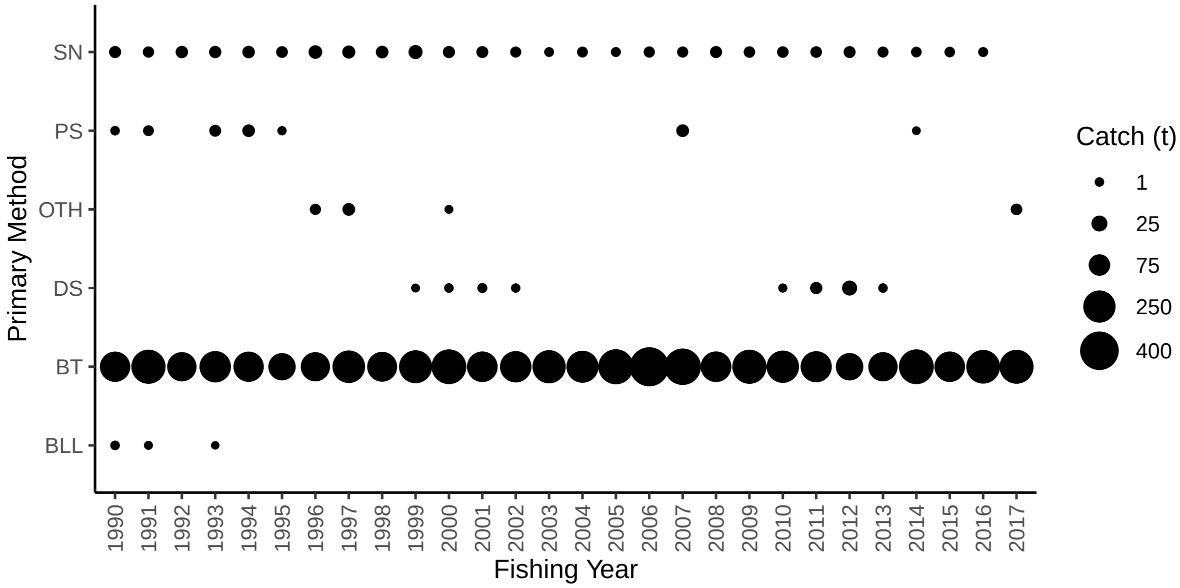

Figure 4: TRE 2 catch by primary method from the 1990 to the 2017 fishing year. BLL = bottom longline, BT = bottom trawl, DS = Danish seine, PS = purse seine, SN = set net. OTH represents all other methods that captured TRE 2.

Figure 5: TRE 2 catch by Statistical Area from the 1990 to the 2017 fishing year.

Most trevally catch since 2008 has occurred in depths less than 100 m (Figure 7). Catch of trevally in TRE 2 arises from fishers targeting a range of species with each target species contributing to the overall distribution of trevally catch depths in TRE 2 (Figure 7). For example, trevally caught by fishers targeting flatfish occurs in the shallowest depths. Trevally catch from fishers targeting snapper, trevally and gurnard peaks at depths around 30 m. On the other hand, catch of trevally by fishers targeting tarakihi tends to occur slightly deeper and over a broader range of depths.

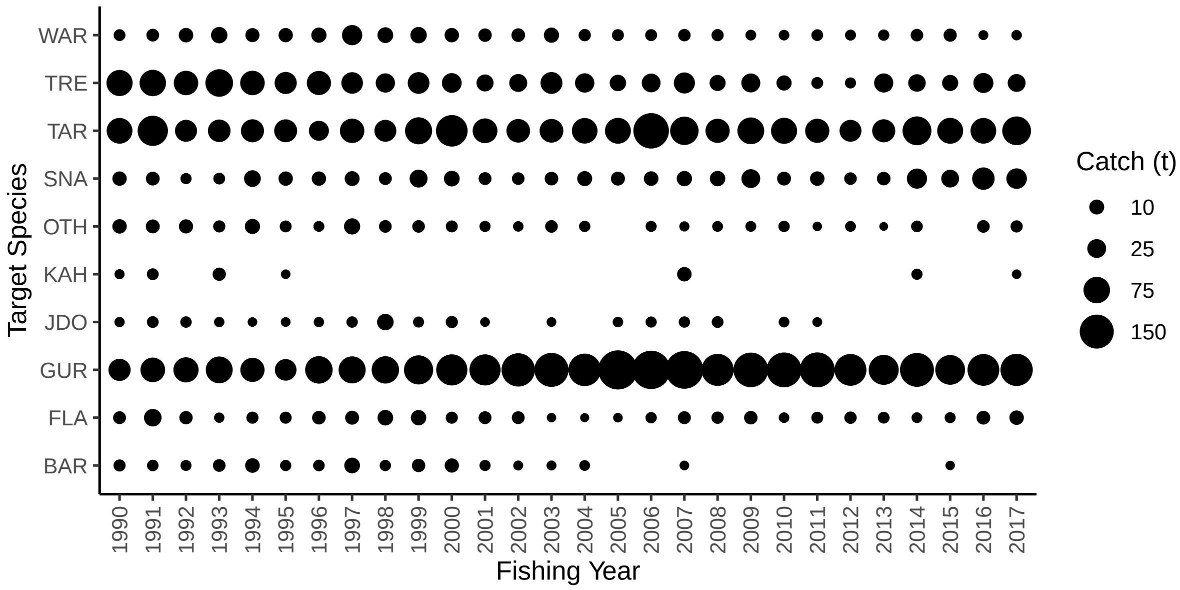

Figure 6: TRE 2 catch by target species from the 1990 to the 2017 fishing year. BAR = barracouta, GUR = red gurnard, JDO = John dory, KAH = kahawai, SNA = snapper, TAR = tarakihi, TRE = trevally, WAR = common warhou. All flatfish species have been encoded FLA; OTH represents all other target species that were reported whilst catching TRE 2.

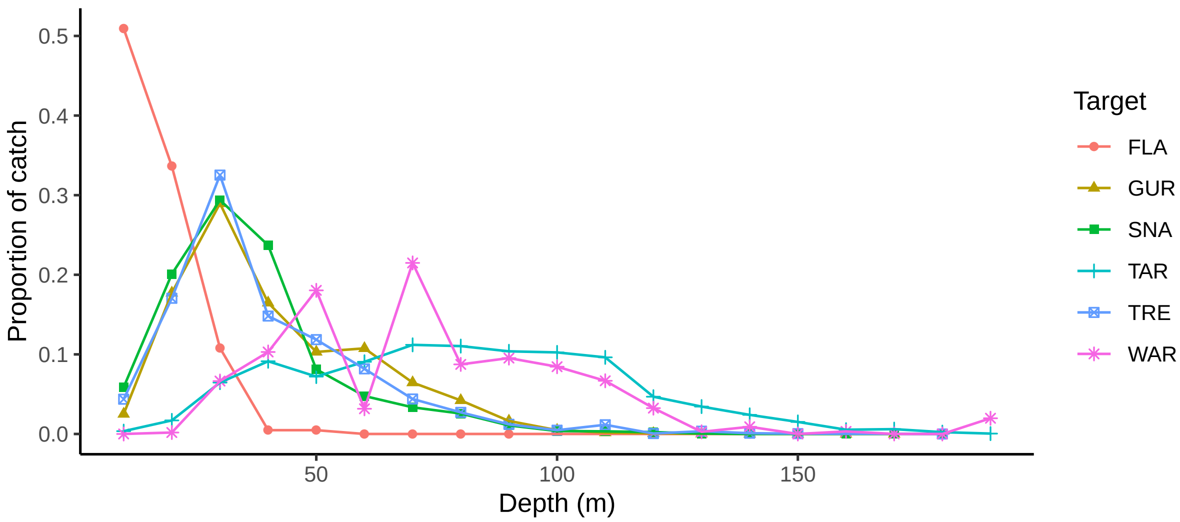

Figure 7: Proportion of trevally catch by depth in the TRE 2 bottom trawl fisheries. Catches have been aggregated into 10 m depth bins. Only TCER data (2008–2017 fishing years) were used.

The majority of the TRE 2 catch was from Statistical Areas 013 and 014 and was principally taken when targeting gurnard or tarakihi (Figure 8). Trevally catches in other target fisheries reflected the distribution of those fisheries; for example, catches when targeting snapper were predominately from the northern Statistical Areas (011:013; Figure 8).

The TRE 2 fishery has had a uniform distribution of catch between October and May, with a decline in catch in all areas between June and August (Figure 9). This temporal distribution of trevally catch was consistent throughout the series (Figure 10). Statistical areas 015 and 016 had an increased trevally catch between March and May (Figure 9).

Trevally catch from all target species declined between June and August; this trend is most pronounced in the trevally target fisheries (Figure 11).

TRE 2 is primarily caught in a mixed species trawl fishery, where tarakihi and gurnard were the predominant target species (Figure 12). The relative contributions of the bottom trawl fisheries have been consistent throughout the series, although 'BT(OTH)' has contributed lower TRE 2 landings since 1997 (Figure 12).

Although the majority of the TRE 2 catch is taken in inshore waters between Tolaga Bay (at the southern end of Statistical Area 012) and Flat Point (in the northern part of Statistical Area 015), there is also an area of high TRE 2 catch in Palliser Bay off the North Island south coast (Statistical Area 016; Figure 13). TRE 2 catch-per-unit-effort was fairly consistent along the FMA 2 coastline with a slight increase between Herbertville and Palliser Bay (Figure 14).

TRE 2 effort was characterised after aggregating the data to vessel-day resolution as recommended by Langley (2014). Aggregation forms a contiguous dataset from 1990 to 2017 by accounting for the change in data resolution with the introduction of TCER forms in 2008 (Figure 15). The pattern of aggregated TRE 2 fishing effort by Statistical Area showed the majority of effort was within Hawke Bay (within Statistical Areas 013–014) with the rest of the Statistical Areas in FMA 2 receiving moderate effort (Figure 16). Fishing effort was targeted at tarakihi and gurnard, with fluctuating levels of flatfish target (Figure 17). The patterns of fishing effort by species and area (Figure 16, Figure 17) were generally consistent with the patterns of catch (Figure 5, Figure 6). However, there is an indication of reduced effort from the 2000 fishing year (Figure 15), without a corresponding decline in catch (Figure 10).

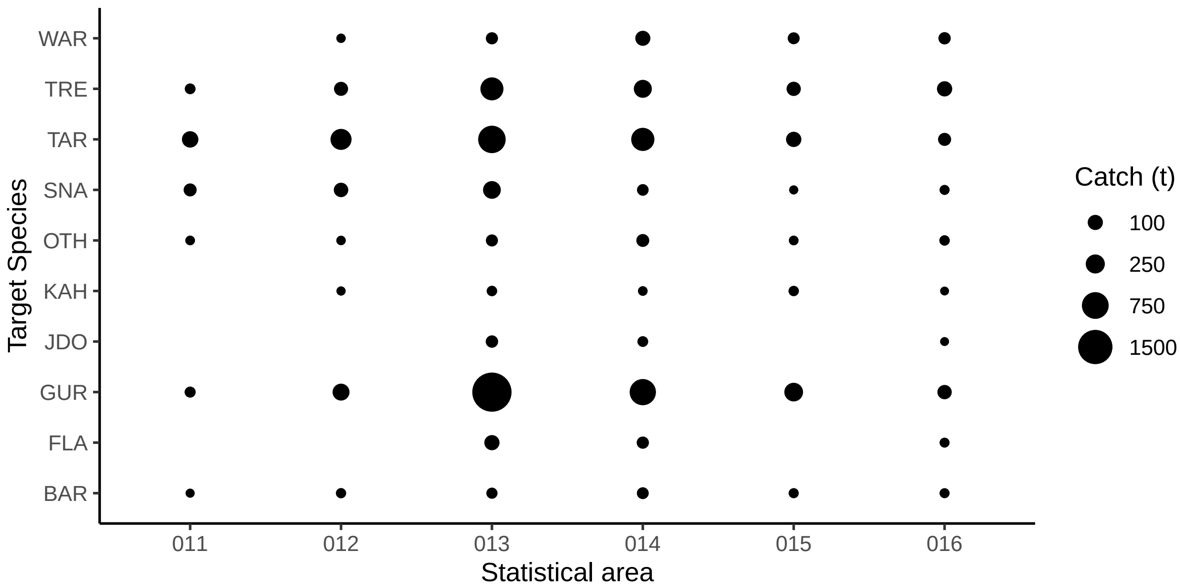

Figure 8: TRE 2 catch by Statistical Area and target species aggregated from the 1990 to the 2017 fishing year.

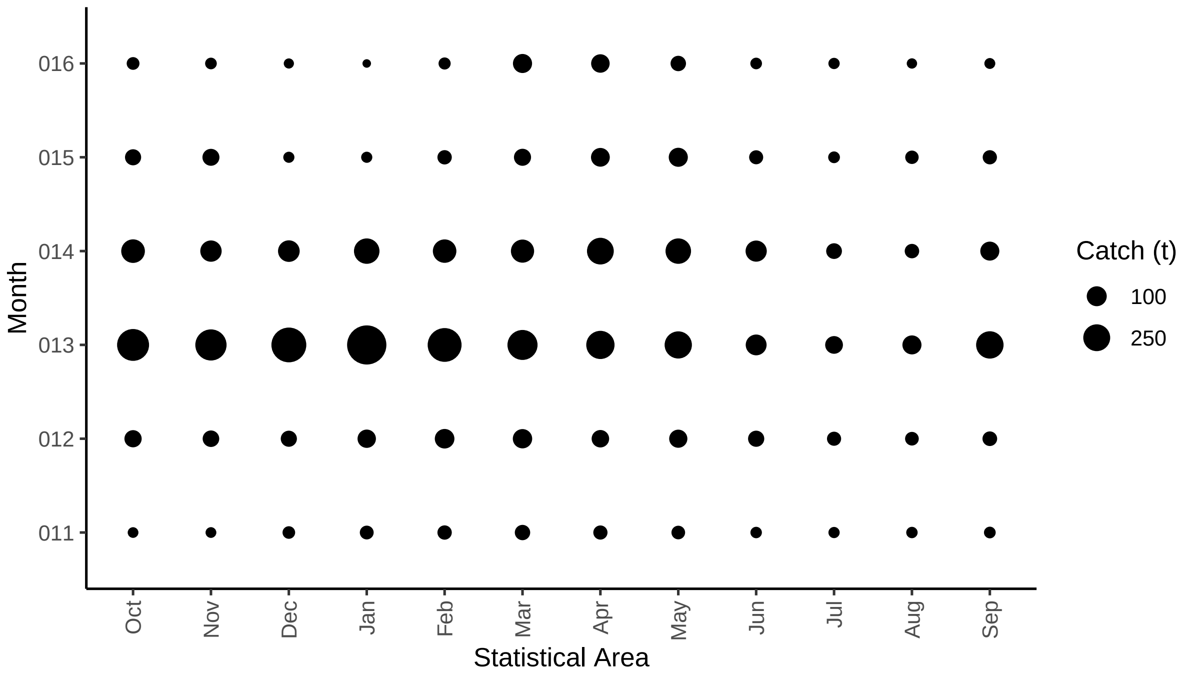

Figure 9: TRE 2 catch by Statistical Area and month aggregated from the 1990 to the 2017 fishing year.

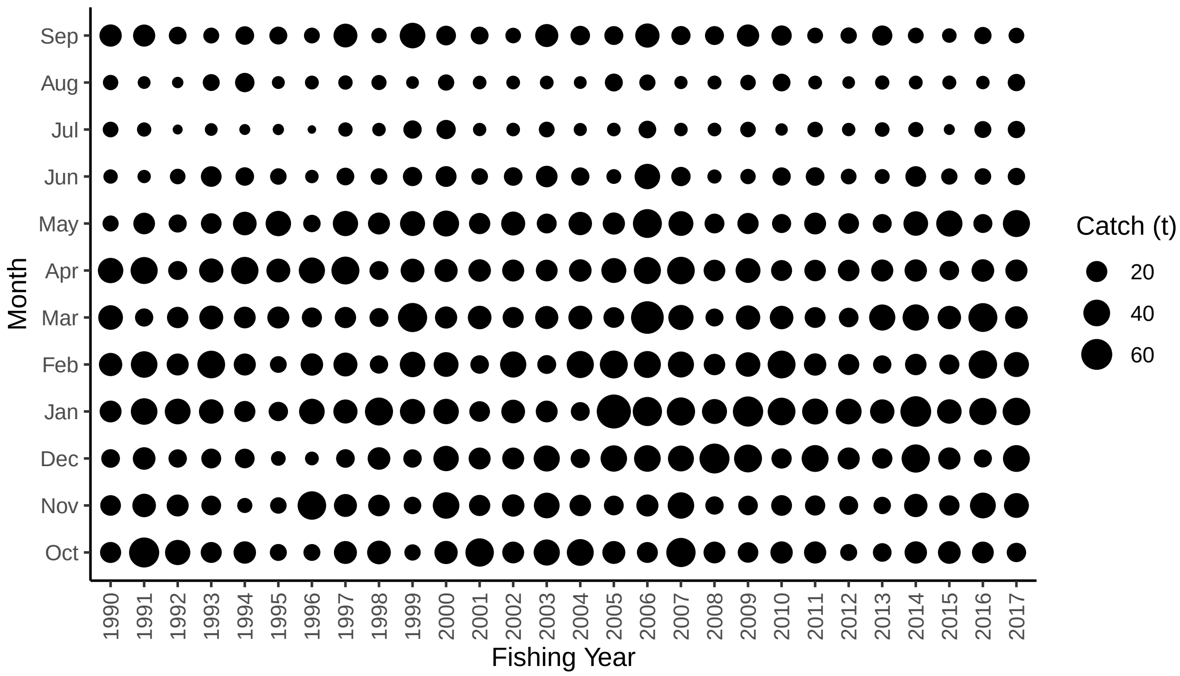

Figure 10: TRE 2 catch by fishing year and month between the 1990 to the 2017 fishing year.

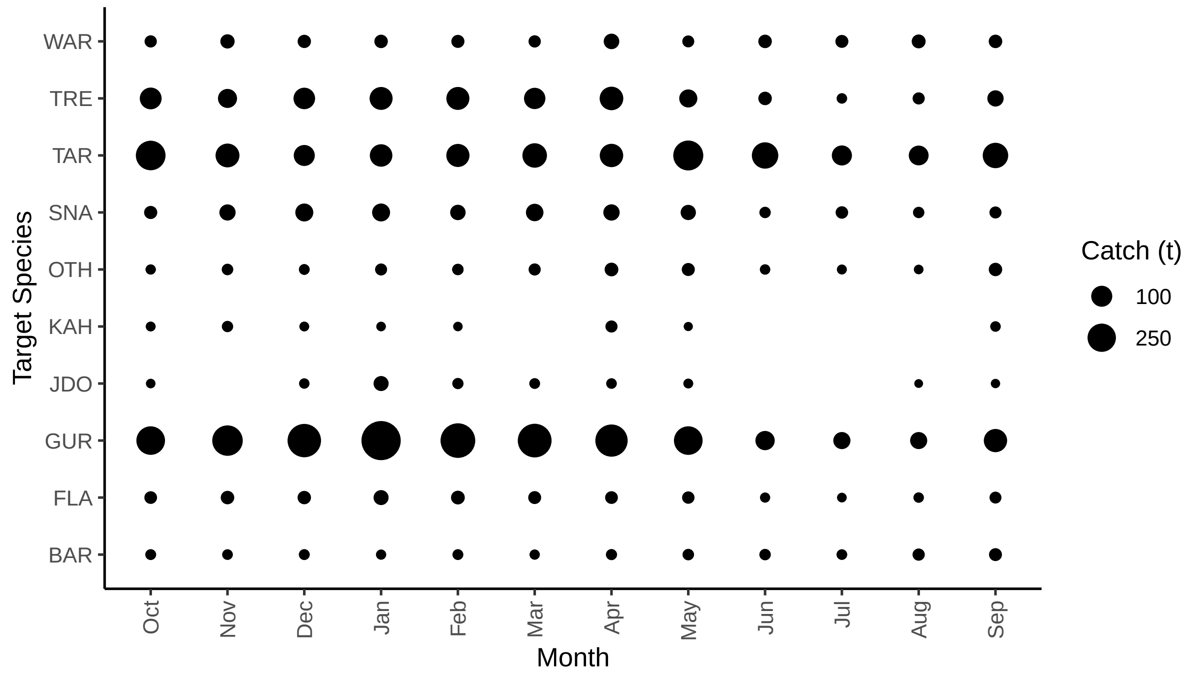

Figure 11: TRE 2 catch by month and target species aggregated from the 1990 to the 2017 fishing year.

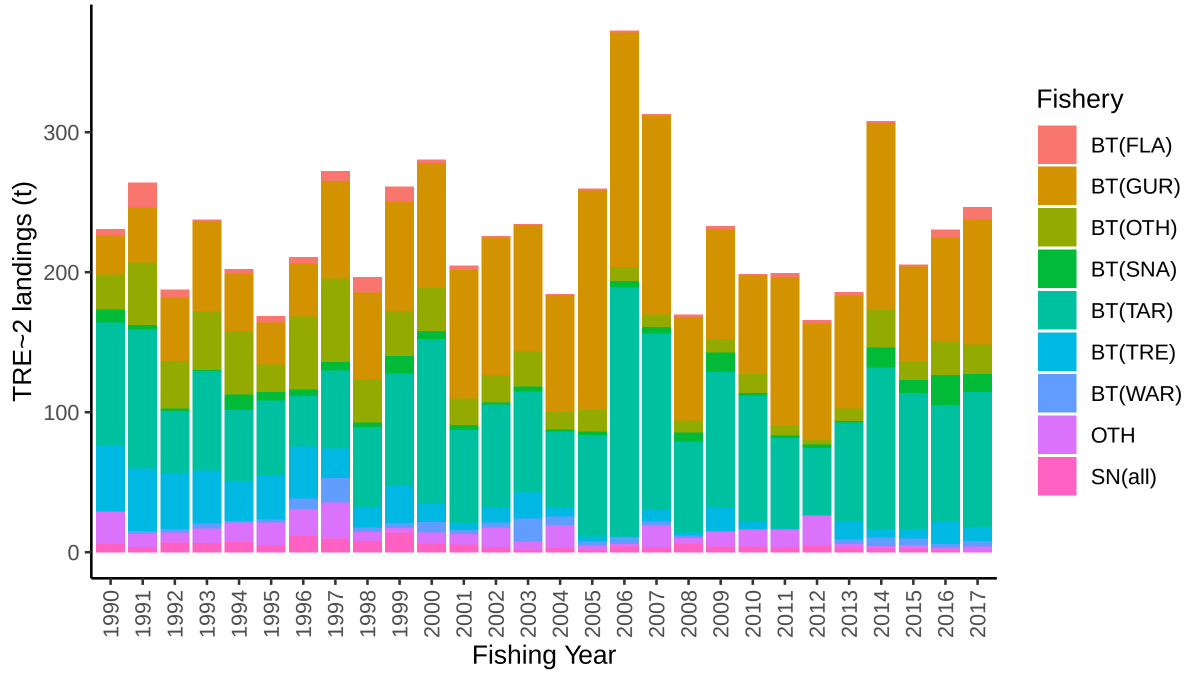

Figure 12: Trevally landings from the key target trawl and set net fisheries in TRE 2 from the 1990 fishing year to the 2017 fishing year, with landings from other fisheries grouped as OTH.

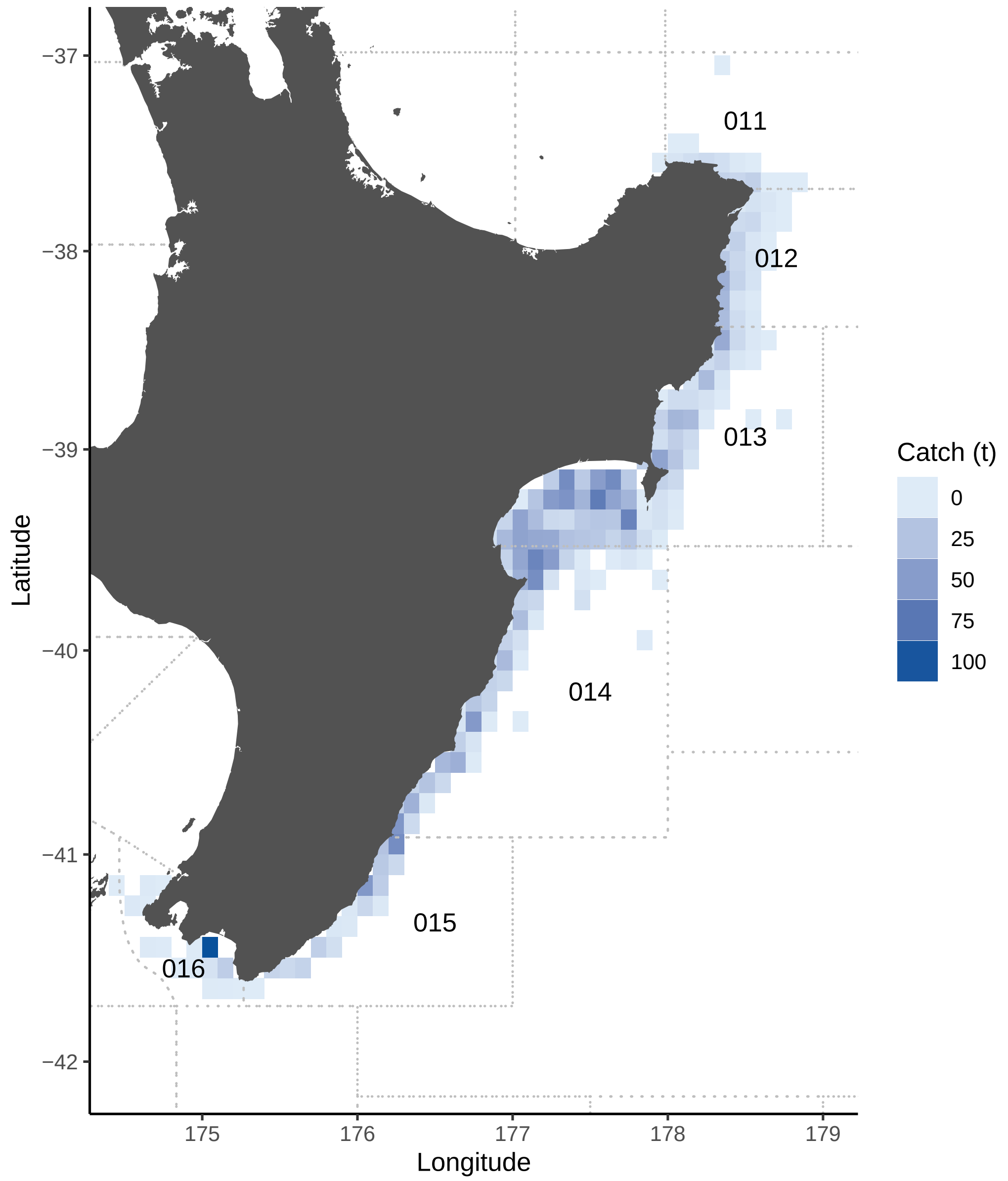

Figure 13: The spatial distribution of TRE 2 catch. Catches are aggregated within a 0.1 x 0.1 degree bin between the 2008 and 2017 fishing years, with Statistical Area boundaries shown for reference.

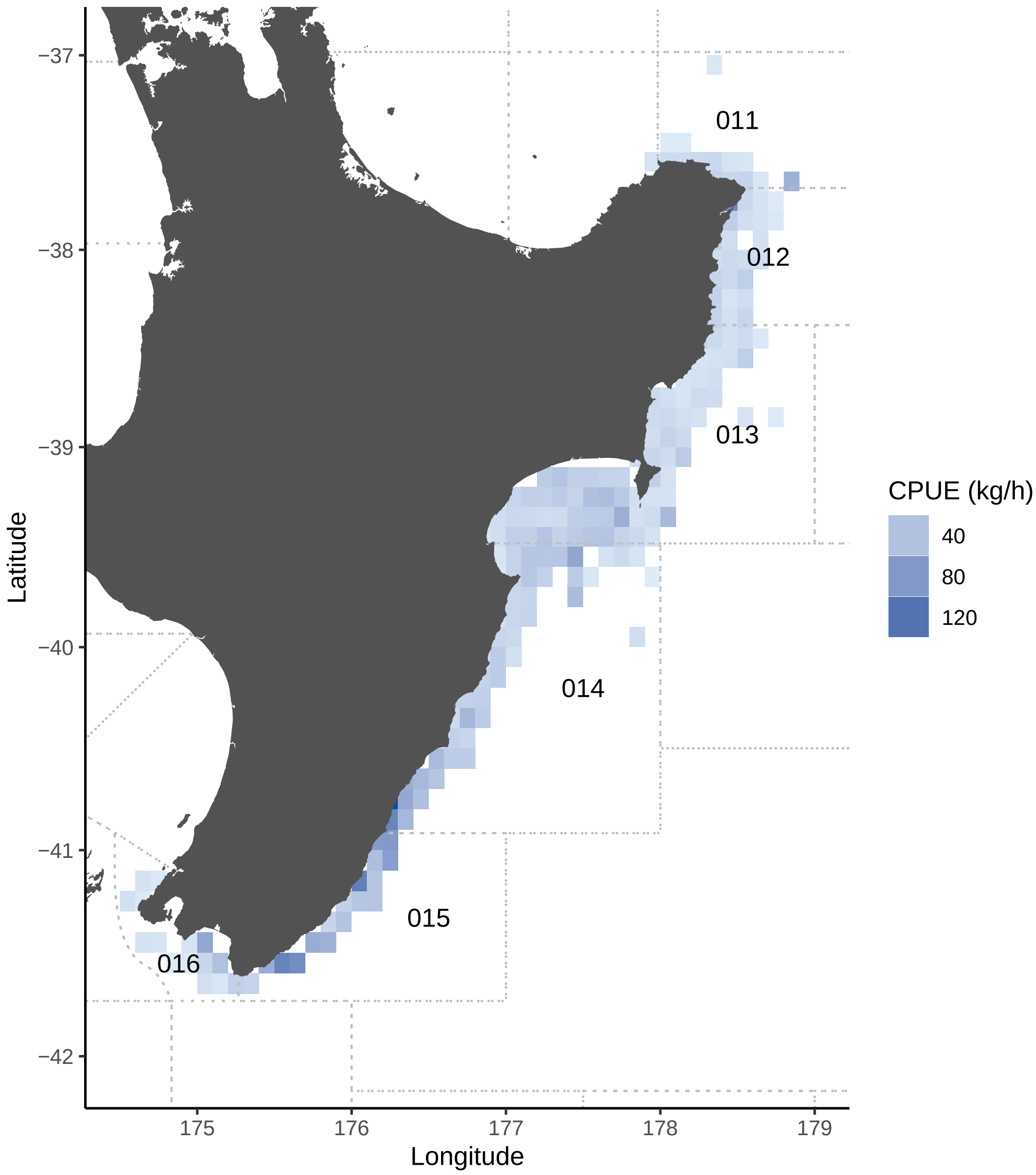

Figure 14: The spatial distribution of TRE 2 catch-per-unit-effort. Raw CPUE is plotted for 0.1 x 0.1 degree bins using data from the 2008 to 2017 fishing years, with Statistical Area boundaries shown for reference.

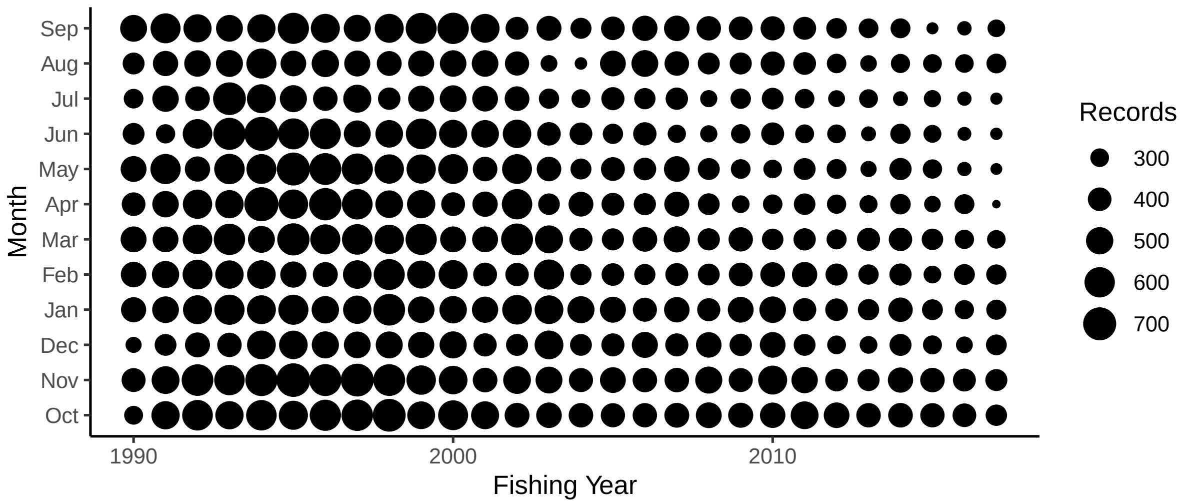

Figure 15: The number of vessel days in the TRE 2 dataset by month and fishing year from the 1990 to the 2017 fishing year.

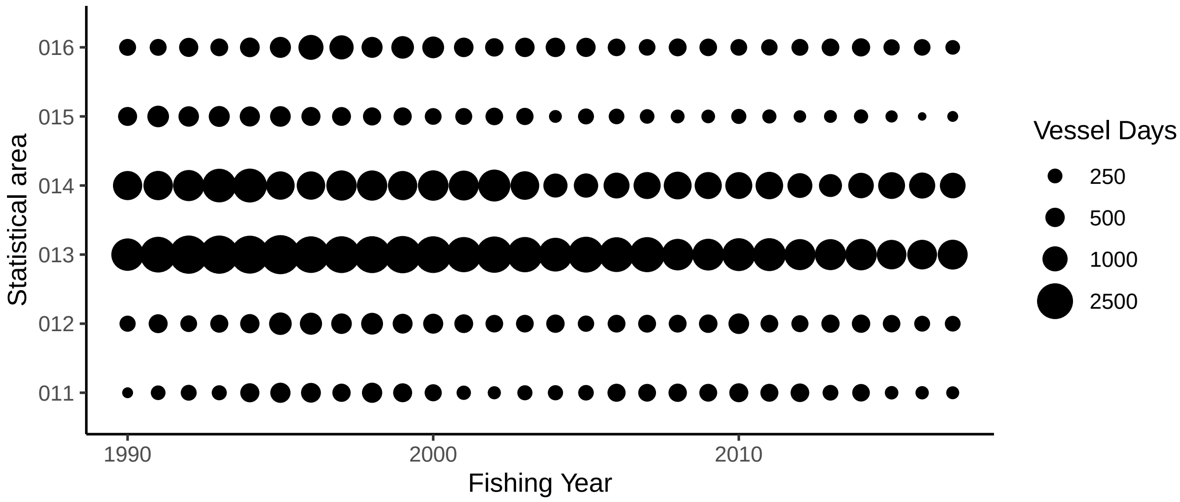

Figure 16: TRE 2 vessel days by Statistical Area from the 1990 to the 2017 fishing year.

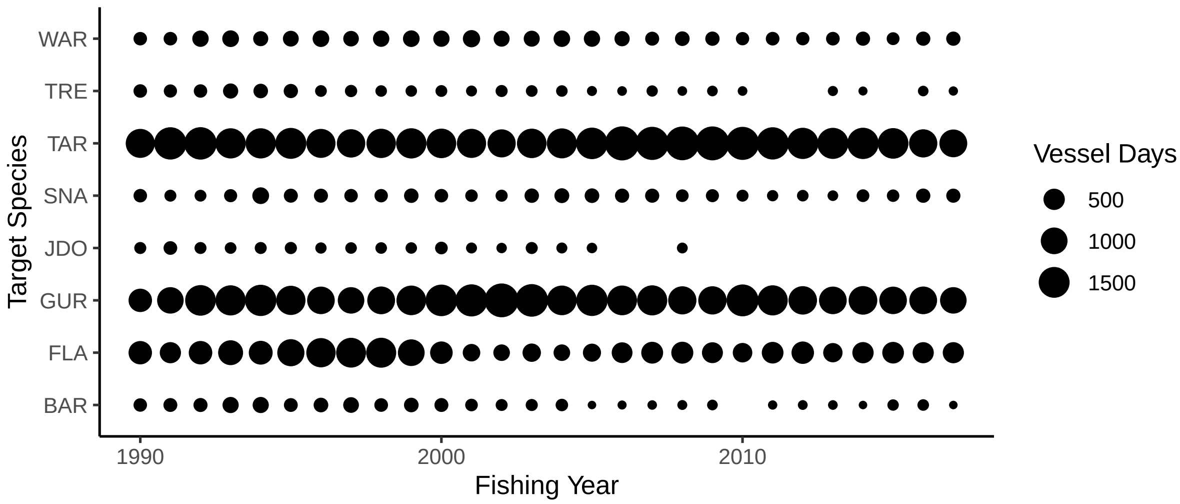

Figure 17: TRE 2 vessel days by reported target species from the 1990 to the 2017 fishing year. The FLA category specifies combined trevally when targeting any flatfish species.

4. BT(MIX) AGGREGATED CPUE ANALYSIS

The BT-MIX vessel-day fishery is defined as follows:

- Form type (CELR, TCEPR, TCER)
- Primary method: bottom trawl (BT) (excluding Precision Bottom Trawl, PRB)
- Target species (GUR, SNA, TRE, TAR)
- Fishing effort conducted within Statistical Areas 011, 012, 013, 014, 015 and 016
- Fishing effort conducted between 1 Oct 1989 and 30 Sept 2017

Trevally became more prevalent in trips within TRE 2 from 1990 to 2017 (Table 4). The number of vessels operating in the fishery has declined throughout the series; however the total effort remained consistent until 2011, after which it declined. TRE 2 catch has fluctuated throughout the series (Table 4).

Table 4: Summary of the TRE 2 vessel-day aggregated data set. Records represent a row in the effort dataset while effort numbers indicate the number of tows. Trips caught and days caught are the percentage of trips and days respectively in the BT-MIX data set with TRE catches.

Fishing Year	Vessels	Trips	Records	Effort (num)	Effort (hrs)	Catch (t)	Trips caught	Days caught
1990	57	1 099	2 141	5 295	18 920	184.6	37.2	29.5
1991	64	1 345	3 012	7 469	26 432	235.8	33.2	27.1
1992	74	1 784	3 701	8 595	32 226	154.1	29.4	23.6
1993	66	1 467	3 187	7 839	30 678	196.2	35.3	26.8
1994	70	1 703	3 774	8 365	31 961	168.4	26.4	21.4
1995	62	1 555	3 728	7 806	28 342	127.6	24.1	18.9
1996	60	1 247	3 375	7 896	23 494	161.8	20.2	15.1
1997	51	1 113	2 874	5 771	21 145	176.9	29.3	24.6
1998	51	1 199	3 124	6 459	23 571	145.2	25.5	20.6
1999	58	1 434	3 765	8 064	27 981	221.9	30.6	26.4
2000	50	1 407	3 617	7 602	29 700	266.7	44.1	35.0
2001	51	1 464	3 761	7 598	28 564	182.1	34.5	26.6
2002	46	1 565	3 945	7 881	28 769	205.5	34.1	28.8
2003	45	1 458	4 052	8 041	30 285	231.4	39.4	31.1
2004	43	1 273	3 782	7 476	27 520	223.7	36.0	27.4
2005	39	1 391	4 407	8 735	32 753	294.0	35.4	25.0
2006	48	1 419	4 687	9 386	34 094	391.2	43.4	33.9
2007	36	1 299	4 747	9 121	32 410	323.1	42.8	34.9
2008	39	1 088	8 579	8 580	30 582	198.7	42.6	29.4
2009	38	1 145	8 856	8 854	31 550	267.7	42.3	30.7
2010	41	1 261	9 705	9 705	34 493	225.1	41.2	29.3
2011	38	1 069	8 990	8 990	31 437	206.0	49.0	33.4
2012	38	1 011	7 875	7 875	27 856	140.3	42.8	29.2
2013	34	915	7 687	7 687	27 669	171.2	39.6	27.6
2014	37	986	8 289	8 289	29 594	269.0	48.1	34.5
2015	38	924	7 395	7 395	27 084	190.6	39.3	28.7
2016	34	935	6 593	6 593	24 645	251.8	35.0	28.7
2017	31	793	6 199	6 199	23 275	247.9	46.9	33.5

4.1 Core vessel selection

This analysis utilised a core fleet definition of vessels operating in the BT-MIX fishery for a minimum of 8 years and conducting 5 trips in each of these years (Figure 18). This resulted in a core fleet of 35 vessels which accounted for 81.5% of the TRE 2 vessel-day catch.

There has been turnover in the TRE 2 fleet over the time series, with a smaller fleet operating over the last decade (Figure 19). The proportion of vessel-days fished by core vessels that caught trevally had no long-term trend over the series (Figure 20A) whilst raw catch-per-unit-effort was at a generally higher level until the late 1990s, then at a somewhat lower level before increasing in 2016 and 2016 to a level similar to that observed in the 1990s (Figure 20B). The dataset after core vessel selection is summarised in Table 5.

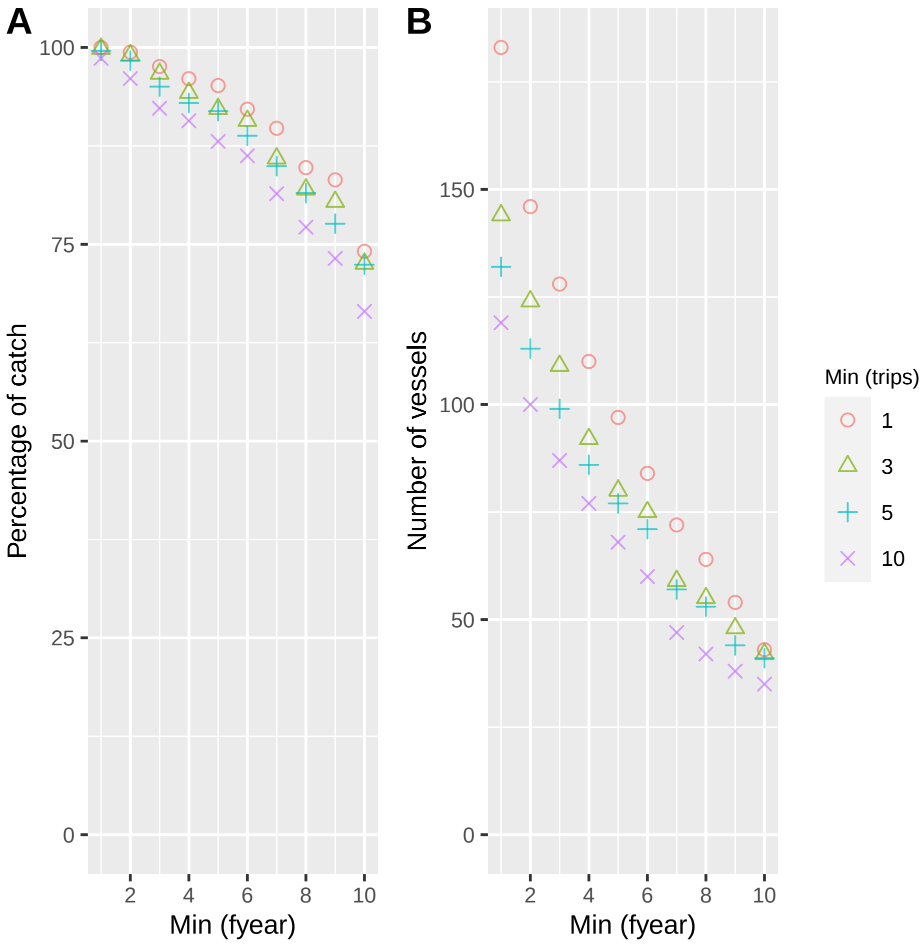

Figure 18: Percentage of catch (left panel) and number of vessels (right panel) in the BT-MIX aggregated dataset with alternative criteria for core fleet selection.

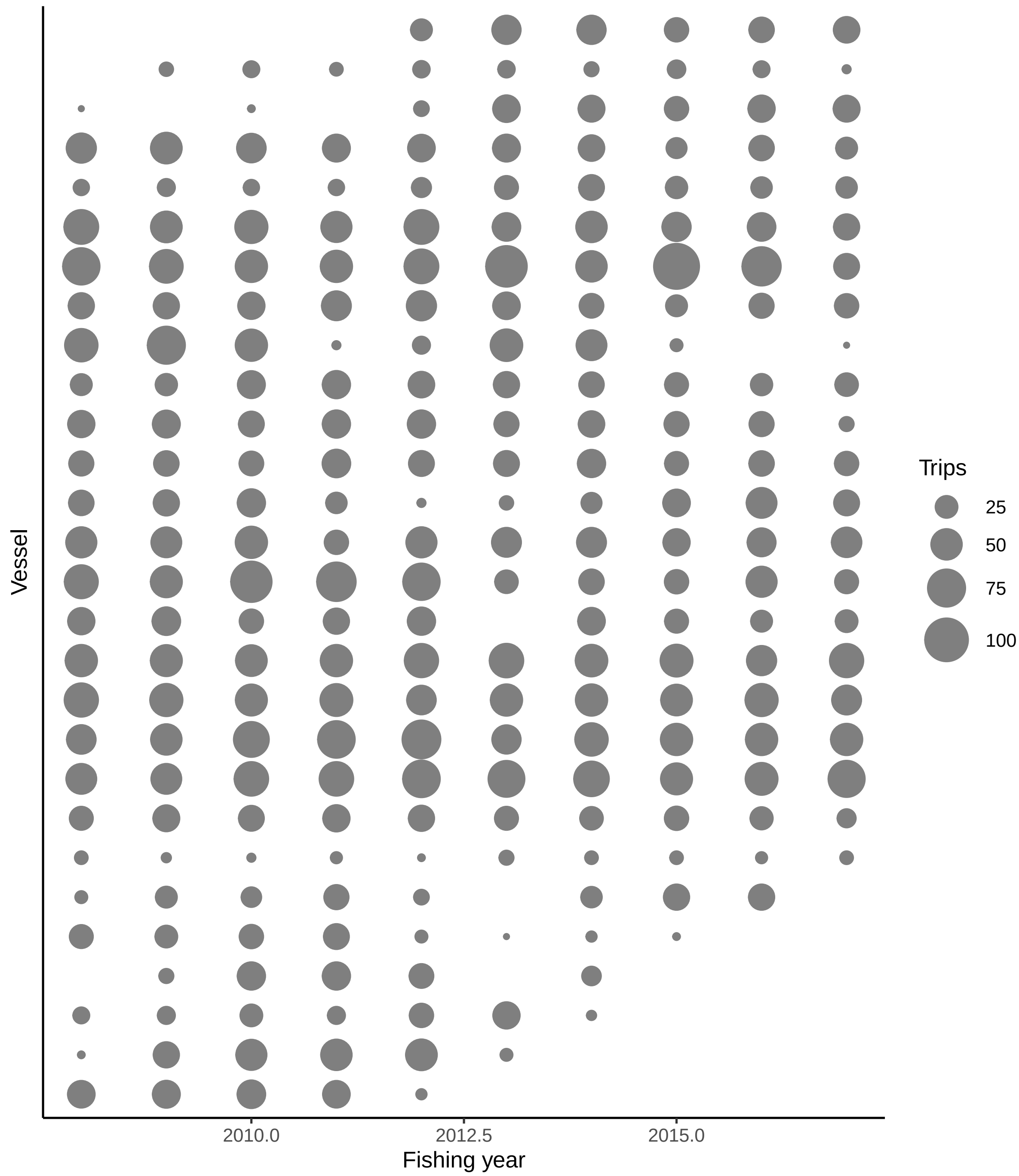

Figure 19: Number of trips by fishing year for core TRE 2 vessel-day vessels. The area of circles is proportional to the number of trips.

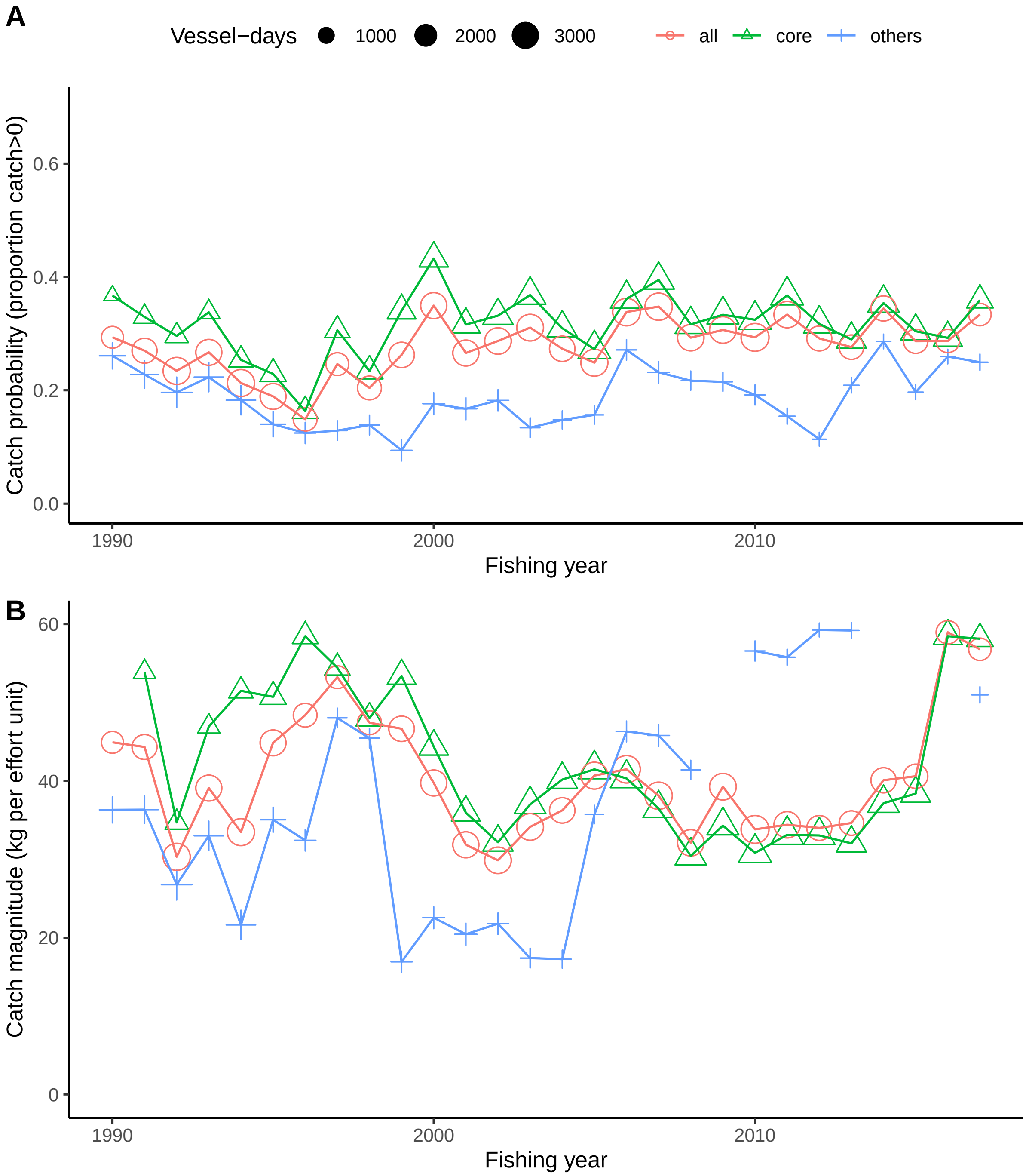

Figure 20: The proportion of (A) vessel-days with positive catch, and (B) the raw CPUE (geometric mean of catch per vessel-day where catch was positive) for all TRE 2 vessels, core vessels and non-core vessels. Point size is proportional to the number of vessel-days.

Table 5: Summary of TRE 2 vessel-day data subset by fishing year after the data was restricted to the core fleet and outliers were removed. Records represent a row in the effort dataset, trips caught represents the percentage of trips which reported catching TRE and days caught represents the percentage of days with positive catch. Fishing years are labelled by the later calendar year e.g. 1990 = 1989–90.

Fishing Year	Vessels	Trips	Records	Effort (num)	Effort (hrs)	Catch (t)	Trips caught	Days caught
1990	14	355	658	1 621	5 917	89.7	47.0	36.7
1991	18	530	1 258	3 055	11 044	133.0	42.3	33.0
1992	20	623	1 445	3 353	12 366	79.9	38.4	29.8
1993	20	512	1 245	3 219	12 001	113.4	46.9	33.8
1994	20	652	1 730	3 576	13 725	110.0	31.9	25.4
1995	20	700	2 113	4 728	16 768	92.3	32.9	22.9
1996	22	581	2 214	4 946	15 494	87.2	26.5	16.3
1997	20	558	1 961	4 049	15 267	138.9	43.4	30.6
1998	22	660	2 108	4 582	17 085	103.9	35.6	23.4
1999	21	796	2 561	5 369	20 498	193.3	45.2	34.0
2000	20	809	2 358	5 308	21 482	232.9	61.7	43.3
2001	24	825	2 496	5 217	20 094	145.8	46.4	31.6
2002	24	939	2 765	5 679	21 011	171.7	44.8	33.3
2003	25	975	3 028	6 157	23 267	219.0	51.7	36.8
2004	24	899	2 899	5 900	21 581	206.4	42.5	31.0
2005	24	1 016	3 458	7 070	26 481	243.8	41.6	27.3
2006	27	1 026	3 275	7 047	25 624	271.9	49.2	36.3
2007	23	900	3 066	6 571	23 137	238.1	49.0	39.6
2008	25	813	6 600	6 601	23 373	159.9	47.7	31.8
2009	24	860	6 886	6 887	24 235	191.6	47.8	33.4
2010	24	910	7 467	7 467	26 285	178.1	47.9	32.4
2011	23	833	7 663	7 663	26 986	183.2	57.4	36.8
2012	24	815	7 006	7 006	24 888	129.9	49.9	31.8
2013	20	722	6 390	6 390	23 242	138.0	42.4	29.0
2014	22	793	7 164	7 164	25 648	218.2	53.2	35.4
2015	21	736	6 229	6 229	22 714	155.9	44.6	30.5
2016	19	764	5 566	5 566	20 654	213.5	36.1	29.2
2017	19	603	4 759	4 759	17 725	199.2	49.1	35.9

4.2 CPUE Models

4.2.1 Occurrence of positive TRE 2 catch

Occurrence of positive trevally catch was modeled with a binomial GLM with a logistic link function. The full list of terms offered to the model is given in Table 2.

The binomial model selected (Table 6) was:
$\sim fyear + vessel + area * month + target + poly(log(duration), 3)$

Table 6: Summary of stepwise selection for TRE 2 vessel-day occurrence of positive catch. Model terms are listed in the order of acceptance to the model. AIC: Akaike Information Criterion; * indiates terms included in final model.

Step	Df	AIC	Deviance explained	Additional deviance	Included
Fishing year	27	85705	0.5	0.5	*
Vessel	34	80837	6.2	5.8	*
Area * Month	71	78462	9.1	2.9	*
Target	3	77009	10.8	1.7	*
Duration	3	76161	11.8	1.0	*
Effort number	3	76110	11.9	0.1	

Trevally is generally caught on 30–40% of vessel days (Figure 21). Occurrence dipped to below 20% of days in the late 1990s, but has subsequently increased, remaining fairly stable since the early 2000s.

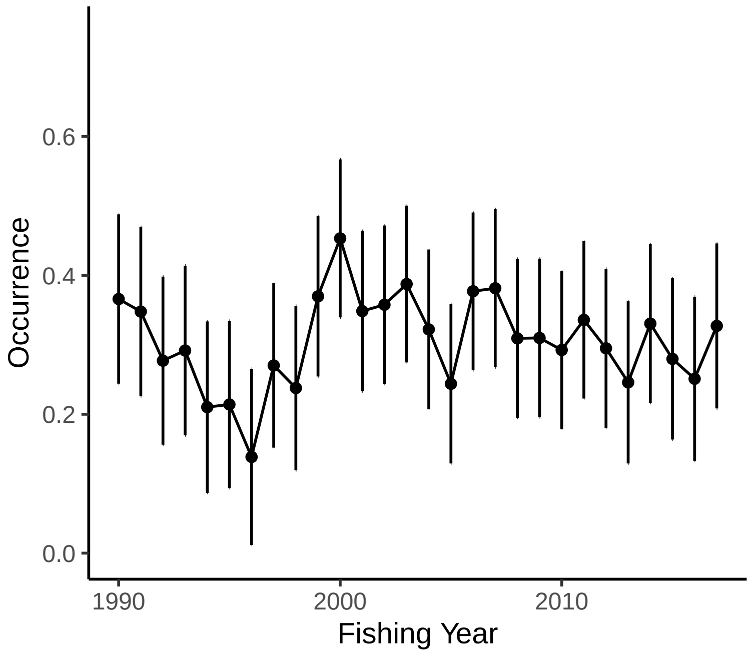

Figure 21: Indices for the occurrence of trevally catch in the BT-MIX fishery.

4.2.2 Magnitude of positive TRE 2 catch

The magnitude of positive trevally catches was modeled with a Weibull GLM. The full list of terms offered to the model is given in Table 2.

The Weibull model selected was (Table 7):
$\sim fyear + vessel + area * month + target + poly(log(duration), 3)$

Table 7: Summary of stepwise selection for TRE 2 vessel-day magnitude of positive catch. Model terms are listed in the order of acceptance to the model. AIC: Akaike Information Criterion; * indicates terms included in final model.

Step	Df	AIC	Deviance explained	Additional deviance	Included
Fishing year	27	394681	1.3	1.3	*
Vessel	34	385353	23.0	21.7	*
Area * Month	71	381552	29.4	6.4	*
Target	3	379889	32.3	2.8	*
Duration	3	378647	34.0	1.8	*

4.3 Model diagnostics

Model residuals from the positive log(catch) model show a reasonable approximation to the Weibull distribution. The Weibull distribution struggled to fit smaller TRE 2 catches (Figure 22).

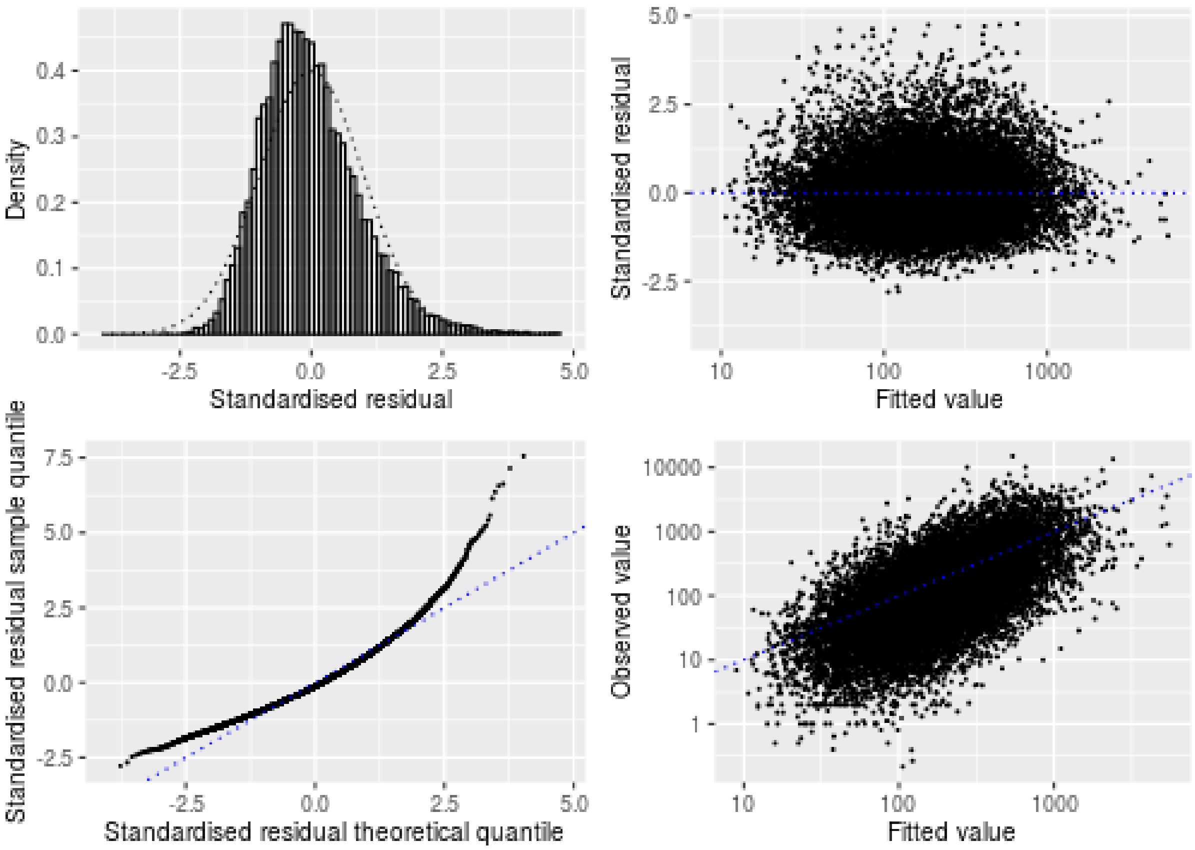

Figure 22: The Weibull diagnostic plots for the TRE 2 vessel-day model. top left: Standardised residuals from the accepted generalised linear model fit; top right: The standardised residuals versus the fitted values; bottom left: Quantile-quantile plot of observed response versus likelihood of the distribution of these values; bottom right: Observed values vs fitted values.

The Weibull distribution was selected based on best fit of model residuals and smallest AIC, compared to alternate distributions (Figure 23). There is no apparent pattern to the annual residuals for TRE 2 target species or Statistical Area (Figure 24).

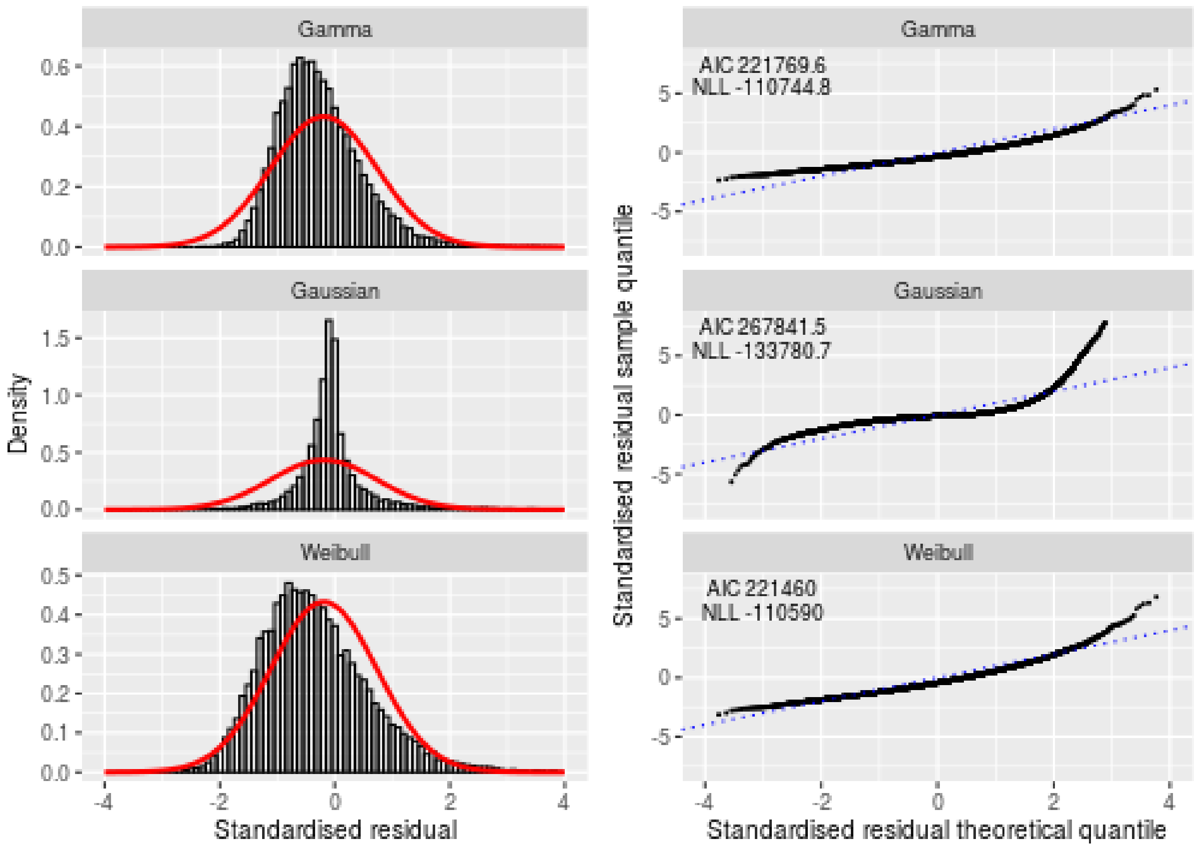

Figure 23: Diagnostics of (top) log gamma (centre), log normal and (bottom) log Weibull models fitted to the TRE 2 vessel-day data. (Left) Density histograms of standardised deviance residuals. Red line is the probability density function of the standard normal distribution. Right: Quantile-quantile of standardised deviance residuals versus theoretical standardised residuals. AIC: Akiake Information Criterion, NLL: Negative log likelihood.

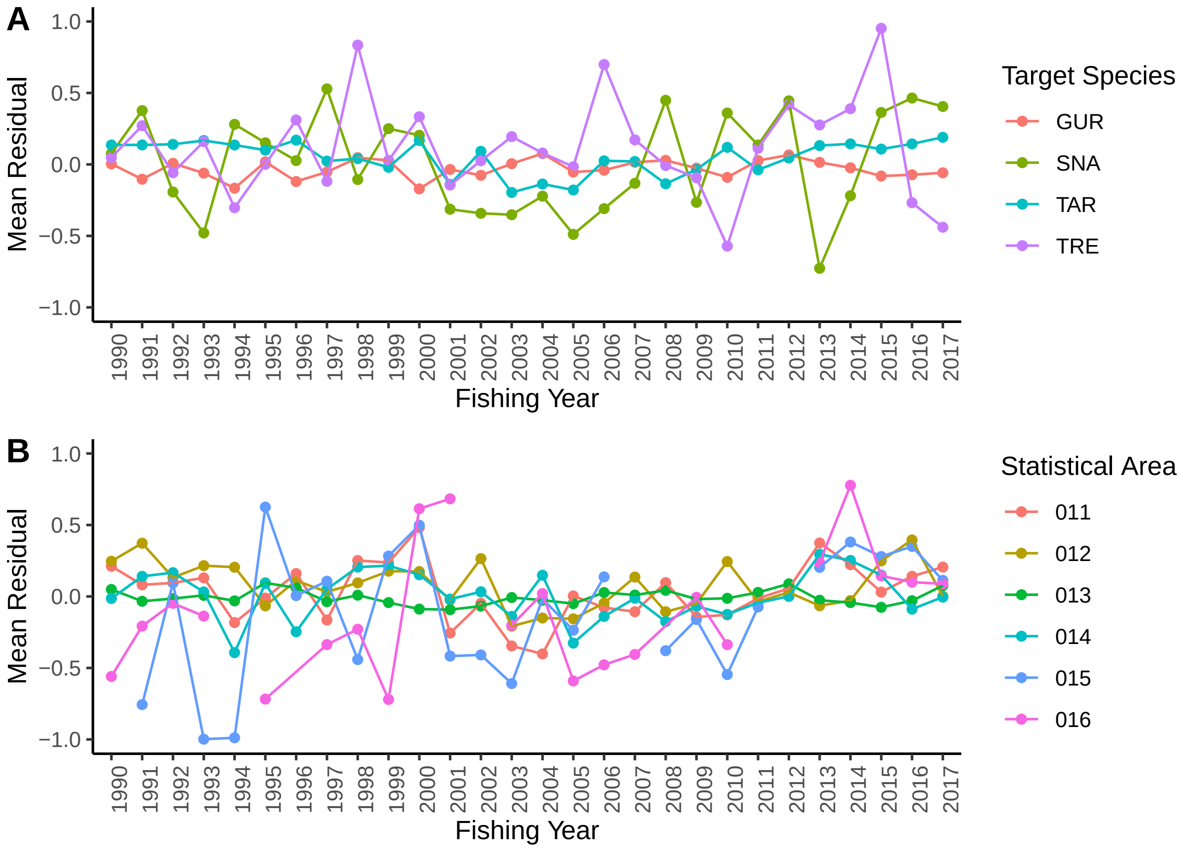

Figure 24: Annual standardised deviance residual plots for TRE 2 target species (A) and Statistical Area (B).

4.4 Influence of model terms

The standardised and unstandardised TRE 2 indices were similar between 1990 and 1998. From 1999 to 2006 the standardised indices were greater than the unstandardised, the indices were similar for 2007 and 2008, and from 2009 to 2017 the standardised indices were less then the unstandardised (Figure 25).

The vessel term in the model had the greatest influence on the standardised indices, with the other terms having little impact (Figure 26).

Vessels active in the TRE 2 fishery since 2008 are estimated to have had a positive influence on observed CPUE (Figure 27). The adjustment for this effect by the CPUE standardisation model is evident in Figure 26.

Statistical Areas 012, 013 and 014 display similar trends throughout the fishing year (Figure 28, Figure 29). In Statistical Area 011 catch rates showed a peak in January, while Statistical Areas 015 and 016 had much more variable monthly coefficients.

The main target species in the TRE 2 fishery are gurnard and tarakihi; these species have been targeted consistently throughout the series (Figure 30). Trevally target produced the highest coefficient but targeting has declined throughout the series (Figure 30).

There has been little change in fishing duration throughout the TRE 2 series (Figure 31).

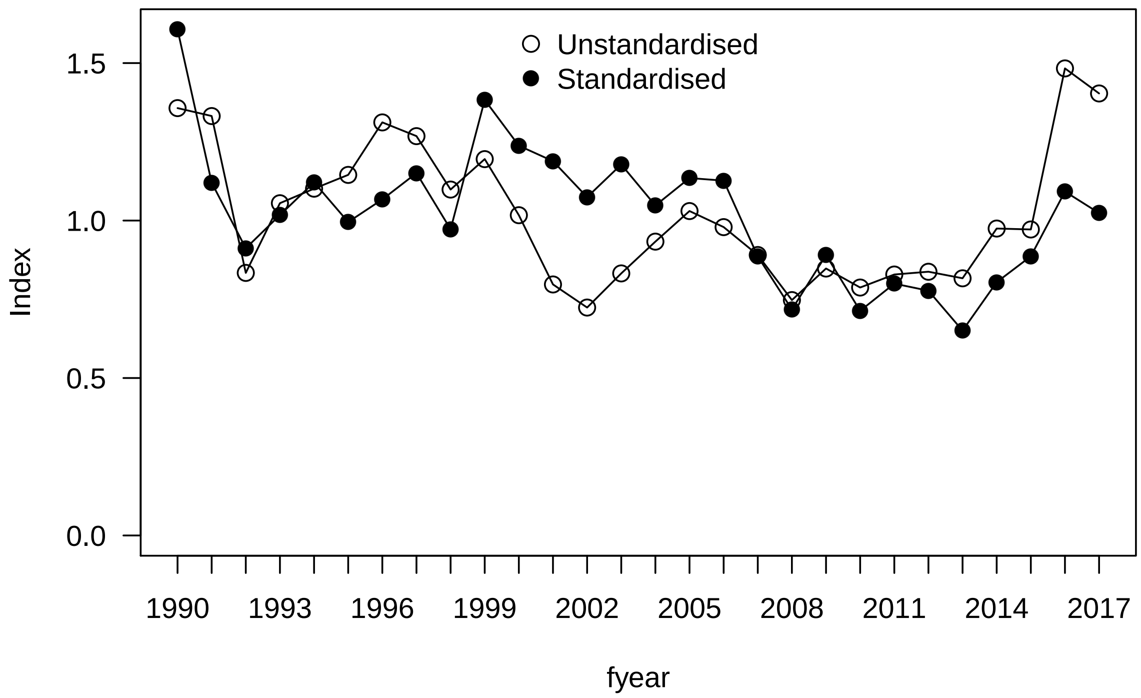

Figure 25: A comparison of the standardised and unstandardised CPUE indices for the TRE 2 vessel-day Weibull model. The unstandardised index is the geometric mean of the catch per vessel-day and is not adjusted for effort.

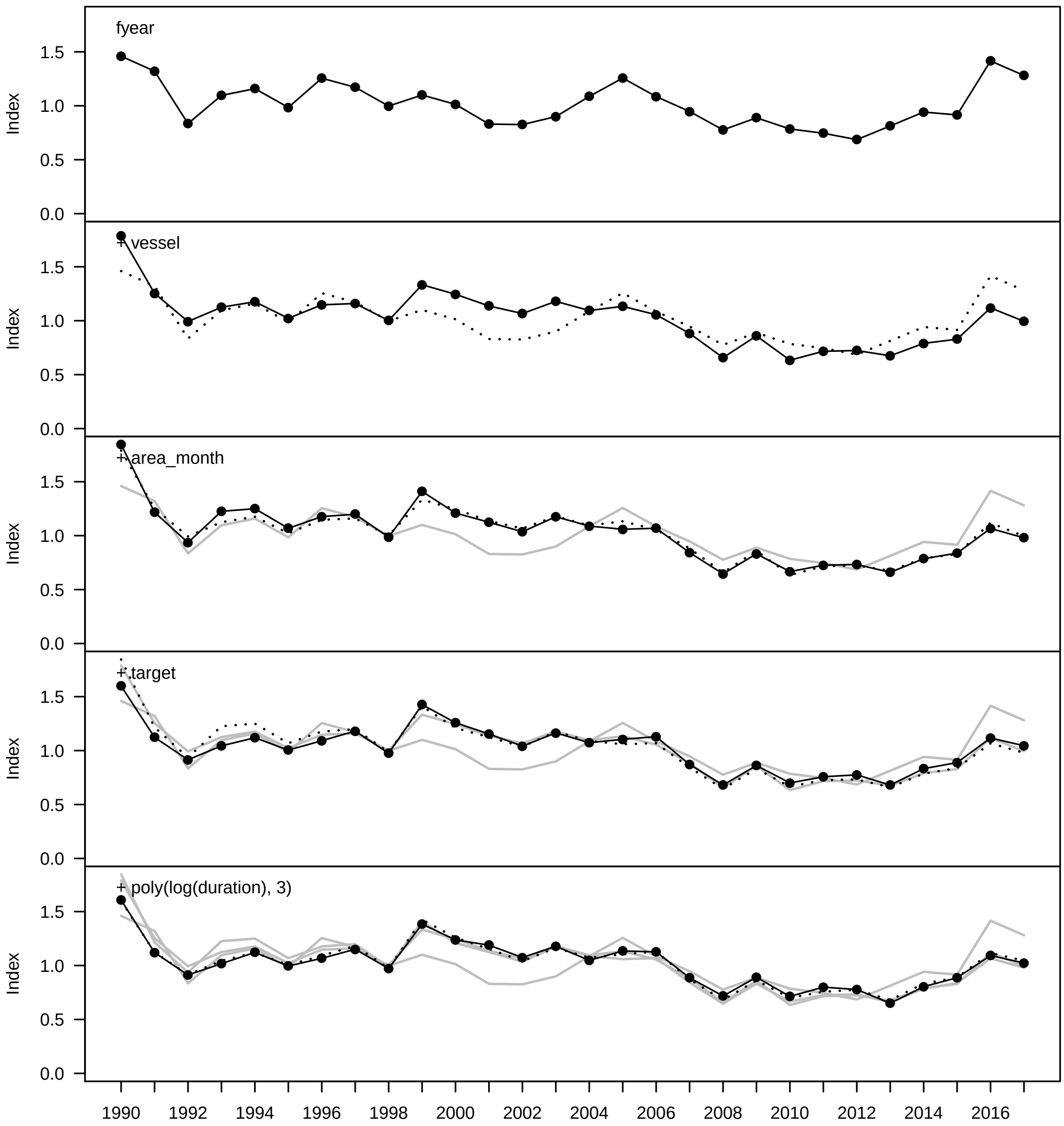

Figure 26: Changes in TRE 2 vessel-day annual CPUE indices as each term is successively added to the model. The indices are normalised to a geometric mean of 1.

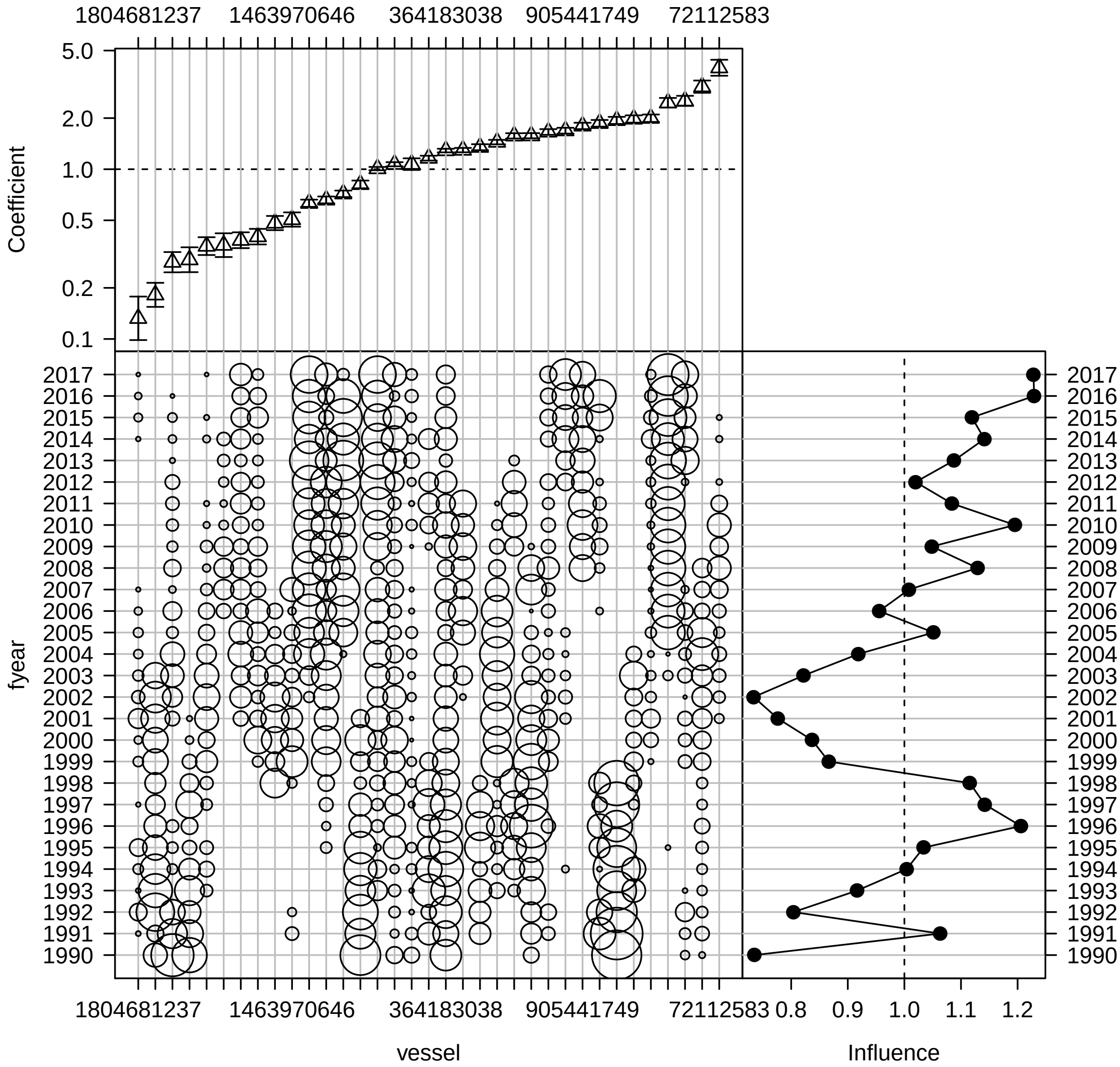

Figure 27: TRE 2 vessel-day coefficient-distribution-influence plot for vessel.

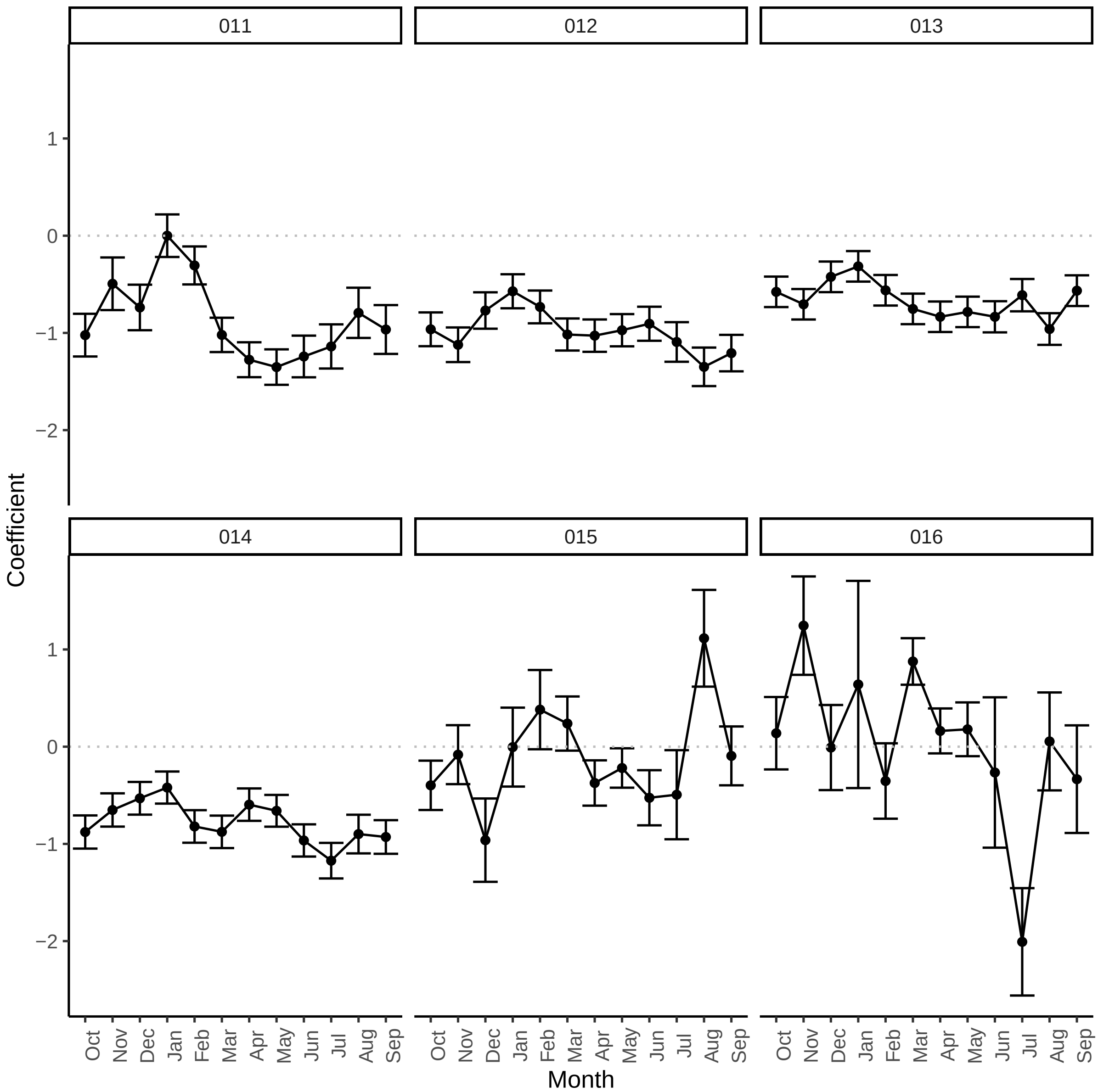

Figure 28: Coefficients for the area * month interaction from the TRE 2 vessel-day model; coefficients are plotted with 1 standard error intervals.

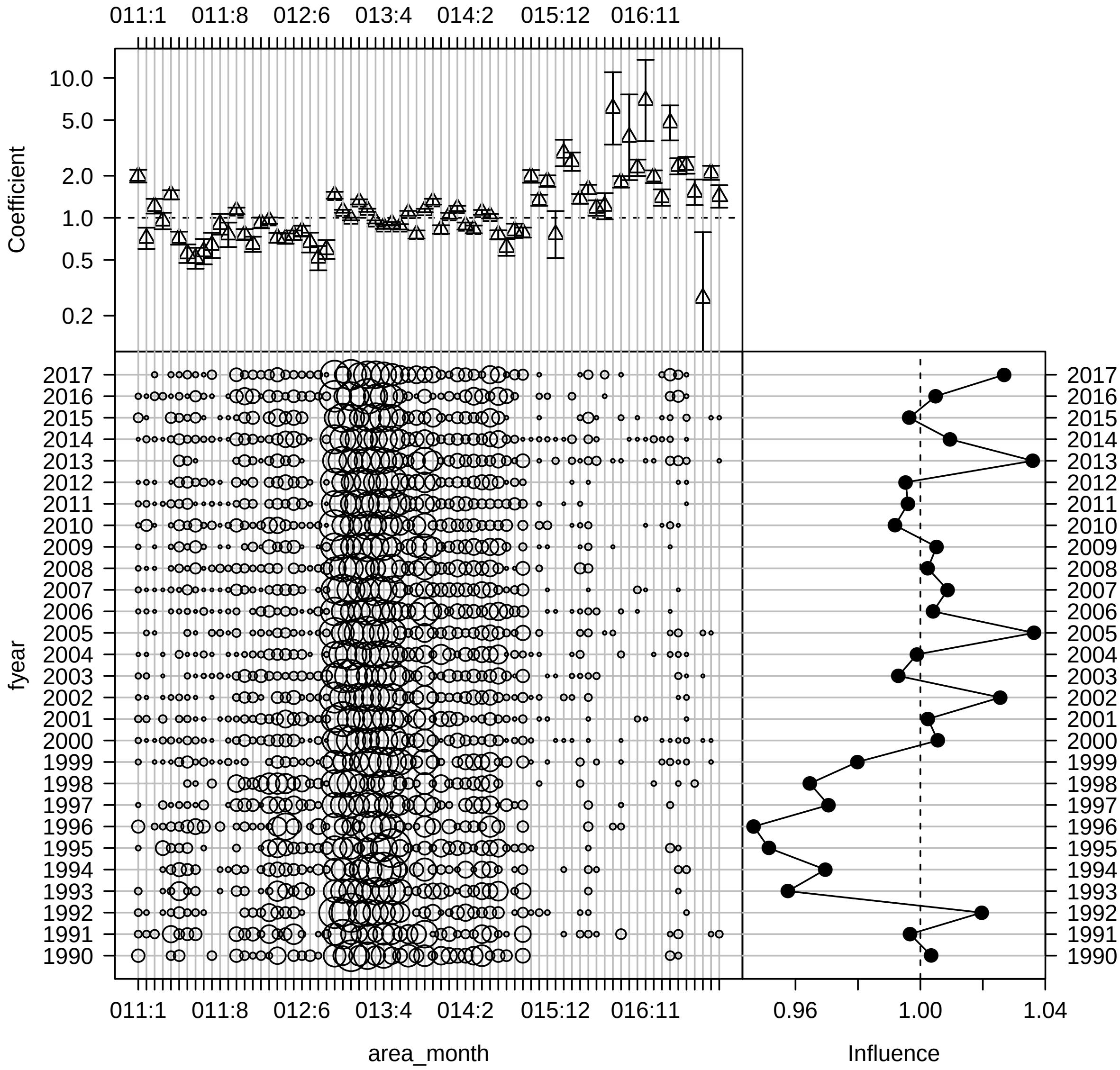

Figure 29: TRE 2 vessel-day coefficient-distribution-influence plot for area * month.

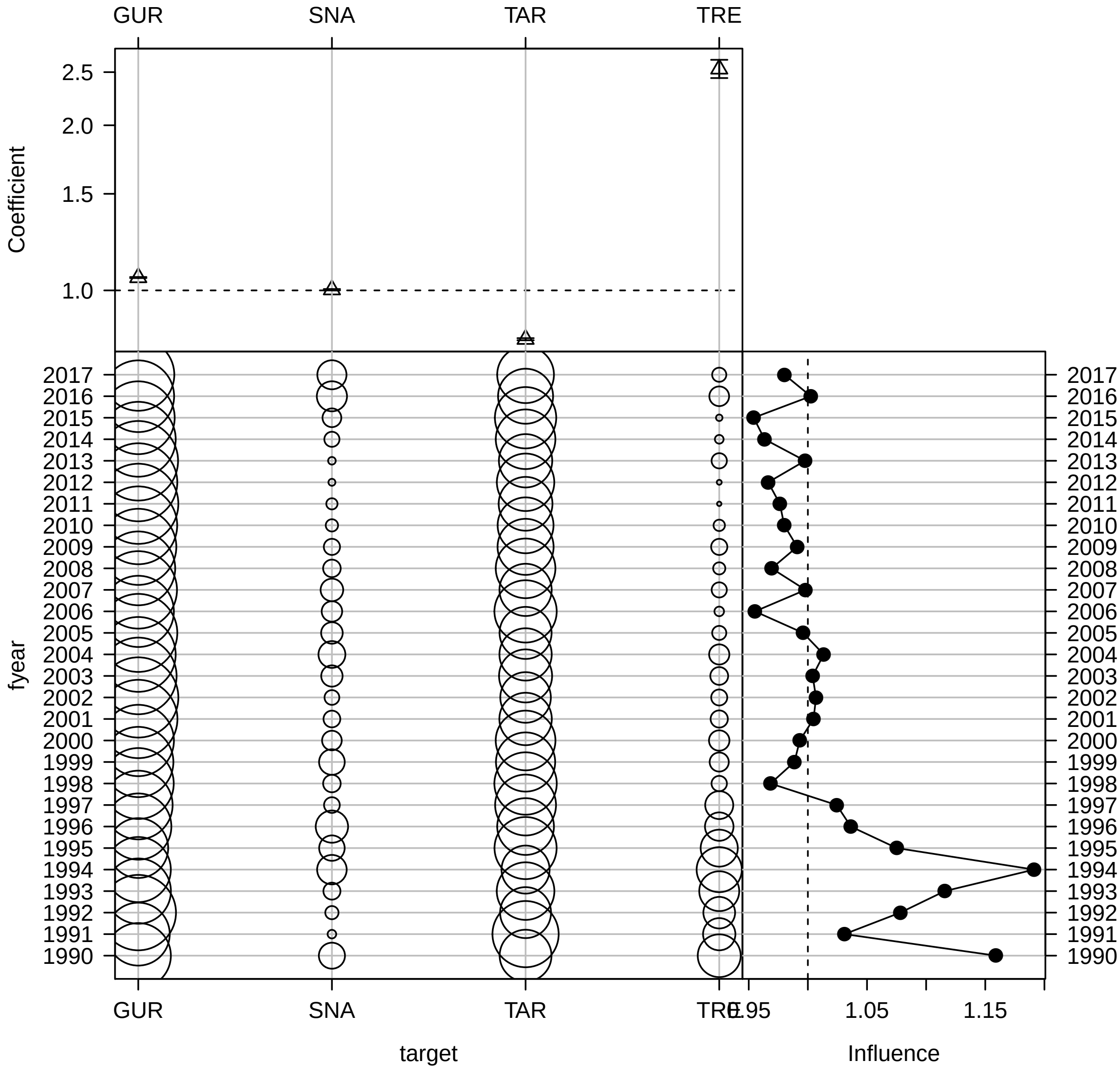

Figure 30: TRE 2 vessel-day coefficient-distribution-influence plot for target species.

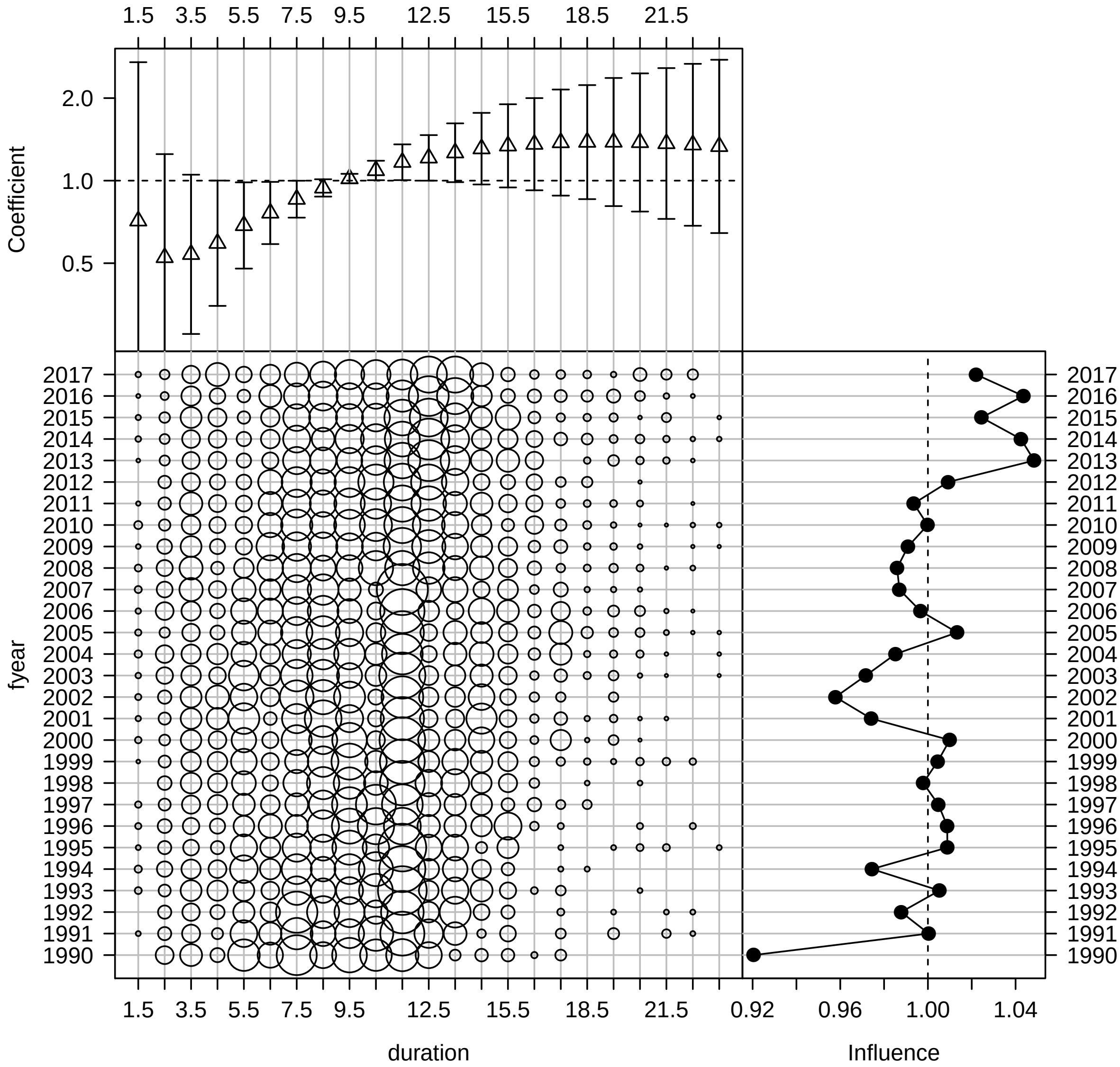

Figure 31: Coefficient-distribution-influence plot for fishing duration in the TRE 2 vessel-day positive catch model.

4.5 CPUE indices

The TRE 2 vessel-day indices suggest large cycles in abundance between 1990 and 2008 (Figure 32). Occurrence of positive TRE 2 catch declined between 1990 and 1997 then increased until 2000 and has been relatively stable to 2017 (Figure 32). The combined CPUE index declined from 1990 to 1996, increased from 1997 until 2000, then declined from 2001 to 2009. In the last decade of the series the index has been more stable, with a gradually increasing trend over the last four years (Figure 32).

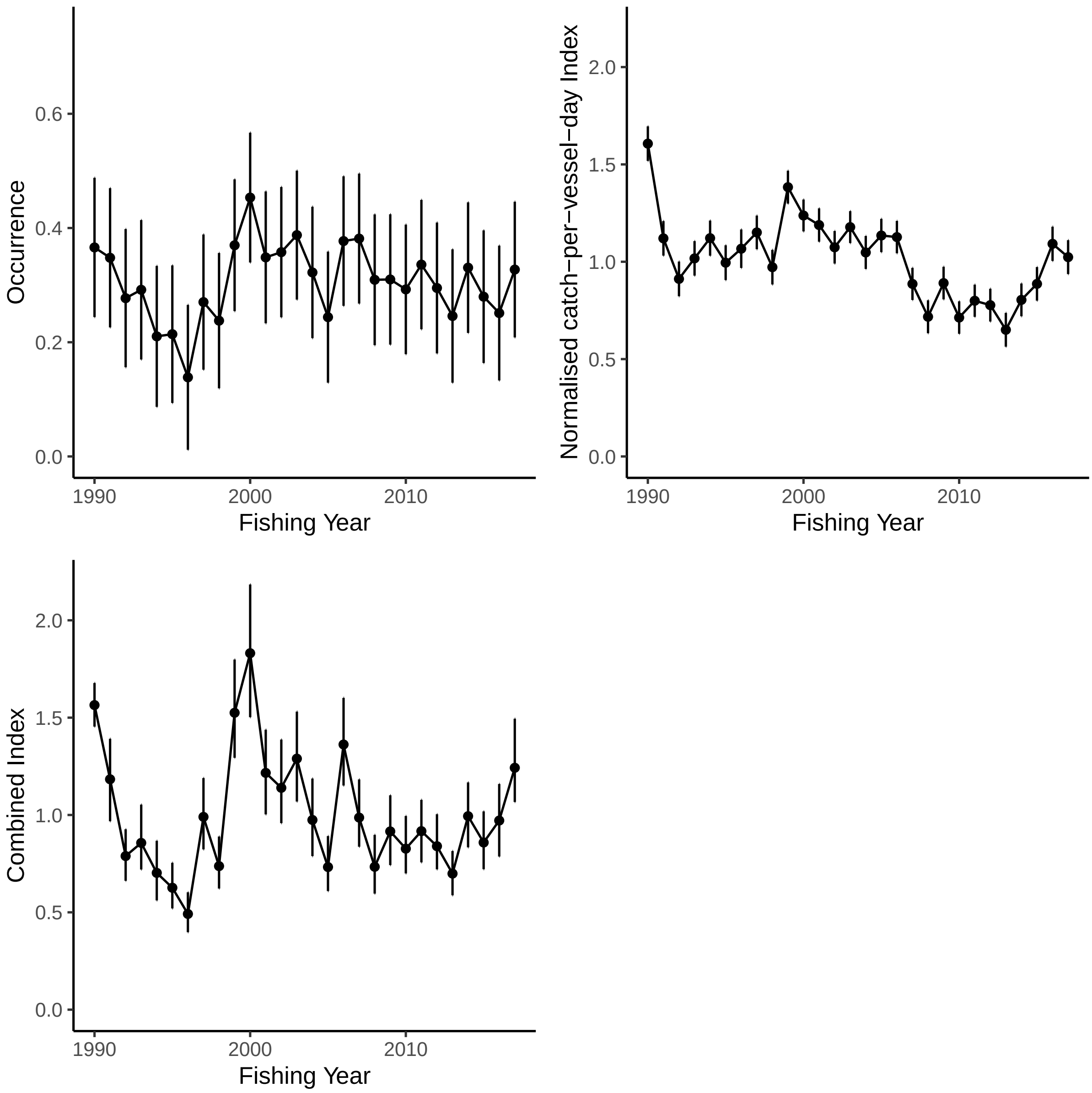

Figure 32: The trevally vessel-day indices: occurrence (proportion of records with catches; top left), positive catch-per-vessel-day (magnitude of catches; top right) and combined index (bottom) from the 1990 to 2017 fishing year.

5. BT(MIX) TCER CPUE ANALYSIS

The BT-MIX TCER fishery is defined as follows:

- Form type (TCER, TCEPR)
- Primary method: bottom trawl (BT) (excluding Precision Bottom Trawl, PRB)
- Target species (GUR, SNA, TRE, TAR)
- Fishing effort conducted within Statistical Areas 011, 012, 013, 014, 015 and 016
- Fishing effort conducted between 1 Oct 2008 and 30 Sep 2017

Here the term 'TCER' is used to indicate that the series is constructed using tow-level fishing events; in fact, tow-level data are available from both the TCER form and the Trawl Catch Effort and Processing Return (TCEPR) (Figure 3).

Fishing effort declined throughout the TCER series, whilst catch varied between 150 and 295 t (Table 8).

Table 8: Summary of the TRE 2 TCER data set. Records represent a row in the effort dataset while effort numbers indicate the number of tows (these are identical for tow-level data). Trips caught and days caught are the percentage of trips and days respectively in the BT-MIX data set with TRE catches.

Fishing Year	Vessels	Trips	Records	Effort (num)	Effort (hrs)	Catch (t)	Trips caught	Days caught
2008	39	1 123	8 575	8 575	30 669	210.5	65.0	52.4
2009	38	1 185	8 855	8 855	31 655	285.3	68.9	59.1
2010	42	1 297	9 680	9 680	34 438	248.4	66.6	57.6
2011	39	1 114	8 936	8 936	31 294	223.2	71.6	60.3
2012	38	1 059	7 866	7 866	27 852	154.5	66.8	58.1
2013	35	950	7 687	7 687	27 702	187.4	69.8	57.4
2014	37	1 040	8 278	8 278	29 671	294.8	70.9	61.4
2015	38	961	7 384	7 384	27 063	208.6	64.3	56.3
2016	34	969	6 610	6 610	24 813	269.2	60.4	55.9
2017	31	828	6 161	6 161	23 243	272.7	71.3	61.8

5.1 Core vessel selection

This analysis utilised a core fleet definition of vessels operating in the BT-MIX fishery for a minimum of 5 years and conducting 5 trips in each of these years (Figure 33). This resulted in a core fleet of 28 vessels which accounted for 82.3% of the TRE 2 catch.

The TRE 2 fleet has been consistent throughout the TCER series, although there has been a decline in the number of participants in recent years (Table 9, Figure 34). The raw trevally catch probability showed little trend over the series while the raw catch-per-unit-effort of core vessels gradually increased (Figure 35).

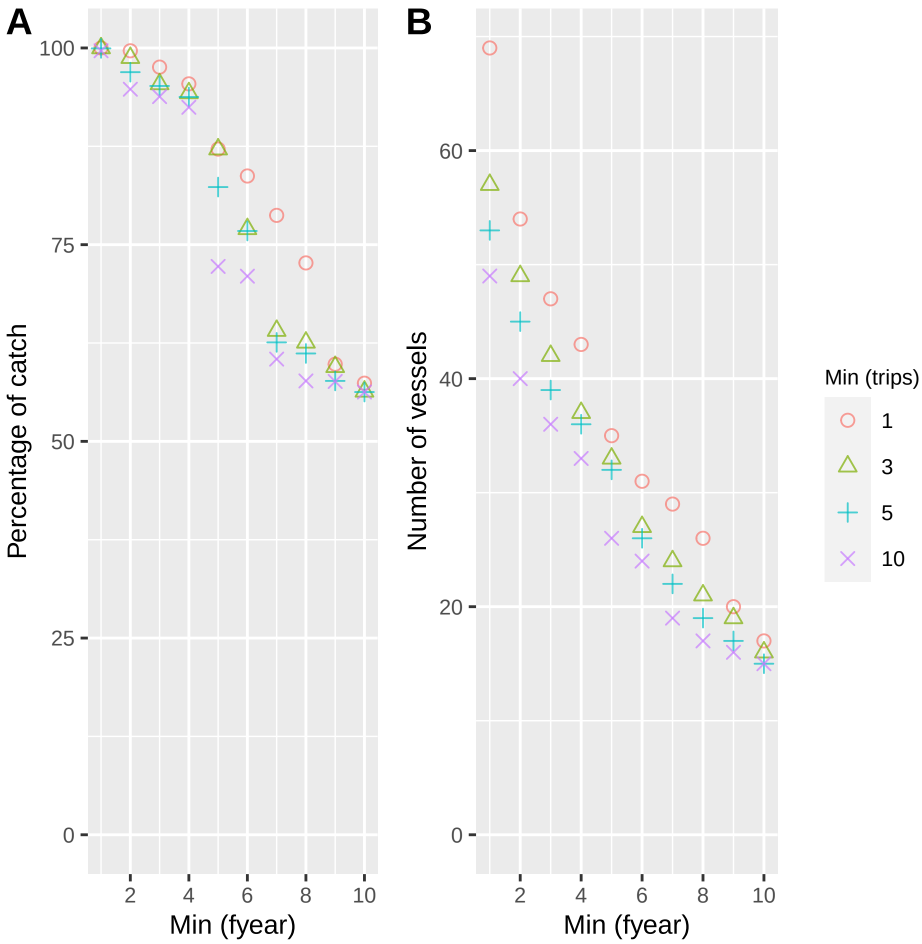

Figure 33: Percentage of catch (left panel) and number of vessels (right panel) in the BT-MIX TCER dataset with alternative criteria for core fleet selection.

Table 9: Summary of TRE 2 TCER data subset by fishing year after the data were restricted to the core fleet and outliers were removed. Records represent a row in the effort dataset while effort numbers indicate the number of tows (these are identical for tow-level data). Trips caught and days caught are the percentage of trips and days respectively in the BT-MIX data set with TRE catches.

Fishing Year	Vessels	Trips	Records	Effort (num)	Effort (hrs)	Catch (t)	Trips caught	Days caught
2008	25	873	6026	6 026	20 863	129.5	65.1	54.2
2009	26	946	6740	6 740	23 620	196.5	71.8	62.1
2010	27	1 046	7796	7 796	27 230	199.3	71.4	61.3
2011	26	978	8134	8 134	28 364	192.0	76.6	62.0
2012	28	978	7629	7 629	27 100	153.3	70.3	59.5
2013	24	868	7067	7 067	25 584	176.6	70.6	58.1
2014	26	884	7453	7 453	26 737	237.1	75.9	63.0
2015	24	799	6460	6 460	23 586	176.5	70.5	58.6
2016	22	803	5799	5 799	21 502	236.4	64.8	56.8
2017	22	662	4955	4 955	18 462	221.4	73.7	63.8

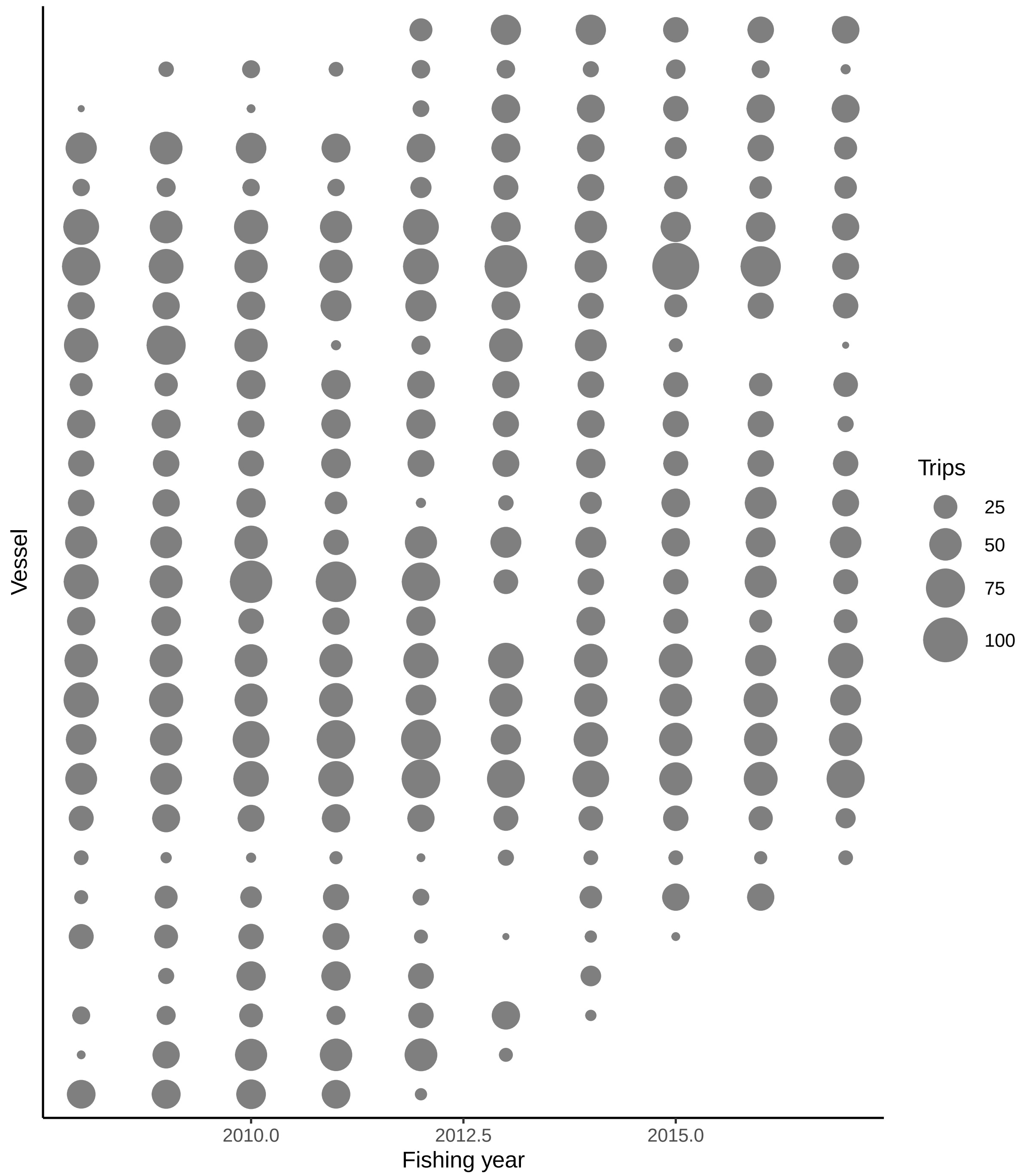

Figure 34: Number of trips by fishing year for core TRE 2 TCER vessels. The area of circles is proportional to the number of trips.

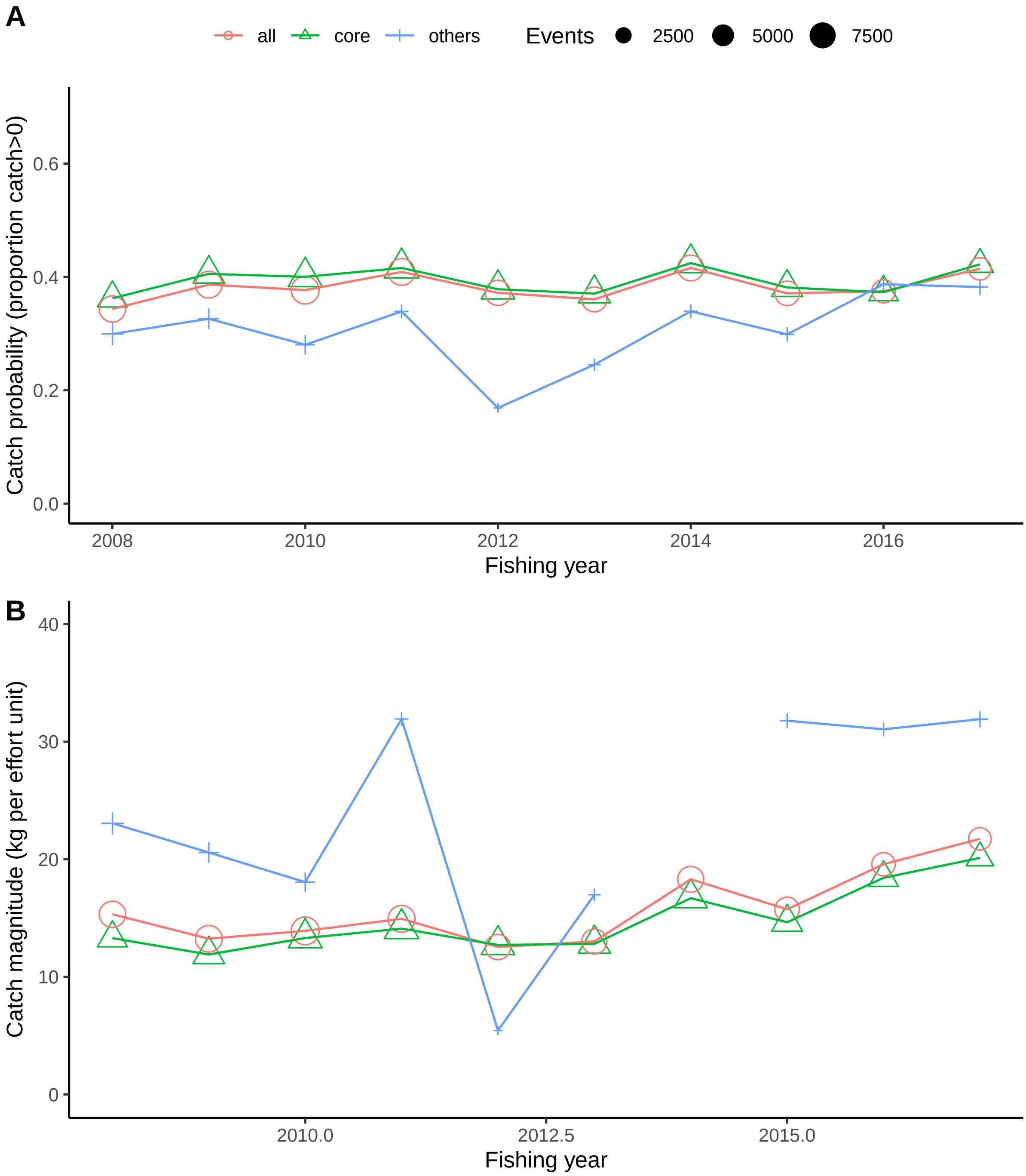

Figure 35: The proportion of strata with positive catch (A) and the raw catch rate (geometric mean of catch per tow where catch was positive) (B) for all TRE 2 TCER vessels, core vessels and non-core vessels. Point size is proportional to the number of tows.

5.2 CPUE Models

5.2.1 Occurrence of positive TRE 2 catch

Occurrence of trevally catch was modeled with a binomial GLM with a logistic link function. The full list of terms offered to the model is given in Table 3.

The binomial model selected (Table 10) was:
$\sim fyear + area * month + poly(log(bottom), 3) + vessel$

Table 10: Summary of stepwise selection for TRE 2 TCER occurrence of positive catch. Model terms are listed in the order of acceptance to the model. AIC: Akaike Information Criterion; * indicates terms included in final model.

Step	Df	AIC	Deviance explained	Additional deviance	Included
Fishing year	26	82422	0.2	0.2	*
Area * Month	71	77929	5.8	5.6	*
Depth	3	74941	9.4	3.6	*
Vessel	26	72632	12.3	2.9	*
Target	3	72185	12.8	0.5	
Start latitude	3	72121	12.9	0.1	
Duration	3	72060	13.0	0.1	

Trevally was generally caught in 40% of tows, although this increased to $\sim$ 50% between 2008 and 2017 (Figure 36).

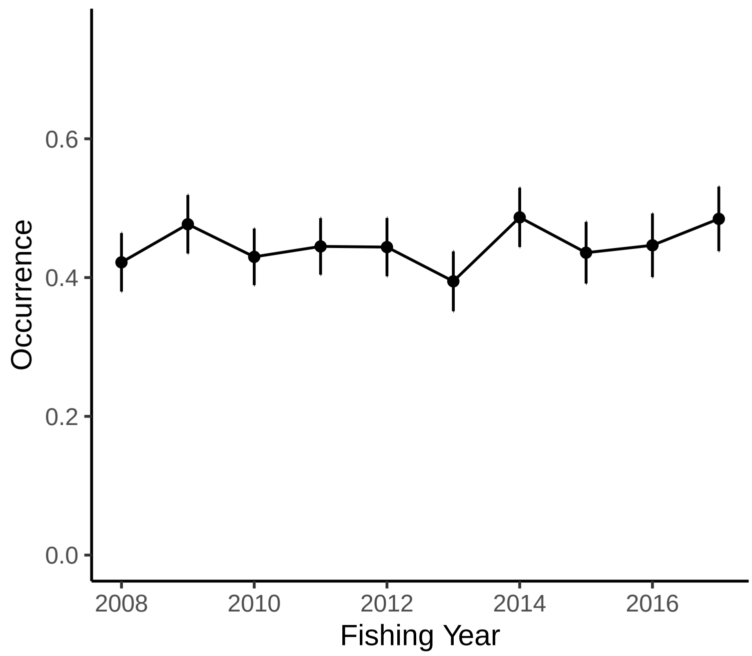

Figure 36: The index for the occurrence of positive catch in the BT-MIX TCER fishery.

5.2.2 Magnitude of positive TRE 2 catch

The magnitude of positive trevally catches was modeled with a Weibull GLM. The full list of terms offered to the model is given in Table 2. The Weibull model selected (Table 11) was:
$\sim fyear + vessel + area * month + poly(depth, 3)$

Table 11: Summary of stepwise selection for TRE 2 TCER magnitude of positive catch. Model terms are listed in the order of acceptance to the model. AIC: Akaike Information Criterion; * indicates terms included in final model.

Step	DF	AIC	Deviance explained	Additional deviance	Included
Fishing year	9	270336	1.5	1.5	*
Vessel	26	262845	19.9	18.4	*
Area * Month	71	260334	25.7	5.7	*
Depth	3	259511	27.4	1.7	*
Target	3	259127	28.2	0.8	
Duration	3	258927	28.6	0.4	

5.3 Model diagnostics

Model residuals from the positive log(catch) model show a reasonable approximation to the Weibull distribution, although the distribution of residuals is slightly right-skewed (Figure 37).

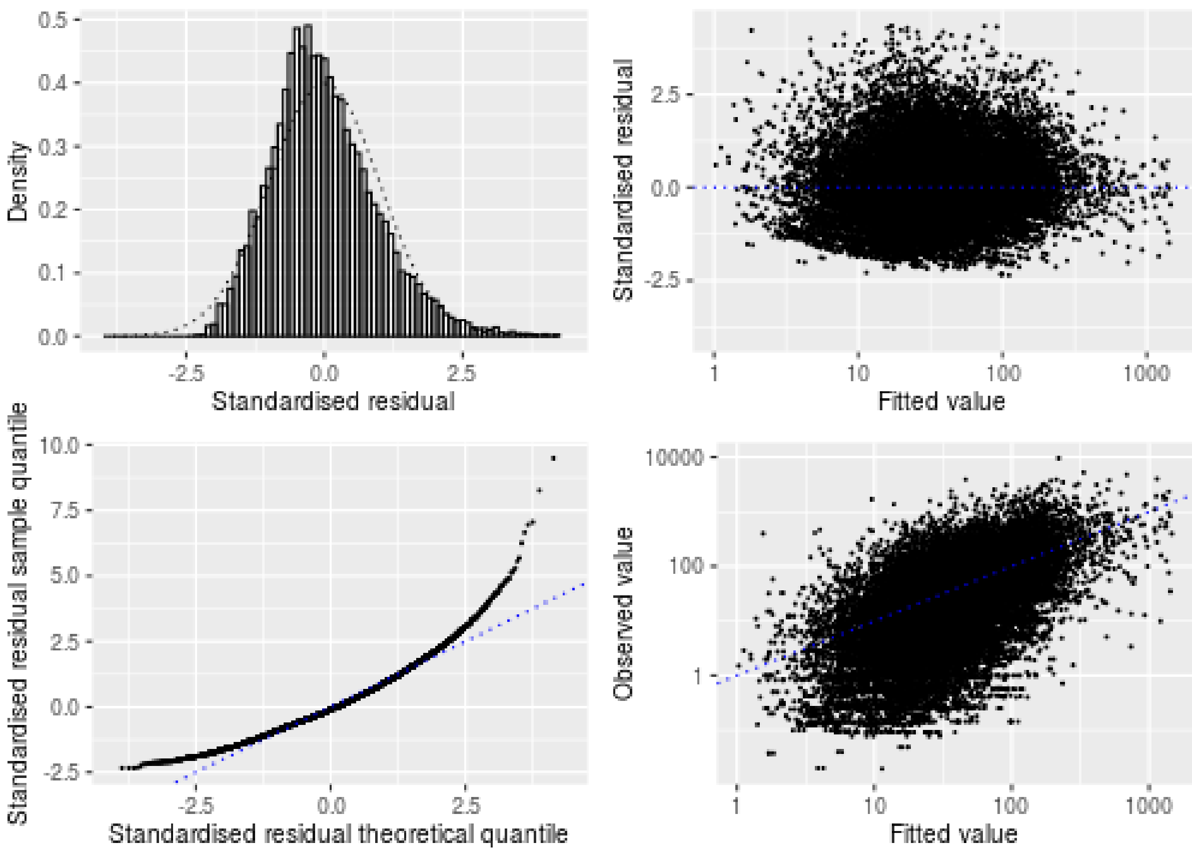

Figure 37: The Weibull diagnostic plots for the TRE 2 TCER model. top left: Standardised residuals from the accepted generalised linear model fit; top right: Standardised deviance residuals versus the fitted values; bottom left: Quantile-quantile plot of Weibull model standardised deviance residuals versus the standard normal distribution; bottom right: Observed values vs fitted values (log-log scale).

The Weibull distribution was selected based on best fit of model residuals and smallest AIC, compared to alternative distributions (Figure 38).

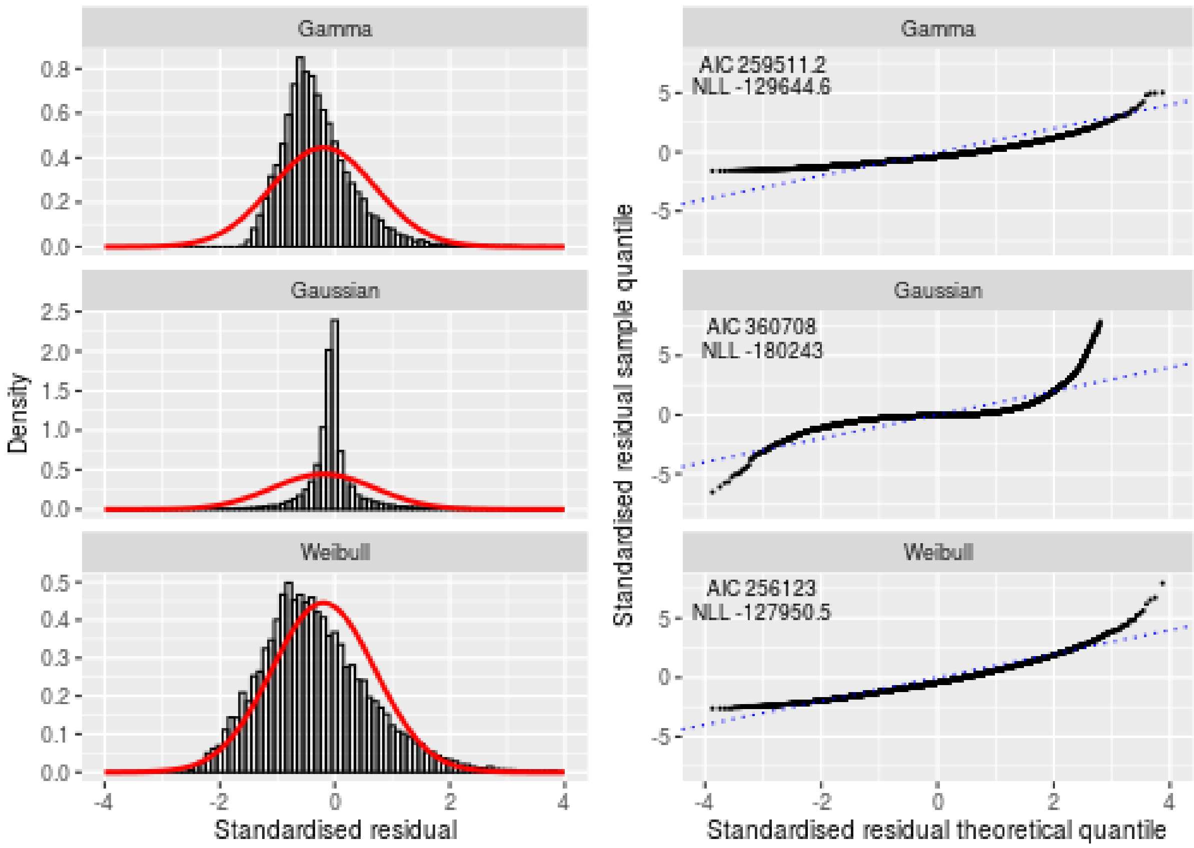

Figure 38: Residual diagnostics of (top) log gamma, (centre) log normal and (bottom) log Weibull fitted to positive TRE 2 catch from TCER data. Left: Standardised deviance residuals versus fitted values from fitted generalised linear models. Red curves are standard normal density functions.; Right: Quantile-quantile plot of standardised deviance residuals versus the standard normal distribution. (AIC: Akaike Information Criterion, NLL: Negative log likelihood.)

5.4 Influence of model terms

There was little difference between the standardised and unstandardised TRE 2 TCER indices (Figure 39). Vessel has a small influence on the CPUE indices in some years, while the other coefficients had minimal influence (Figure 40).

The model estimates a range of coefficients for vessels in the TRE 2 fleet, with a generally stable fleet composition throughout the series (Figure 41).

Statistical Areas 012, 013 and 014 display similar trends throughout the fishing year, with higher coefficients in January to May (Figure 42, Figure 43). Statistical Area 011 shows lower variation between months, while Areas 015 and 016 had greater monthly variation, with coefficients peaking in February to May (Figure 42, Figure 43).

The majority of TRE2 fishing effort is between 20 and 80 metres, and depth dependence in catch rates is not strong (Figure 44).

The main target species in the TRE 2 fishery are gurnard and tarakihi, these species have been targeted consistently throughout the series (Figure 45). Snapper and trevally were targeted infrequently, with snapper target fishing increasing over the last three years (Figure 45).

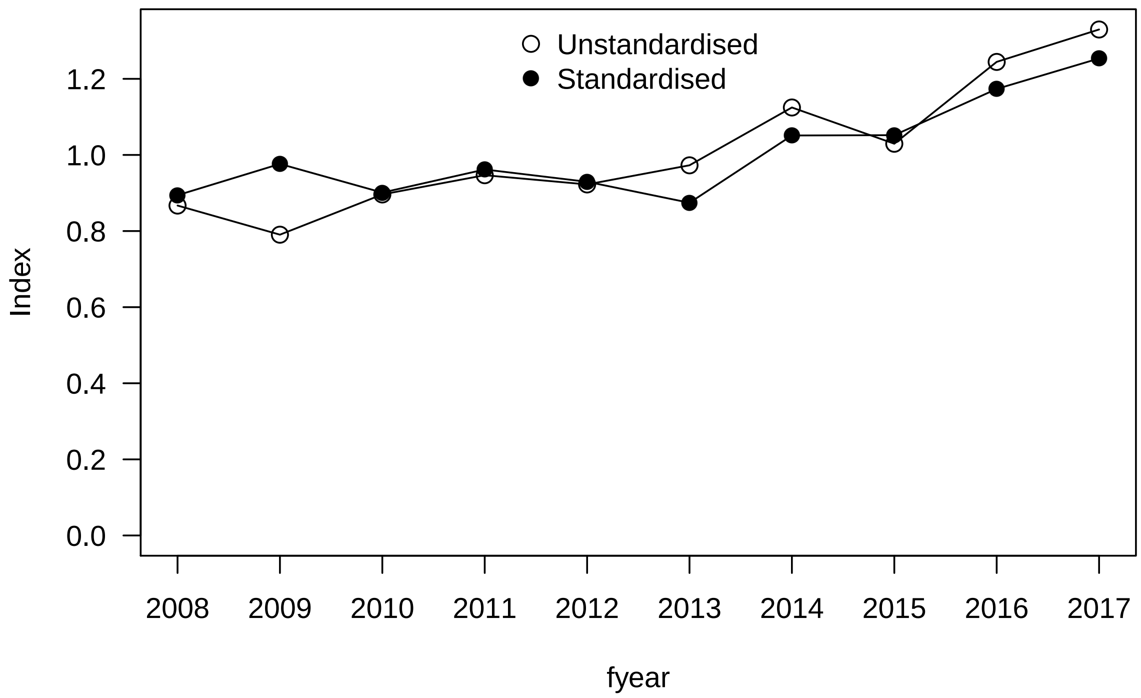

Figure 39: A comparison of the standardised and unstandardised CPUE indices for the TRE 2 TCER Weibull model. The unstandardised index is derived from the geometric mean of the catch per tow each year. The plotted indices are normalised so each series has a geometric mean of one.

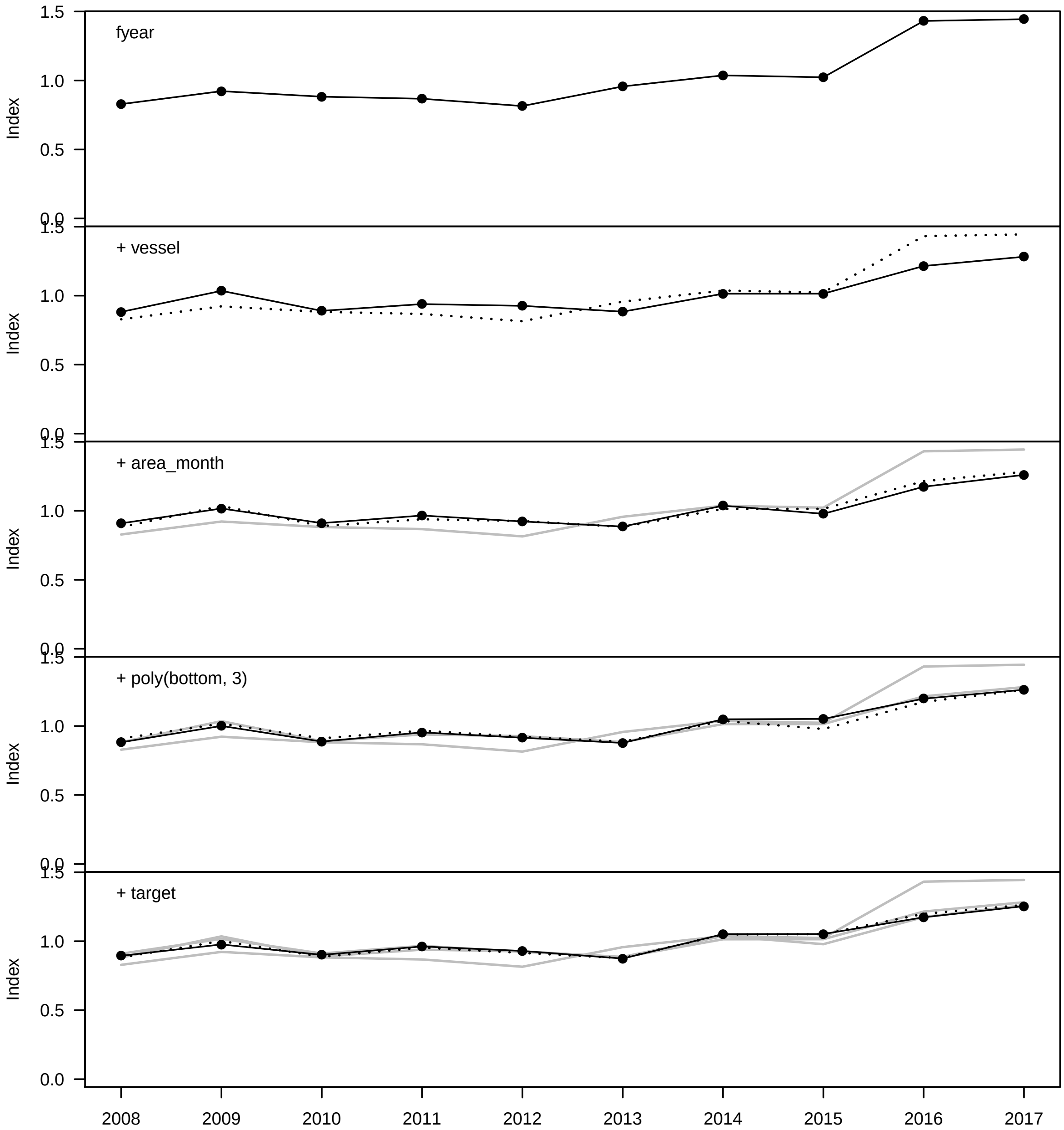

Figure 40: Changes in TRE 2 TCER annual CPUE indices as each term is successively added to the model. The indices are normalised to a geometric mean of one.

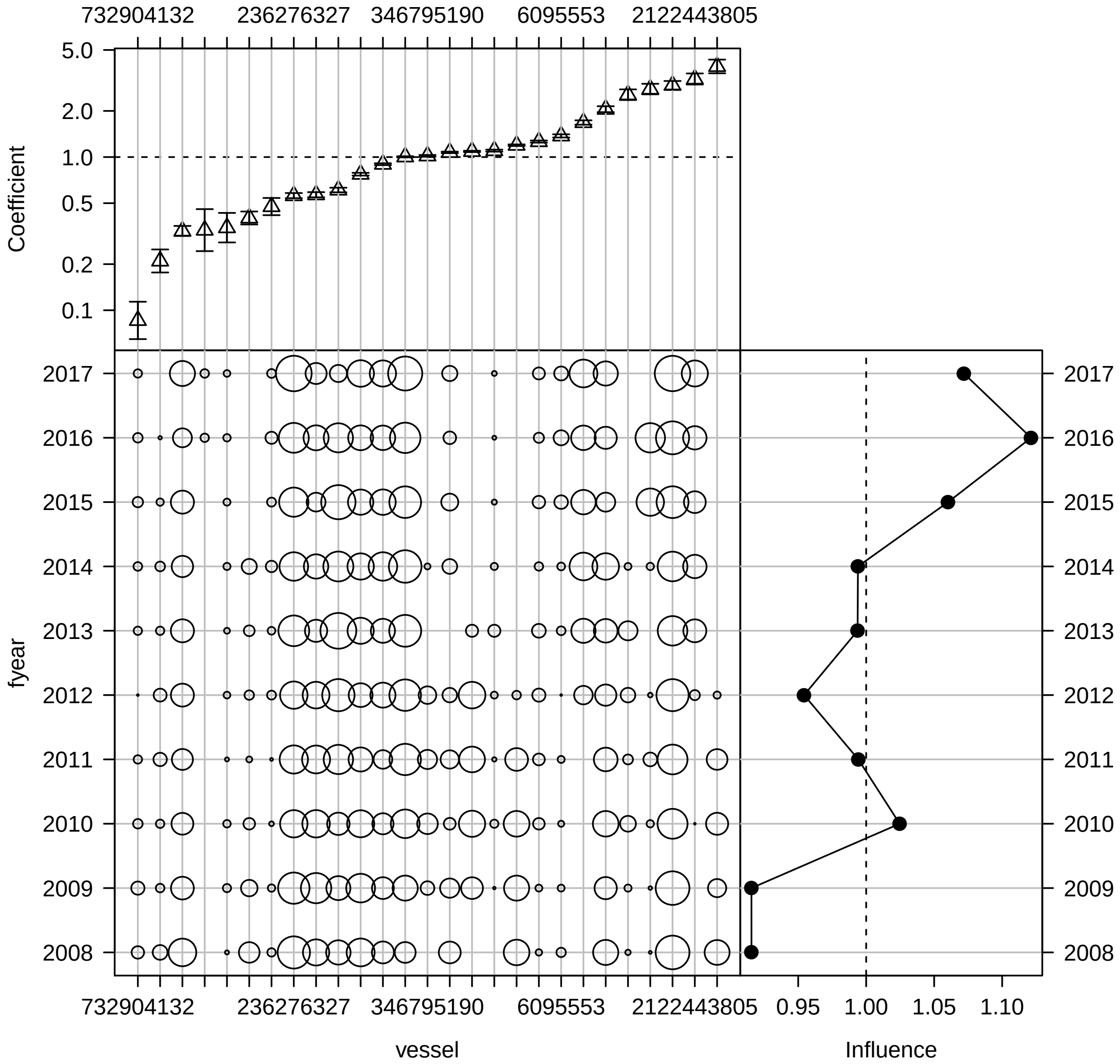

Figure 41: TRE 2 TCER coefficient-distribution-influence plot for vessel.

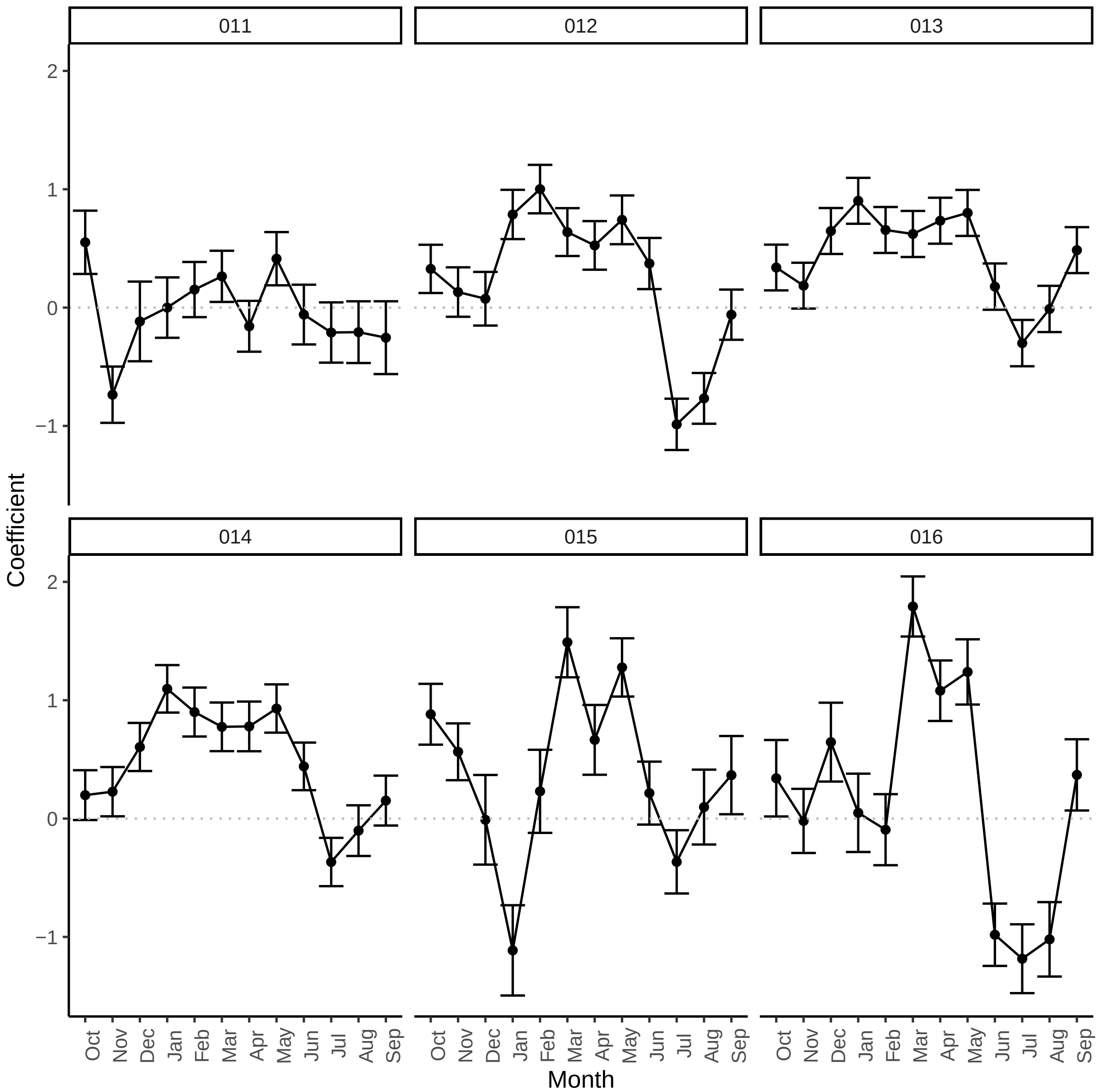

Figure 42: Coefficients for the area * month interaction from the TRE 2 TCER model, coefficients are plotted with 1 standard error intervals.

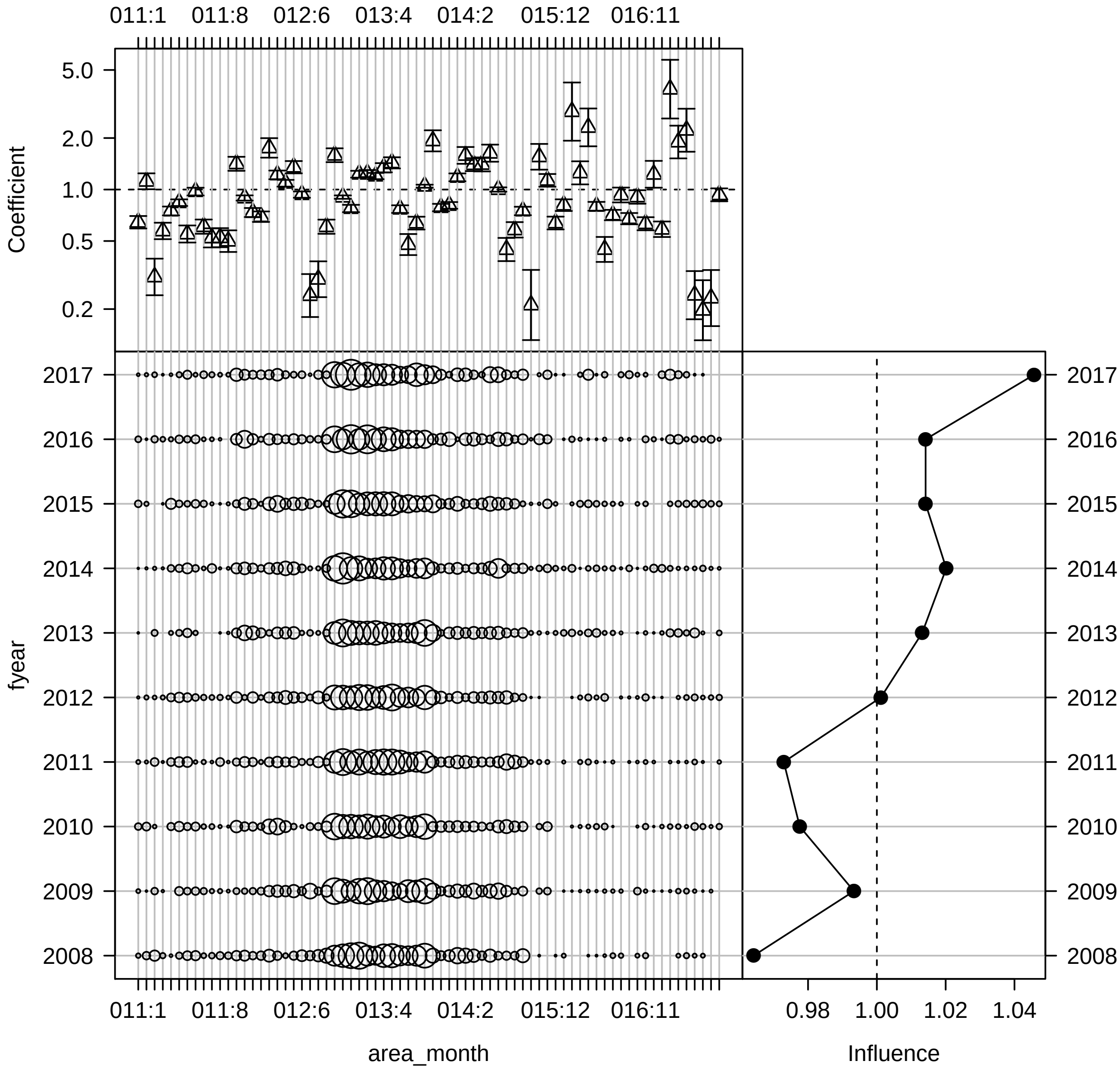

Figure 43: TRE 2 TCER area * month coefficient-distribution-influence plot

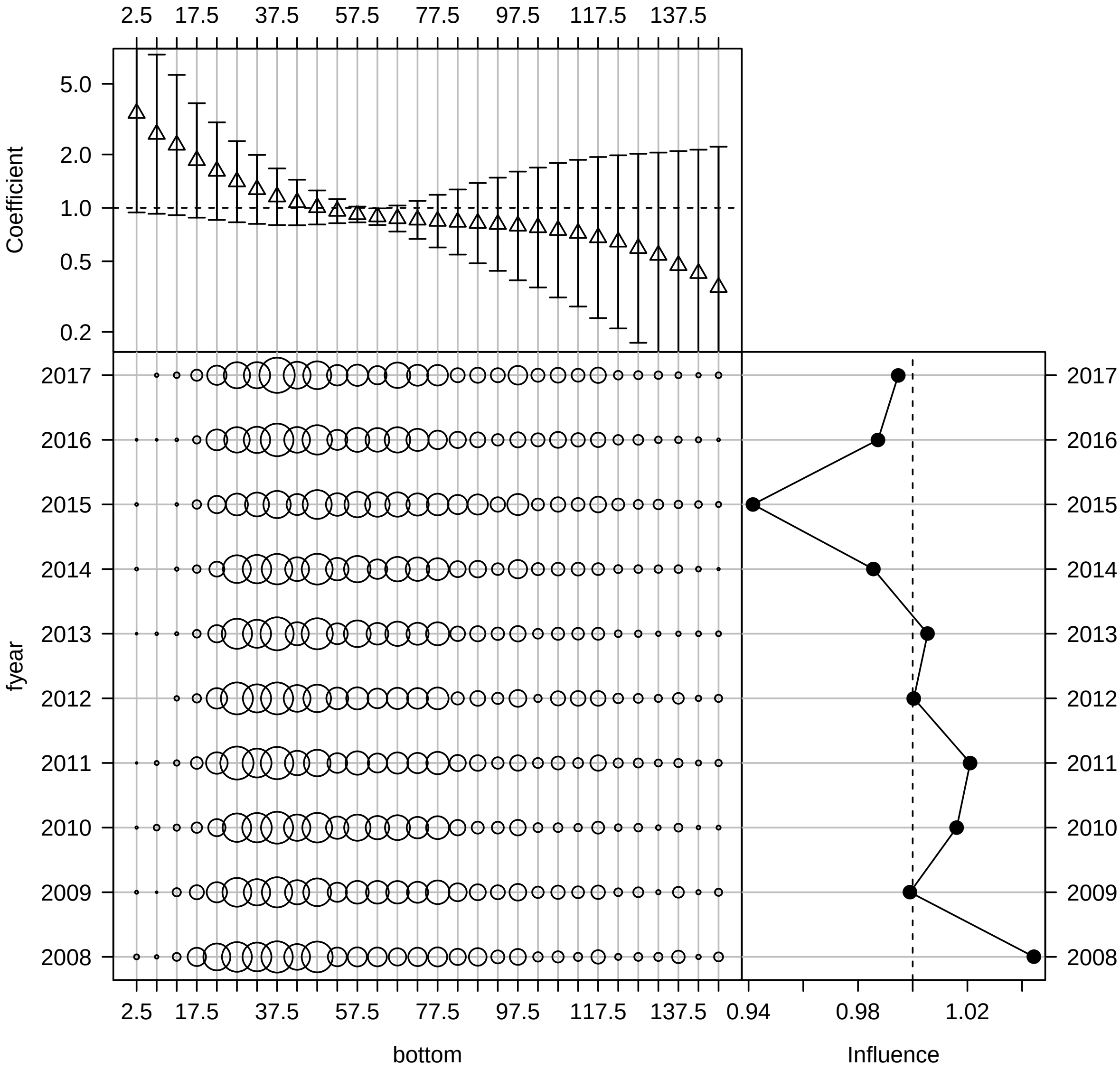

Figure 44: Coefficient-distribution-influence plot for fishing depth in the TRE 2 TCER positive catch model.

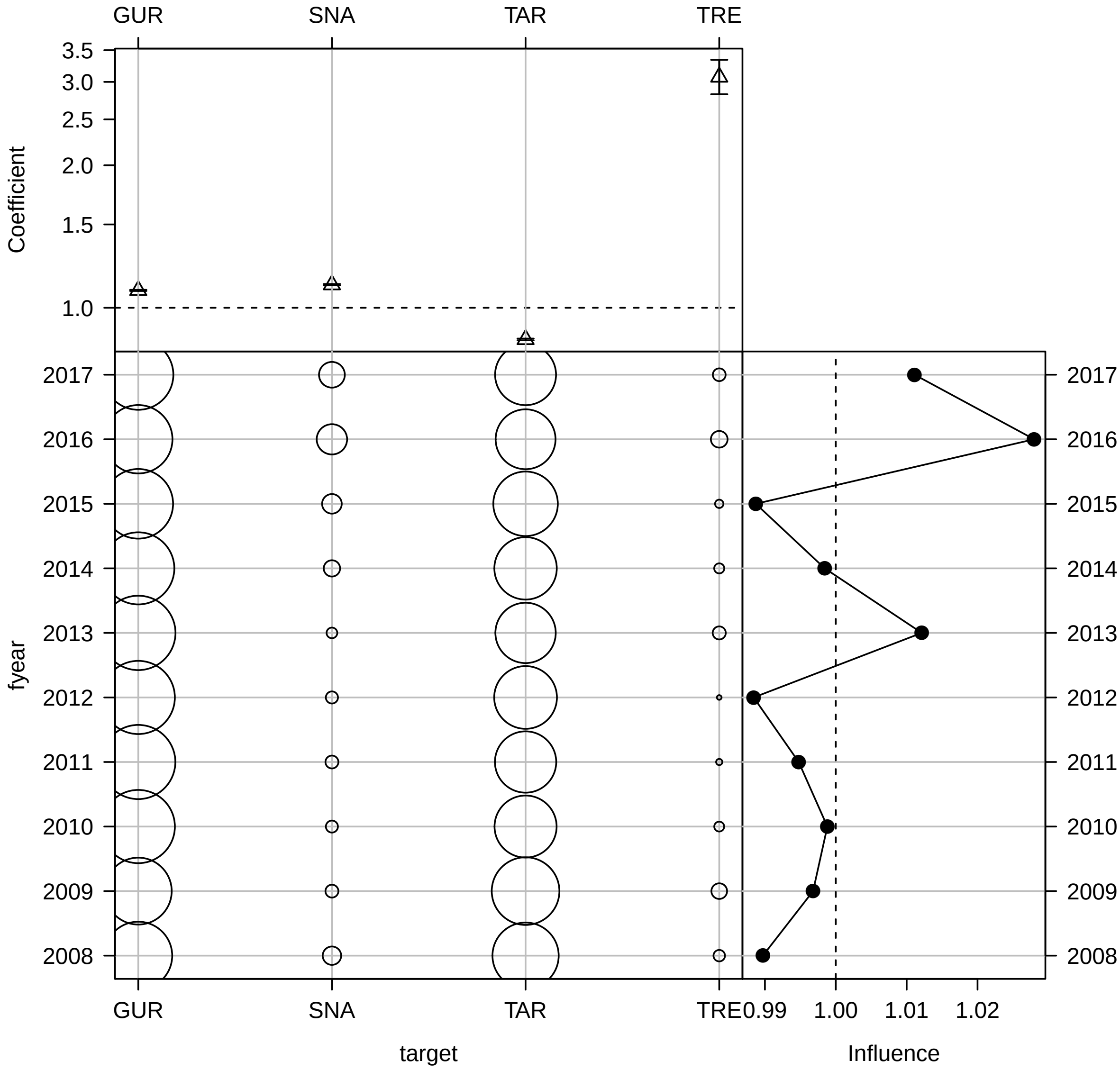

Figure 45: TRE 2 TCER coefficient-distribution-influence plot for target species.

5.5 Spatial residuals

The introduction of the fine scale spatial reporting in 2008 with the TCER form allowed examination of the spatial distribution of residuals.

Positive spatial residuals were not consistently distributed throughout the series (Figure 46). From 2008–2014 there were positive residuals in southern Hawke Bay between Waipatiki and Cape Kidnappers (39.3–39.6° S) and also in the north of Hawke Bay inside Mahia Peninsula (39.1° S); this pattern was not as strong in 2014–2016 (Figure 46). Negative spatial residuals were distributed throughout FMA 2, although consistent areas of negative residuals occured at the northern and southern ends of the distribution, around East Cape (37.7° S) and within Palliser Bay (41.1° S ; Figure 46).

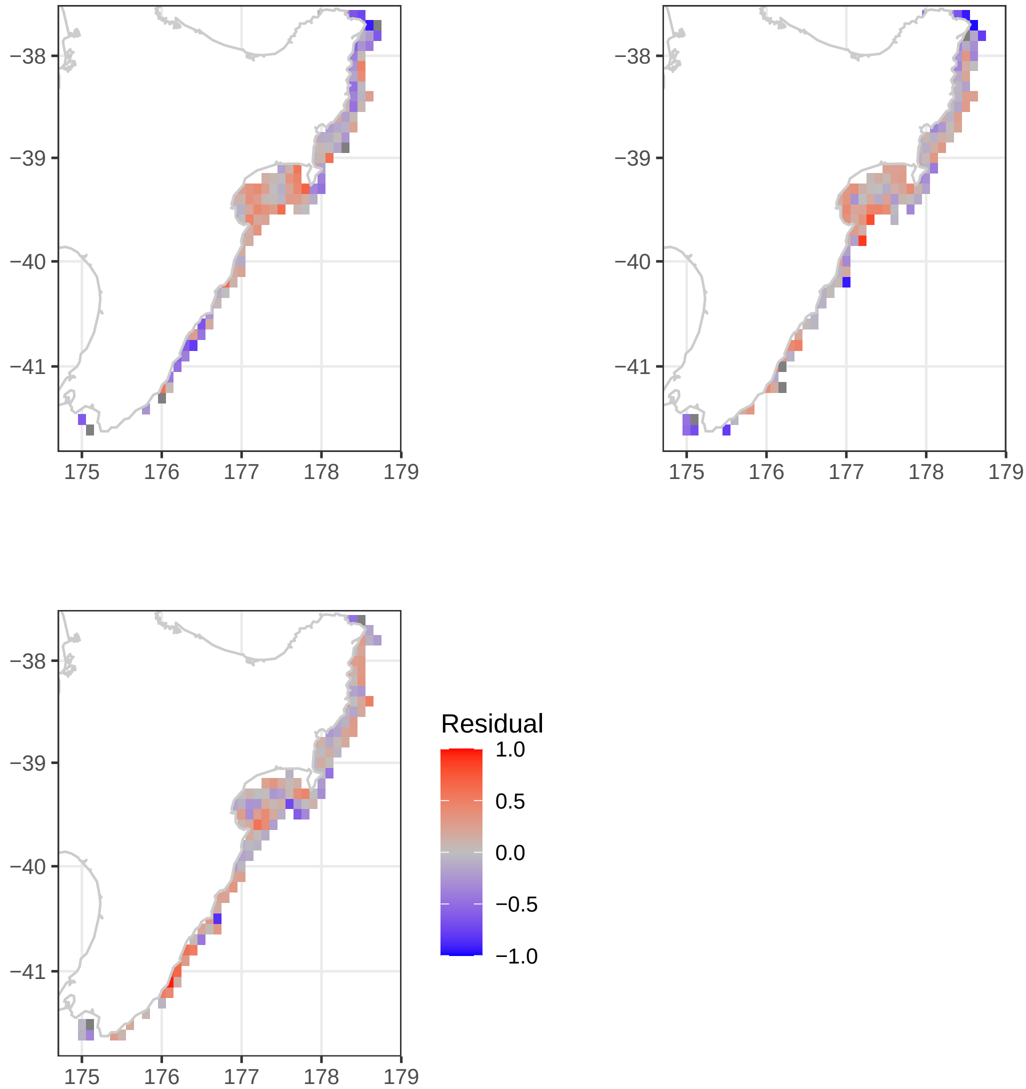

Figure 46: The mean residuals from the abundance model for GUR 2, residuals are plotted with 0.1 degree lat long bins and a threshold of 30 tows before a bin was included. Top left: 2008–2010, Top right: 2011–2013, Bottom: 2014–2016.

Examining the seasonal patterns of spatial residuals provided an opportunity to look for movement of trevally throughout the fishing year. There is a seasonal pattern in the spatial residuals: from June to August residuals are negative across FMA 2 (Figure 47). There are positive residuals within Hawke Bay in December and January, however there is no particular evidence of movement of fish into Hawke Bay to explain this (Figure 47). Positive residuals along the FMA 2 coastline between February and March provide some evidence for fish spreading out from Hawke Bay (Figure 47). These patterns are consistent with the patterns of catch and effort from the fisheries characterisation (Figures 15 and 10), as well as the area*month interaction in both vessel day (Figure 28) and TCER models (Figure 42). The area*month interaction was included in the final model but had negligible influence on the CPUE indices (Figure 40).

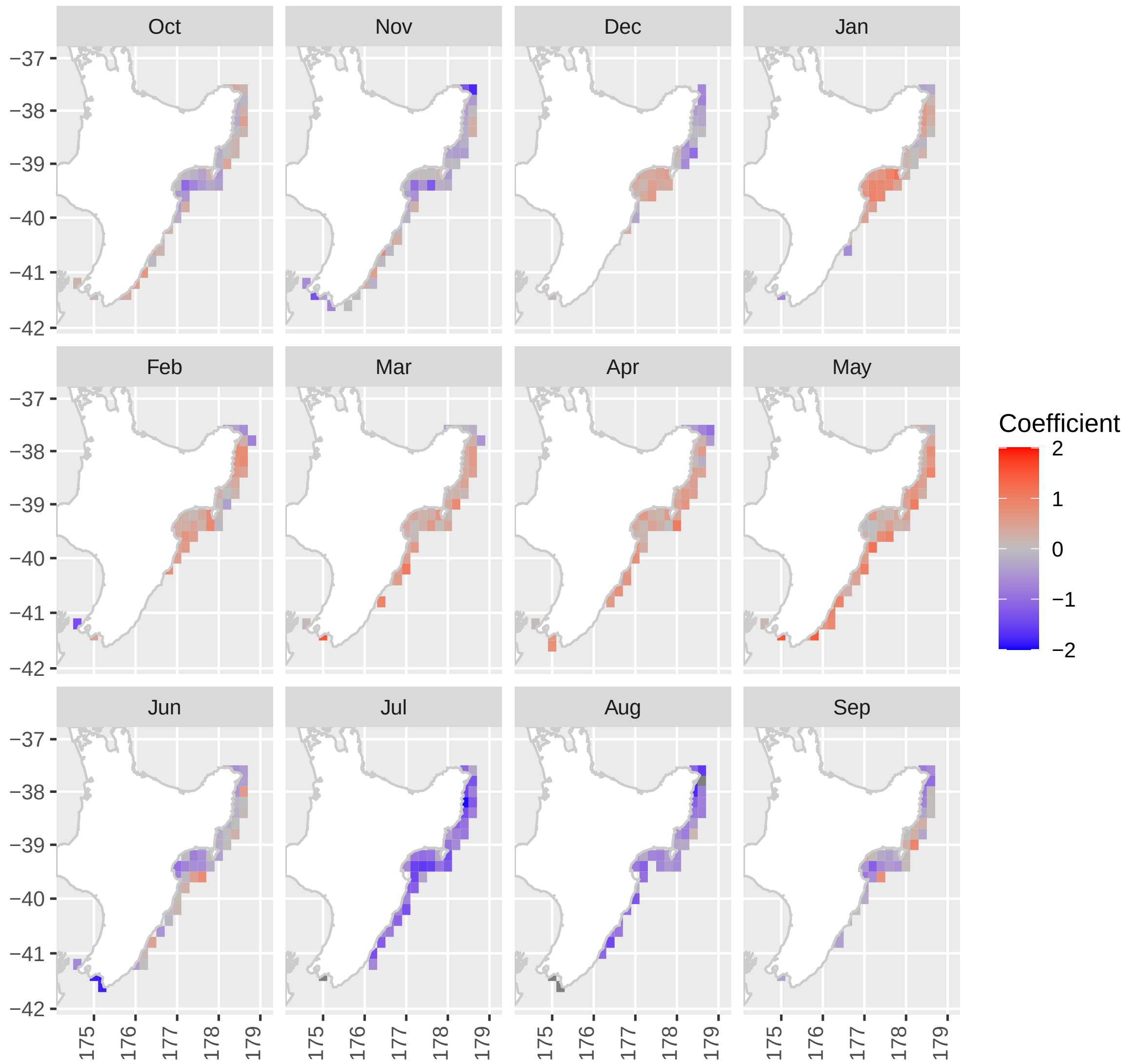

Figure 47: Residual implied coefficients for each position in each month. Implied coefficients are calculated as the mean, in each position in each month, of the sum of the model fit and the residual for each stratum.

5.6 CPUE indices

The TRE 2 TCER occurrence of positive catch, magnitude of positive catch indices and combined indices show a slight decrease from 2008 to 2013, followed by an increase to 2017 (Figure 48).

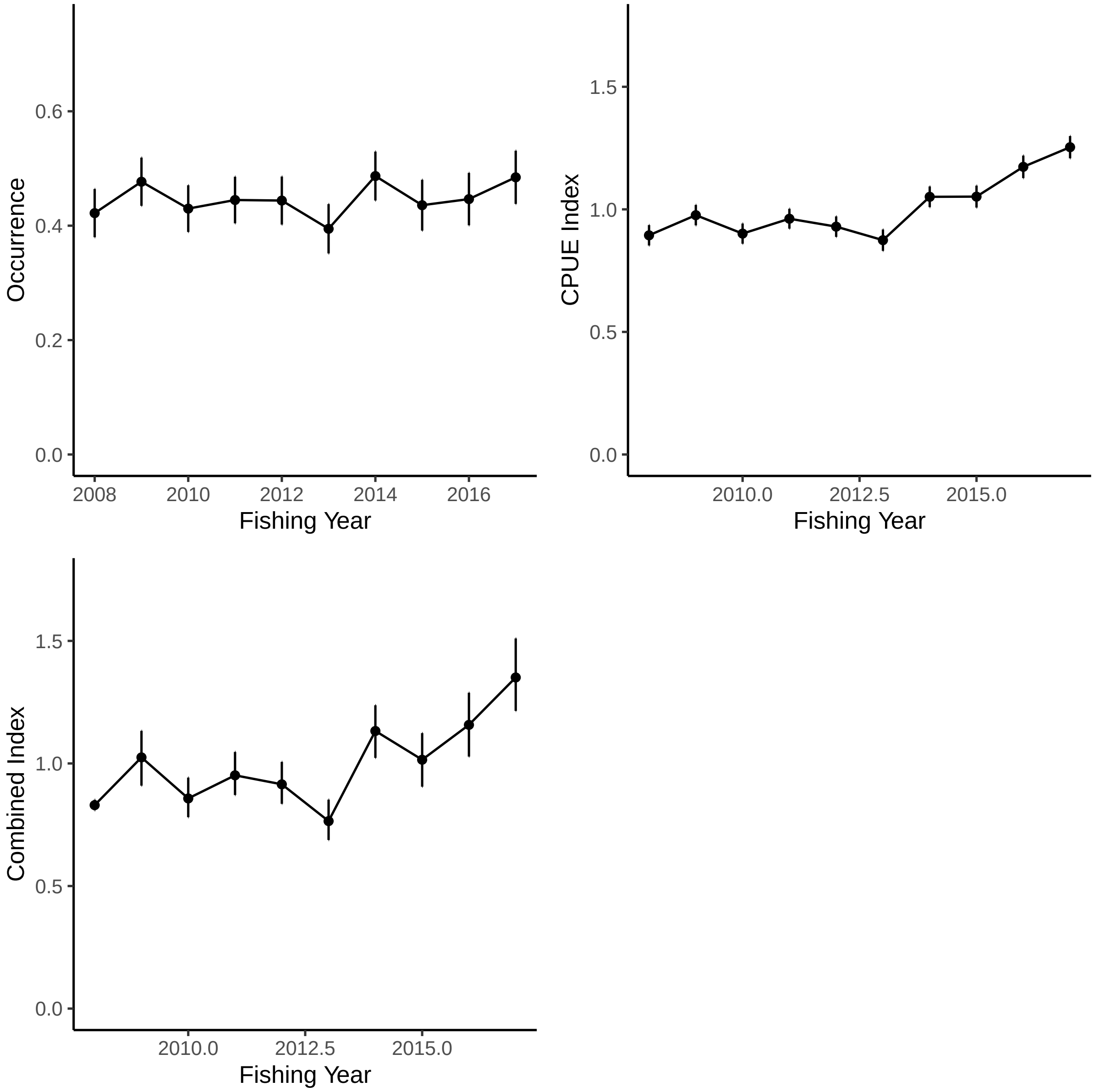

Figure 48: The trevally TCER indices: occurrence (proportion of records with catches; top left), CPUE indices (magnitude of catches; top right) and combined (occurrence x magnitude normalised; bottom) from the 1990 to 2017 fishing year.

6. DISCUSSION

The TRE 2 fishery is primarily a bottom trawl fishery, focused in inshore waters of Statistical Areas 013–016. Trevally are captured within a mixed species fishery, with snapper, gurnard, tarakihi and trevally the most common target species reported.

The Inshore Working Group concluded the magnitudes of changes in the previous TRE 2 CPUE indices were greater than could be expected in a closed population, taking into account the longevity of the species. This analysis generated comparable indices between 1990 to 2008; however, in the following nine years the TRE 2 indices were relatively stable with an increasing trend over the last four years of the series (Figure 49). The TRE 2 and the TRE 1 Bay of Plenty sub-stock indices are similar between 1990 and 2007, with the trend in the TRE 1 indices mirrored in the TRE 2 indices although sometimes with a one year lag (Figure 50). Between 2007 and 2013 the TRE 2 and TRE 1 indices display different trends, with TRE 2 not displaying the large fluctuations evident in TRE 1 (Figure 50).

The spatial residuals and area*month coefficients provided limited information on the relationship of the TRE 2 fishery to the Bay of Plenty sub-stock of TRE 1. There were large seasonal coefficient changes, as well as a spatial residual pattern. However the area * month coefficient is not influential on the TRE 2 CPUE indices. Catch sampling data exploring relative year class strengths and growth rates in TRE 1 and TRE 2 are required to further explore stock relationships, and both QMAs should be included in the next TRE 1 CPUE analysis and stock assessment.

In the BT-MIX vessel-day series there were large cycles in abundance, with a decline between 1990 and 1996, and a corresponding increase between 1997 and 2000 at which point there was another decline until 2008 (Figure 49). From 2008 to 2017 the indices were relatively stable with an increasing trend over the last four years of this series. The tow-based TCER indices showed a similar trend to the daily series, for the corresponding period.

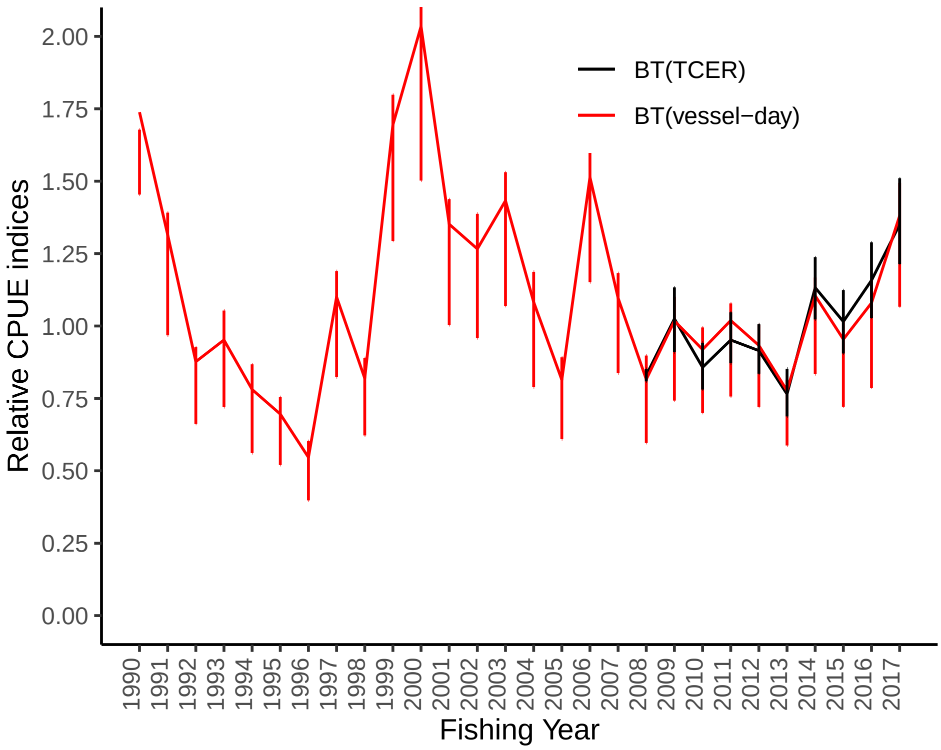

Figure 49: The combined CPUE indices for the TRE 2 vessel-day series from the 1990 to the 2017 fishing year and the TRE 2 TCER series from the 2008 to the 2017 fishing year.

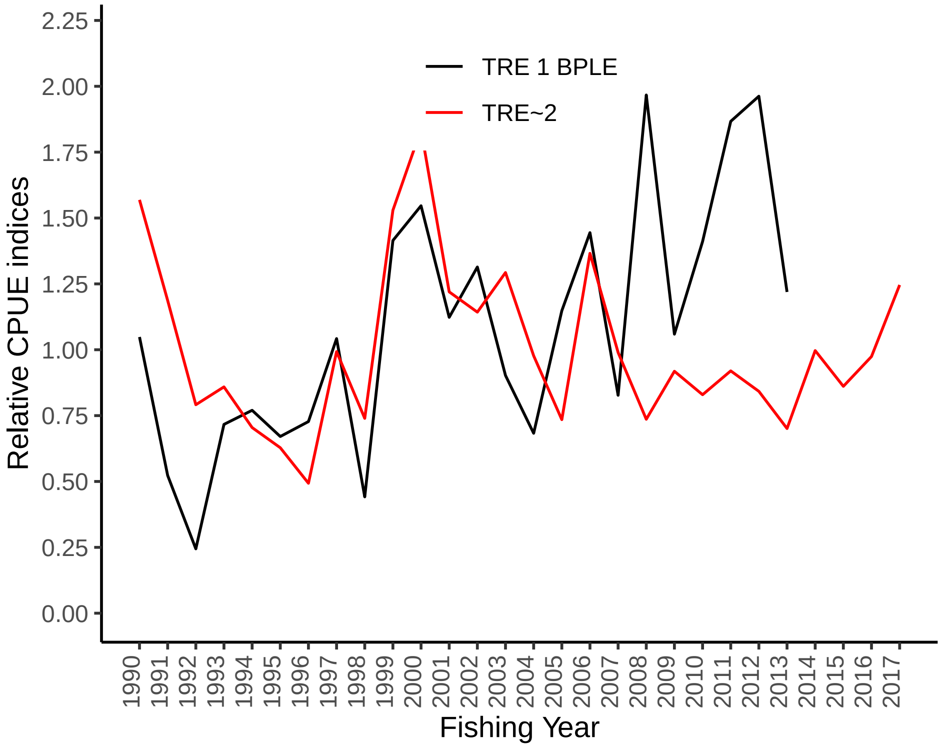

Figure 50: The combined CPUE index for the TRE 2 vessel-day series for the 1990 to 2017 fishing years and the combined TRE 1 Bay of Plenty sub-stock trip-level index for the 1990 to 2013 fishing years (McKenzie et al. 2016).

7. MANAGEMENT IMPLICATIONS

No CPUE index has previously been accepted by the Northern Inshore Working Group as an index of abundance for TRE 2 because of alternating sharply increasing and decreasing trends (see Bentley & Kendrick 2015, Ministry for Primary Industries 2018). The historic sharp fluctuations in trend between 1990 and the mid-2000s are still evident in the series presented in this report. However, this highly variable period is followed by a nine year period of greater stability, with an increase over the last four years of the series. Nevertheless, the Northern Inshore Working Group did not accept these series as indexing the TRE 2 stock because of the possibility that trevally in TRE 2 are part of a wider biological stock that includes the Bay of Plenty (part of TRE 1). From the mid-1990s to mid-2000s, there are similarities between the TRE 2 index and the index for the TRE 1 Bay of Plenty stock. However, these indices diverge in the early 1990s and post-2010.

8. ACKNOWLEDGEMENTS

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