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Catch-per-unit-effort (CPUE) analyses for SNA 2

New Zealand Fisheries Assessment Report 2018/15

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

Schofield, M.I.; Langley, A.D.; Bentley, N.; Middleton, D.A.J. (2018). Catch-per-unit-effort (CPUE) analyses for SNA 2.

***New Zealand Fisheries Assessment Report 2018/15.* 87 p.**

The snapper fishery in Quota Management Area (QMA) SNA 2 was analysed from 2001/02 to 2015/16 based on compulsory reported commercial catch and effort data held by the Ministry for Primary Industries (MPI). This time series has been reduced because of uncertainty in the reporting of commercial catch in a period where the TACC was consistently over caught (1989/90–2001/02). SNA 2 comprises the eastern North Island from Cape Runaway around to Mana Island on the west coast. Snapper is predominantly caught as a by-catch species of the trawl fishery within SNA 2, with the majority of the SNA 2 catch captured in a mixed species (snapper, tarakihi, trevally and red gurnard) target fishery between Cape Runaway and Cape Kidnappers.

SNA 2 is composed of two distinct sub-stocks, this is the first analysis to form distinct CPUE indices for each sub-stock. The sub-stocks are divided by the Mahia Peninsula, with the northern sub-stock including Statistical Areas 011, 012 and 013 east of Mahia Peninsula and the southern sub-stock including Statistical Areas 013 west of Mahia Peninsula and 014. Statistical Area 013 was sub-divided, into east and west of Mahia Peninsula, using trawl start positions for TCER data and a regression partitioning tree for CELR data.

A delta Generalised Linear Model (GLM) approach was applied to the daily aggregated dataset to model the occurrence of snapper catches (presence/absence) and the magnitude of positive snapper catches. The presence/absence of snapper catch was modelled based on a binomial distribution, for the positive catch CPUE model a Weibull error structure was adopted, following an evaluation of alternative distributions. Combined indices were formed as the product of the occurrence of positive catch and magnitude of positive catch, the associated error structure was obtained via bootstrapping. The combined series for the northern sub-stock increased from 2001/02 to 2005/06, declined from 2005/06 to 2009/10, then gradually increased from 2009/2010 to 2015/2016. The southern sub-stock also increased from 2001/02 to 2005/06, then declined substantially from 2006/07 to 2009/10. There was an uplift in 2011/12 and 2012/13 but the index subsequently showed a gradual decrease to 2015/16. The catalyst of the divergence in sub-stock trends is a steady decline in occurrence of SNA 2 catch in the southern sub-stock. The CPUE trends in both sub-stocks are corroborated by the tow based TCER series.

The NINS WG adopted the combined vessel day CPUE indices as indices of abundance for the SNA 2 sub-stocks (22 June 2017).

1. INTRODUCTION

Snapper (*Pagras auratus*) are an important component of inshore trawls on the lower eastern coastline of the North Island in Fisheries Management Area 2 (FMA 2, often referred to as Area 2) (Ministry for Primary Industries 2016). Annual commercial catches from the fishery peaked at 600–700 t during the early–mid 1970s following the development of the pair trawl fishery (Ministry for Primary Industries 2016). Catches declined substantially in the early 1980s and an initial TACC was set at 130 t in 1986/87. Since the introduction of the Quota Management System in 1986 the SNA 2 TACC has been consistently over-caught . The Total Allowable Commercial Catch (TACC) has increased from 130 tons to 315 tons and since 2001/02 landings have been similar to TACC. The current analysis focuses on the period from 2001/02 to 2015/16 because there were a number of strategies employed by fishers with insufficient quota prior to this period that resulted in Catch Per Unit Effort Indices being considered unreliable.

Catch at age sampling (Walsh et al., 2012) found evidence for two sub-stocks within SNA 2: a northern stock located between Mahia Peninsula and Cape Runaway, and a southern stock occurring within Hawke Bay. Previous analyses CPUE analysis of SNA 2 (Kendrick & Bentley 2014) used sub-stock as a factor within their analysis, however this analysis was not accepted by the Northern Inshore Working Group (NINS WG). A stock assessment for SNA was conducted in 2010 based on CPUE indices from 1989/90 to 2008/09 and limited age composition data (Langley 2010). The stock assessment results were sensitive to fisheries selectivity and the resultant model fit was considered poor (Langley 2010, Ministry for Primary Industries 2016). This analysis did not consider different sub-stocks in SNA 2. The current analysis derives separate CPUE indices for the northern and southern sub-stocks of SNA 2, providing CPUE indices for monitoring SNA 2 abundance. The project was funded by Fisheries Inshore New Zealand and conducted by Trident Systems.

Throughout this report fishing years are referred to as the later year; thus the 2001/02 fishing year (1 October 2001 to 30 September 2002) is referred to as 2002.

2. METHODS

Statutory catch, effort and landings data for SNA 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 dataset captured all fishing effort in FMA 2 that had potential to capture snapper (inshore trawls in Statistical Areas 011:016) regardless of whether snapper 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 two effort records were corrected using values from 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, as well as to remove duplicate landings.

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

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

Grooming rule	Description	Records dropped
FELLS	Coordinate outside of Statistical Area	340
FETSW	Target species invalid	66

The majority of the landings removed during grooming were removed by rule LADTH (Figure 1) 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)). Earlier in the timeseries some data were removed by the check LADUP which identifies duplicate landings (Figure 1).

The groomed landing data were comparable to the consolidated Quota Management Returns (QMRs) and Monthly Harvest Returns (MHRs) (Figure 2).

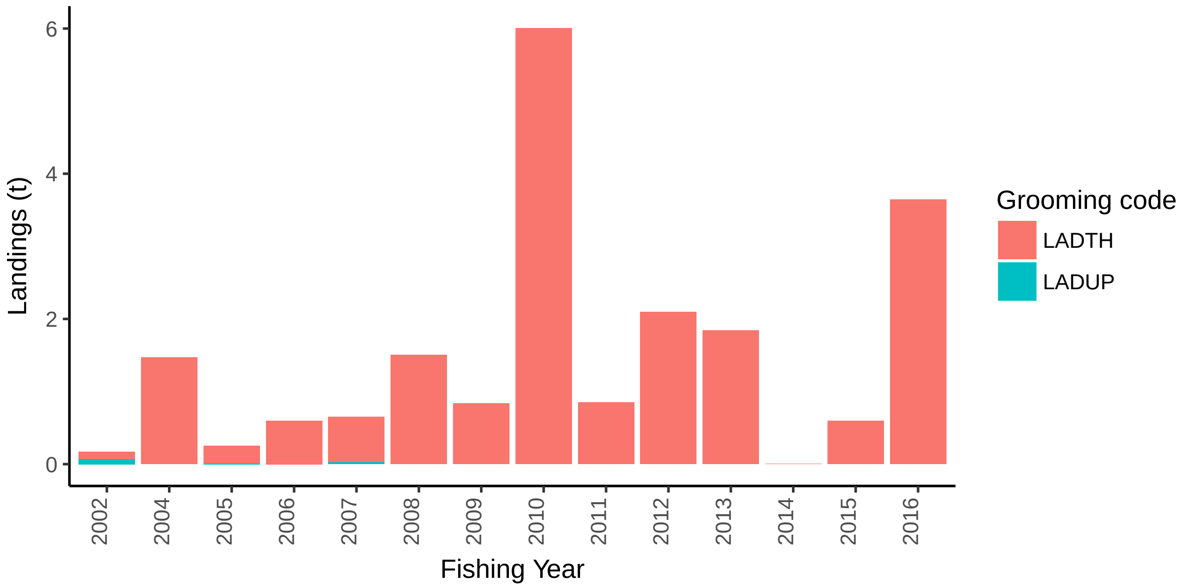

Figure 1: The snapper landings data removed from the SNA 2 CPUE analysis dataset, the bar colour indicates the grooming checks contributing to the removals.

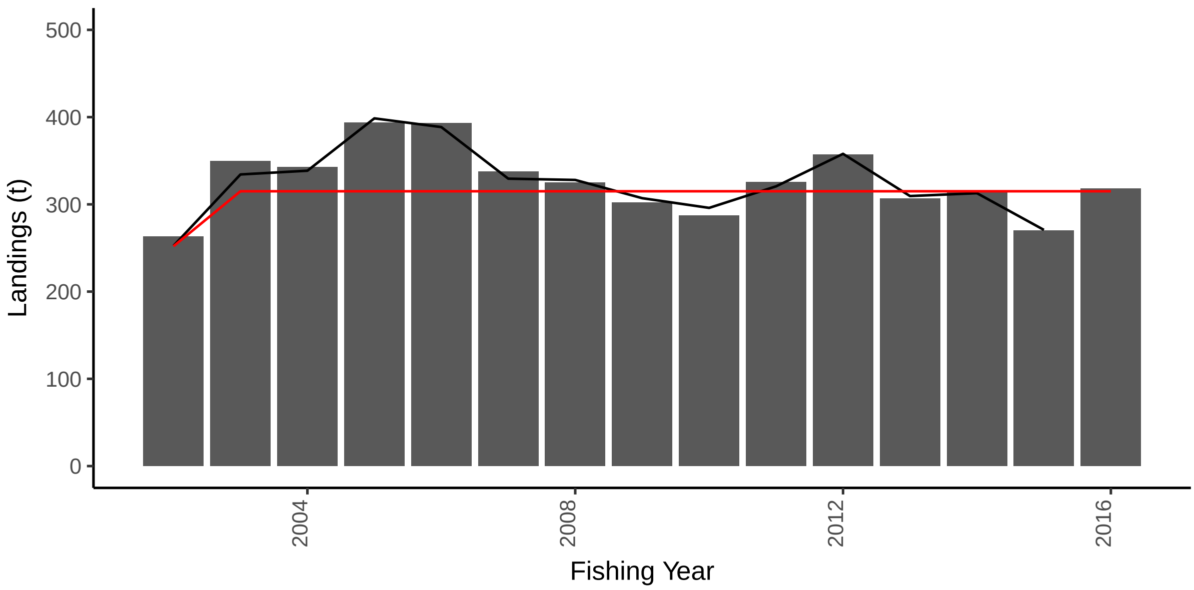

Figure 2: A comparison between the reported SNA 2 groomed annual landed catch (bars), the combination of Quota Management Returns (QMR, 1990–2001) and Month Harvest Returns (MHR, 2002-2016, black) and the SNA 2 Total Allowable Commercial Catch (TACC, red).

2.1.1 SNA 2 History

Historic SNA 2 catches between 1960 and 1980 were commonly in excess of 600 tons (Figure 3), whereas the current TACC is 315 tons. Since the introduction of the QMS the SNA 2 TACC has steadily increased, the TACC was exceeded consistently from 1987/88 to 2000/01. This analysis has been restricted to between 2001/02 and 2015/16 due to uncertainty around the consistency of both fishing and reporting behavior in SNA 2 prior to 2001/02.

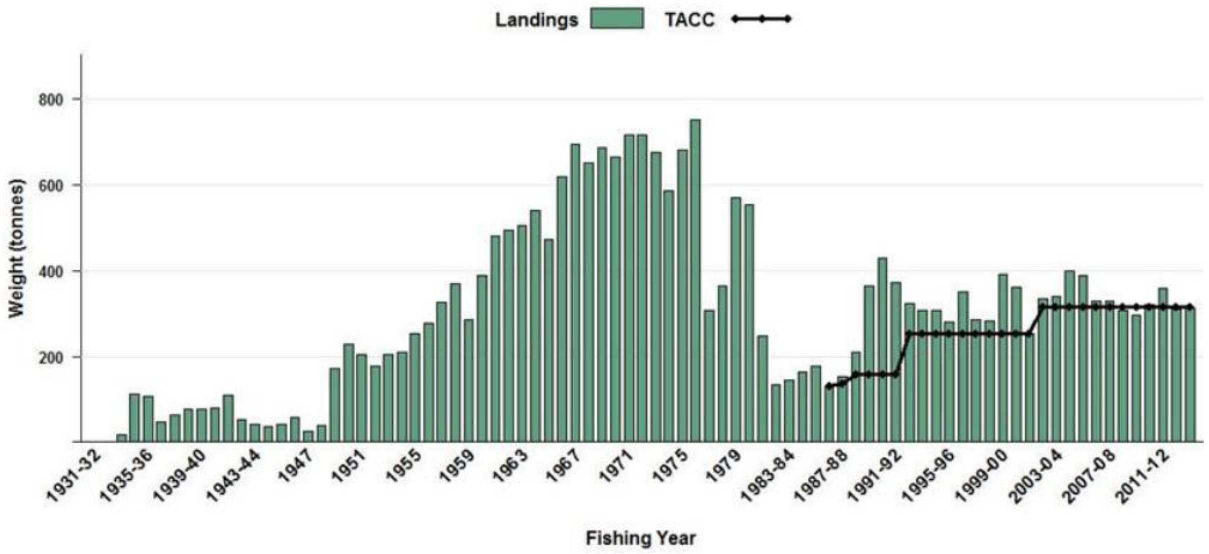

Figure 3: Total reported landings and TACC for SNA 2 from the 1931/32 to 2014/15 fishing year.

2.2 Data description

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. 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.

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. 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 2001/02 to 2015/16 and 2) a trawl event based data set that retains the detail of the TCER data format from 2007/08–2015/16. 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).

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. 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 Data filtering for CPUE analyses

When carrying out CPUE analyses, records were dropped if the reported fishing duration was less than 1 hour or greater than the 99.5th percentile. Landings were excluded if they exceeded the 99th percentile and the estimated catch differed significantly from the reported landing.

2.4 Partitioning data to the northern and southern sub-stocks

The proposed sub-stock boundary for SNA 2 occurs off the southern tip of the Mahia Peninsula, splitting Statistical Area 013 into Eastern and Western sub-areas at 177.87°E (Figure 4). Data reported on TCER and TCEPR forms can be readily allocated to the appropriate sub-stocks using trawl start position (Table 2). However, this is problematic for assessing SNA 2 sub-stocks prior to the introduction of TCER forms because effort was only reported at the level of the Statistical Area.

Table 2: The number of trawls in the TCER data (2008 fishing year to 2016 fishing year) within each of the Statistical Areas of SNA 2, with Area 013 split at 177.87°E.

Statistical Area	Trawls
011	8 009
012	11 109
013E	18 753
013W	19 280
014	14 410
015	2 331
016	2 623

Data prior to 2007/2008 reported on CELR forms, with fishing events originating in Statistical Area 013 were allocated based on a classification partitioning model (Therneau et al. 2015). The classification

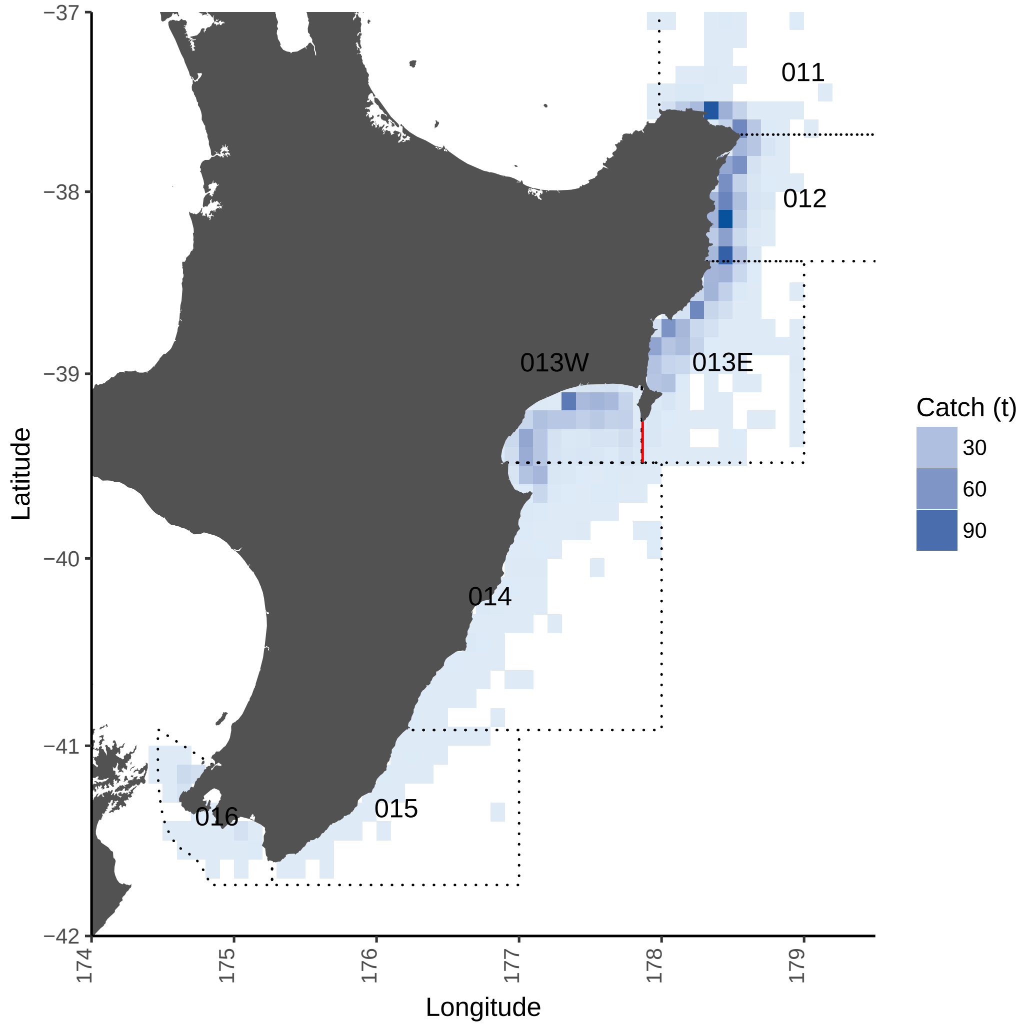

Figure 4: The distribution of TCER SNA 2 bottom trawl catch between the Statistical Areas of SNA 2 from the 2008 to the 2016 fishing year. Trawls were aggregated to 0.1° ×0.1° bins plotted based on reported starting positon. The proposed sub-stock boundary of Statistical Area 013 is plotted in red.

partitioning model builds a binary tree to predict if a Statistical Area 013 catch should be classified as 013W or 013E (Figure 5). Regression partitioning of the CELR dataset was conducted on the aggregated vessel-day resolution data, this ensured that the TCER and CELR data were comparable.

The variables month, vessel, height, target, duration, season and landing port were offered at TCER resolution to the partitioning model as potential predictors of Statistical Area 013 sub-area. The tree was built by the following process: first a single variable was found which best split the data into two groups. The data was separated, and then this process was reapplied separately to each sub-group, and so on recursively until the subgroups either reached a minimum size or until no improvement could be made.

The regression partition model used landing port for the primary split and then target species as the secondary split (when landing port was not Auckland, Gisborne or Tauranga (Figure 5)). The classification partitioning model was created using a training dataset comprising of only the TCER data (where Area 013W and 013E was known). The training dataset predicted Area 013 split with 88.9% accuracy (88.62%, 89.19%).

The model sensitivity was trialed by re-fitting the model using a random subset of the TCER data. This model was assessed using another random subset and resulted in the same model being selected with a prediction accuracy of 89%.

The decision tree shows that events with a landing port of Auckland, Gisborne and Tauranga were allocated 013E, this represented a 98% correct allocation (Figure 5). Events landing elsewhere were further segregated by whether they targeted tarakihi (TAR). If TAR was the target species they were allocated 013E, otherwise they were allocated 013W. The 013E TAR target catches were 75% correctly allocated, whereas the non-TAR target catches were 88% correctly allocated. These criteria were then applied to partition the 013 CELR data to either 013E or 013W, the distribution of Area 013 catches predicted by the decision tree are summarised in Table 3.

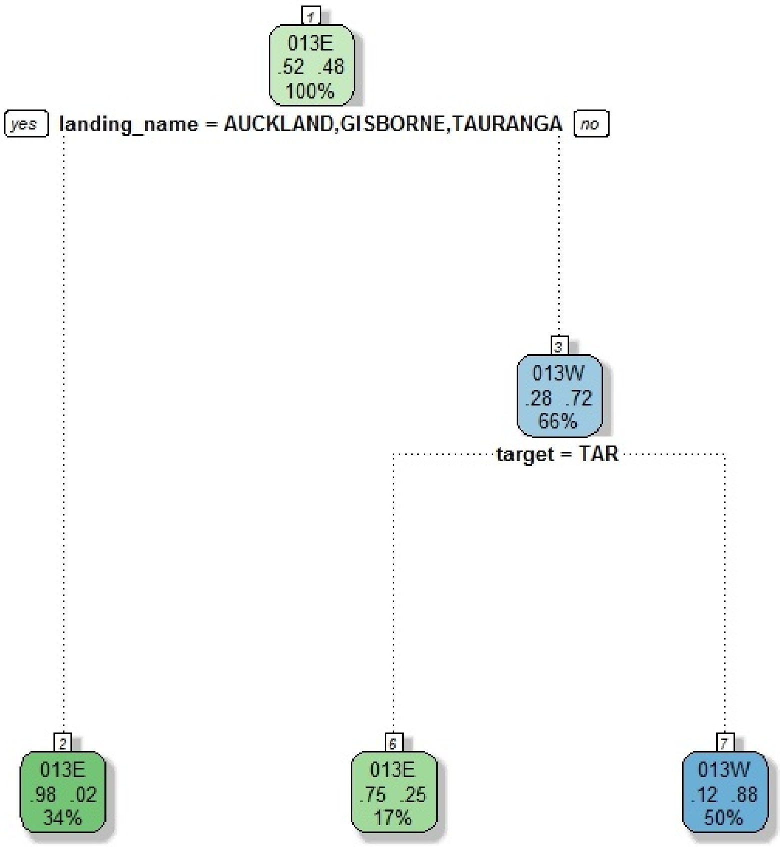

Figure 5: Decision tree for Area 013 catch split, the proportions indicate the proportions of data in each direction, i.e. lhs 013E and rhs 013W. The percentages indicate the amount of the total data at each node.

Table 3: The distribution of Statistical Area 013 fishing events from the 2002 to 2007 fishing year, split using the classification partitioning model.

	011	012	013E	013W	014	015	016
011	1 131						
012		1 984					
013			4 452	7 290			
014					3 316		
015						337	
016							224

The decision tree is heavily reliant on the primary split of landing port, Table 4 shows the reported landing ports from 2002 to 2016. There has been consistent reporting of landings by port through the series (Table 4), which provides confidence when using the decision tree on the CELR dataset.

Table 4: The number of trips landing to each port in FMA 2 from the 2002 to the 2016 fishing year.

	AUCKLAND	GISBORNE	NAPIER	TAURANGA	WELLINGTON
2002	3	288	661	46	8
2003	7	215	706	84	8
2004	3	241	551	80	5
2005	4	265	638	63	18
2006	7	242	686	113	25
2007		264	671	68	13
2008		237	519	89	16
2009		268	495	94	7
2010		294	505	96	12
2011		243	501	75	9
2012		246	431	88	15
2013	2	245	351	85	26
2014		234	397	99	44
2015	1	197	311	64	21
2016	7	184	442	49	36

2.5 CPUE models

A Generalised Linear Model (GLM) approach was used to model the occurrence (presence/absence) of positive snapper catch and the magnitude of positive snapper 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 (Log logistic, lognormal, Gamma). The presence/absence of snapper 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 5 and the model terms offered to the tow resolution models in Table 6. Fishing year (fyear) was forced into all CPUE models. Models were selected by forward stepwise selection, where the selection criteria were a reduction in Akaike's Information Criterion (AIC) and at least an addition 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 5: The variables offered to the Binomial and Weibull vessel-day resolution CPUE model for model selection. * varies with sub-stock.

Variable	Definition	Data type	Range
Fishing Year	Fishing year	Categorical (15)	2002:2016
Vessel	Fishing vessel	Categorical (*)	
Area	Statistical Area	Categorical (*)	
Month	Month	Categorical (12)	Jan-Dec
Area * Month	Area and month combination	Categorical (*)	
Duration	Natural logarithm of trawl duration (hours)	Continuous	ln(1:24)
Effort	Number of trawls in the vessel–day	Continuous	1-6
Target Species	Most frequent target species for the vessel–day	Categorical (4)	GUR, TAR, SNA, TRE

Table 6: The variables offered to the Binomial and Weibull TCER resolution CPUE model for model selection. * varies with sub-stock.

Variable	Definition	Data type	Range
Fishing Year	Fishing year	Categorical (9)	2008:2016
Vessel	Fishing vessel	Categorical (*)	
Month	Month	Categorical (12)	Jan-Dec
Area	Statistical Area	Categorical (*)	
Area * Month	Area month combination	Categorical (*)	
Duration	Duration of fishing effort for the day (hours)	Continuous	ln(1–6)
Effort	Number of trawls in the day	Continuous	1–6
Target Species	Most frequent target species for the vessel–day	Categorical (4)	GUR, TAR, SNA, TRE
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	1–200

3. CHARACTERISING THE COMMERCIAL FISHERIES IN SNA 2

The data in SNA 2 were primarily reported on Catch Effort Landing Return (CELR) forms from 2002 to 2007 at which point the fleet switched to reporting on Trawl Catch Effort Return Forms (TCER) (Figure 6).

The SNA 2 fishery is primarily a bottom trawl fishery with occasional snapper catches by Danish seine vessels, and smaller, more sporadic snapper catches by set net and bottom longline vessels (Figure 7). As a result the trawl fishery was the focus for SNA 2 CPUE indices.

The majority of the SNA 2 trawl catch is taken in an inshore mixed trawl fishery that targets red gurnard, trevally and snapper and tarakihi (Figure 8, Figure 9, Figure 10). Snapper target fishing activity forms a small component of the inshore mix trawl fishery, and is more prevalent in the northern areas of SNA 2 (Statistical Areas 011, 012 and 013) (Figure 8, Figure 10). In SNA 2N the dominant target species is tarakihi and in SNA 2S the dominant target species is gurnard (Figure 8).

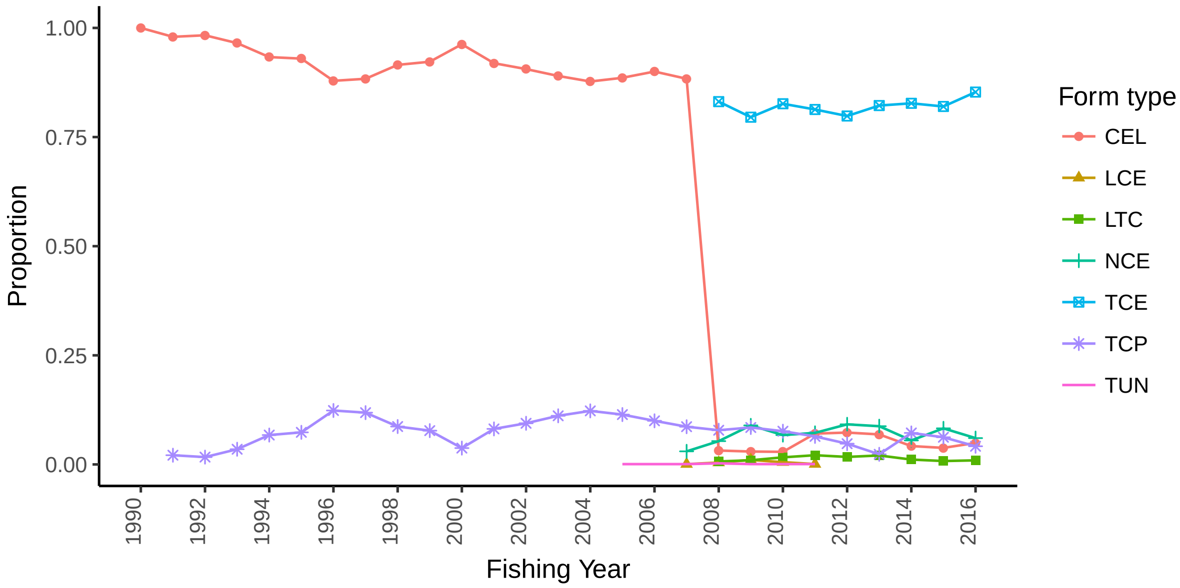

Figure 6: The proportion of trips reported on each form type in the SNA 2 fishery from the 2002 to the 2016 fishing year, TCER forms were introduced for the inshore trawl fleet in the 2008 fishing year.

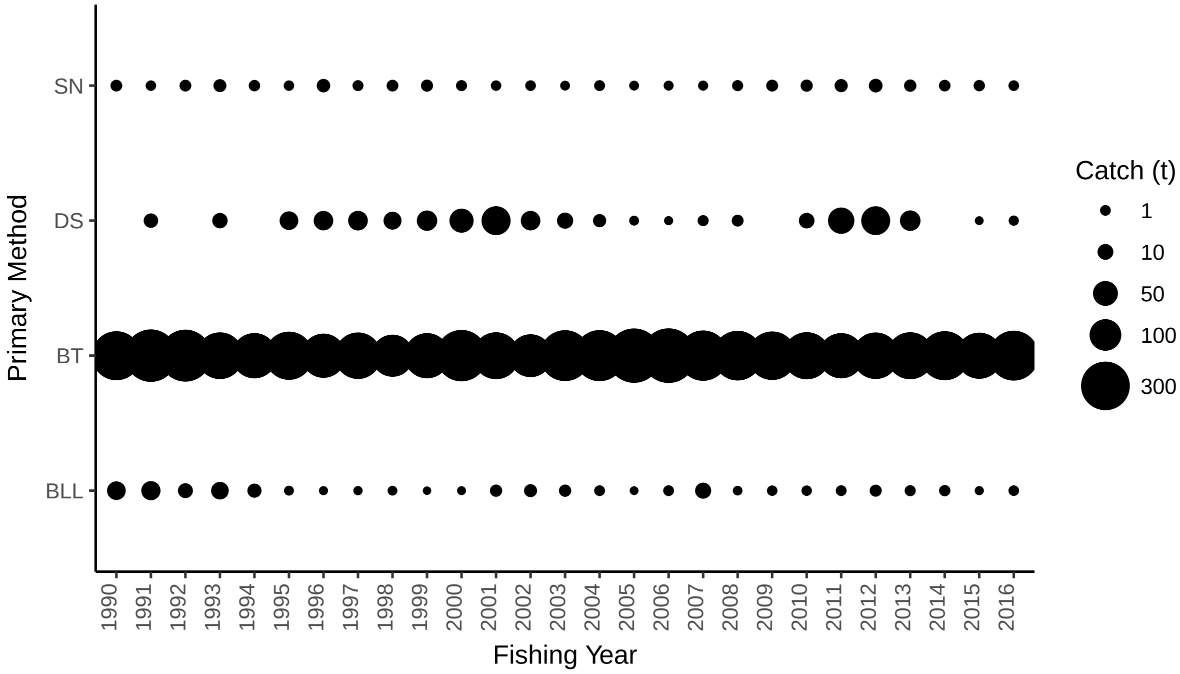

Figure 7: Snapper catch by method from the 1990 to the 2016 fishing year in the SNA 2 fishery, the area of the circle is indicative of the SNA 2 catch (t).

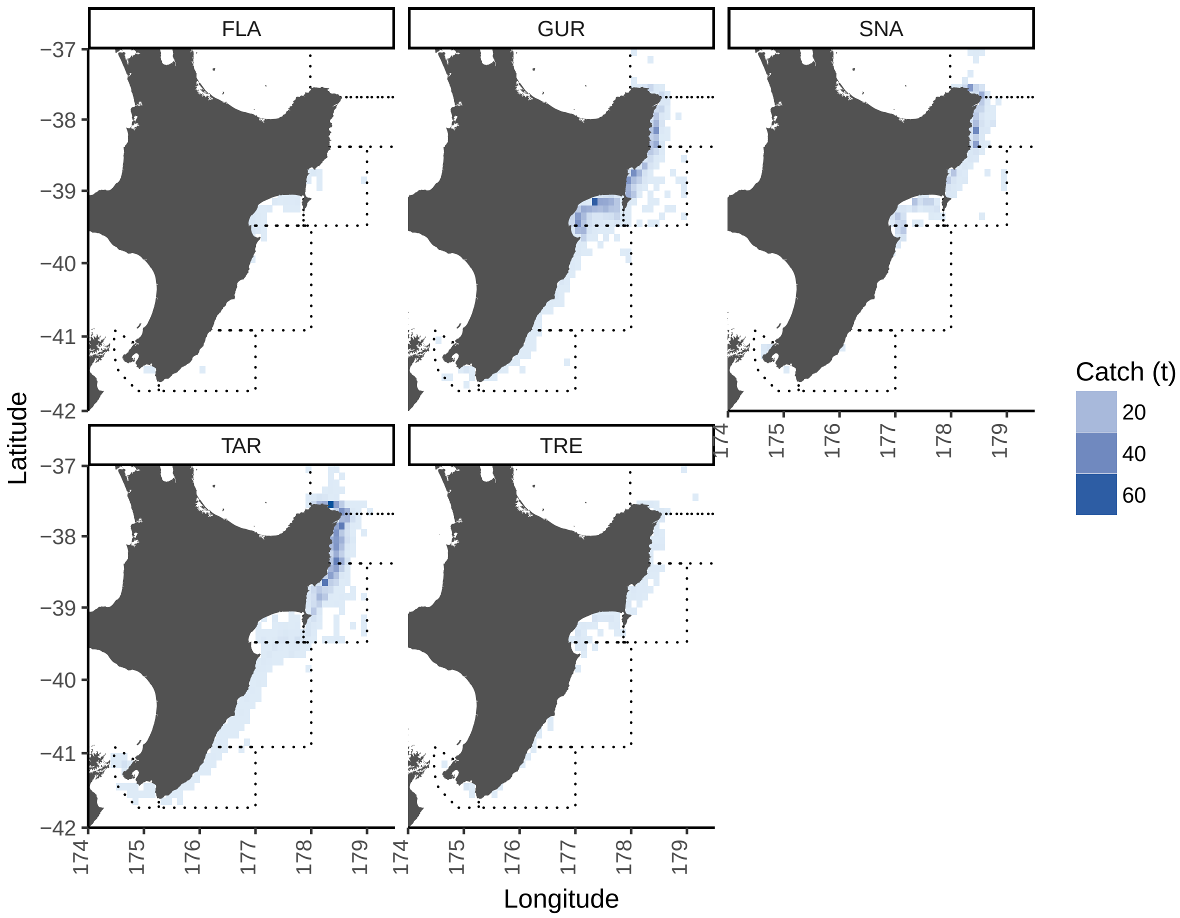

Figure 8: The distribution of SNA 2 bottom trawl catch by reported target species. Trawls reported on TCER forms from the 2008 to the 2016 fishing year are plotted based on reported starting positon aggregated to 0.1° ×0.1° bins. Target species aggregated into the OTH category are a relatively homogenous spread of barracouta, warehou, hoki, ling and gemfish.

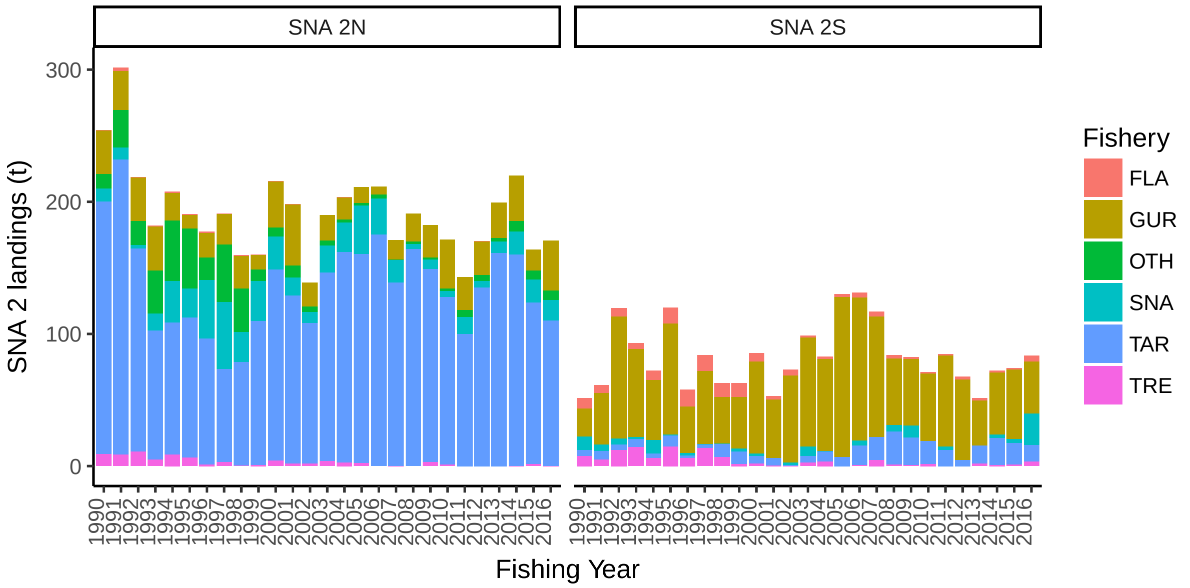

Figure 9: The snapper bottom trawl catch by target species in each sub-stock of SNA 2 from the 2002 to the 2016 fishing year.

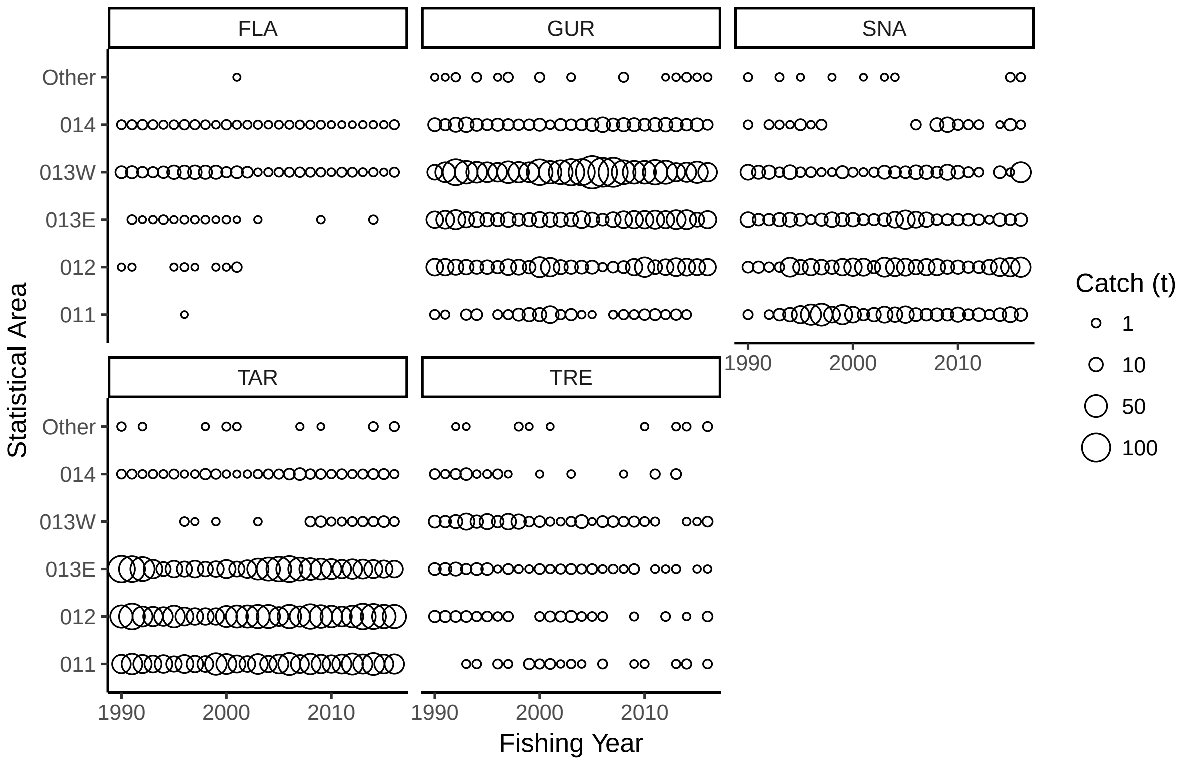

Figure 10: The distribution of SNA 2 bottom trawl catch (aggregated from the 1990 to the 2016 fishing year) by Statistical Area (011 - 016) and target species.

Gurnard target trawling predominates in SNA 2 catches from Poverty Bay to Cape Kidnappers, with large catches in the inshore waters, whereas deeper catches along the FMA 2 coastline occur in tarakihi target trawling (Figure 11). SNA 2S snapper catch is captured in trevally, gurnard and snapper target fisheries between 30 and 50 m depth, the flatfish target fishery contributes some snapper catch in shallower waters (Figure 12). SNA 2N catch is centered between 40 and 60 m in all target species, although the tarakihi target fishery is spread over a broader and deeper depth range (Figure 12).

The SNA 2 catch is primarily taken between Mahia Peninsula and East Cape in inshore waters (Figure 13), lesser catches occur further offshore and also within Hawke Bay. The SNA 2 CPUE is greatest in inshore waters between Poverty Bay and Cape Runaway (Figure 14).

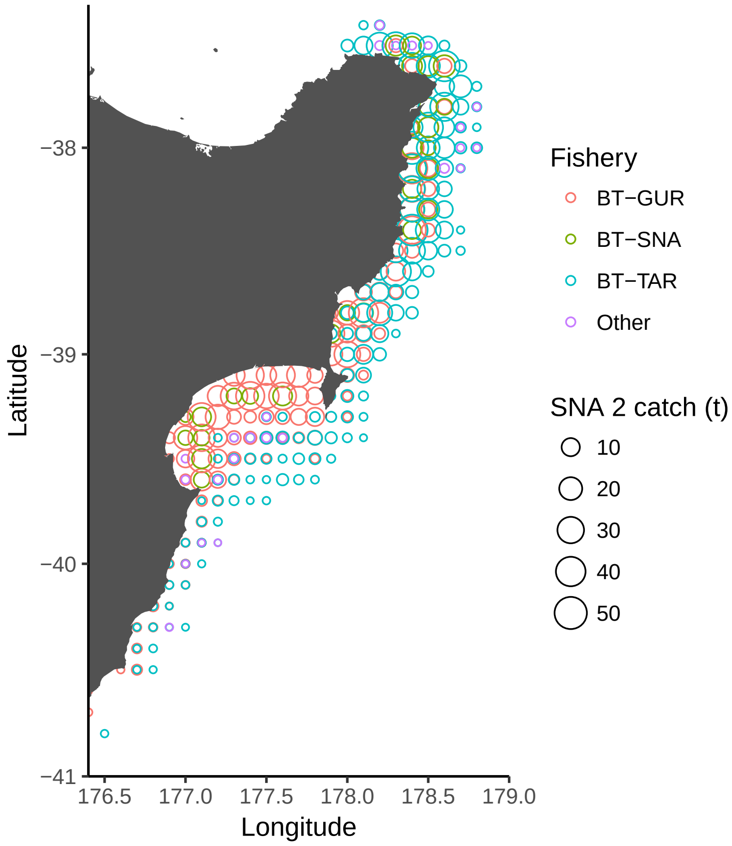

Figure 11: The spatial distribution of snapper catch from each of the target bottom trawl fisheries within SNA 2 (TCER dataset from the 2008 to the 2016 fishing year). The sizes of the circles are proportional to snapper catch.

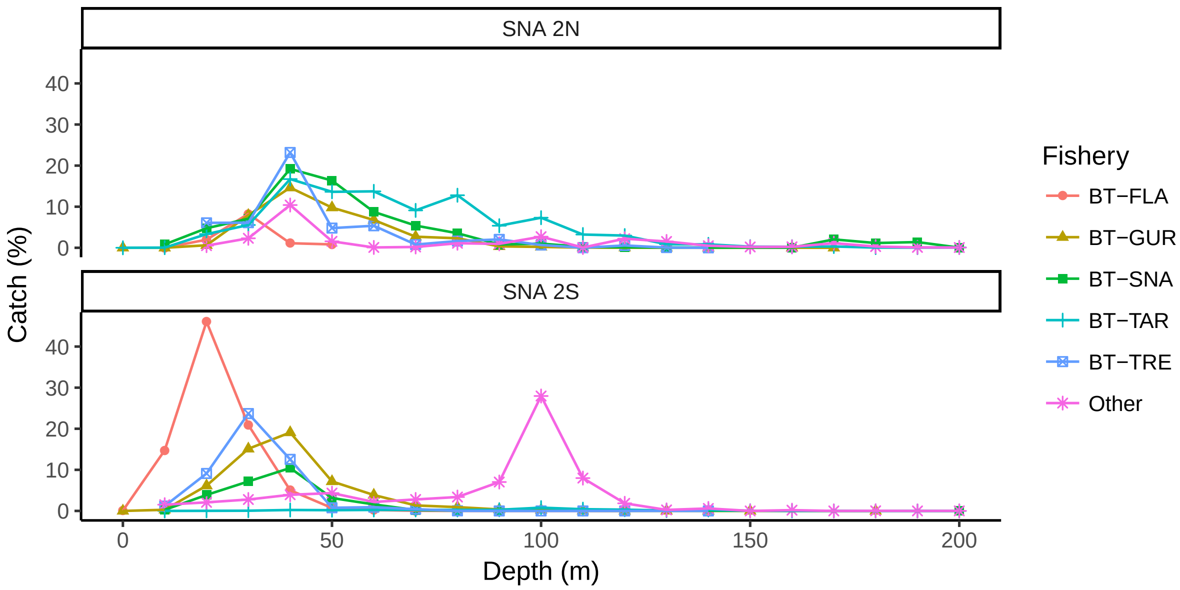

Figure 12: The depth distribution of snapper catch from each of the target bottom trawl fisheries operating within SNA 2N and SNA 2S (using data from the 2015 and 2016 fishing years).

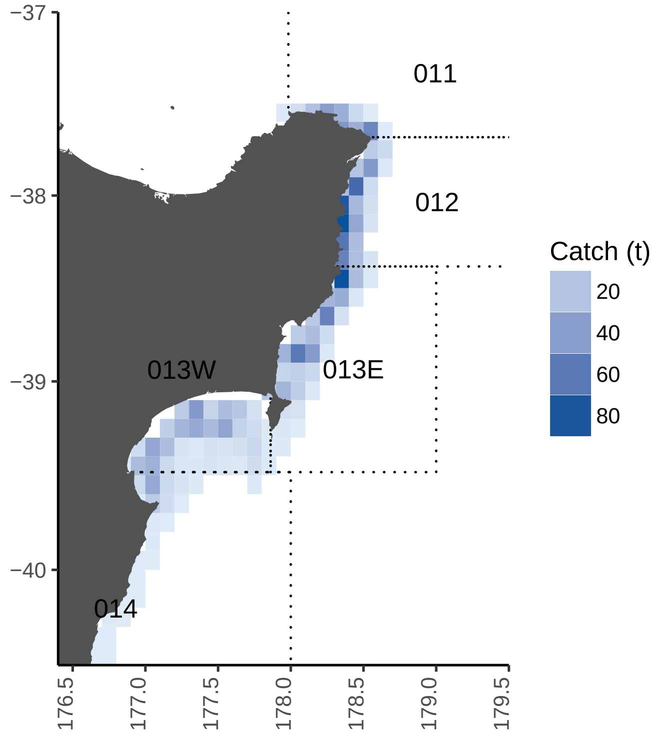

Figure 13: The spatial distribution of the SNA 2 TCER catch in tonnes from the 2008 to the 2016 fishing year. Catches are aggregated to 0.1° ×0.1° cells, and only cells with at least 20 records are displayed.

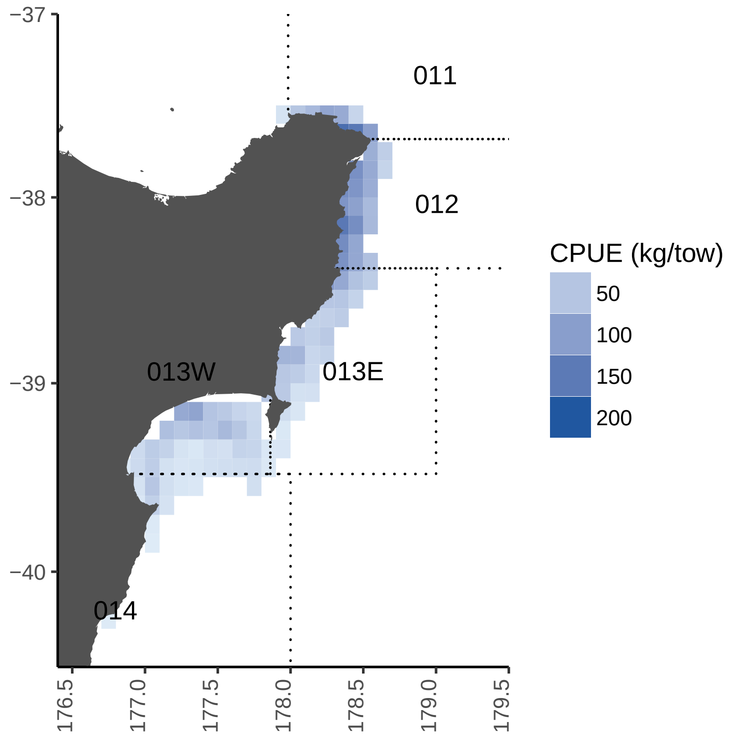

Figure 14: The spatial distribution of the SNA 2 TCER mean CPUE in kg/tow from the 2008 to the 2016 fishing year. Catches are aggregated to 0.1° ×0.1° cells, and only cells with at least 20 records are displayed.

3.1 Fisheries for CPUE analyses

The main fishery in SNA 2 is the BT-MIX target fishery, separate BT-MIX indices were developed for each sub-stock (north and south of Mahia Peninsula). In addition full dataset (CELR + TCER/TCEPR) and tow-by-tow (TCER/TCEPR data only from 2008 onwards) indices are considered. The full set of CPUE indices considered is summarised in Table 7.

Table 7: The fisheries defined for CPUE analysis.

Fishery	Target Species	Form	Years	Aggregation
BT Mix Tow N	SNA, GUR, TRE, TAR	TCER	2008:2016	None
BT Mix Tow S	SNA, GUR, TRE, TAR	TCER	2008:2016	None
BT Mix N	SNA, GUR, TRE, TAR	TCER, TCEPR, CELR	2002:2016	vessel-date
BT Mix S	SNA, GUR, TRE, TAR	TCER, TCEPR, CELR	2002:2016	vessel-date

4. SNA 2 SOUTH TCER

4.1 SNA 2 TCER Definition

The SNA 2 south bottom trawl TCER fishery (SNA 2S TCER) was defined as:

- Primary method: bottom trawl (BT)
- Target species: gurnard, trevally, tarakihi or snapper (GUR, TRE, TAR, SNA)
- Fishing effort conducted within Statistical Areas 013W and 014 where 013W refers to Statistical Area 013 with reported starting positions west of the longitudinal boundary 177.87°E.
- Fishing effort conducted between 1 Oct 2007 and 30 Sept 2016 and reported on a TCER or TCEPR form

The SNA 2S TCER fishery has similar levels of fishing effort annually, however, the SNA 2 catch varies considerably between years (Table 8). The percentage of trips that caught snapper has declined over the time series from about 65 % to about 50 %.

Table 8: Summary of data by fishing year after the SNA 2S TCER fishery definition has been 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 SNA.

Fishing Year	Vessels	Trips	Records	Effort (num)	Effort (hrs)	Catch (t)	Trips caught	Days caught
2008	23	587	3 632	3 632	13 493	96.5	67.3	57.0
2009	23	592	3 530	3 530	13 249	104.6	66.0	59.9
2010	20	684	3 788	3 788	14 221	81.2	61.7	56.2
2011	22	607	3 714	3 714	14 102	91.7	67.4	57.5
2012	19	506	2 833	2 833	10 872	76.9	66.0	64.5
2013	17	433	2 545	2 545	9 650	47.5	58.4	56.2
2014	19	515	3 037	3 037	11 581	55.2	59.4	51.9
2015	20	501	3 168	3 168	12 218	70.2	51.1	49.8
2016	19	544	2 746	2 746	10 793	79.2	54.0	49.8

4.2 Data filtering

Records were dropped if fishing duration was less then 1 hour, or greater then 6 hours (99.5th percentile). Landings were examined for accuracy if they exceeded 473 kg (99.5th percentile), of the 65 records affected one was removed because it could not be internally corroborated.

4.3 Core Vessel Selection

The last tow based analysis of a SNA 2 mixed target fishery (Kendrick & Bentley 2014) considered 013E and 013W as separate Statistical Areas within a full SNA 2 model. This analysis selected core vessels that had operated in the SNA 2 fishery for at least 3 years and had undertaken at least 3 trips per year. Reapplying these criteria would retain a core fleet that accounted for 95% of the catch (Figure 15).

In this analysis, the time series was three years longer, as a consequence a more stringent vessel selection criteria could be applied: vessels operating in the SNA 2S TCER fishery for 5 years and conducting at least 5 trips in each of these years (Figure 15). Applying these criteria resulted in a core fleet of 14 vessels which accounted for 83.32% of the SNA 2S TCER catch.

The majority of the core fleet have operated throughout the SNA 2S TCER time series (Figure 16). The SNA 2S TCER raw catch magnitude has oscillated around 15 kg per tow, whereas the catch probability

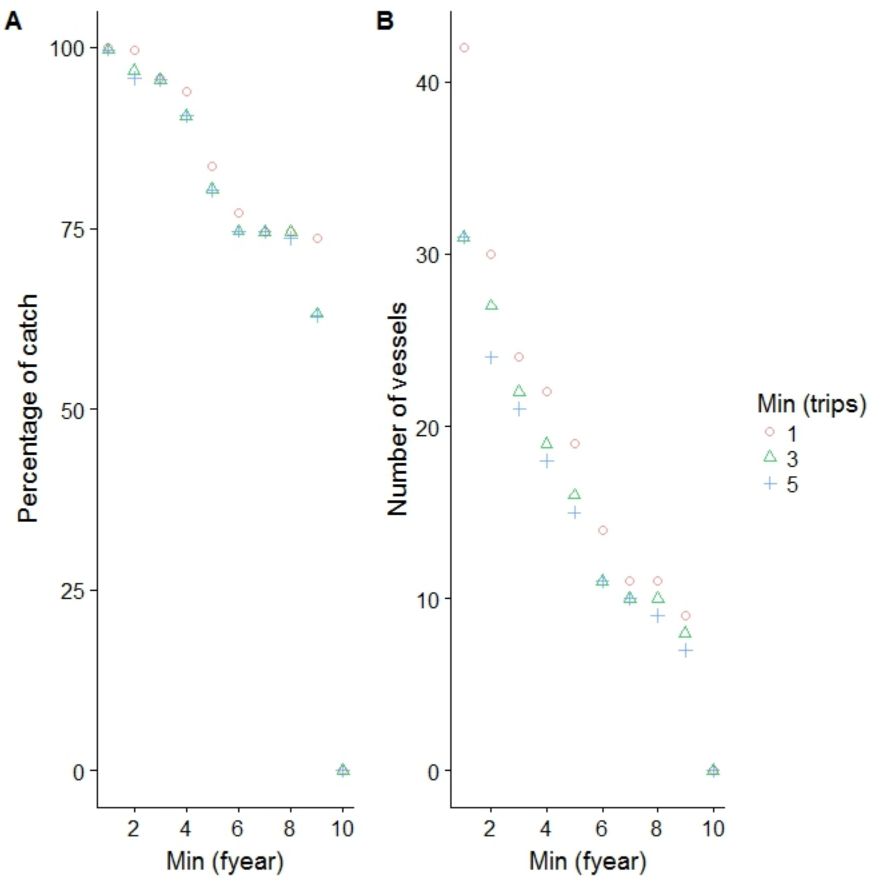

Figure 15: The percentage of catch (A) and number of vessels (B) represented by each alternate core vessel criteria: each unique combination of trips and fishing years

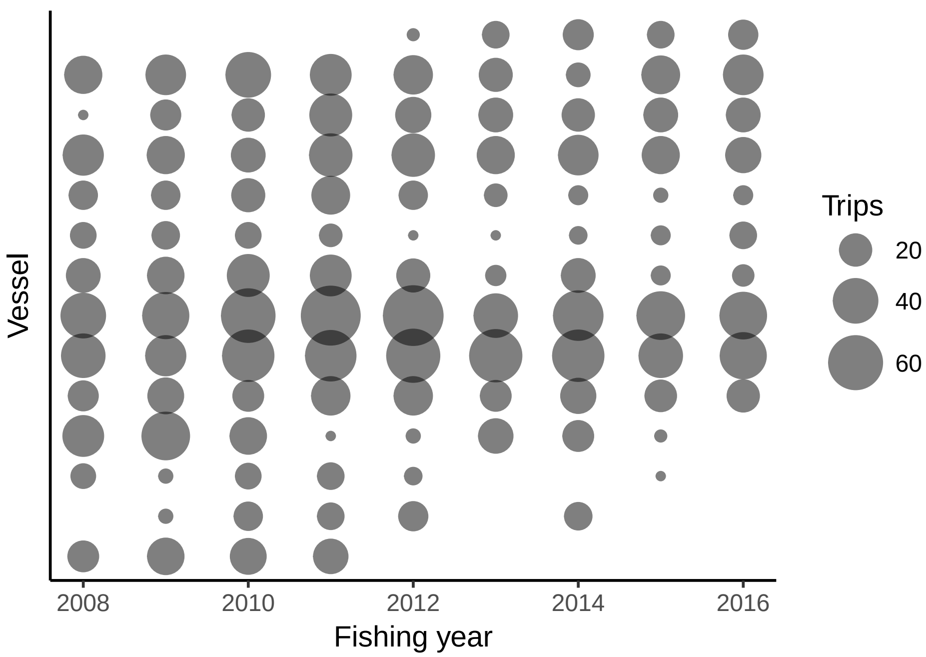

Figure 16: Number of trips by fishing year for core vessels in the SNA 2S TCER fishery. The area of circles is proportional to the number of trips for a vessel in a fishing year.

has gradually declined over the timeseries (Figure 17), these trends are consistent between the core and the overall fleet.

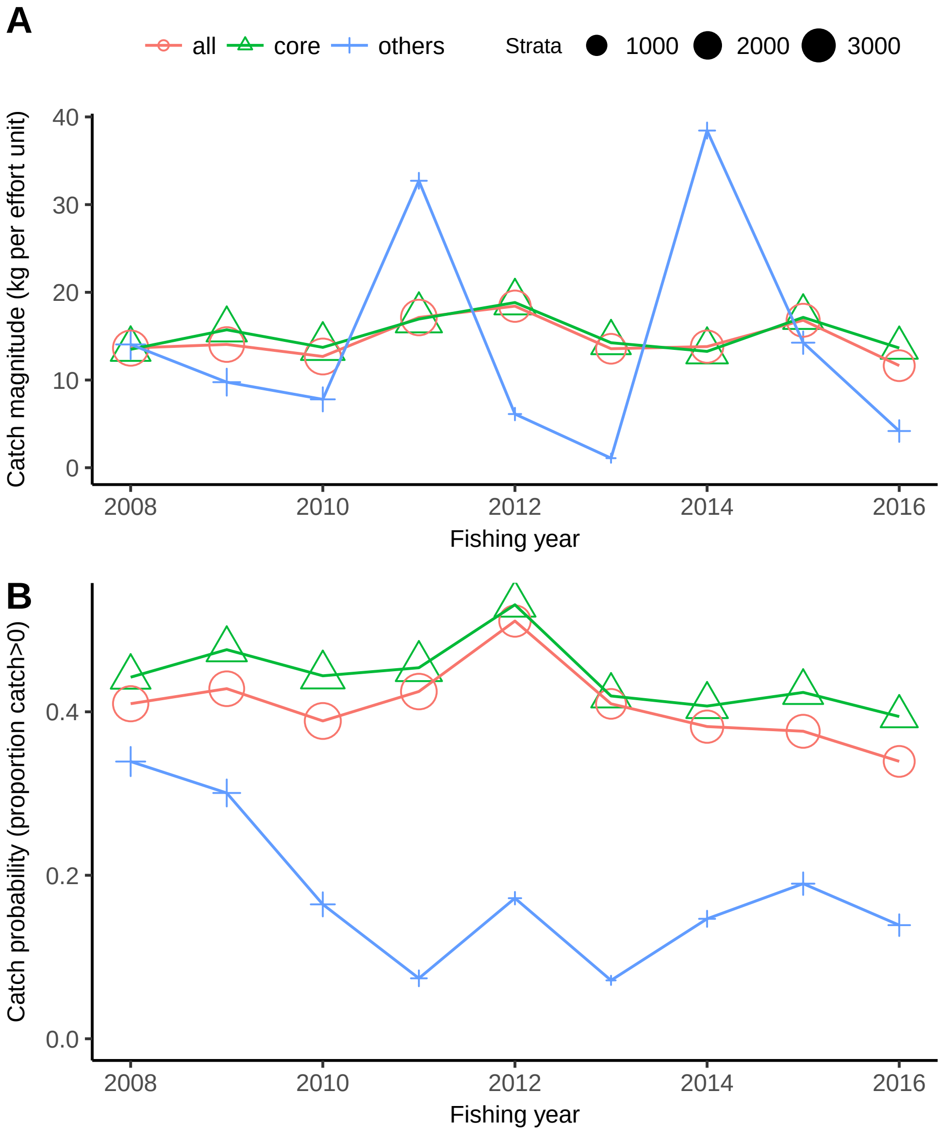

Figure 17: Comparison of the proportion of strata with positive catch (lower) and the unstandardised CPUE (geometric mean of catch divided by effort where catch was positive; upper) for all vessels and core vessels in the SNA 2S TCER fishery.

A summary of the SNA 2S TCER data used for CPUE analysis after filtering and restricting to the core fleet is provided in Table 9.

Table 9: Summary of the SNA 2S TCER core data aggregated by fishing year. 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 number of trips and days which reported catching SNA.

Fishing year	Vessels	Trips	Records	Effort (num)	Effort (hrs)	Catch (t)	Trips caught	Days caught
2008	12	419	2 491	2 491	9 130	66.3	68.0	59.9
2009	13	445	2 569	2 569	9 613	69.3	73.7	65.7
2010	13	544	3 040	3 040	11 414	61.2	70.0	61.5
2011	13	516	3 430	3 430	13 095	85.6	76.4	62.1
2012	13	443	2 676	2 676	10 349	76.4	73.1	67.9
2013	11	406	2 475	2 475	9 369	47.5	60.3	57.1
2014	12	405	2 744	2 744	10 597	47.2	70.6	56.3
2015	12	366	2 525	2 525	9 822	57.8	61.8	56.7
2016	10	388	2 156	2 156	8 360	74.5	62.9	55.0

4.4 Occurrence

The probability of positive catch (True/False) was modelled using a binomial GLM with a logit link function. The maximal set of model terms offered to the stepwise selection algorithm was:
$\sim fyear + vessel + target + area * month + poly(log(duration), 3) + area + month + poly(depth, 3) + poly(speed, 3) + poly(distance, 3) + poly(abs(lat), 3)$
The final model after the selection criteria of an improvement by 1% of explanatory power (Table 10) was:
$\sim fyear + poly(abs(lat), 3) + vessel + area * month + poly(depth, 3)$

Table 10: Summary of stepwise selection for SNA 2S TCER 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	32 413	0.4	0.4	*
+ poly(abs(lat), 3)	3	28 960	11.1	10.6	*
+ vessel	13	27 943	14.3	3.2	*
+ area_month	23	27 247	16.6	2.3	*
+ poly(depth, 3)	3	26 666	18.4	1.8	*
+ poly(lon, 3)	3	26 530	18.8	0.4	
+ target	3	26 428	19.1	0.3	
+ poly(distance, 3)	3	26 387	19.3	0.1	
+ poly(log(duration), 3)	3	26 380	19.3	0.0	
+ poly(speed, 3)	3	26 377	19.3	0.0	

The SNA 2S TCER occurrence indices show that the probability of non–zero catch has declined from 50% to 40% (Figure 18).

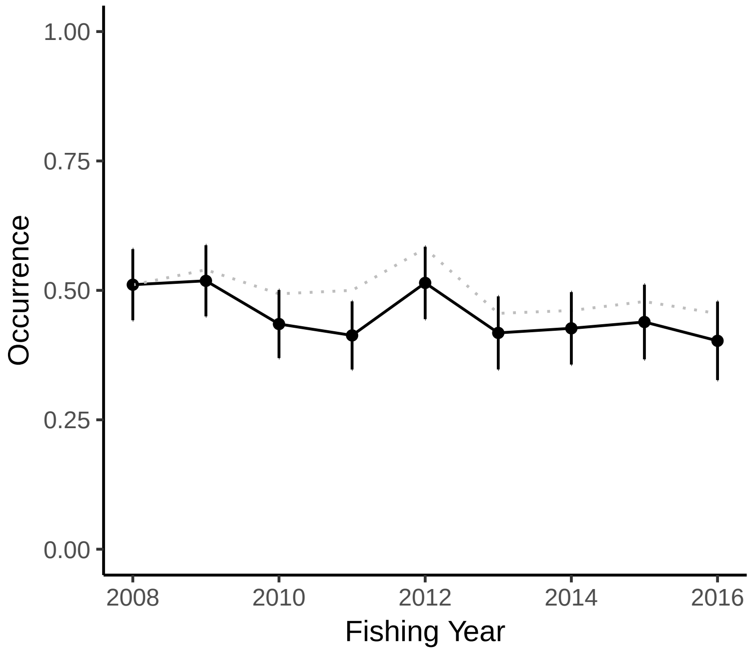

Figure 18: The occurrence of positive catch indices in the SNA 2S TCER fishery, raw indices are plotted with dashed grey lines.

4.5 Positive Catch

The magnitude of non-zero catches was modelled by Kendrick & Bentley (2014) using a Weibull distribution. In this analysis a Weibull distribution had the lowest AIC of the distributions examined.

The full set of model terms offered to the stepwise selection algorithm was:
$\sim fyear + vessel + target + poly(log(duration), 3) + area + month + area * month + poly(speed, 3) + poly(depth, 3) + poly(abs(lat), 3) + poly(lon, 3)$

The final model after stepwise selection (Table 11) was:
$\sim fyear + vessel + area * month + poly(abs(lat), 3) + poly(depth, 3) + target$

Table 11: Summary of stepwise selection for SNA 2S TCER 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	110 747	1.4	1.4	*
+ vessel	13	109 054	12.1	10.7	*
+ area_month	23	107 073	23.5	11.3	*
+ poly(abs(lat), 3)	3	106 393	27.0	3.5	*
+ poly(depth, 3)	3	105 911	29.5	2.4	*
+ target	3	105 771	30.2	0.7	
+ poly(log(duration), 3)	3.0	94 703	28.6	0.3	
+ poly(speed, 3)	1.0	94 689	28.7	0.1	
+ poly(lon, 3)	1.0	94 689	28.7	0.1	

4.5.1 Diagnostics

Model residuals from the positive log(catch) model show a reasonable approximation to the Weibull distribution (Figure 19), although there are deviations at the extremes (outside of 2 standard deviations).

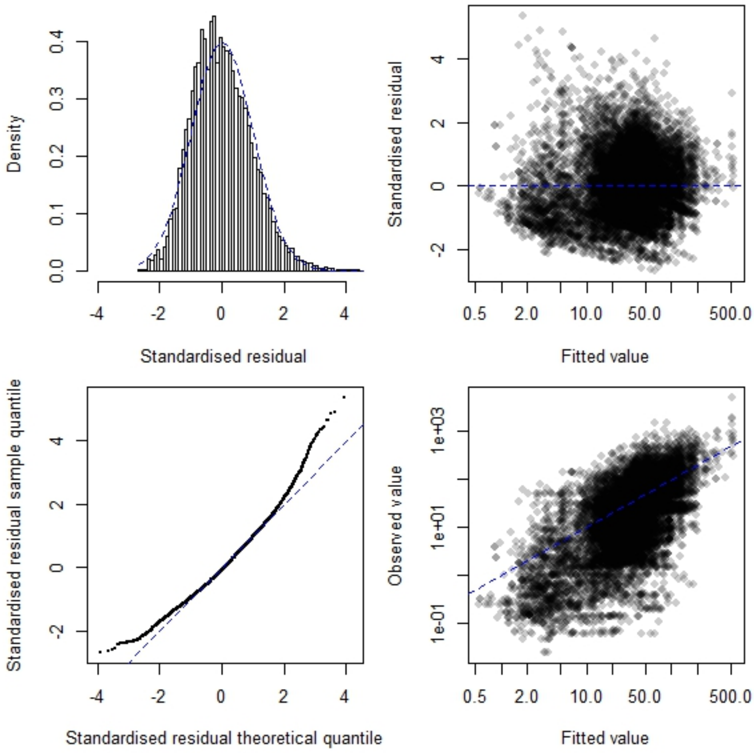

Figure 19: The Weibull diagnostic plots for the SNA 2S TCER model. top left: Standardised residuals from the accepted generalised linear model fit; top right: The standardised residuals versus the fitted values; bottom left: Quantile-quantile plot of observed response versus likelihood of the distribution of these values; bottom right: Observed values vs fitted values.

4.5.2 Influence of Model Terms

The standardisation process had little effect on the CPUE indices (Figure 20). Consequently, the addition of coefficients into the model also had a negligible influence on the CPUE indices (Figure 21).

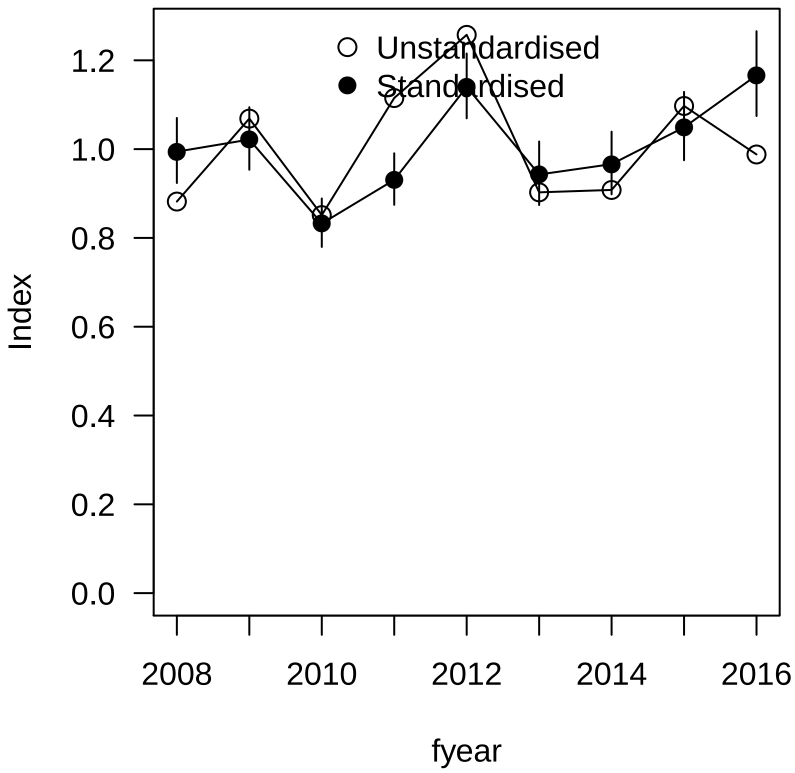

Figure 20: A comparison of the standardised CPUE indices and unstandardised indices of the SNA 2S TCER model. The unstandardised index is based on the geometric mean of the catch per strata and is not adjusted for effort.

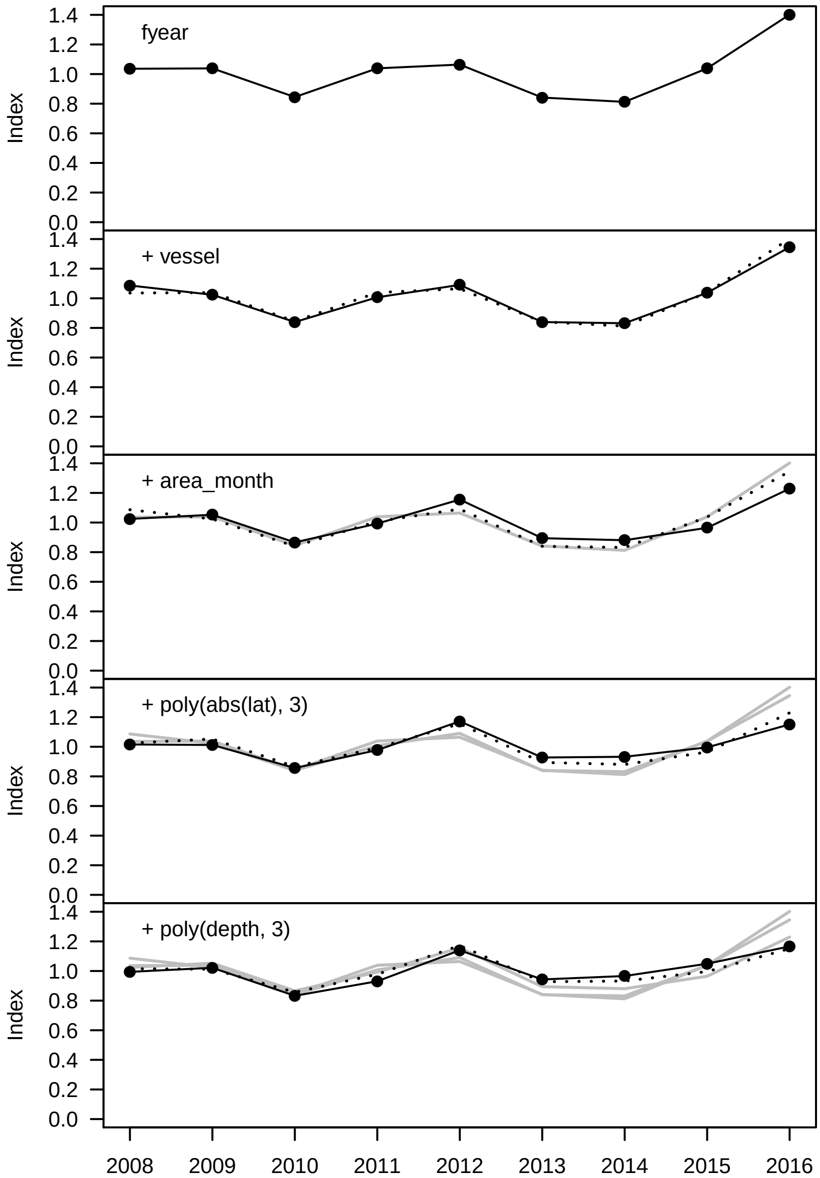

Figure 21: Annual indices of CPUE for the SNA 2S TCER model as each term was successively added. The indices are normalised to an overall geometric mean of 1.

There is a range of vessel coefficients in the SNA 2S TCER fleet (Figure 22). The influence of vessel varies as a consequence of the composition of the fleet (Figure 22).

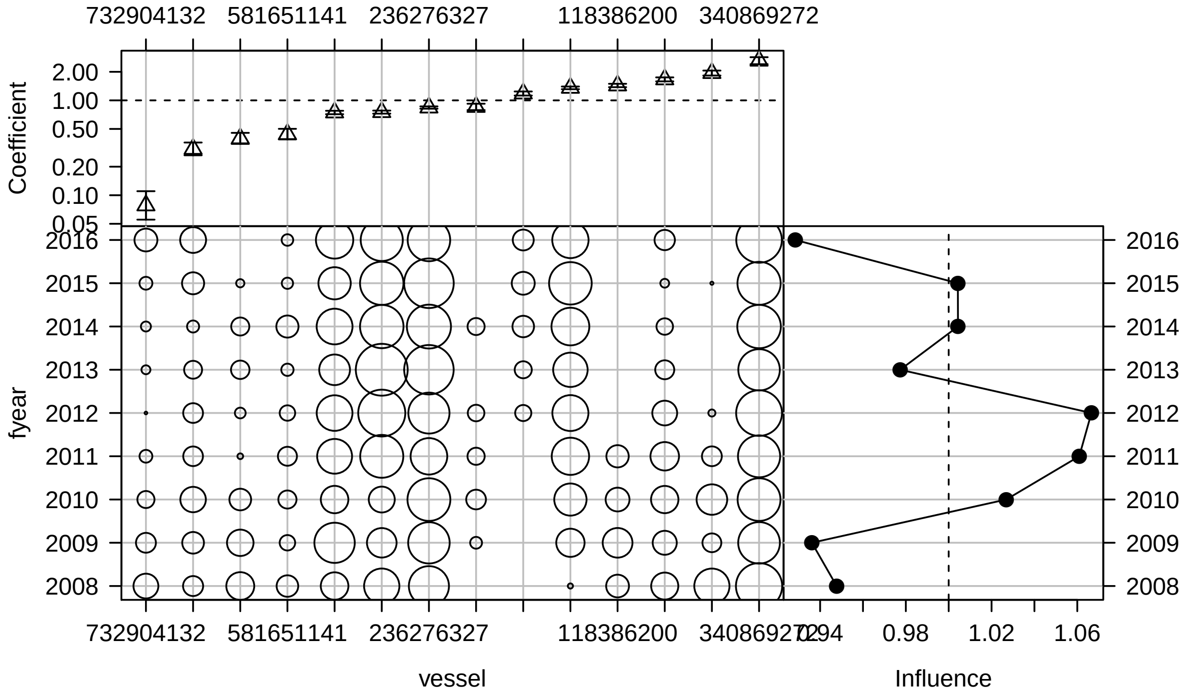

Figure 22: Coefficient-distribution-influence plot for vessel.

Both Areas coefficients followed broadly similar trajectories (Figure 23). Area 013W increased from October to November then steadily declined from December to August with a major dip in February and then an increase in September (Figure 23). Area 014 was more variable, it increased from October to December then generally declined from January until June, before increasing in July and August, followed by a decline in September (Figure 23).

The latitude coefficients were influenced by the amount of fishing in the southern area of the SNA 2S (Figure 24). Coefficients were maximized at northern latitudes, between -39.575 to -39.175.

The depth distribution of fishing effort in SNA 2S TCER fishery was between depths of 10 and 50 m (Figure 25). There has been an increase in fishing effort at shallower depths since 2011. Depth coefficients were maximized between 5 and 40 m (Figure 25).

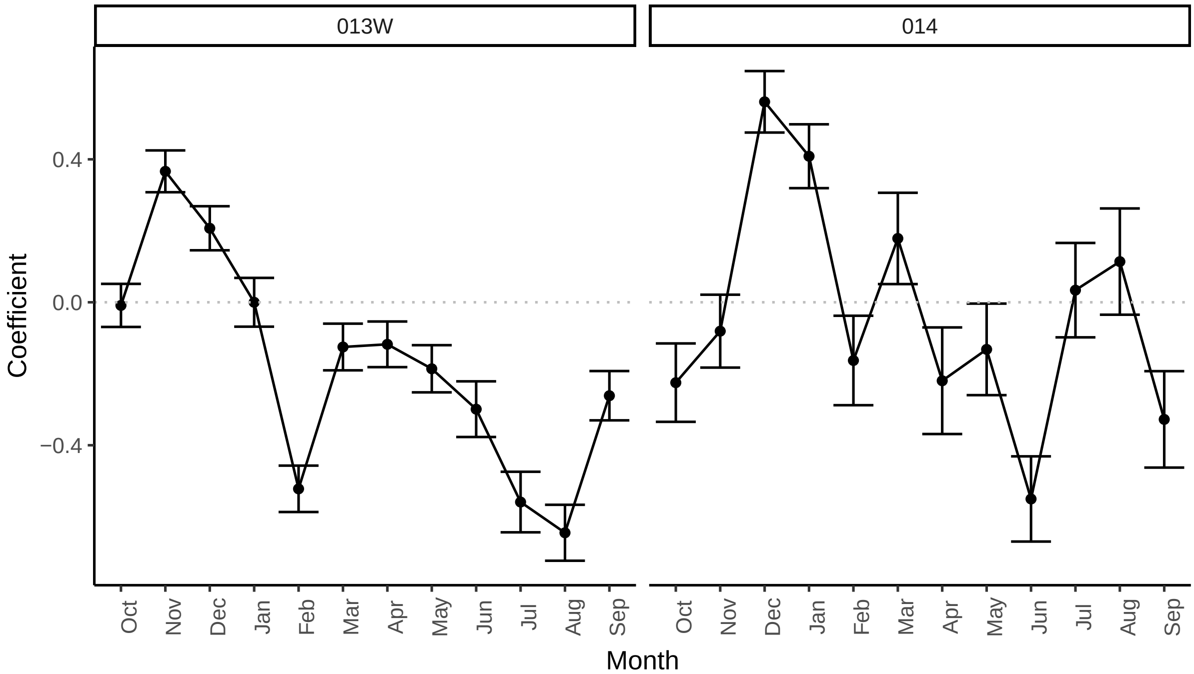

Figure 23: Coefficients for the area * month interaction from the SNA 2S TCER model, coefficients are plotted with 1 standard error intervals.

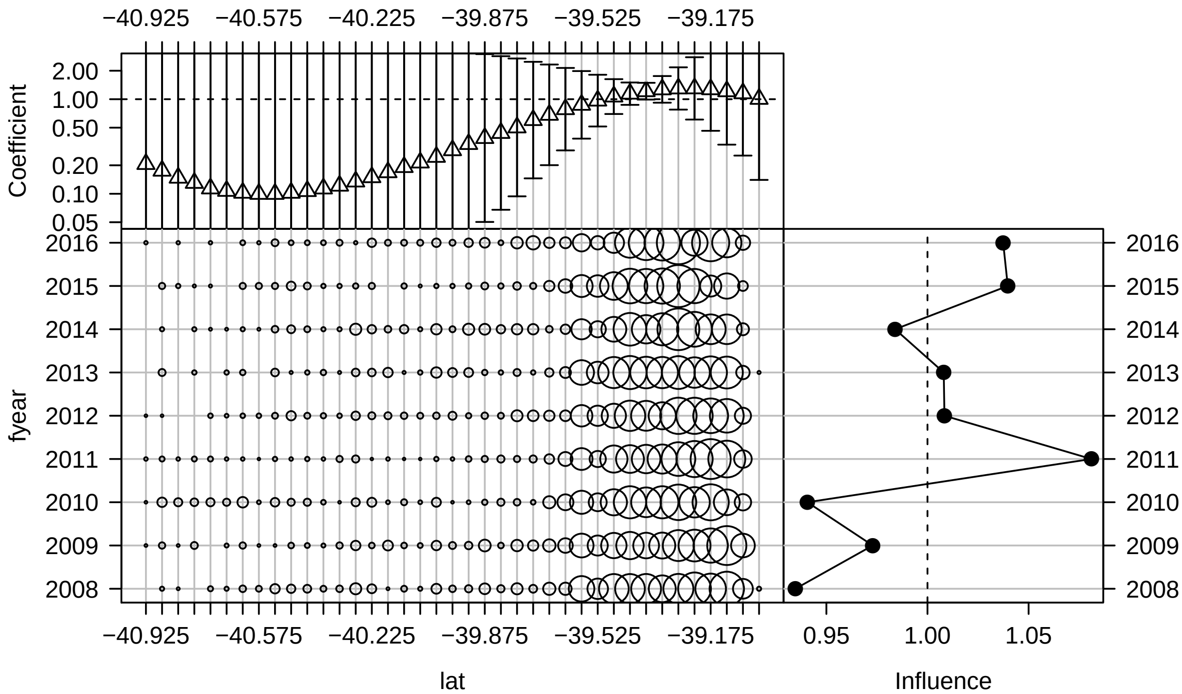

Figure 24: SNA 2S TCER model coefficient-distribution-influence plot for latitude.

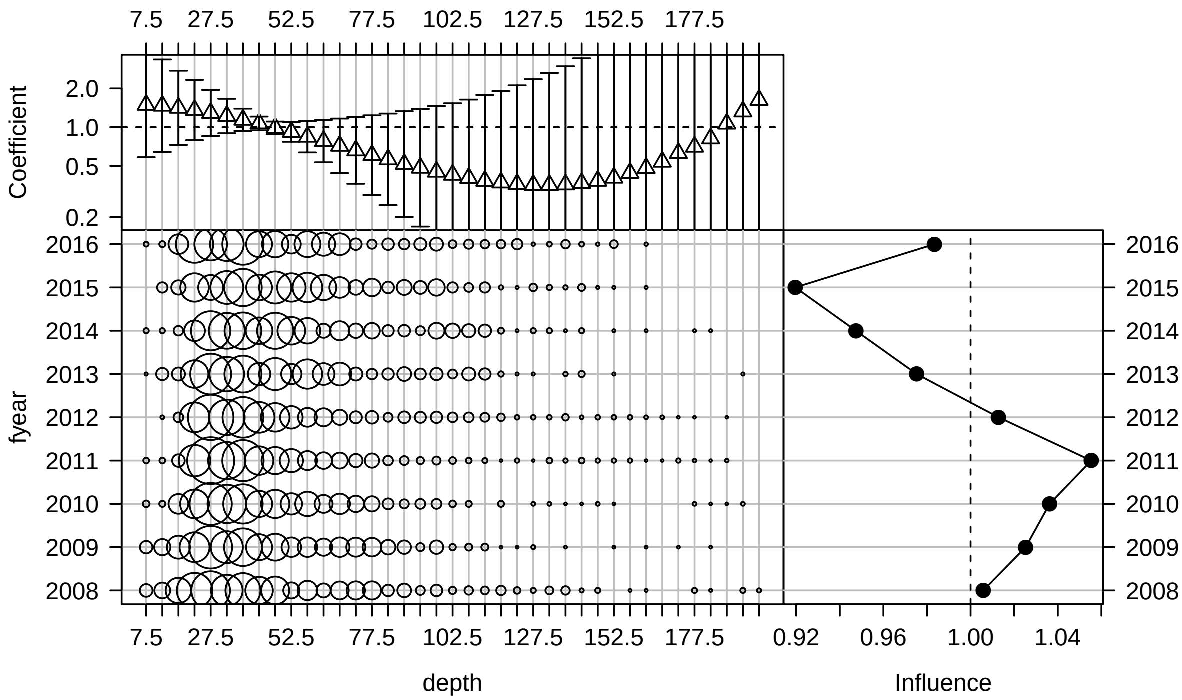

Figure 25: SNA 2S TCER model coefficient-distribution-influence plot for fishing depth.

4.5.3 Implied coefficients

SNA and TRE target generated positive coefficients, although they were seldom targeted in the SNA 2S TCER fishery (Figure 26). GUR was the dominant target species in terms of records, and consequently, the SNA 2 CPUE indices closely mirror the GUR target indices (Figure 26).

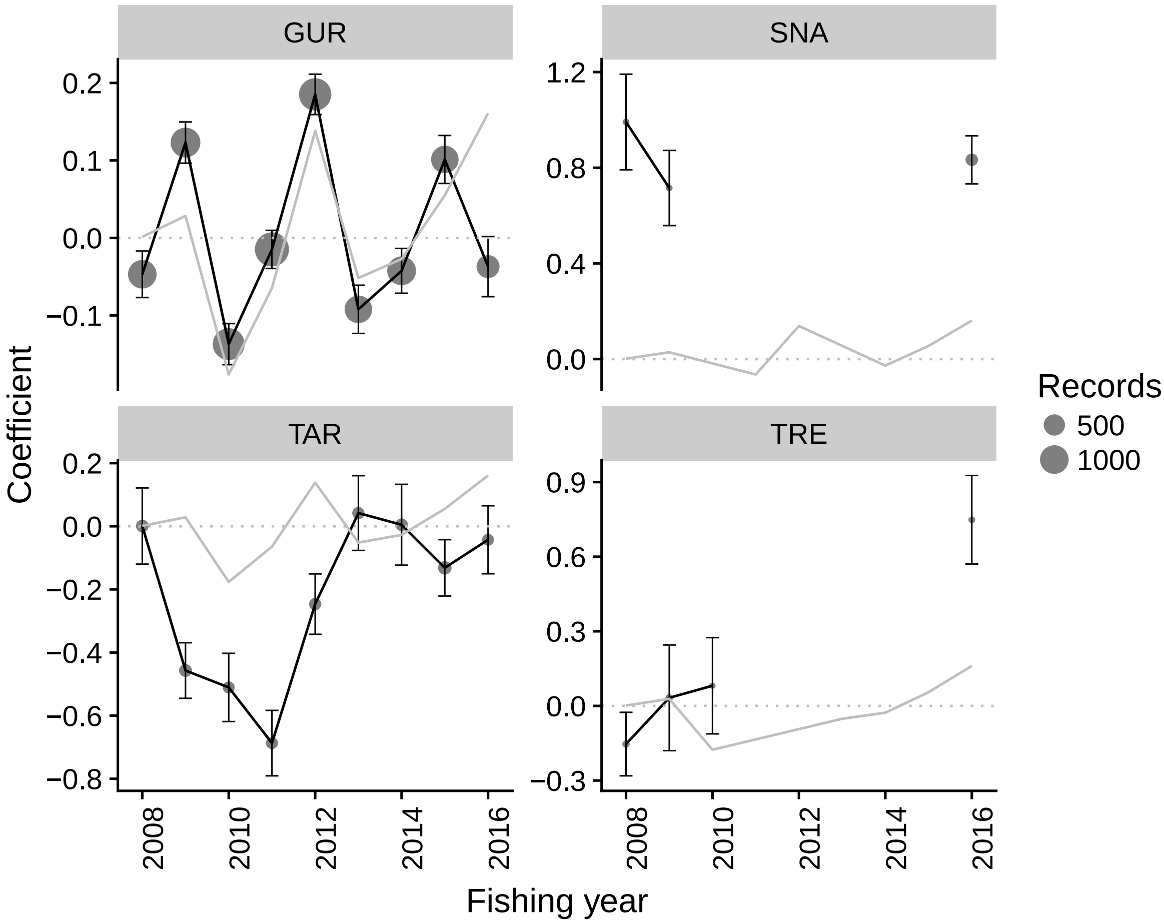

Figure 26: Implied CPUE indices (in log space) for the different target species in the SNA 2S TCER fishery over time. Error bars indicate one standard error of the standardised residuals, and the grey line shows the standardised SNA 2S TCER index normalised to the mean of the target species index.

4.5.4 Spatial Residuals

Spatial residuals display a clear pattern of the SNA 2S TCER fishery. Positive residuals are more frequent in shallower areas and negative residuals occur in deeper areas, this pattern is consistent through the time series (Figure 27). Specifically, there is an area of positive residuals between Cape Kidnappers to Waipatiki and a second area of positive residuals to the west of the Wairoa Hard, conversely there are negative residuals consistently in the center of Hawke Bay (Figure 27).

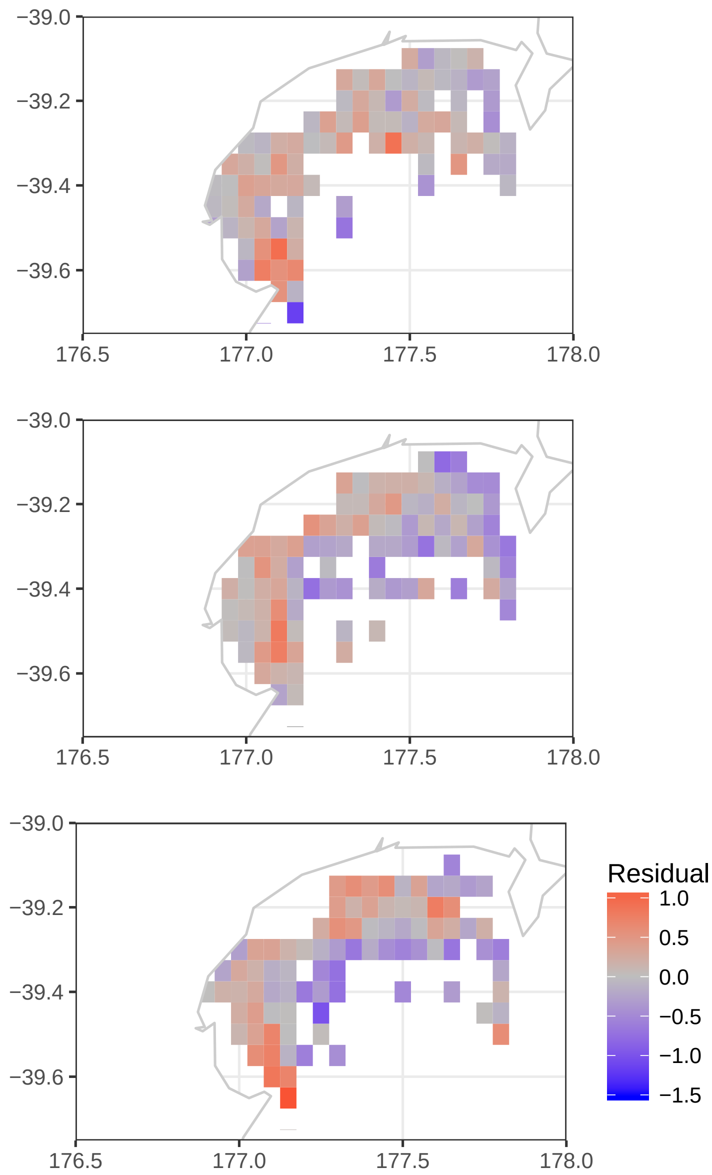

Figure 27: The mean residuals from the SNA 2S TCER abundance model, residuals are plotted with 0.1 degree lat long bins and a threshold of 10 tows before a bin was included. Top: represents 2008 - 2010; Middle: 2011–2013; Bottom: 2014-2016

4.6 CPUE indices

The occurrence of snapper catches in the SNA 2S TCER fishery, has gradually declined throughout the time series, whereas the positive catch indices show a slight increase (Figure 28). The combined indices also fluctuate around the geometric mean but show a slight decline (Figure 28).

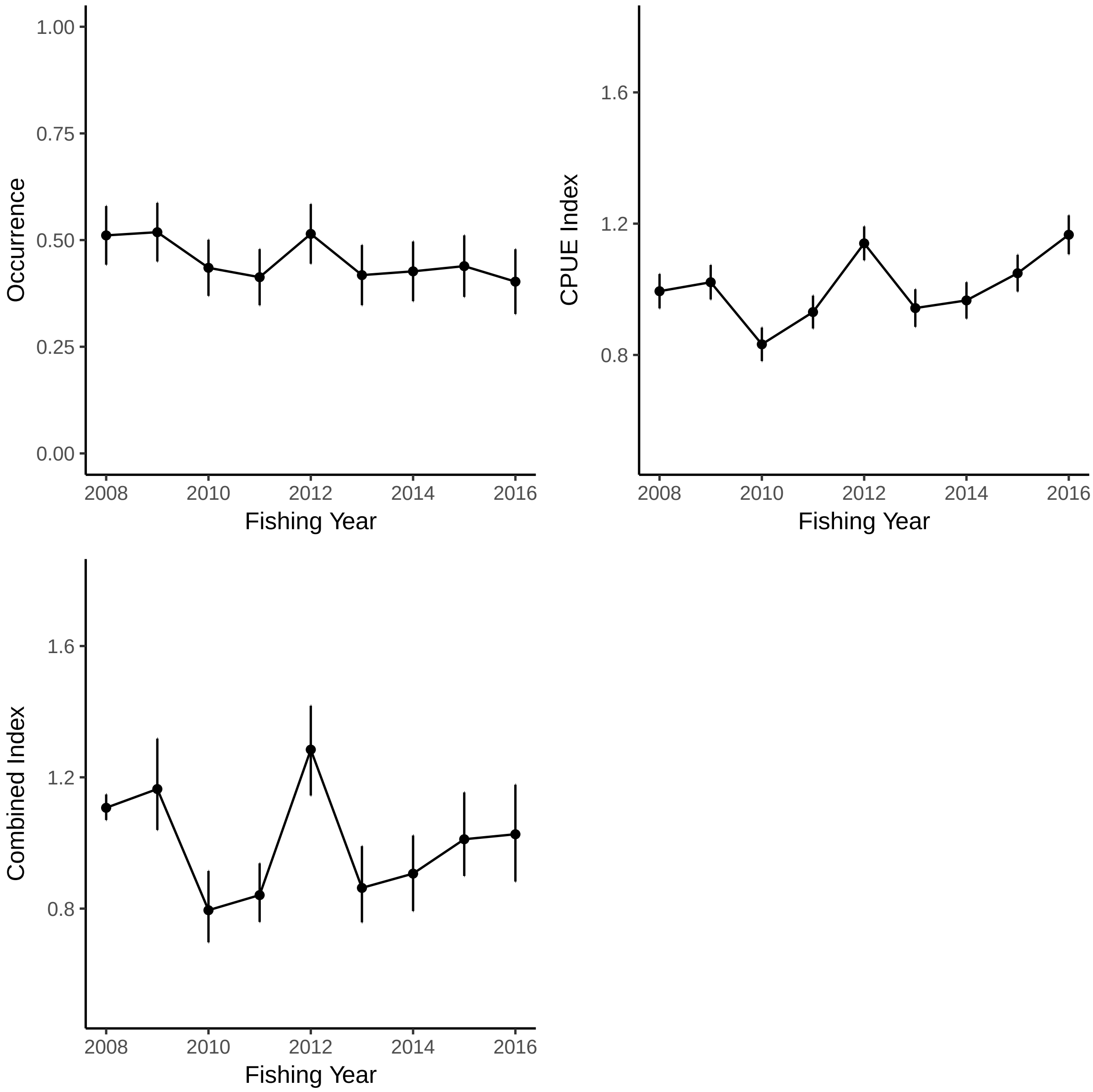

Figure 28: The SNA 2S TCER indices: occurrence (proportion of records with catches; top left), CPUE indices (magnitude of catches; top right) and combined (occurrence ×magnitude normalised; bottom) from 2008 to 2016. The size of the points are proportional to the number of records.

5. SNA 2 NORTH TCER

5.1 Fishery definition and trends

The SNA 2 North mixed bottom trawl TCER fishery (SNA 2N TCER) was defined as:

- Primary method: bottom trawl (BT)
- Target species: gurnard, trevally, tarakihi or snapper (GUR, TRE, TAR, SNA)
- Fishing effort conducted within Statistical Areas 011, 012 and 013E where 013E refers to Statistical Area 013 with reported starting positions east of 177.87°E.
- Fishing effort conducted between 1 Oct 2007 and 30 Sept 2016 and reported on a TCER or TCEPR form.

The SNA 2N(MIX) catch was consistent through the TCER series but effort has declined in the last two years (Table 12). The percentage of trips that caught snapper has remained relatively constant at about 95%.

Table 12: Summary of data by fishing year after the SNA 2N TCER fishery definition has been 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 SNA.

Fishing Year	Vessels	Trips	Records	Effort (num)	Effort (hrs)	Catch (t)	Trips caught	Days caught
2008	25	448	3 988	3 988	13 591	211.4	95.8	83.7
2009	25	504	4 311	4 311	14 663	189.9	95.0	82.9
2010	24	531	4 882	4 882	16 582	209.8	94.5	84.5
2011	24	469	4 384	4 384	14 422	159.0	93.0	79.8
2012	22	434	4 236	4 236	14 206	186.0	94.0	81.5
2013	20	418	4 274	4 274	14 848	221.4	96.4	86.7
2014	21	422	4 349	4 349	14 781	238.9	94.5	83.4
2015	18	335	3 363	3 363	11 600	192.1	93.7	85.0
2016	20	321	3 100	3 100	11 164	221.0	96.3	84.7

5.2 Data filtering

Records were dropped if fishing duration was less than 1 hour or greater than 5.5 hours (99.5th percentile). Forty nine landings exceeded 577 kg (99th percentile) but in all cases the reported estimated catch supported the landed catch.

5.3 Core Vessel Selection

The last tow based analysis of a SNA 2 mixed target fishery (Kendrick & Bentley 2014) considered 013E and 013W as separate Statistical Areas within a full SNA 2 model. This analysis selected core vessels that had operated in the SNA 2 fishery for at least 3 years and undertaken at least 3 trips in each of these years. Applying these criteria would retain a core fleet that accounted for 95% of the catch (Figure 29).

In this analysis the time series was three years longer and a more stringent vessel selection criteria could be applied: vessels operating in the SNA 2N TCER fishery for 4 years conducting at least 5 trips per year. Applying these criteria resulted in a core fleet of 22 vessels which accounted for 90.65% of the SNA 2N TCER catch.

The majority of vessels in the core fleet have operated throughout the SNA 2N TCER time series (Figure 30). The raw catch magnitude and catch probability have both been stable over the SNA 2N TCER

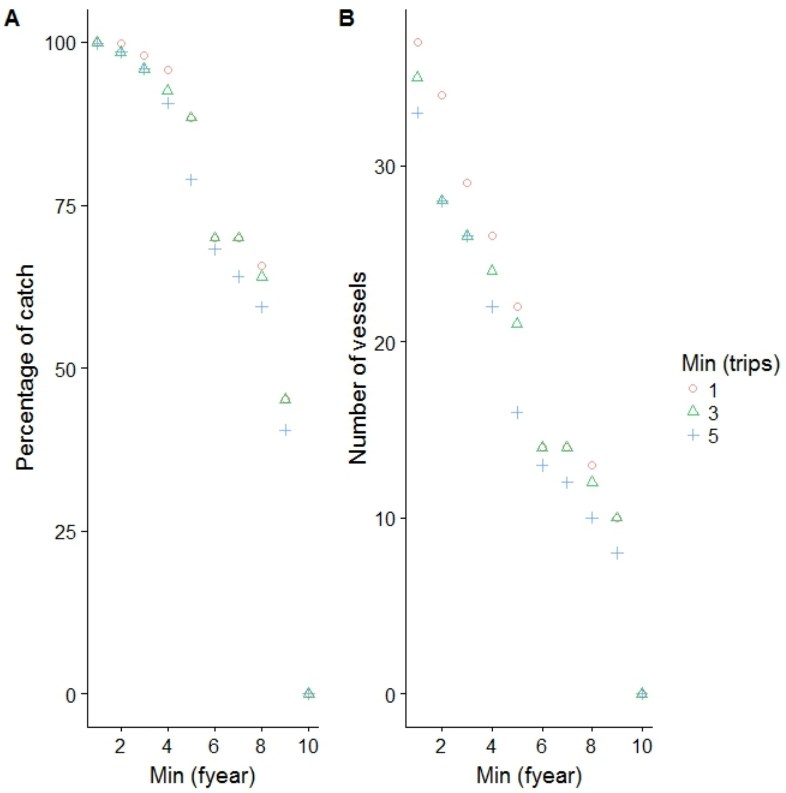

Figure 29: The percentage of catch (A) and number of vessels (B) represented by alternate core vessel criteria.

time series, in both the core and overall fleet (Figure 31).

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

Table 13: Summary of core data aggregated by fishing year. 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 number of trips and days which reported catching SNA.

Fishing year	Vessels	Trips	Records	Effort (num)	Effort (hrs)	Catch (t)	Trips caught	Days caught
2008	17	394	3 541	3 541	11 955	189.8	97.2	85.6
2009	19	467	3 995	3 995	13 416	174.9	95.1	83.1
2010	19	479	4 532	4 532	15 196	187.9	95.2	85.1
2011	20	455	4 274	4 274	13 992	155.2	93.4	80.5
2012	20	428	4 133	4 133	13 741	180.5	94.2	81.5
2013	16	389	3 919	3 919	13 593	196.4	96.4	86.4
2014	17	386	3 924	3 924	13 149	207.8	96.1	84.4
2015	16	326	3 232	3 232	11 059	179.2	94.2	85.9
2016	15	297	2 862	2 862	10 217	186.6	96.6	85.0

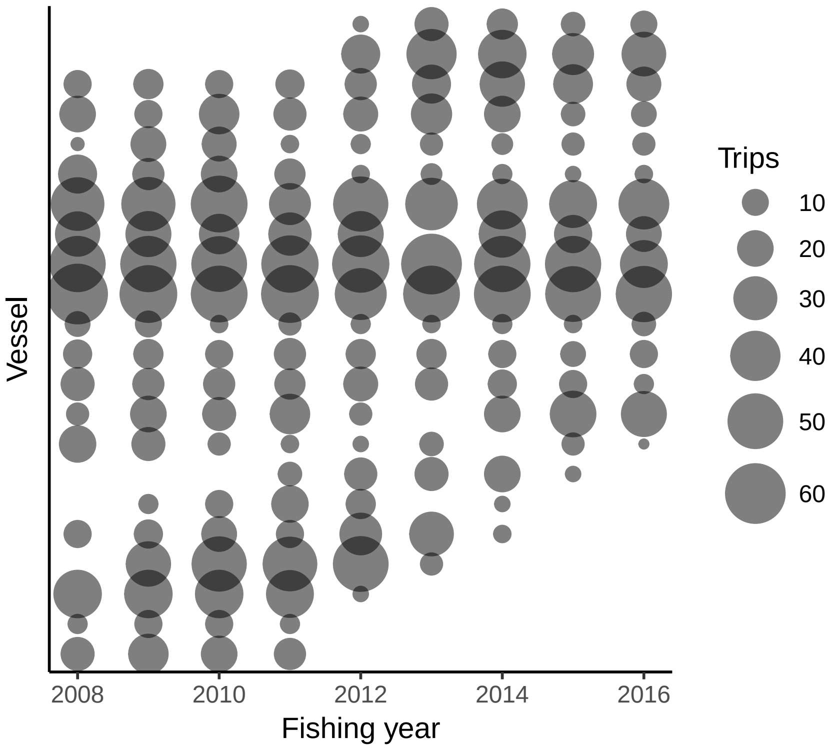

Figure 30: Number of trips by fishing year for core vessels. The area of circles is proportional to the number of trips for a vessel in a fishing year.

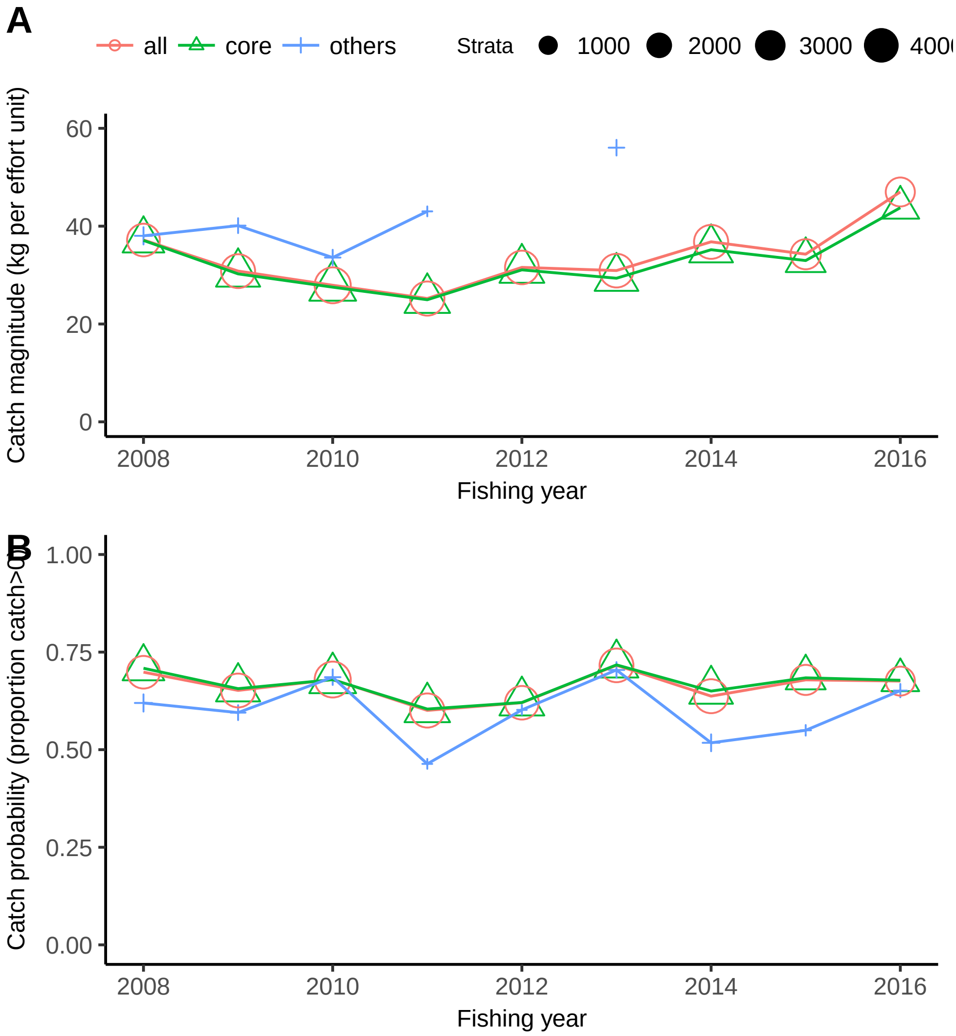

Figure 31: The unstandardised CPUE (A; geometric mean of catch divided by effort where catch was positive) and the proportion of strata with positive catch (B) for all, core and other vessels. The size of the points are proportional to the number of records.

5.4 Occurrence

The probability of positive catch (True/False) was modelled using a binomial GLM with a logit link function.

The full set of model terms offered to the stepwise selection algorithm was:
$\sim fyear + vessel + target + area * month + poly(duration, 3) + area + month + poly(depth, 3) + poly(speed, 3) + poly(abs(lat), 3) + poly(lon, 3) + poly(distance, 3)$

The final model after selection (Table 14) was
$\sim fyear + poly(depth, 3) + poly(abs(lat), 3) + area * month + vessel + target + poly(lon, 3)$

Table 14: Summary of stepwise selection for SNA 2N TCER occurrence of snapper 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	41 993	0.5	0.5	*
+ poly(depth, 3)	3	35 837	15.1	14.6	*
+ poly(abs(lat), 3)	3	33 225	21.3	6.2	*
+ area_month	35	31 792	24.9	3.6	*
+ vessel	21	30 423	28.2	3.3	*
+ target	3	30 106	29.0	0.8	
+ poly(lon, 3)	3	29 864	29.6	0.6	
+ poly(distance, 3)	3	29 754	29.8	0.3	
+ poly(log(duration), 3)	3	29 736	29.9	0.1	

The SNA 2N TCER occurrence indices show that the probability of non-zero catch has remained consistent at about 70% throughout the time series (Figure 32).

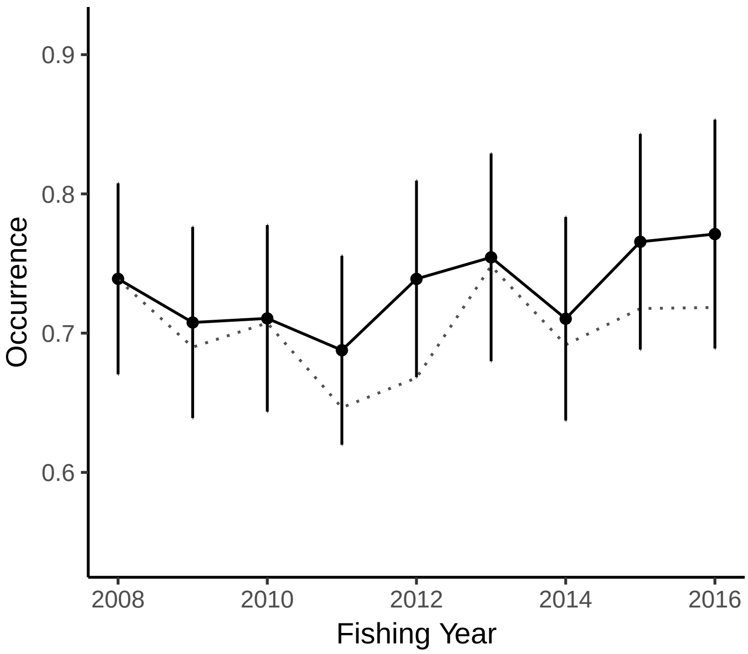

Figure 32: The occurrence of positive catch indices for SNA 2N TCER model, raw indices are plotted with dashed grey lines.

5.5 Positive Catch

The magnitude of non-zero catch was modelled by Kendrick & Bentley (2014) using a Weibull distribution. In this analysis a Weibull distribution had the lowest AIC of the distributions examined.

The full set of model terms offered to the stepwise selection algorithm was:
$\sim fyear+vessel+target+poly(log(duration),3)+area+month+area*month+poly(speed,3)+poly(depth,3)+poly(abs(lat),3)+poly(lon,3)$

The final model after stepwise selection (Table 15) was:
$\sim fyear+target+area*month+poly(depth,3)+vessel$

Table 15: Summary of stepwise selection for SNA 2N TCER 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	278 136	1.0	1.0	*
+ target	3	274 870	14.2	13.2	*
+ area_month	35	272 473	22.9	8.8	*
+ poly(depth, 3)	3	271 282	26.9	3.9	*
+ vessel	21	270 240	30.3	3.4	*
+ poly(distance, 3)	3	270 036	30.9	0.6	
+ poly(abs(lat), 3)	3	269 926	31.2	0.3	
+ poly(lon, 3)	3	269 803	31.6	0.4	
+ poly(speed, 3)	3	269 757	31.8	0.2	

The final SNA 2N TCER model explained 30.3% of the model deviance with 69 degrees of freedom (Table 15)

5.5.1 Diagnostics

Model residuals from the positive log(catch) model show a close approximation to the Weibull distribution (Figure 33) although there are deviations at the extremes (outside of two standard deviations).

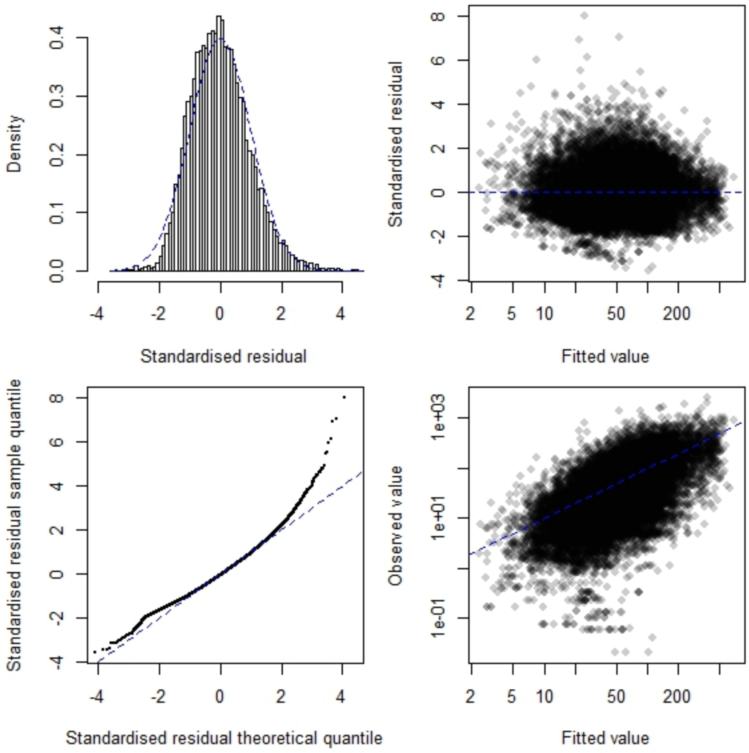

Figure 33: Diagnostic plots for the SNA 2N TCER positive catch model. Top left: standardised residuals; top right: standardised residuals versus the fitted values; bottom left: quantile-quantile plot for standardised residuals; bottom right: observed vs fitted values.

5.5.2 Influence of Model Terms

The standardisation process has the effect of dampening a slightly increasing trend in CPUE (Figure 34). Between 2008 and 2013 the standardised CPUE indices are greater than the unstandardised index, whereas from 2014 to 2016 the standardised CPUE indices were smaller (Figure 34).

Vessel was most influential on positive catch indices and is responsible for the change in pattern noted in the index (Figure 35). The other coefficients: area * month, target species, depth and duration had little influence on the indices (Figure 35).

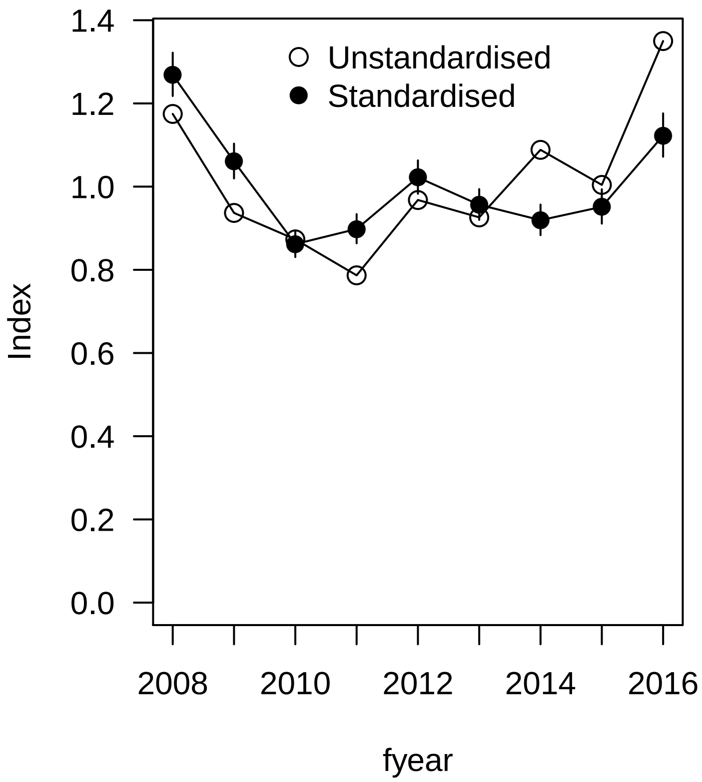

Figure 34: A comparison of the standardised CPUE indices and unstandardised indices for the SNA 2N TCER postive catch model. The unstandardised index is based on the geometric mean of the catch per strata and is not adjusted for effort.

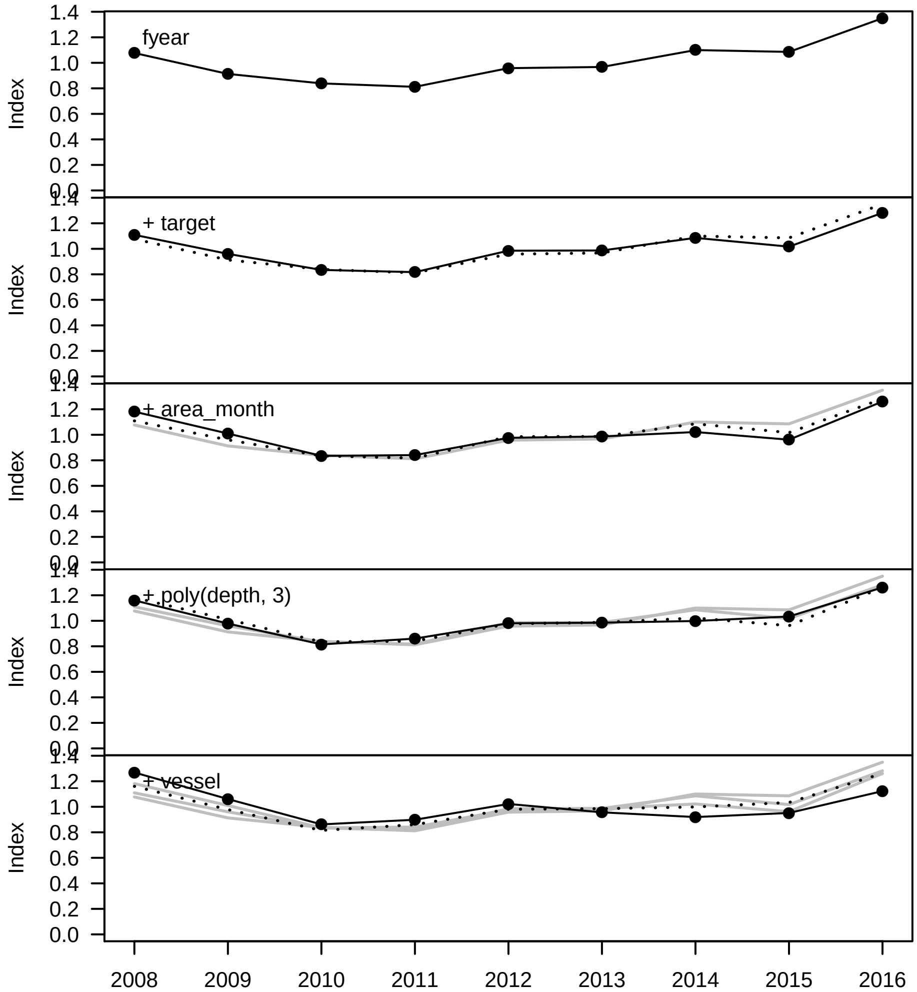

Figure 35: Annual CPUE indices as each term was successively added to the SNA 2N TCER positive catch model. The indices are normalised to an overall geometric mean of 1.

There was an increase in the targeting of snapper during 2009 to 2016 in the SNA 2N TCER fishery, this has led to an increase in the influence of target species in the CPUE model (Figure 36).

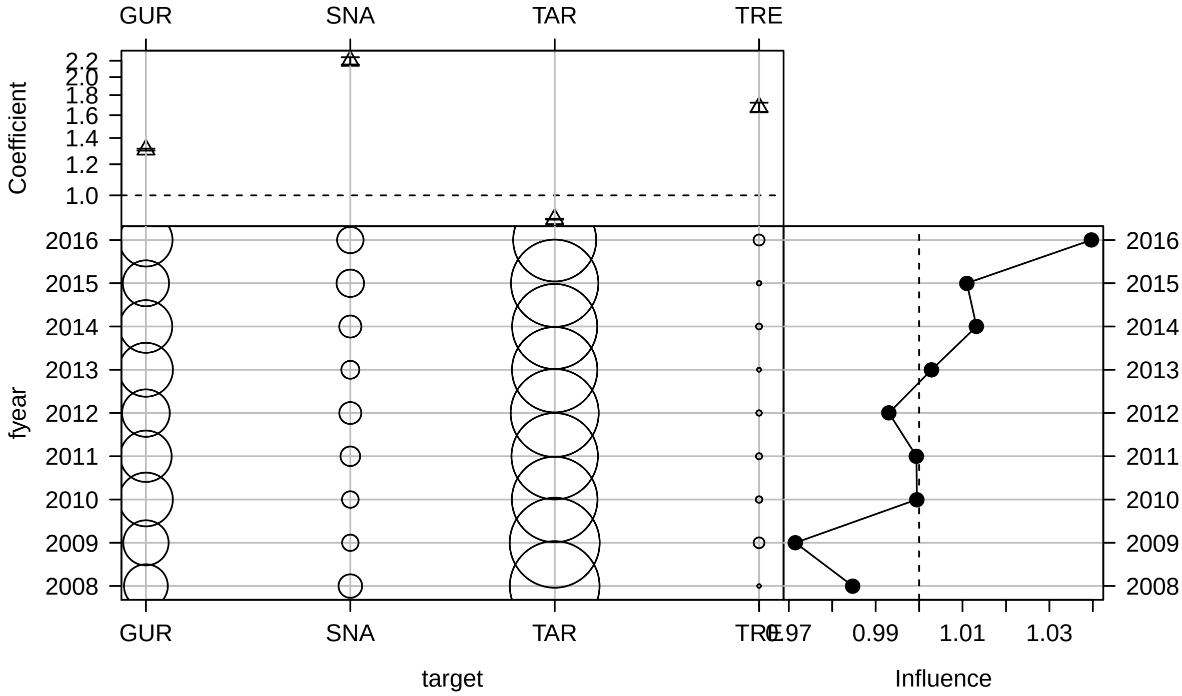

Figure 36: SNA 2N TCER model coefficient-distribution-influence plot for target species.

The area:month coefficients are generally higher for Areas 011 and 012 than Area 013E (Figure 37). In all Areas, coefficients follow similar trajectories between October and March, with a decline from October to December then an increase from January to a peak in May (Figure 37). In Areas 012 and 013E coefficients decline from June to August before increasing in September, with a steeper decline in Area 013E. In Area 011 coefficients are stable from June to September with a slight dip in July.

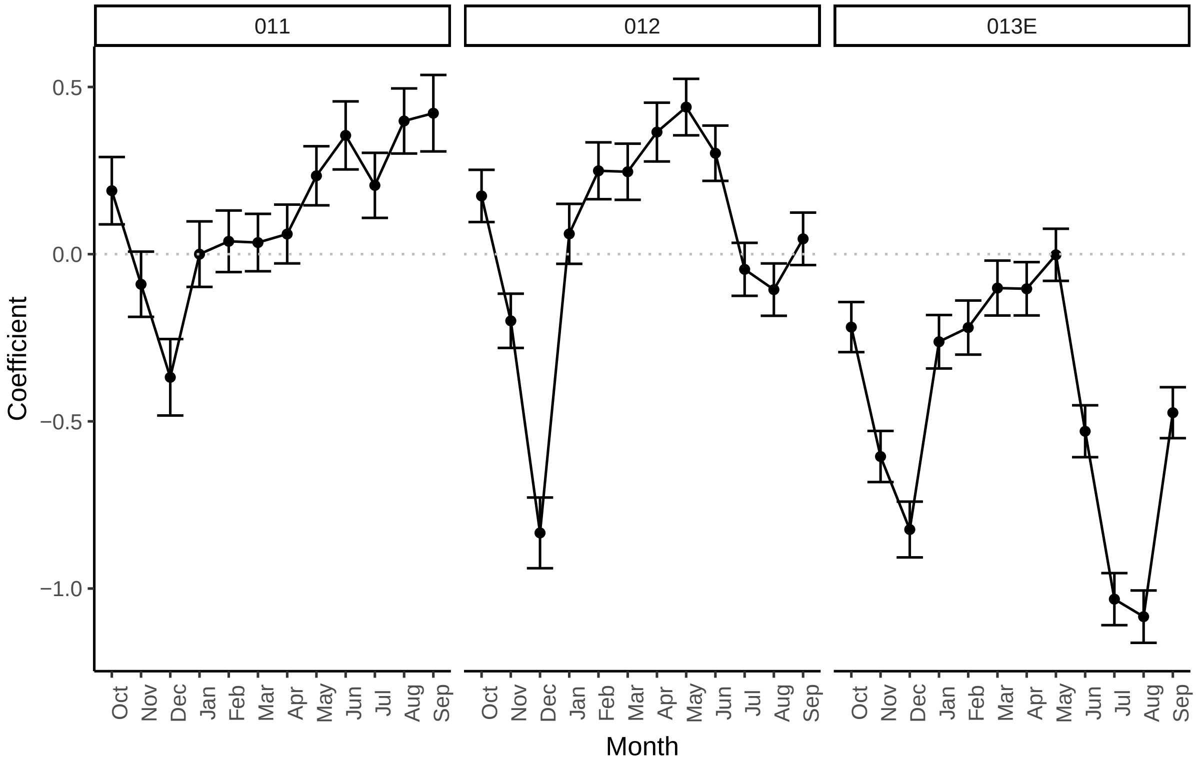

Figure 37: Coefficients for the area * month interaction from the SNA 2N TCER model, coefficients are plotted with 1 standard error intervals.

The influence of fishing depth has declined over the time series, although the magnitude of the change is small (Figure 38). Catches are highest between depths of 10 and 40 m, with fishing depths increasing slightly over the time series (Figure 38).

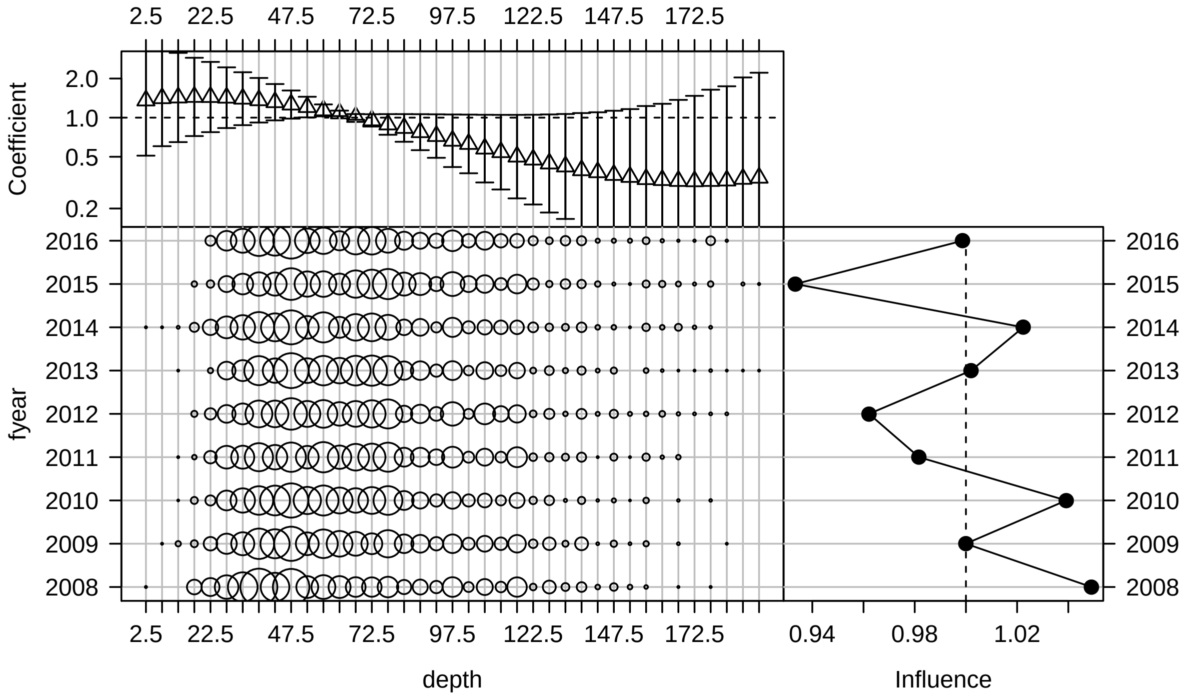

Figure 38: SNA 2N TCER model coefficient-distribution-influence plot for fishing depth.

The influence of vessel generally increased through the time series (Figure 39). There appears to be a slight shift in effort towards the more efficient vessels over the time series (Figure 39).

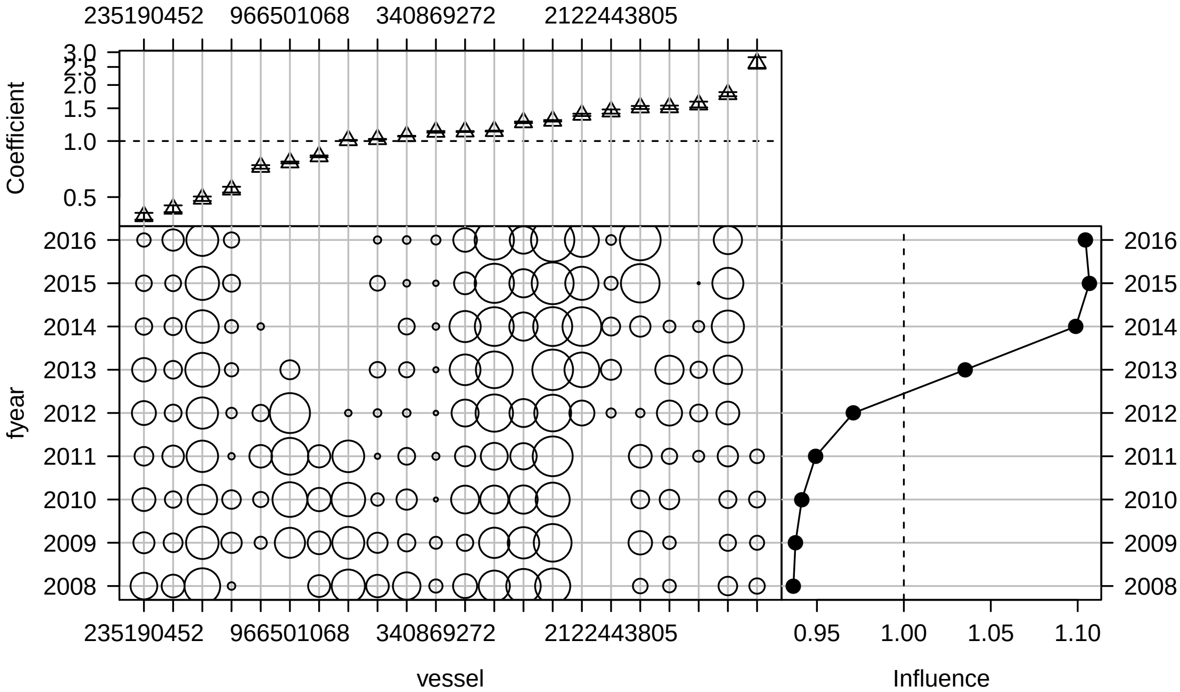

Figure 39: Coefficient-distribution-influence plot for the effect of vessel in the SNA 2N TCER positive catch model.

5.5.3 Implied coefficients

The dominant target species in the SNA 2N TCER fishery are TAR and GUR, consequently the standardised CPUE indices are between the implied coefficients of these species (Figure 40).

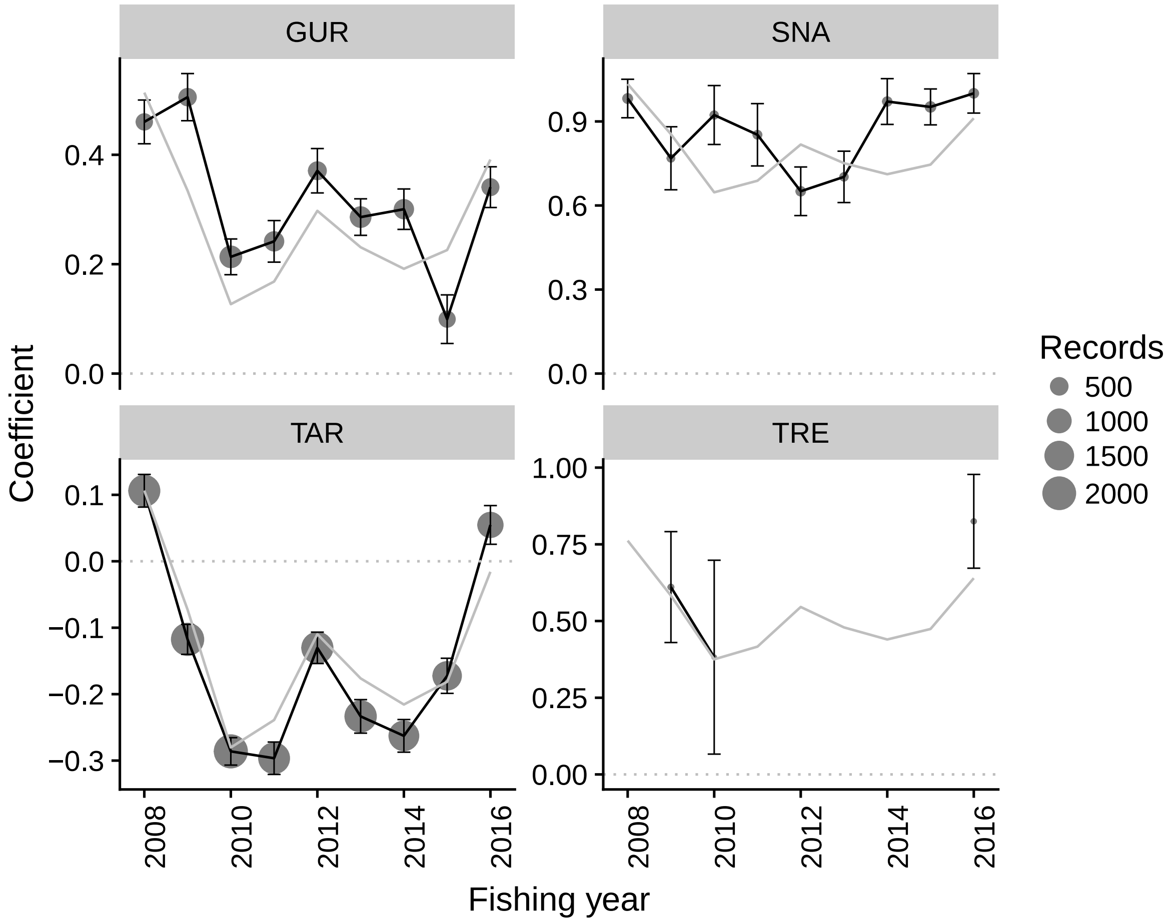

Figure 40: Implied CPUE indices (in log space) for the different target species in the SNA 2N TCER fishery over time. Error bars indicate one standard error of the standardised residuals, and the grey line shows the standardised SNA 2N TCER index normalised to the mean of the target species index.

5.5.4 Spatial Residuals

Spatial residuals show a clear pattern in the SNA 2N TCER fishery. North of -38.5°S residuals are generally positive, whereas south of -38.5°S they are negative (Figure 41). This pattern was consistent through the time series (Figure 41).

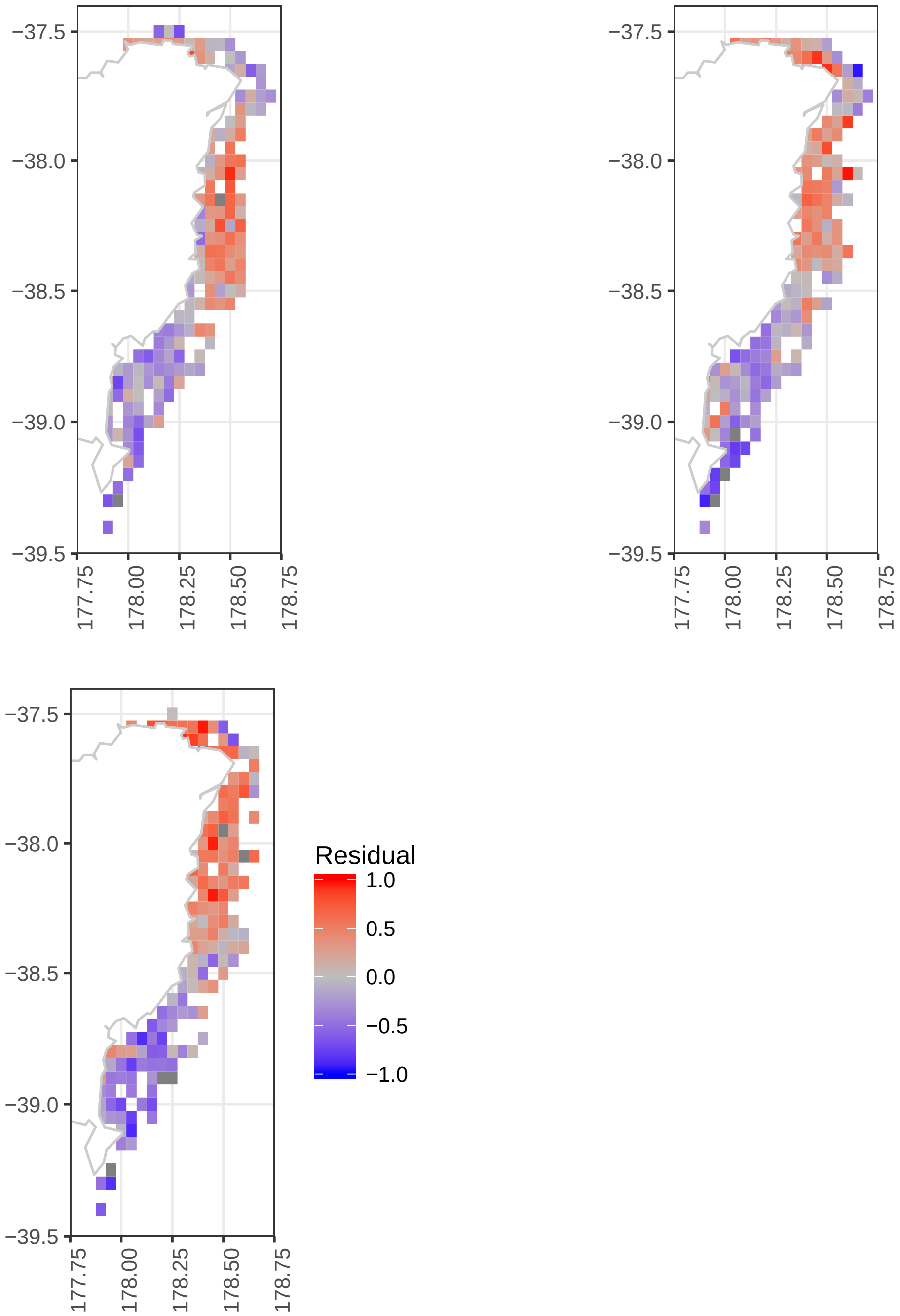

Figure 41: The mean residuals from SNA 2N TCER model; residuals are plotted with 0.1 ×0.1° with a threshold of 10 tows before a cell was included. Left: 2008 – 2010; Right: 2011–2013; Bottom: 2014–2016.

5.6 CPUE indices

The occurrence of snapper catch has shown little trend over the period 2008 to 2016, whereas the positive catch and combined indices declined from 2008 to 2010 then have fluctuated without trend to 2016 (Figure 42).

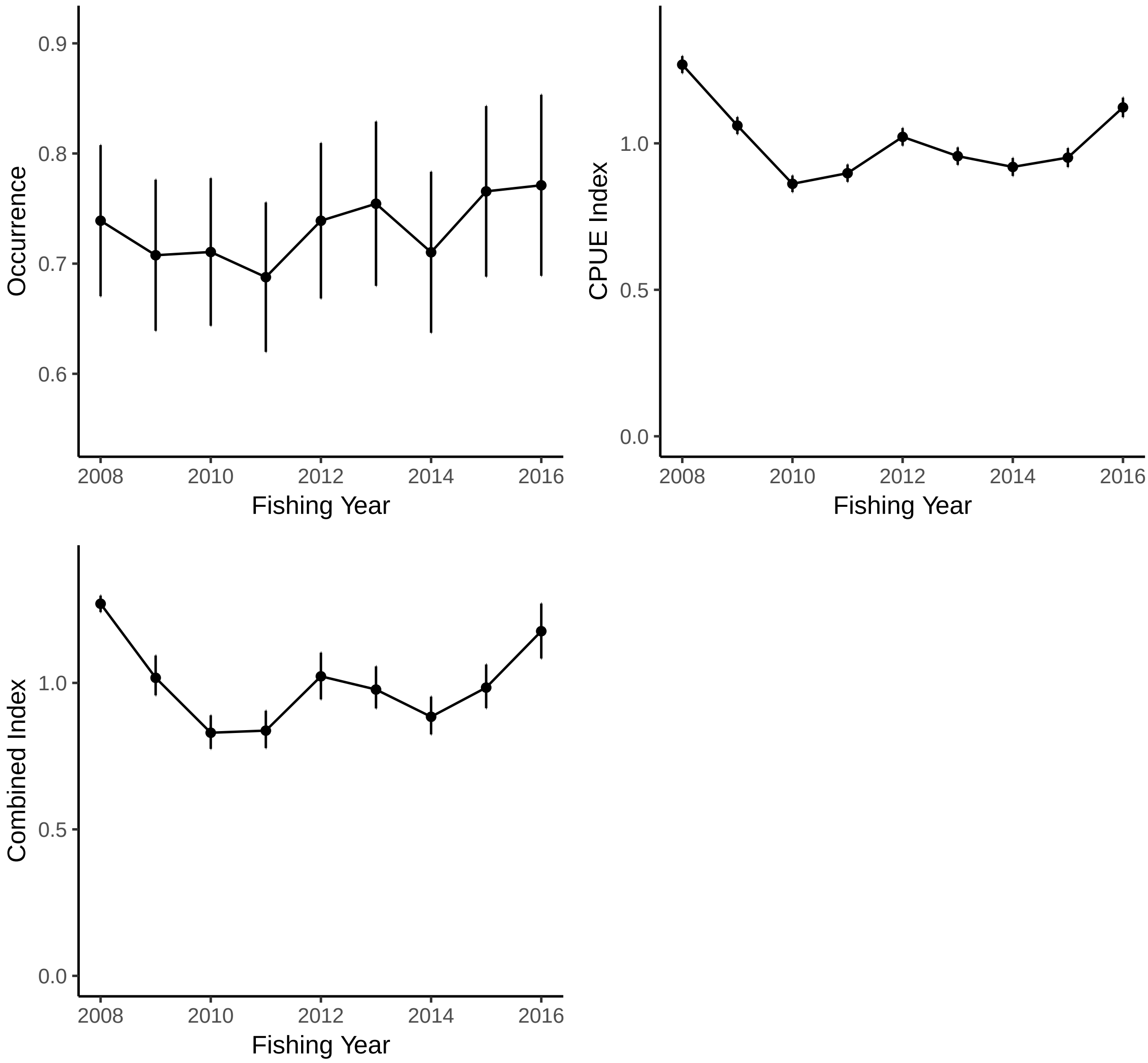

Figure 42: The SNA 2N TCER CPUE indices: occurrence (left), positive catch (top right) and combined (occurrence ×magnitude normalised; bottom) indices from 2008 to 2016.

6. SNA 2 SOUTH

6.1 Aggregation

The SNA 2 south mixed-target (SNA 2S) dataset comprised both TCEPR, TCER and CELR data. The TCER/TCEPR data required aggregation to ensure it was comparable to the lower resolution CELR data (Langley 2014). Most aggregations grouped two fishing events per stratum, with the trip-only stratification aggregating more events (Figure 43). The percentage of events, trips and strata with positive catch fluctuated around 40% in the initial years to 2007 but declined to 25% in 2016 (Figure 43). The vessel-date aggregation recommended by Langley (2014) was used in the CPUE analyses.

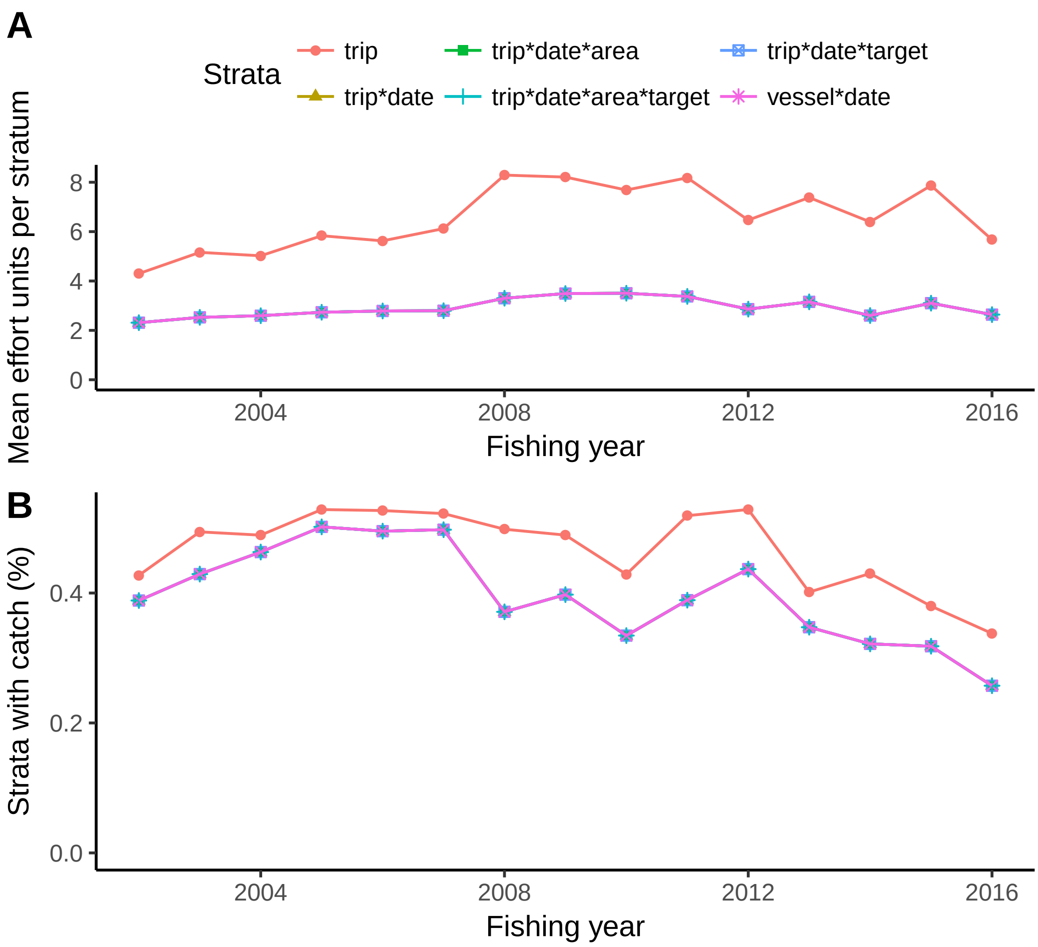

Figure 43: Comparison of alternate strata aggregations in the SNA 2S fishery, A: The mean number of effort units (i.e tows or shots) per stratum and B: the percentage of strata with positive catch.

6.2 Fishery definition and trends

The SNA 2S bottom trawl fishery (SNA 2S) was defined as:

- Primary method: bottom trawl (BT)
- Target species: gurnard, trevally, tarakihi or snapper (GUR, TRE, TAR, SNA)
- Fishing effort conducted within Statistical Areas 013W and 014, where '013W' refers to Statistical Area 013 with reported starting positions west of the longitudinal boundary 177.87°E or allocated 013W by the partitioning tree (pre 2008 data).
- Fishing effort conducted between 1 Oct 2001 and 30 Sept 2016 reported on CELR, TCER or TCEPR form.

The vessel-day aggregated SNA 2S fishery had similar levels of fishing effort annually until 2011 where effort declined substantially, whereas the SNA 2 catch varies considerably from year to year (Table 16).

Table 16: Summary of data subset by fishing year after the SNA 2S fishery definition has been 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 number of trips and days which reported catching SNA.

Fishing Year	Vessels	Trips	Records	Effort (num)	Effort (hrs)	Catch (t)	Trips caught	Days caught
2002	28	969	2 003	4 166	16 427	69.4	43.0	39.0
2003	28	850	2 217	4 387	18 208	96.7	49.4	43.0
2004	28	685	1 756	3 440	14 320	99.7	49.6	46.8
2005	27	772	2 146	4 504	18 316	153.2	53.1	50.3
2006	24	780	1 999	4 389	17 187	138.6	52.8	49.6
2007	24	718	2 286	4 396	16 698	133.4	52.5	49.9
2008	22	556	4 609	4 609	17 172	90.3	49.8	37.2
2009	20	552	4 532	4 532	16 985	100.0	49.1	39.8
2010	18	653	5 018	5 018	18 885	74.5	43.0	33.5
2011	21	578	4 729	4 729	17 962	86.1	51.9	38.9
2012	19	490	3 169	3 169	12 201	71.5	52.9	43.7
2013	16	406	2 997	2 997	11 443	42.5	40.1	34.7
2014	19	479	3 063	3 063	11 683	48.5	43.0	32.2
2015	18	466	3 666	3 666	14 255	65.4	38.2	31.9
2016	18	524	2 974	2 974	11 710	75.1	33.8	25.7

6.3 Data filtering

Records were dropped if fishing duration was less then 1 hour or greater than 24 hours (99.5th percentile). Landings were assessed for accuracy if they exceeded 1500 kg (99.5th percentile). Of the 112 records affected, five appeared erroneous due to order of magnitude differences between estimated and landed catch.

6.4 Core Vessel Selection

The last analysis of vessel-day aggregated SNA 2 mixed target fishery (Kendrick & Bentley 2014) considered SNA 2 as a whole fishery from 1990 to 2014. This analysis selected core vessels that had operated in the SNA 2 fishery for at least 5 years and undertaken at least 5 trips per year between 2002 and 2016.

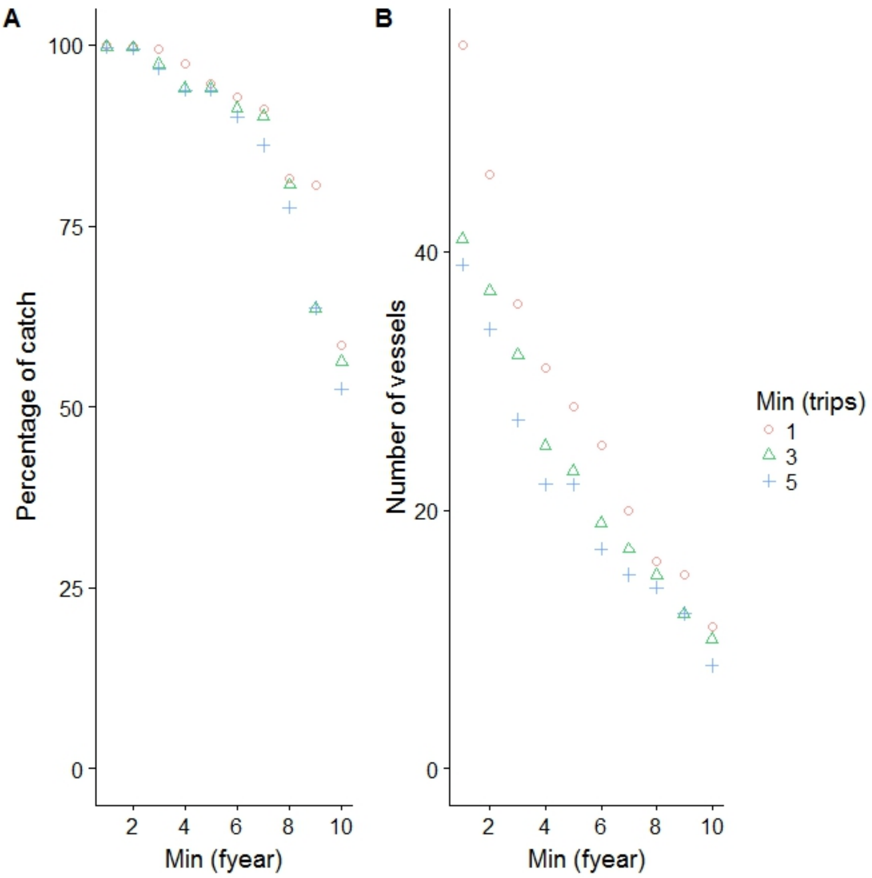

Figure 44: The percentage of catch (A) and number of vessels (B) represented by each alternate core vessel criteria: each unique combination of trips and fishing years.

These criteria were reapplied in this analysis, resulting in a core fleet of 18 vessels which accounted for 85.41% of the SNA 2S catch (Figure 57).

There has been a shift in the core fleet through time, with only six vessels operating in the vessel-day aggregated SNA 2S fishery throughout the time series (Figure 45). The raw catch magnitude and catch probability have been relatively stable through the time series (Figure 46).

A summary of the data used for SNA 2S CPUE analysis after filtering and restriction to the core fleet is provided in Table 17.

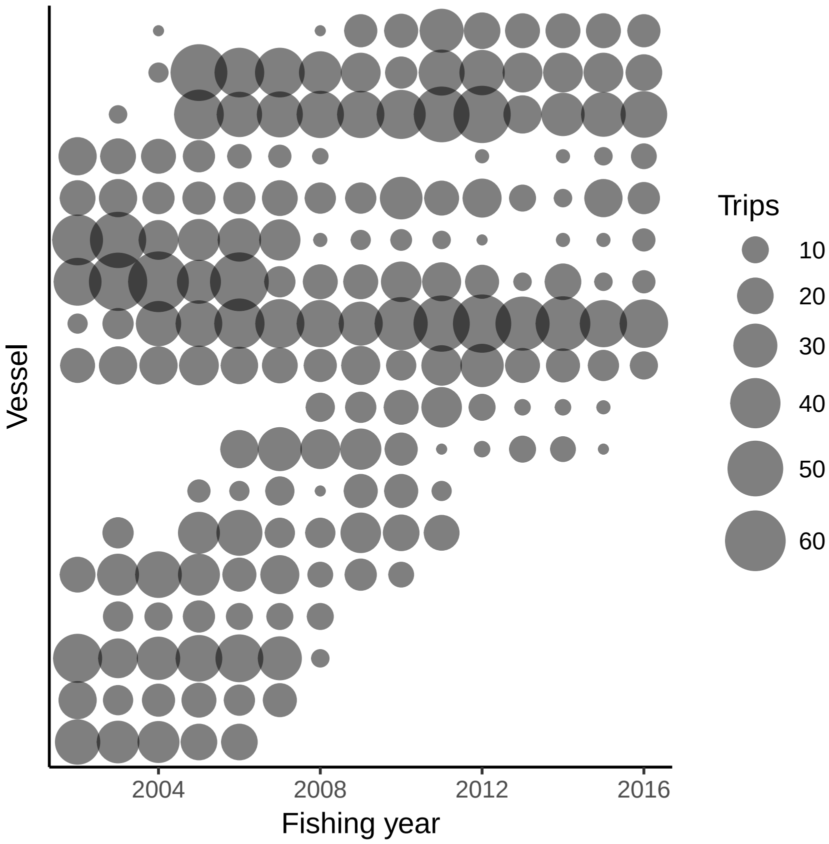

Figure 45: Number of trips by fishing year for core vessels in the SNA 2S fishery. The area of circles is proportional to the number of trips for a vessel in a fishing year.

Table 17: Summary of core SNA 2S vessel-day aggregated data by fishing year. 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 number of trips and days which reported catching SNA.

Fishing year	Vessels	Trips	Records	Effort (num)	Effort (hrs)	Catch (t)	Trips caught	Days caught
2002	11	465	992	2 128	8 172	46.3	54.2	48.2
2003	14	525	1 280	2 618	10 807	71.1	58.3	49.5
2004	14	500	1 073	2 499	10 203	79.6	59.2	54.2
2005	16	631	1 543	3 702	14 967	141.6	61.0	58.1
2006	16	685	1 656	3 913	15 263	127.1	58.0	53.4
2007	15	573	1 617	3 332	12 582	109.4	57.6	54.9
2008	16	443	2 981	2 981	10 961	62.2	50.8	41.7
2009	13	466	4 095	4 095	15 308	97.2	56.4	43.8
2010	13	518	4 208	4 208	15 817	71.4	51.5	38.7
2011	12	458	4 059	4 059	15 445	79.1	62.0	44.1
2012	11	416	2 817	2 817	10 887	65.6	58.9	47.9
2013	11	375	2 836	2 836	10 792	40.2	41.6	36.1
2014	11	378	2 532	2 532	9 649	38.0	46.6	35.1
2015	11	371	2 956	2 956	11 506	51.8	42.6	37.4
2016	10	419	2 349	2 349	9 037	68.2	37.2	30.3

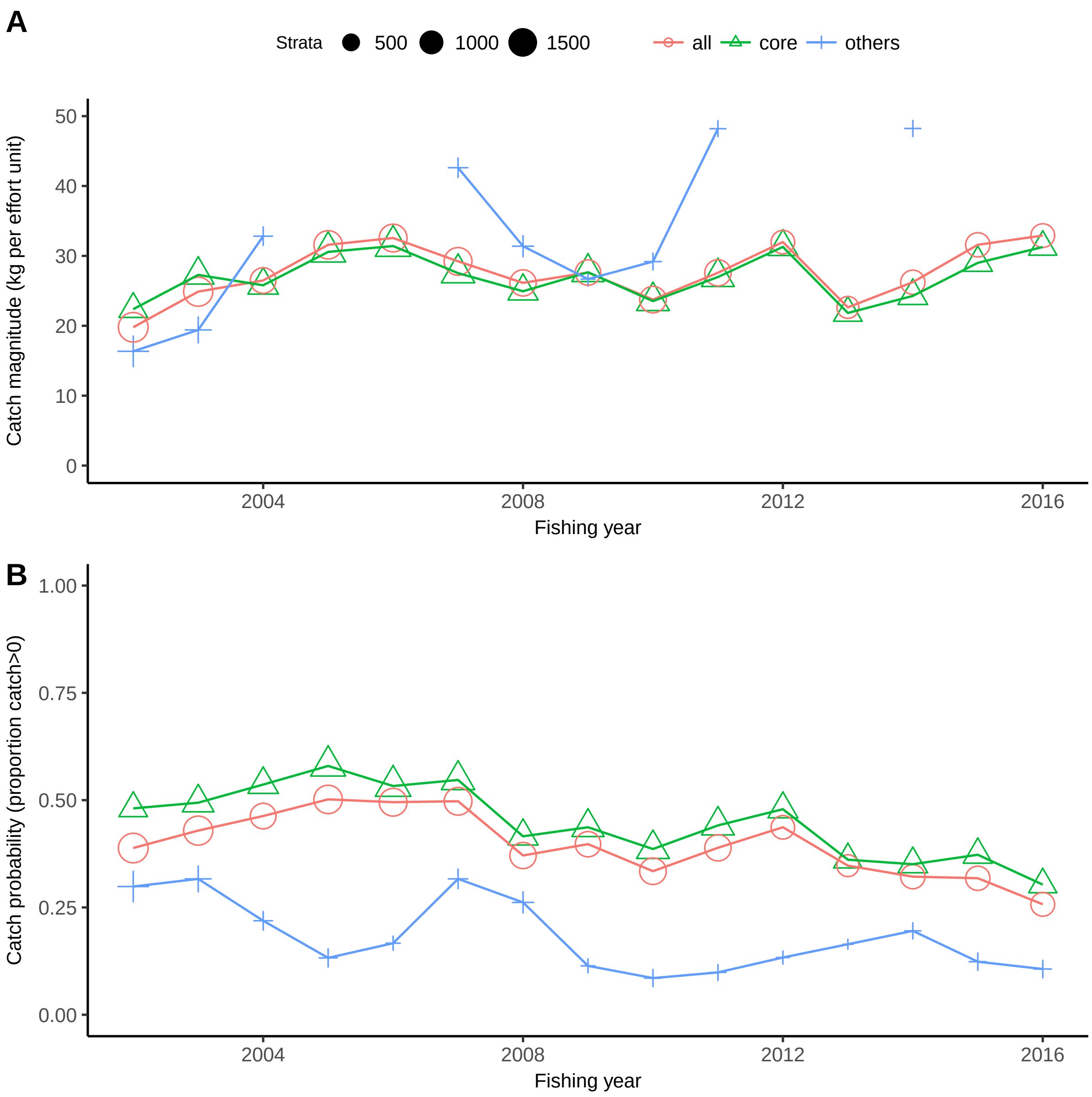

Figure 46: Comparison of the proportion of strata with positive catch (upper) and the unstandardised CPUE (geometric mean of catch divided by effort where catch was positive; lower) for all vessels and core vessels in the SNA 2S fishery. The size of the points are proportional to the number of records.

6.5 Occurrence

The occurrence of positive catch for the vessel-day (True/False) was modelled using a binomial GLM with a logit link function. The full set of model terms offered to the stepwise selection algorithm was:
$\sim fyear{+}vessel{+}target{+}area{*}month{+}poly(log(duration),3){+}area{+}month{+}poly(log(num),3)$

The final model after selection (Table 18) was:
$\sim fyear + area * month + vessel + target$

Table 18: Summary of stepwise selection for SNA 2S 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	13	20 287	1.9	1.9	*
+ area_month	23	17 240	16.9	15.0	*
+ vessel	17	15 848	23.8	6.9	*
+ target	3	15 408	25.9	2.2	*
+ poly(log(duration), 3)	3	15 303	26.5	0.5	
+ poly(log(num), 3)	3	15 296	26.5	0.1	

The SNA 2S occurrence indices show that the probability of non-zero catch was increasing to about 50% from 2002 to 2007 at which point the indices declined to reach about 20% in 2016 (Figure 47).

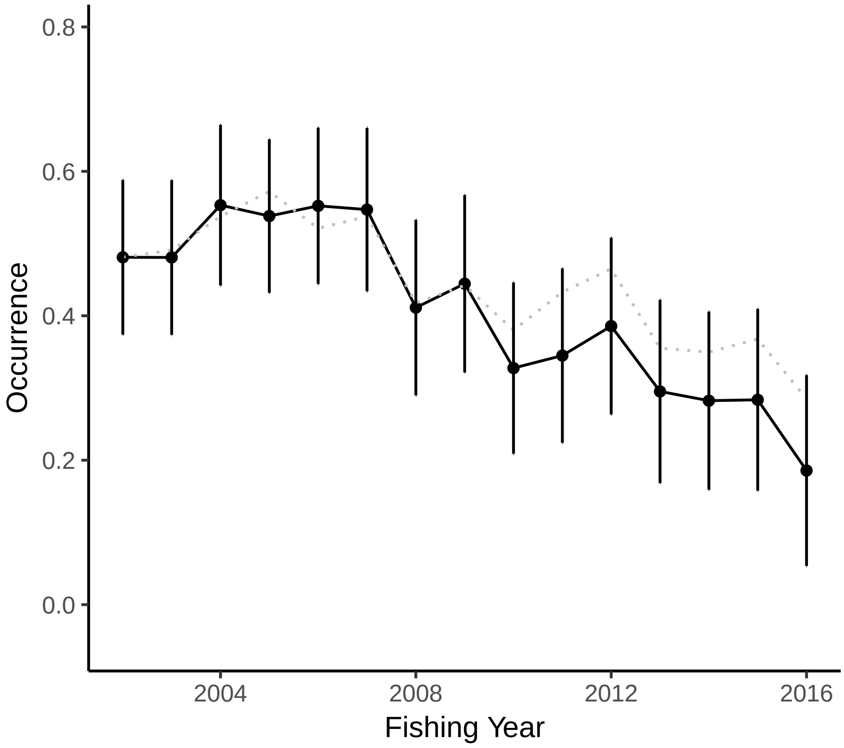

Figure 47: The occurrence of positive catch indices for the SNA 2S fishery, raw indices are plotted with dashed grey lines.

6.6 Positive Catch

The magnitude of non-zero catches were modelled by Kendrick & Bentley (2014) using a Weibull distribution. In this analysis a Weibull distribution had the lowest AIC of the distributions examined.

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

The final model after selection (Table 19) was:
$\sim fyear + vessel + poly(log(num), 3) + area * month + target$

Table 19: Summary of stepwise selection for SNA 2S magnitude of positive catch for the vessel-day aggregated dataset. 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	13	80 559	1.0	1.0	*
+ vessel	17	78 279	25.6	24.6	*
+ poly(num, 3)	3	77 358	33.8	8.2	*
+ area_month	23	76 871	38.2	4.4	*
+ target	3	76 664	39.9	1.7	*
+ poly(log(duration), 3)	3	76 570	40.7	0.8	

6.6.1 Diagnostics

Model residuals from the positive log(catch) model show a reasonable approximation to the Weibull distribution (Figure 48), there are deviations at the extremes (outside of 2 standard deviations).

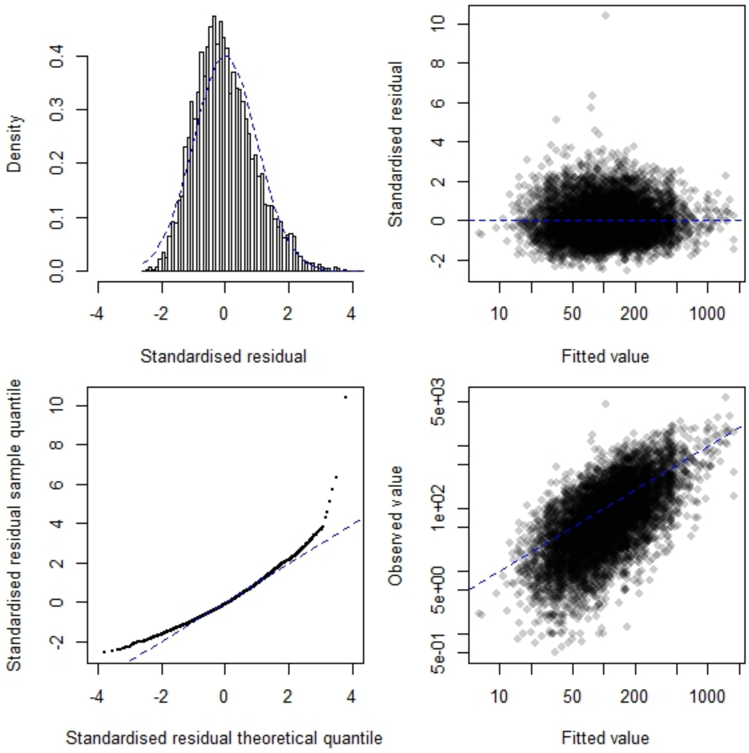

Figure 48: The Weibull diagnostic plots for the SNA 2S model fit. top left: Standardised residuals from the accepted generalised linear model fit; top right: The standardised residuals versus the fitted values; bottom left: Quantile-quantile plot of observed response versus likelihood of the distribution of these values; bottom right: Observed values vs fitted values.

6.6.2 Influence of model terms

The trend in the standardised indices differed considerably from unstandardised. Standardised indices decline markedly from 2006 to 2008 and have fluctuated about the lower level since then (Figure 49).

Vessel was the most influential variable included in the CPUE model (Figure 50). Target species was influential in 2016, whilst the number of tows, area * month interaction and fishing duration had little influence (Figure 50).

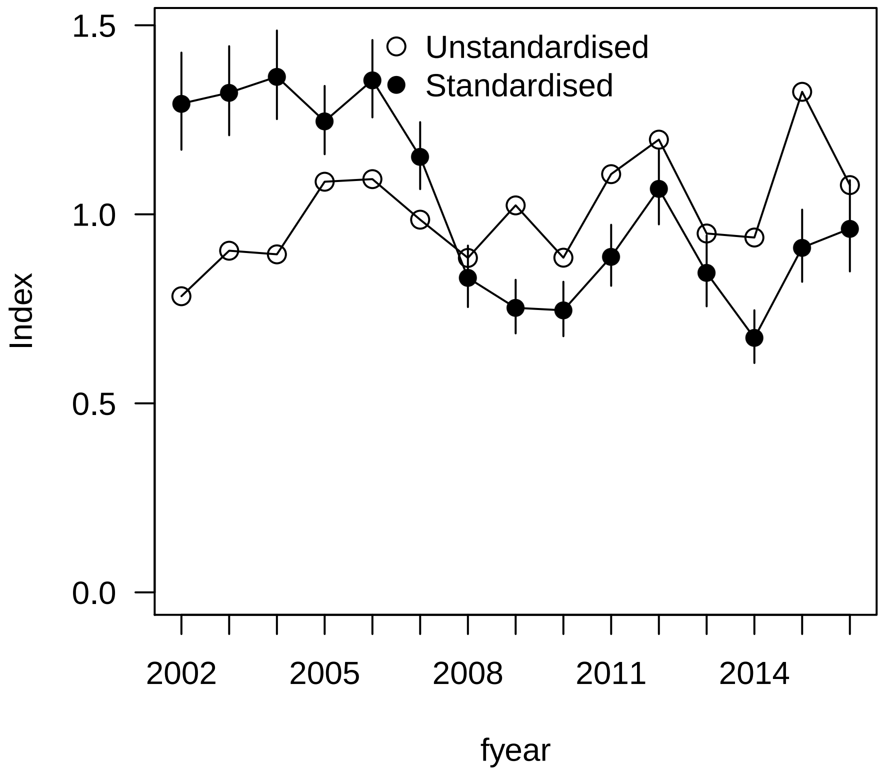

Figure 49: A comparison of the standardised CPUE indices and unstandardised indices of the SNA 2S vessel-day model. The unstandardised index is based on the geometric mean of the catch per strata and is not adjusted for effort.

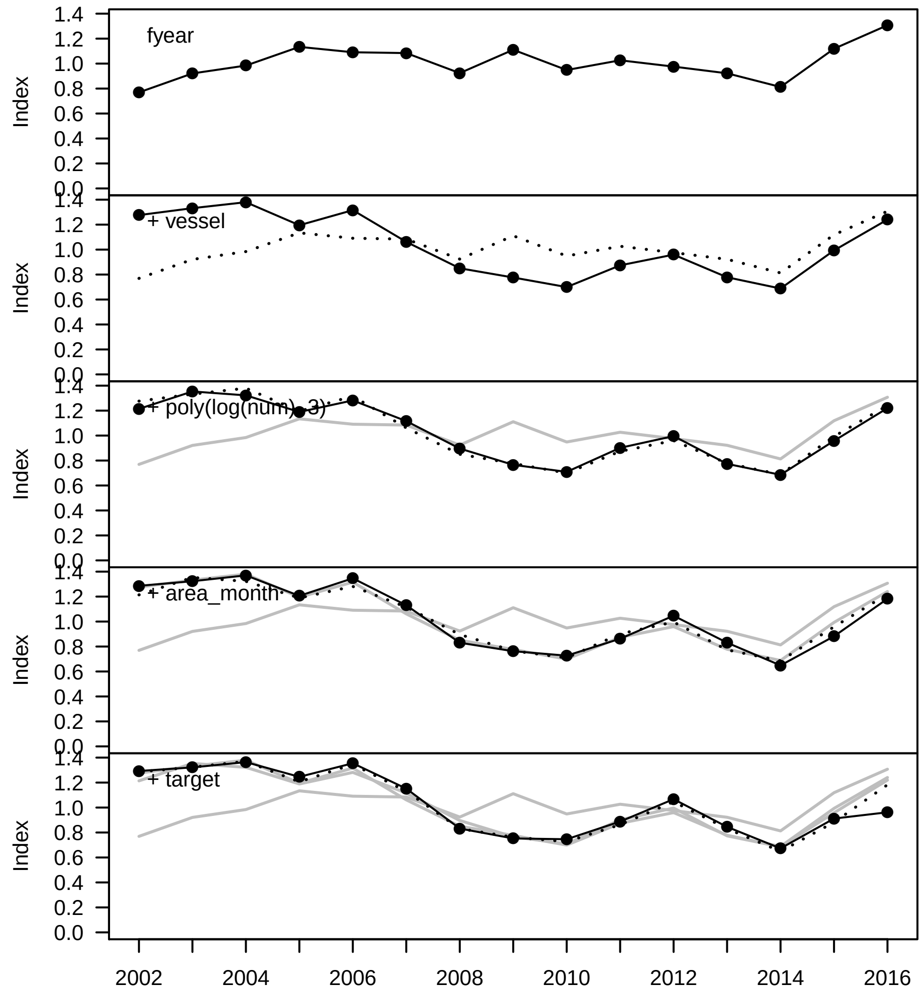

Figure 50: Annual indices of CPUE as each term was successively added to the SNA 2S vessel-day model. The indices are normalised to an overall geometric mean of 1.

There was a range of vessel coefficients across the SNA 2S vessel-day fleet. Vessel is influential on the CPUE indices, the influence has switched from a lower efficiency fleet in 2002 to 2004 to a higher efficiency relatively stable fleet from 2009 to date (Figure 51).

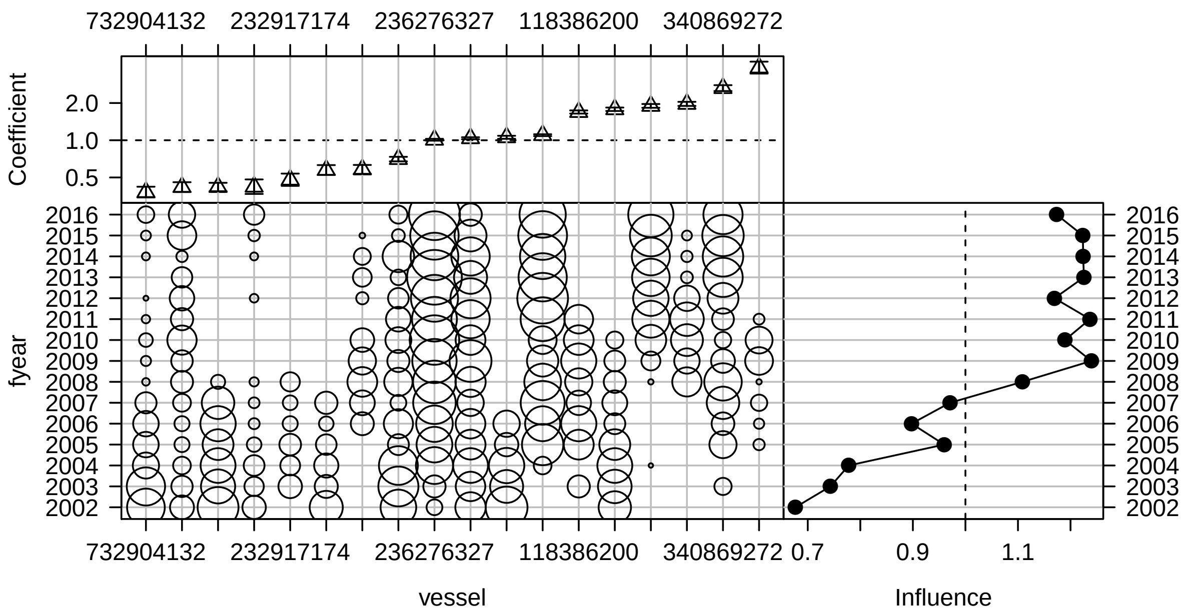

Figure 51: SNA 2S vessel-day model coefficient-distribution-influence plot for vessel.

Vessels in the SNA 2S fishery generally conducted 1–3 tows per vessel day, there has been a gradual increase in the number of tows per vessel day (Figure 52).

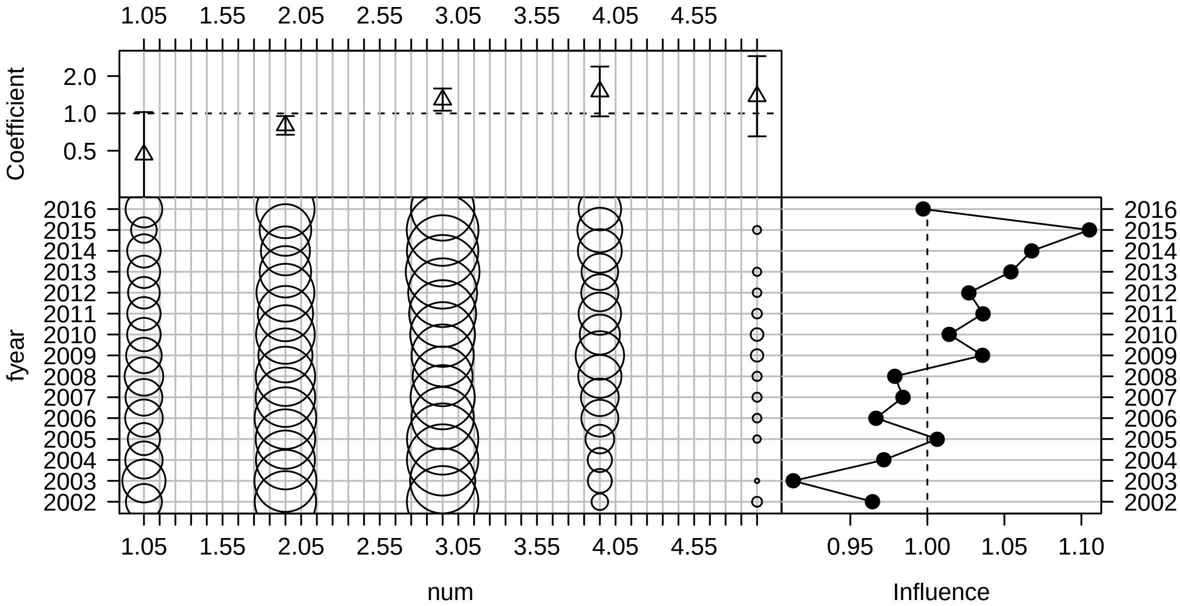

Figure 52: SNA 2S vessel-day coefficient-distribution-influence plot for number of tows.

Both Areas coefficients increased from October to a December peak, declined in January and February and then had a stable period between March and May. Both Areas had a minima in August, in Area 13W coefficients declined from June to August, whereas in Area 014 the decline was sharper between July and August, both Areas had an increase in September (Figure 53).

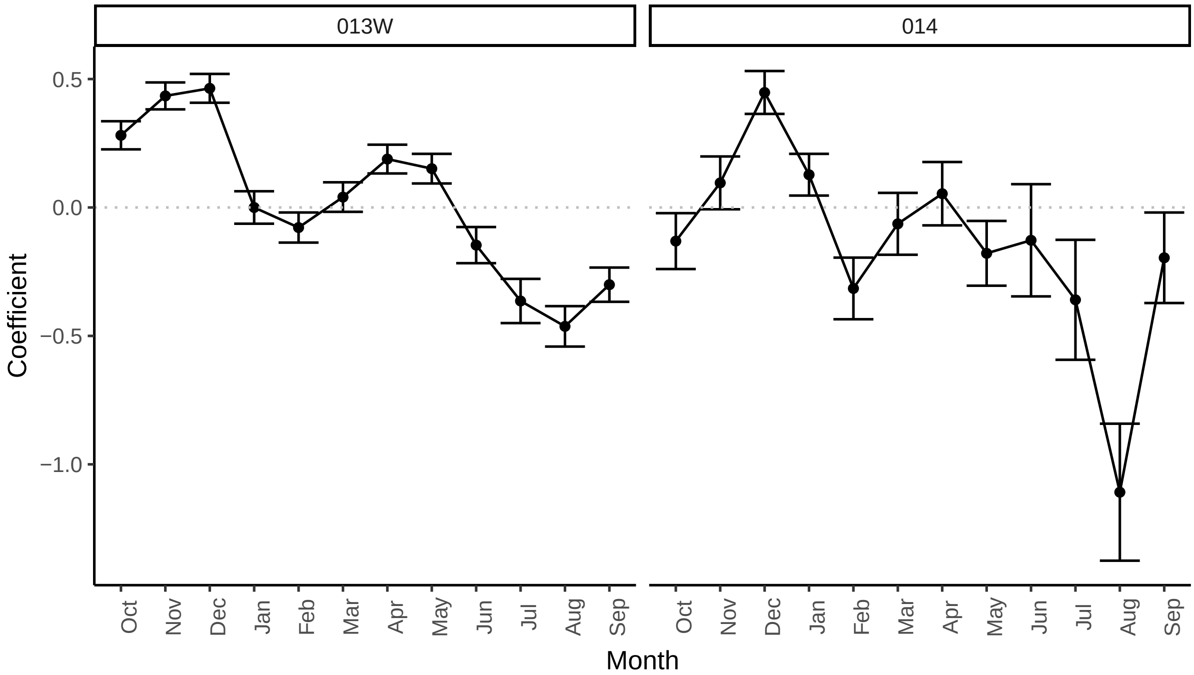

Figure 53: Coefficients for the area * month interaction from the SNA 2S vessel-day model, coefficients are plotted with 1 standard error intervals.

6.6.3 Implied Coefficients

SNA and TRE target generated positive coefficients, although both species were seldom targeted (Figure 54). GUR was the dominant target species in terms of data, and as a consequence the SNA 2S CPUE indices closely mirror the GUR target indices (Figure 54). The trend in the TAR target fishery is also generally comparable to the overall CPUE indices (Figure 54).

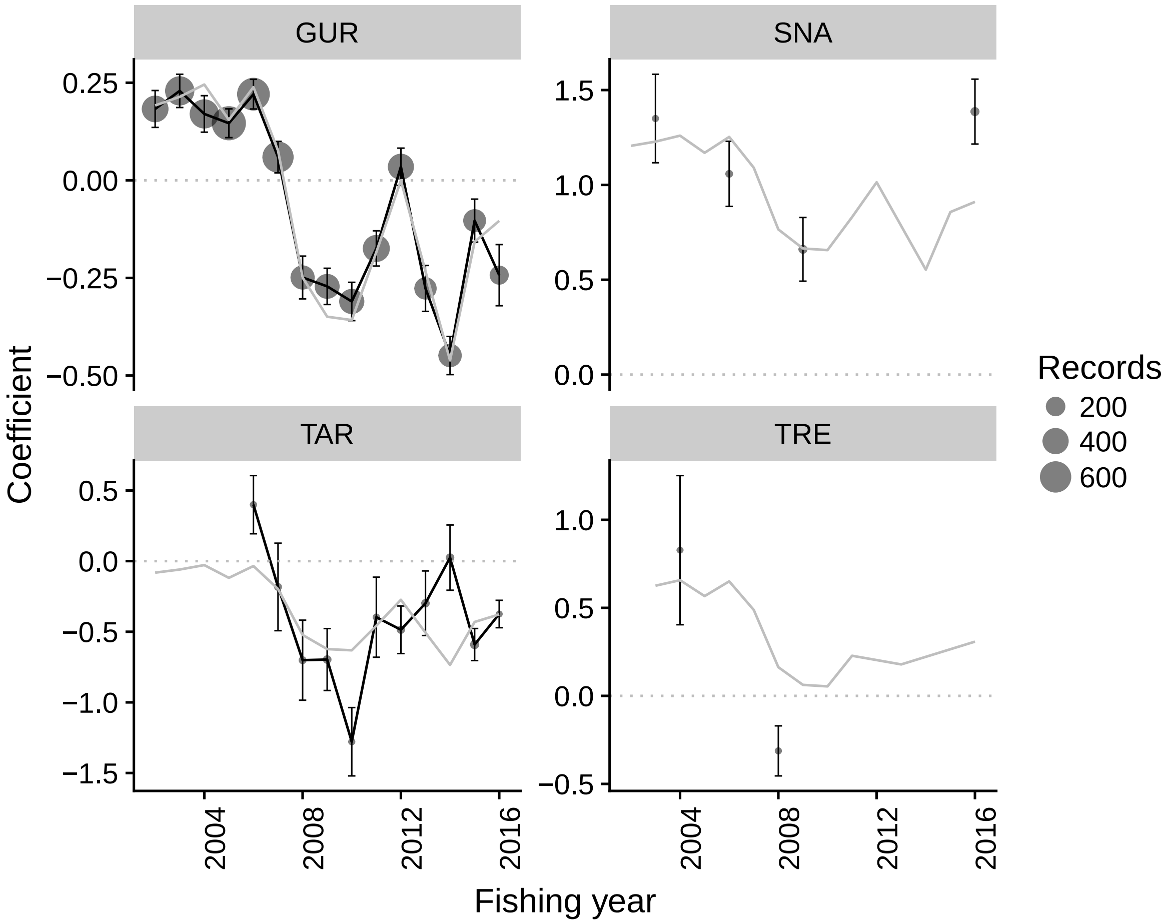

Figure 54: Implied SNA 2S CPUE indices (in log space) for the different target species in the SNA 2S vessel-day fishery over time. Error bars indicate one standard error of the standardised residuals, and the grey line shows the standardised SNA 2S vessel-day index normalised to the mean of the target species index.

6.7 CPUE indices

Occurrence of snapper catch was stable between 2002 and 2007 at about 40%, but from 2008 to 2016 snapper occurrence steadily declined to a minimum of about 20% in 2016 (Figure 55). The positive catch indices follow an analogous trend being stable from 2002 to 2006, between 2006 and 2009 the indices declined to a low level and then the indices fluctuated about the lower level (Figure 55). The combined indices had a flat trajectory from 2002 to 2006, from 2007 the indices steadily declined for three years reaching a low level by 2010 and fluctuated with a declining trend over the subsequent years (Figure 55). The indices from 2014–16 were the lowest for the entire series (Figure 55).

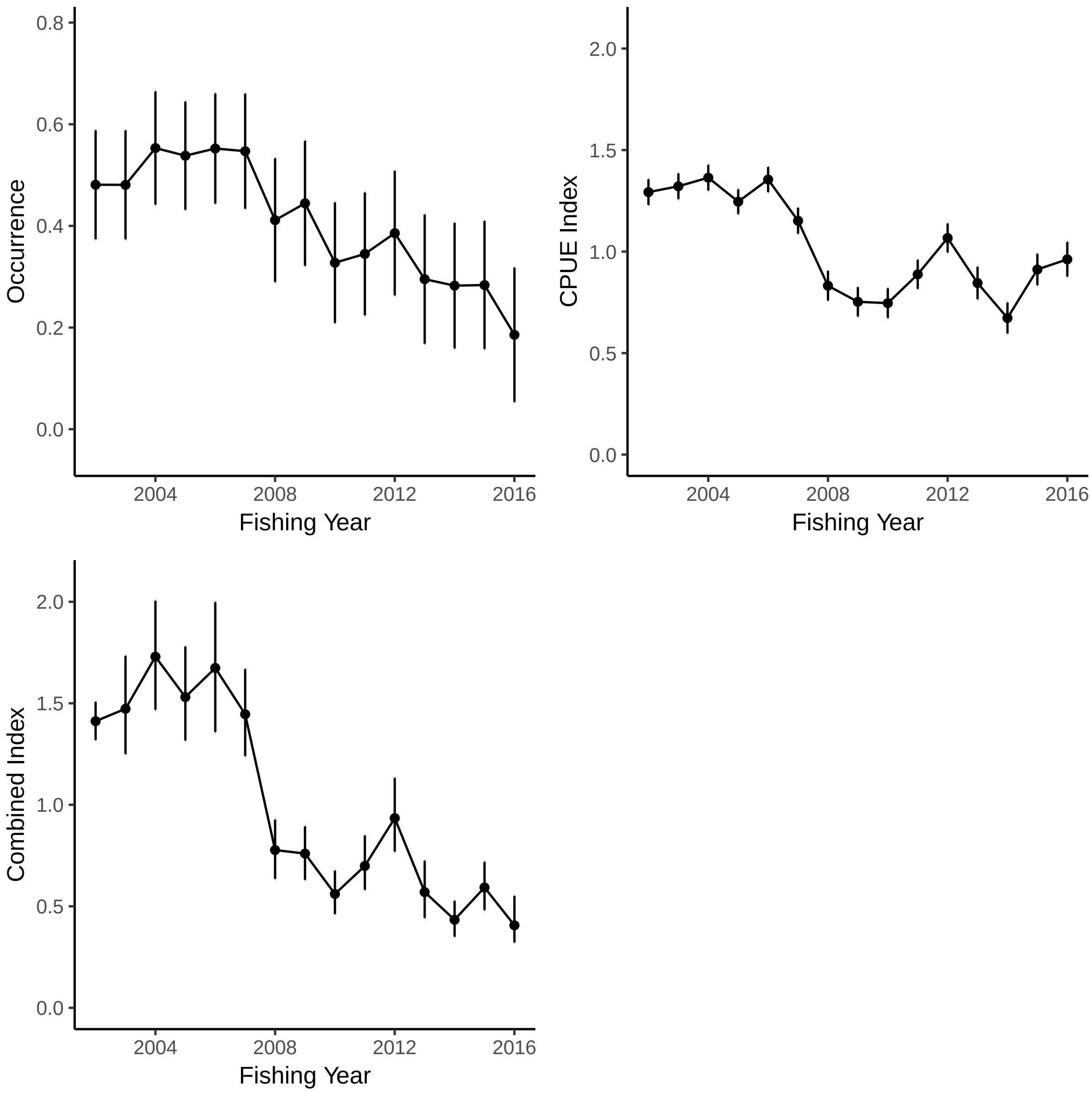

Figure 55: The SNA 2S vessel-day indices: occurrence (proportion of records with catches; top left), CPUE indices (magnitude of catches; top right) and combined (occurrence ×magnitude normalised; bottom) from 2002 to 2016.

7. SNA 2 NORTH

7.1 Aggregation

The SNA 2 north dataset, like SNA 2S, was composed of TCEPR, TCER and CELR data. The TCER/TCEPR data required aggregation to ensure it was comparable to the lower resolution CELR data (Langley 2014). Most aggregations grouped two fishing events per stratum, with the trip only stratification aggregating more events together (Figure 56). The percentage of events, trips and strata with positive catch fluctuated around 65% (Figure 56). The vessel-date aggregation recommended by Langley (2014) was used in the CPUE analyses.

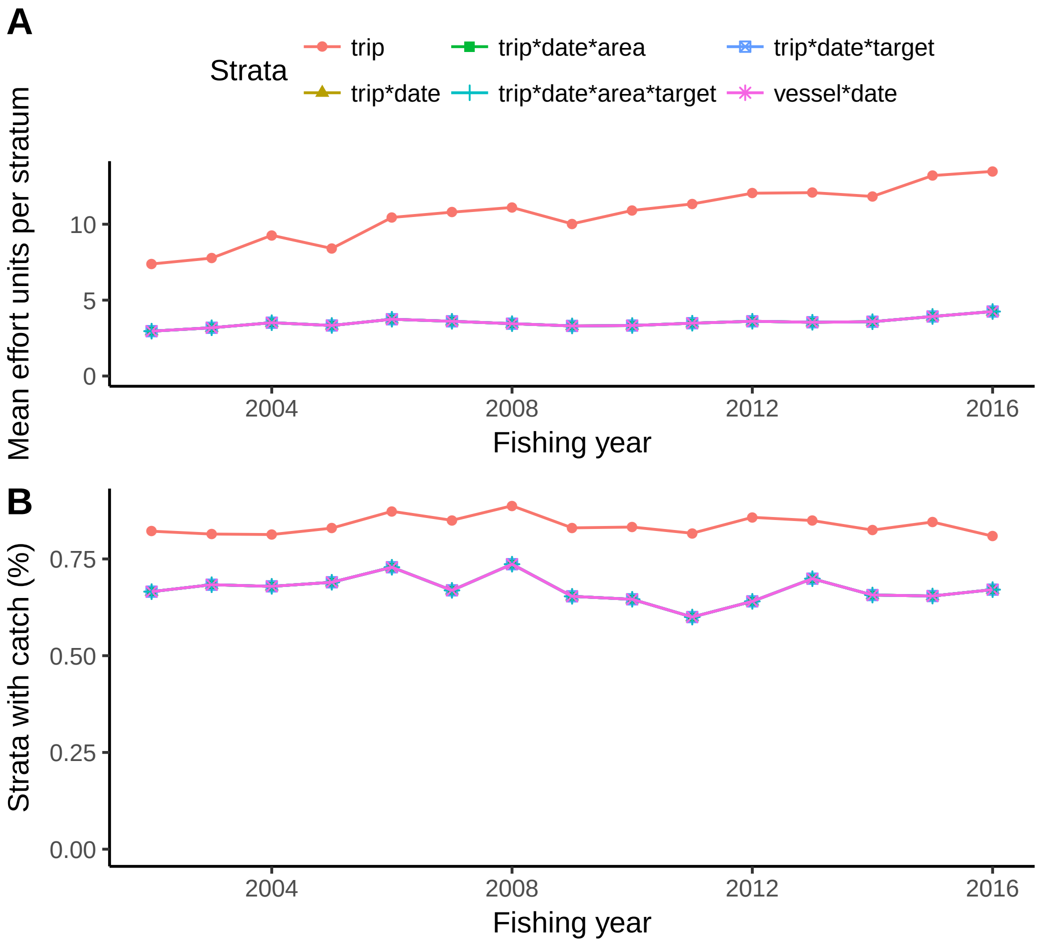

Figure 56: Comparison of alternate SNA 2N strata aggregations, A The mean number of effort units (i.e tows or shots) per stratum and B the percentage of strata with positive catch.

7.2 Fishery definition and trends

The SNA 2 north bottom trawl fishery (SNA 2N) was defined as:

- Primary method: bottom trawl (BT)
- Target species: gurnard, trevally, tarakihi or snapper (GUR, TRE, TAR, SNA)
- Fishing effort conducted within Statistical Areas 011, 012 and 013E, where 013E refers to Statistical Area 013 with reported starting positions west of the longitudinal boundary 177°87E or allocated 013E by the partitioning tree (pre 2008 data).

- Fishing effort conducted between 1 Oct 2001 and 30 Sept 2016 reported on CELR, TCER or TCEPR forms.

The SNA 2N fishing effort increased for the first five years of the series then stabilised, whereas the SNA 2N catch varied between 180 and 220 tonnes (Table 20).

Table 20: Summary of data subset by fishing year after the SNA 2N vessel-day fishery definition has been 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 number of trips and days which reported catching SNA.

Fishing Year	Vessels	Trips	Records	Effort (num)	Effort (hrs)	Catch (t)	Trips caught	Days caught
2002	32	443	1 735	3 270	10 806	146.2	82.4	66.6
2003	31	490	1 916	3 807	12 916	232.0	81.4	68.3
2004	28	476	2 502	4 413	14 683	229.1	81.9	68.2
2005	27	493	2 269	4 143	14 431	231.8	83.4	69.1
2006	28	496	2 743	5 182	17 205	241.0	87.5	72.9
2007	24	466	2 487	5 030	17 021	182.3	85.0	66.9
2008	24	435	4 831	4 831	16 621	219.0	88.7	73.6
2009	25	495	4 962	4 962	17 168	188.5	83.2	65.4
2010	24	519	5 662	5 662	19 351	202.9	83.2	64.6
2011	24	452	5 124	5 124	16 960	157.4	81.9	60.1
2012	22	414	4 986	4 986	16 855	189.1	85.8	64.0
2013	20	411	4 965	4 965	17 296	222.1	84.9	69.9
2014	21	416	4 922	4 922	16 778	251.0	82.7	65.8
2015	18	317	4 186	4 186	14 595	188.4	84.5	65.4
2016	20	314	4 233	4 233	15 281	204.9	80.9	67.1

7.3 Data filtering

Records were dropped if fishing duration was less then 1 hour or greater then 24 hours. Landings were assessed for accuracy if they exceeded 1500 kg (99.5th percentile). Of the 91 records affected, five were removed due to an order of magnitude difference between estimated and allocated catch.

7.4 Core Vessel Selection

The last analysis of a SNA 2, mixed target fishery (Kendrick & Bentley 2014) considered SNA 2 as a whole fishery and selected core vessels that had operated in the SNA 2 fishery for at least 5 years and undertook at least 5 trips per year.

Figure 57 demonstrates that the same criteria were appropriate for selecting the core fleet in SNA 2N (Figure 58). This resulted in a core fleet of 23 vessels which accounted for 87.76% of the SNA 2N catch.

Both the catch probability and catch magnitude were consistent throughout the SNA 2N time series (Figure 59). The overall fleet was well represented by the core fleet (Figure 59).

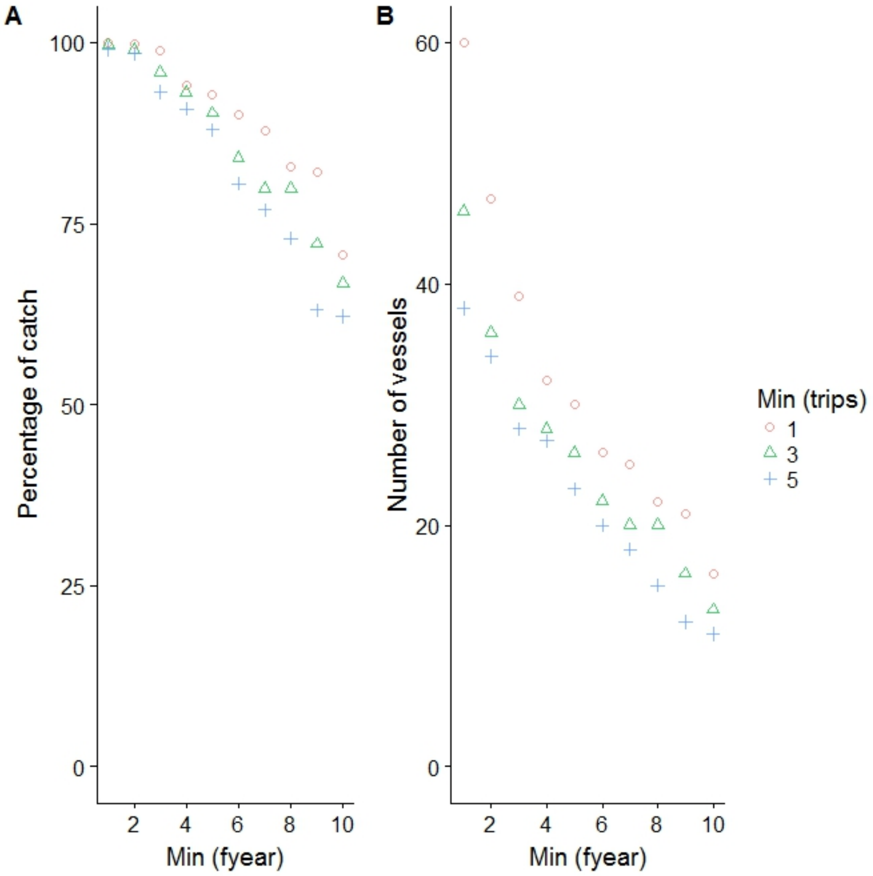

Figure 57: The percentage of catch (A) and number of vessels (B) represented by each alternate core vessel criteria: each unique combination of trips and fishing years for the SNA 2N vessel-day dataset.

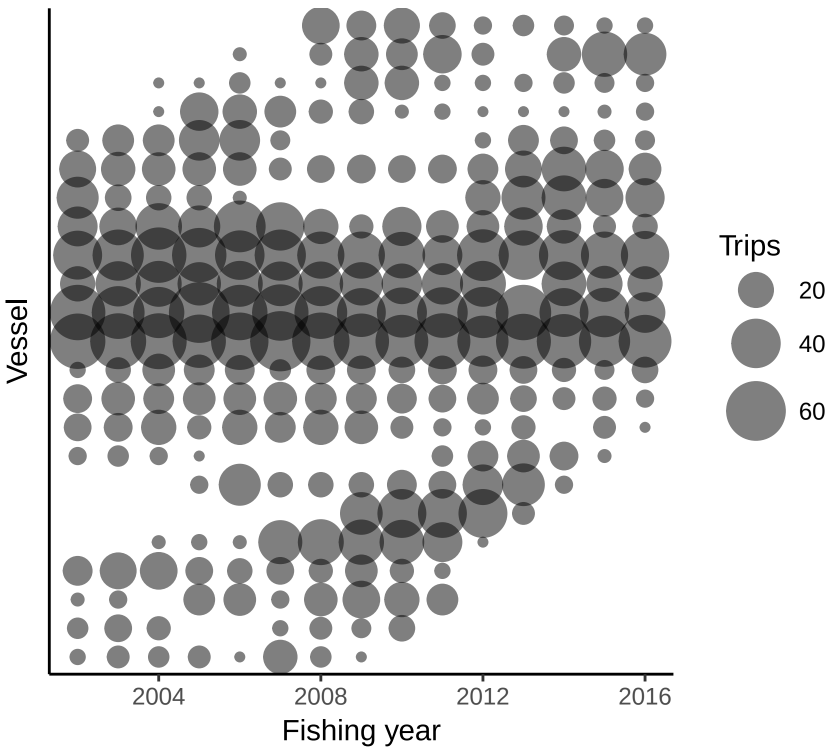

Figure 58: Number of trips by fishing year for core SNA 2N vessel-day vessels. The area of circles is proportional to the number of trips for a vessel in a fishing year.

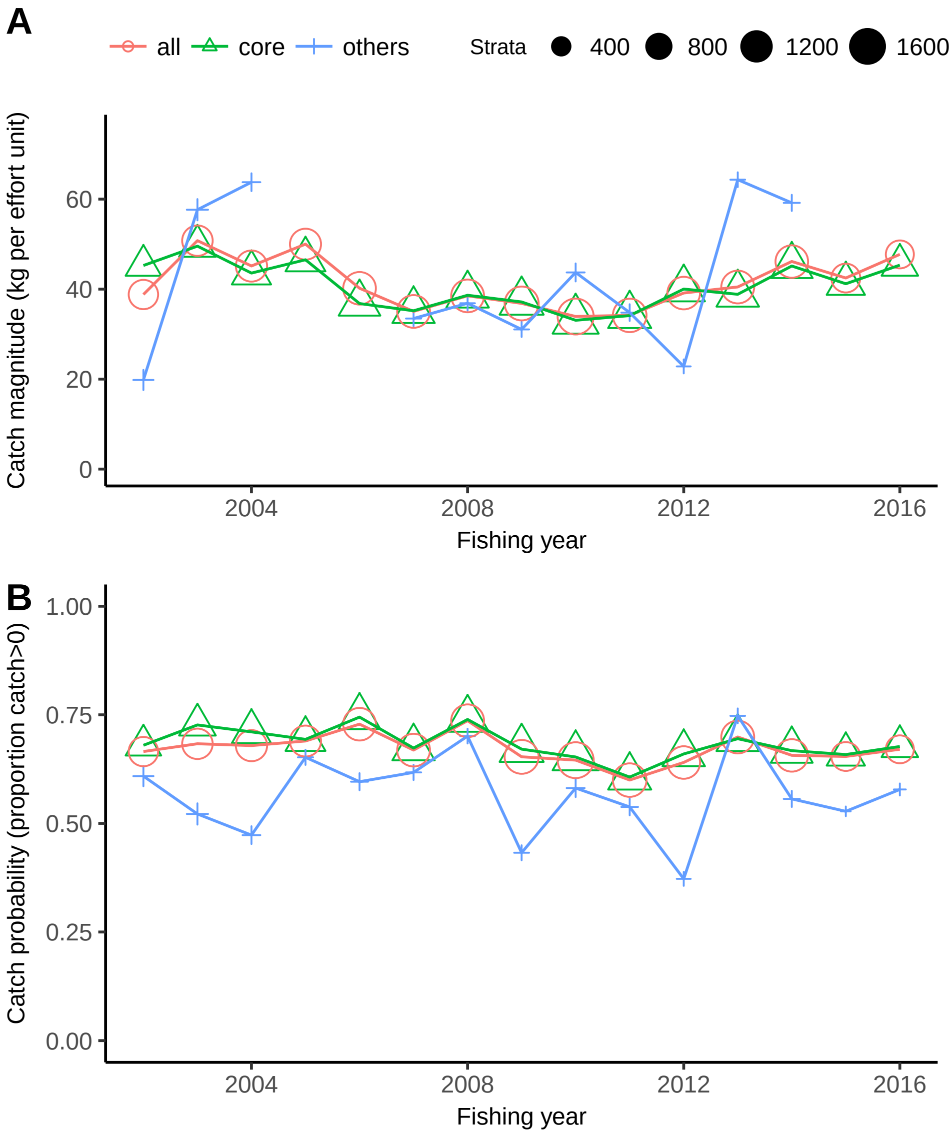

Figure 59: The unstandardised CPUE (A; geometric mean of catch divided by effort where catch was positive) and the proportion of strata with positive catch (B) for all, core and other vessels. The size of the points are proportional to the number of records.

A summary of the data used for SNA 2N CPUE analysis after filtering and restriction to the core fleet is provided in Table 21.

Table 21: Summary of core SNA 2N vessel-day data aggregated by fishing year. 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 number of trips and days which reported catching SNA.

Fishing year	Vessels	Trips	Records	Effort (num)	Effort (hrs)	Catch (t)	Trips caught	Days caught
2008	17	394	3 541	3 541	11 955	189.8	97.2	85.6
2009	19	467	3 995	3 995	13 416	174.9	95.1	83.1
2010	19	479	4 532	4 532	15 196	187.9	95.2	85.1
2011	20	455	4 274	4 274	13 992	155.2	93.4	80.5
2012	20	428	4 133	4 133	13 741	180.5	94.2	81.5
2013	16	389	3 919	3 919	13 593	196.4	96.4	86.4
2014	17	386	3 924	3 924	13 149	207.8	96.1	84.4
2015	16	326	3 232	3 232	11 059	179.2	94.2	85.9
2016	15	297	2 862	2 862	10 217	186.6	96.6	85.0

7.5 Occurrence

The occurrence of positive catch (TRUE/FALSE) was modelled using a binomial GLM with a logit link function. The maximal set of model terms offered to the stepwise selection algorithm was:
$\sim fyear+vessel+target+area*month+poly(log(duration),3)+area+month+poly(log(num),3)$

The final model formula after selection (Table 22) was:
$\sim fyear + area * month + target + vessel$

Table 22: Summary of stepwise selection for SNA 2N vessel-day occurence 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	13	20 267	0.4	0.4	*
+ area_month	35	18 841	7.8	7.4	*
+ target	3	18 093	11.5	3.7	*
+ vessel	22	17 584	14.2	2.7	*
+ poly(log(num), 3)	3	17 476	14.8	0.6	

The SNA 2N occurrence indices show that the probability of non-zero catch has fluctuated around around 70% throughout the series (Figure 60).

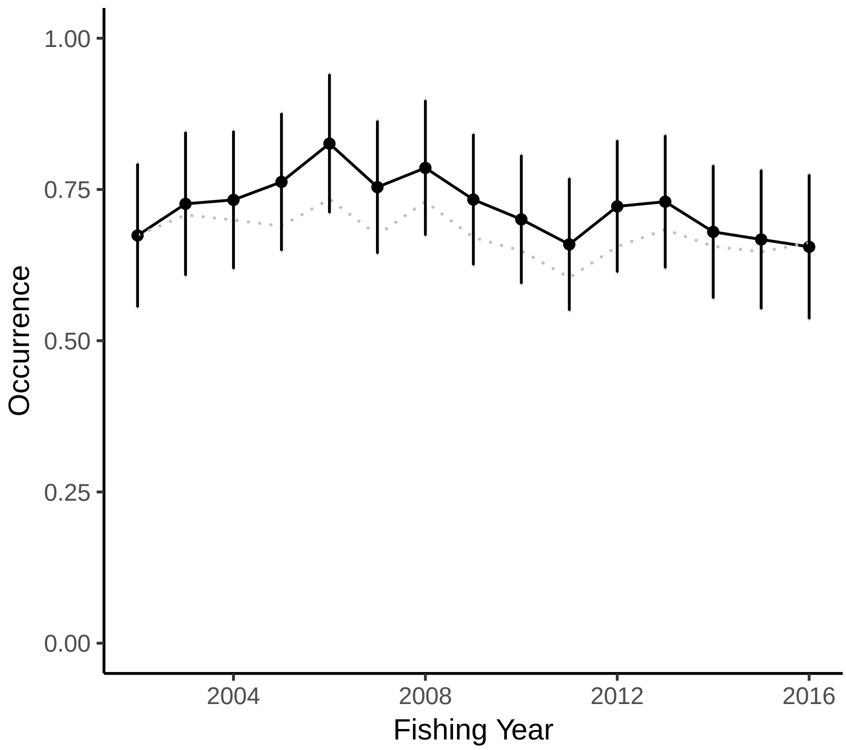

Figure 60: The occurrence of positive catch indices for SNA 2N vessel-day fishery, raw indices are plotted with dashed grey lines.

7.5.1 Positive Catch

The magnitude of non-zero catches were modelled by Kendrick & Bentley (2014) using a Weibull distribution. In this analysis a Weibull distribution had the lowest AIC of the distributions examined.

The maximal set of model terms offered to the stepwise selection algorithm was:
$\sim fyear + vessel + target + poly(log(duration), 3) + area + month + area * month + poly(log(num), 3)$

The final model after selection (Table 23) was:
$\sim fyear + vessel + area * month + poly(log(duration), 3) + target$

Table 23: Summary of stepwise selection for SNA 2N 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	13	133 068	1.5	1.5	*
+ vessel	22	131 405	14.3	12.8	*
+ area_month	35	130 158	23.1	8.8	*
+ poly(log(duration), 3)	3	129 298	28.4	5.4	*
+ target	3	128 442	33.4	5.0	*
+ poly(log(num), 3)	3	128 426	33.6	0.1	

7.5.2 Diagnostics

Model residuals from the positive log(catch) model show a reasonable approximation to the Weibull distribution (Figure 61), there are deviations at the extremes (outside of 2 standard deviations).

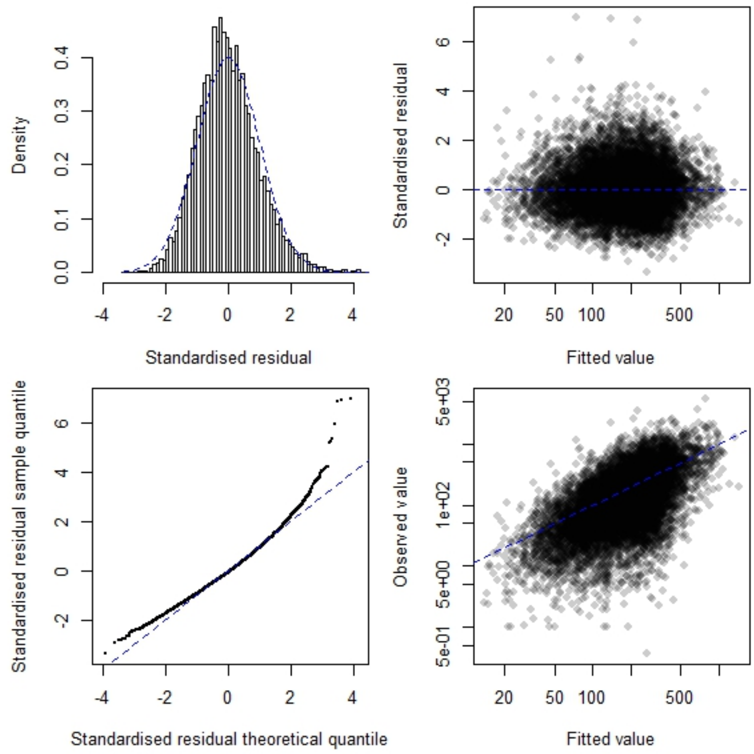

Figure 61: The Weibull diagnostic plots for the SNA 2N vessel-day model. top left: Standardised residuals from the accepted generalised linear model fit; top right: The standardised residuals versus the fitted values; bottom left: Quantile-quantile plot of observed response versus likelihood of the distribution of these values; bottom right: Observed values vs fitted values.

7.5.3 Influence of Model Terms

The trend in the standardised indices differed considerably from unstandardised, although their trajectories were similar (Figure 62). Standardised indices are greater than the unstandardised from 2002 to 2009, then from 2010 to 2016 the standardised indices are smaller (Figure 62).

Vessel and the area * month interaction were influential on the positive catch indices (Figure 63). Target and duration had little influence on the indices (Figure 63).

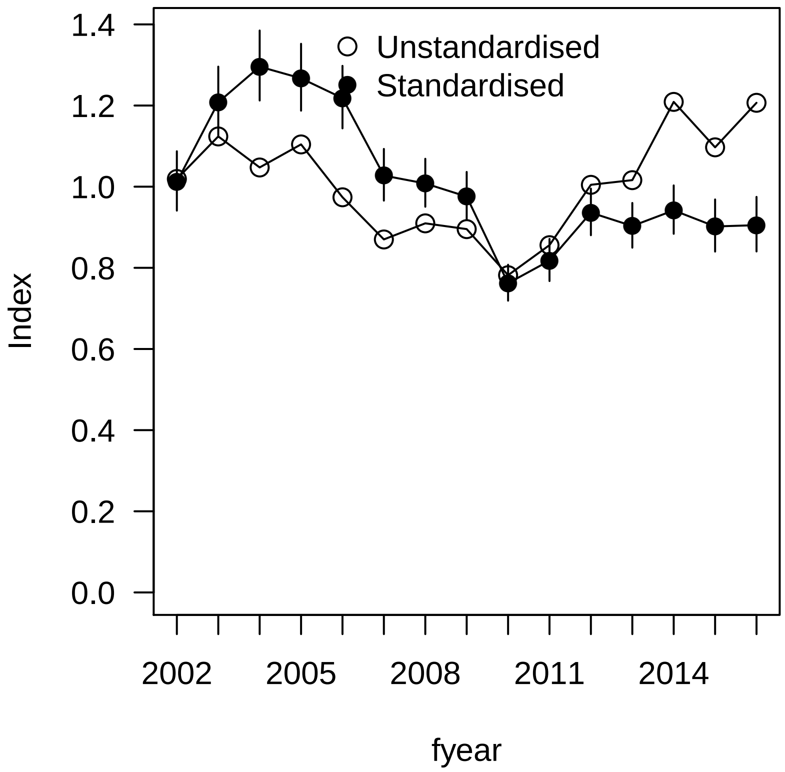

Figure 62: A comparison of the standardised CPUE indices and unstandardised indices of the SNA 2N vessel-day model. The unstandardised index is based on the geometric mean of the catch per strata and is not adjusted for effort

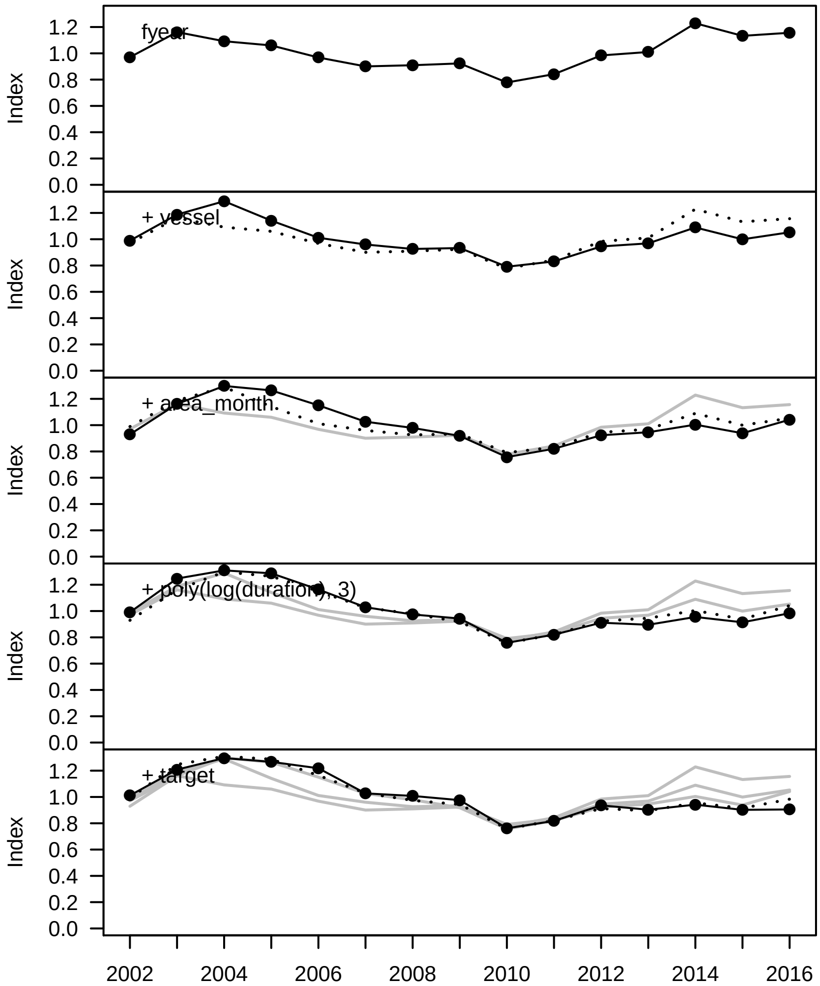

Figure 63: Changes in SNA 2N vessel-day CPUE indices as each term was successively added to the model. The indices are normalised to an overall geometric mean of 1.

There was a range of vessel coefficients in the SNA 2N fishery, the influence of vessel has increased in the last 6 years due to a shift towards a more efficient fleet (Figure 64).

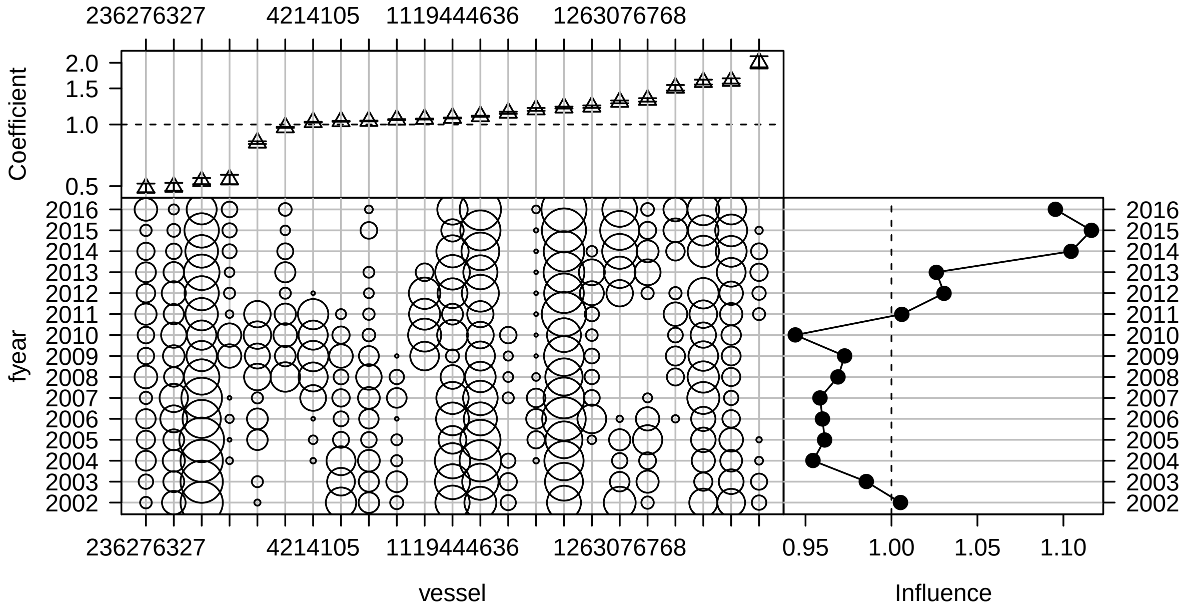

Figure 64: SNA 2N vessel-day coefficient-distribution-influence plot for vessel.

Coefficients are higher for areas 011 and 012 relative to Area 013E (Figure 65). Area 011 coefficients declined from October to December then increased from January until September (Figure 65). The patterns of coefficients in Areas 012 and 013E are similar, in Area 012 coefficients declined from October to December then increased to the January coefficient where it remained until May, whereas Area 013E had stale coefficients from January until May (Figure 65). Both Areas declined from June to a July trough with a September increase (Figure 65).

The majority of SNA 2N records had fishing durations between 1.5 to 12.5 hours, there was a general increase in fishing duration through the timeseries (Figure 66).

Tarakihi was the dominant target species in the SNA 2N fishery, it was consistently targeted through the series (Figure 67). The degree to which snapper was targeted dictated the influence of target species on the indices (Figure 67).

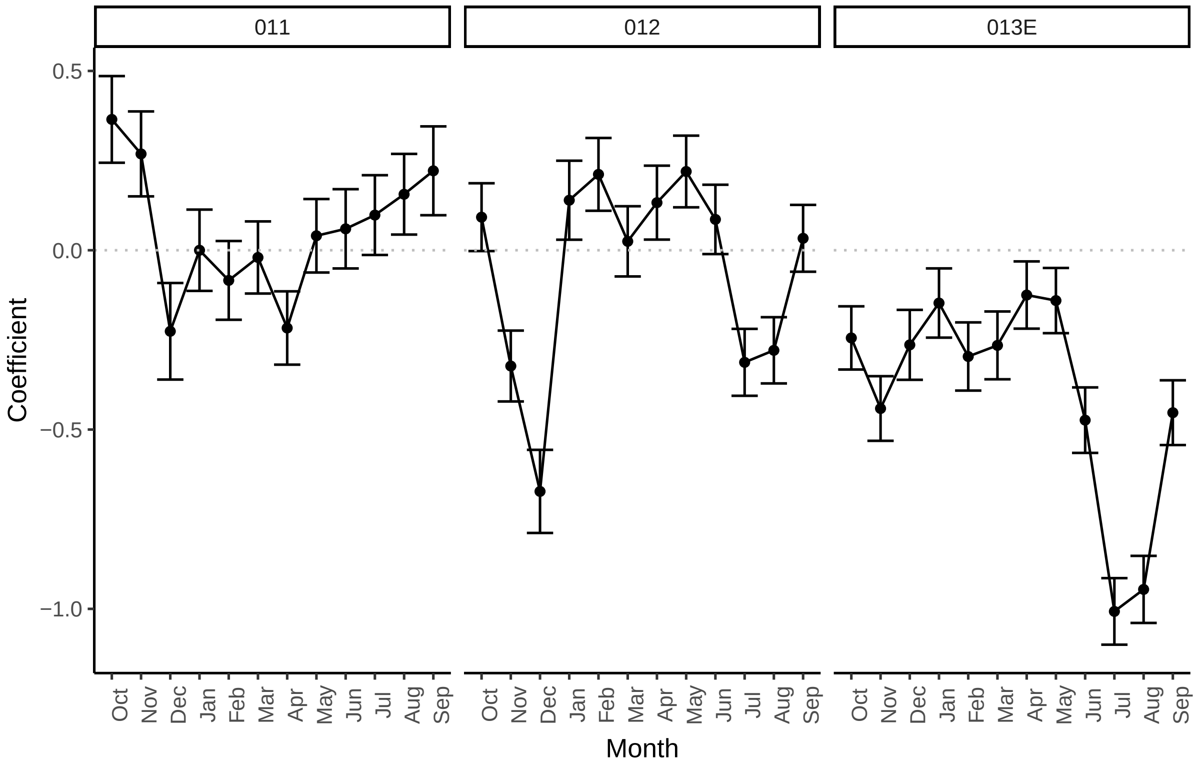

Figure 65: Coefficients for the area * month interaction from the SNA 2N vessel-day model, coefficients are plotted with 1 standard error intervals.

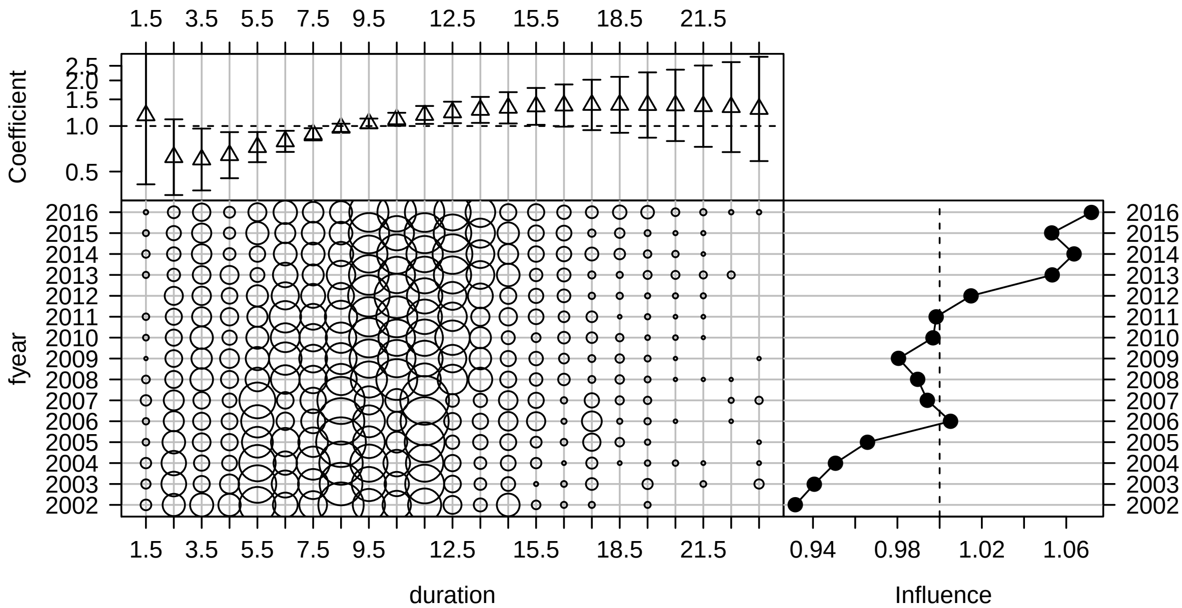

Figure 66: SNA 2N vessel-day coefficient-distribution-influence plot for fishing duration.

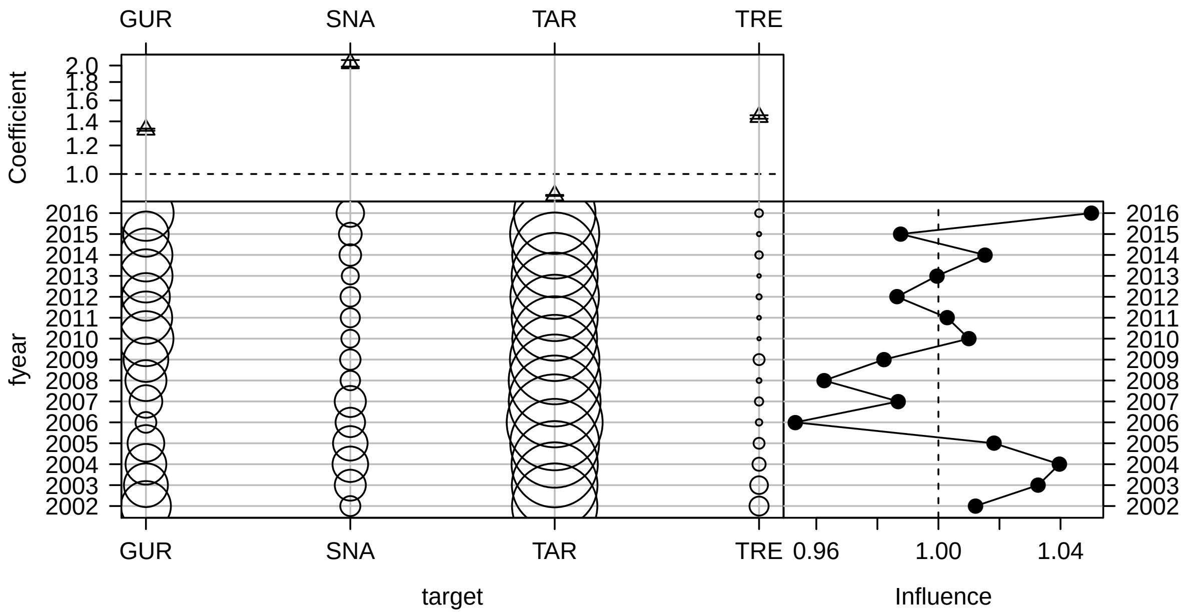

Figure 67: SNA 2N vessel-day coefficient-distribution-influence plot for target species.

7.5.4 Residual Implied Coefficients

The CPUE indices resemble the TAR target implied coefficients because tarakihi was the dominant target species in the SNA 2N fishery (Figure 68). There was a reasonable correlation with the SNA coefficients until 2011 where they diverged. The GUR implied coefficients are broadly similar to the CPUE indices although there is considerably more inter-annual variation (Figure 68).

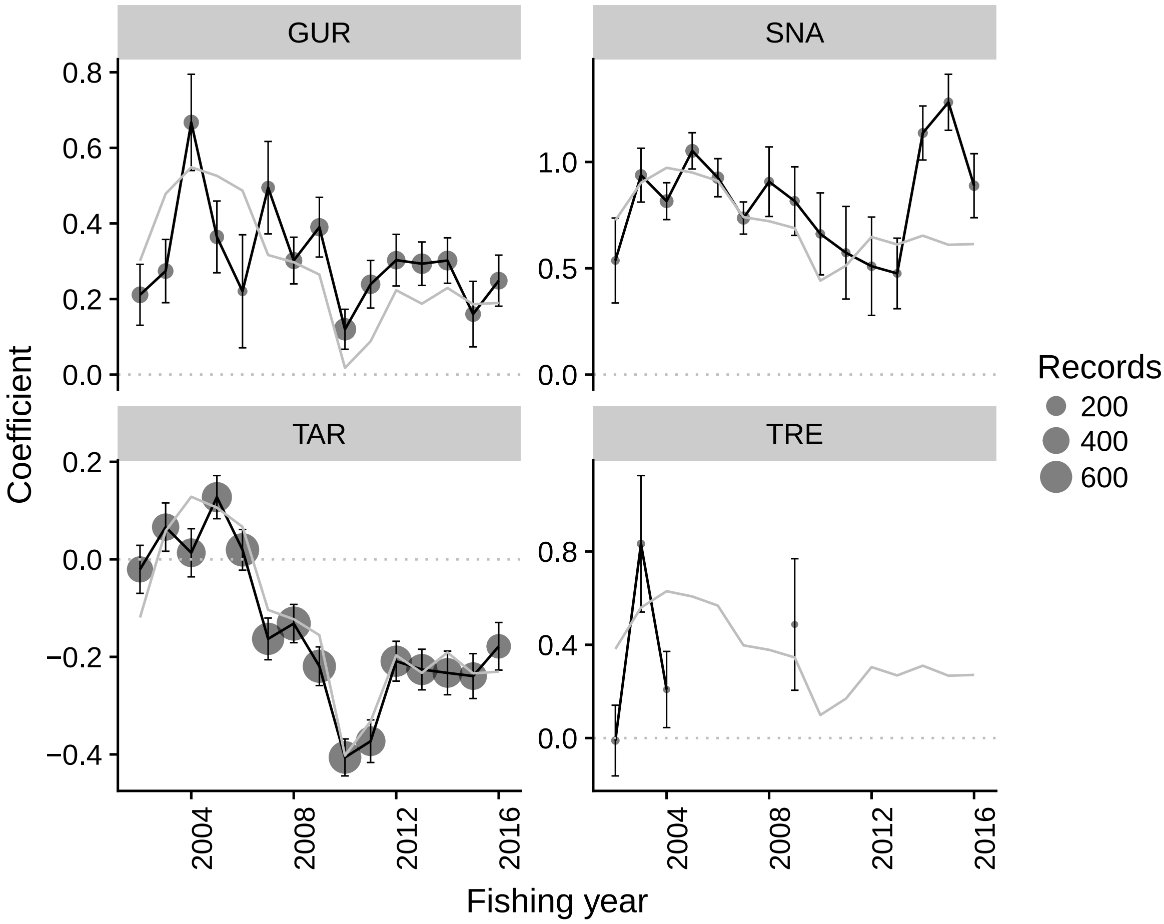

Figure 68: Implied SNA 2N CPUE indices (in log space) for the different target species in the SNA 2N vessel-day fishery over the time series. Error bars indicate one standard error of the standardised residuals, and the grey line shows the standardised SNA 2N vessel-day index normalised to the mean of the target species index.

7.6 CPUE indices

The snapper occurrence increased from about 70% in 2002 to 80% in 2006 then declined to 70% in 2016 (Figure 69). The positive catch indices increased for the first two years of the series, then gradually declined from 2004 to 2010 and then increased slightly in 2011 and 2012 and remained at about that level over subsequent years (Figure 69). The combined indices increased over the first two years where they stabilised, from 2006 to 2010 the indices declined and then were relatively stable to from 2011 to 2016 (Figure 69).

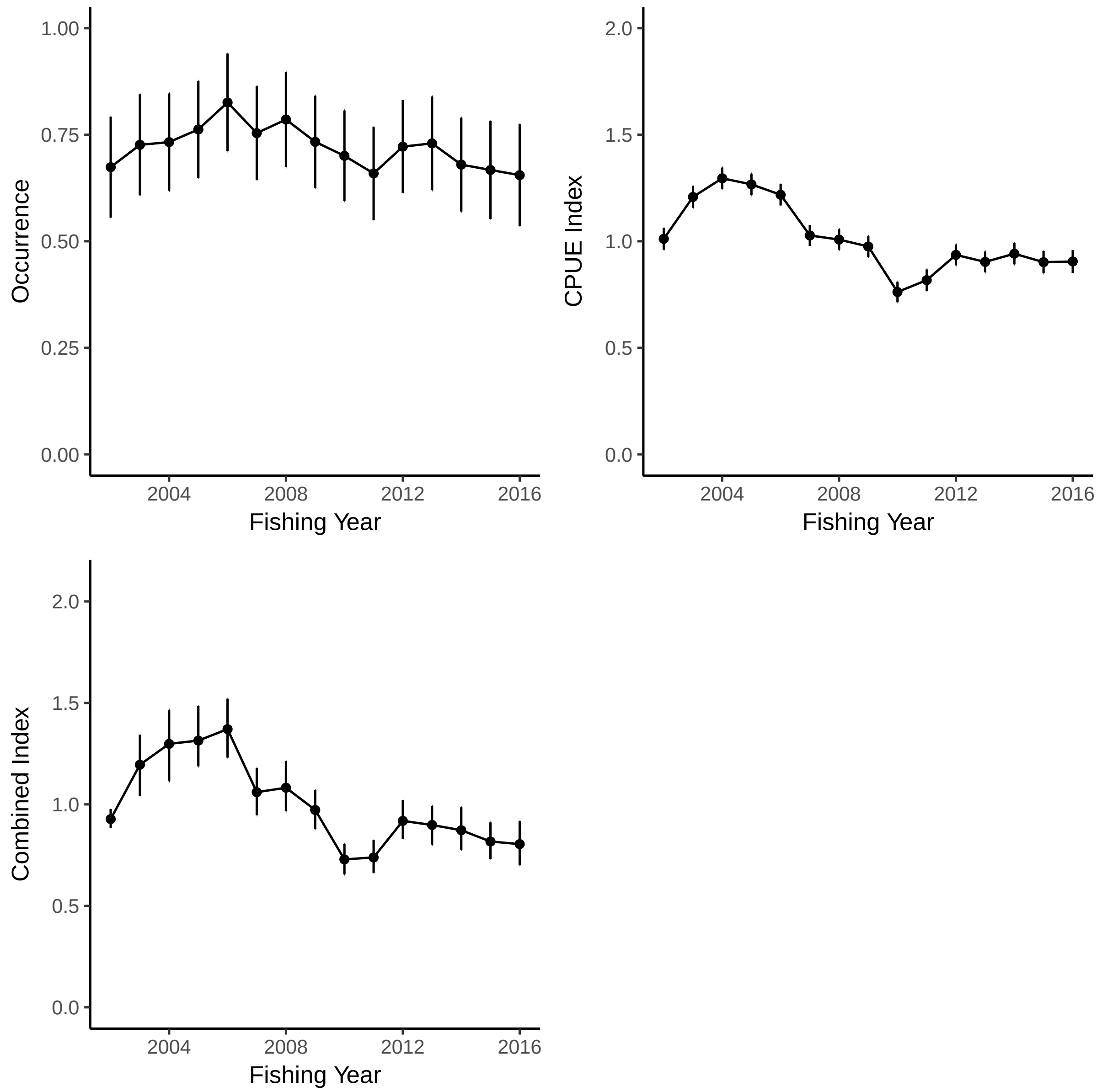

Figure 69: The SNA 2N vessel-day indices: occurrence (proportion of records with catches; top left), CPUE indices (magnitude of catches; top right) and combined (occurrence ×magnitude normalised; bottom) from 2002 to 2016.

8. DISCUSSION

There is some uncertainty about snapper stock structure within FMA 2, SNA 2 is assumed to occur in two sub-stocks (Walsh et al. 2012). The northern sub-stock occurs between the southern tip of the Mahia Peninsula and Cape Runaway. The distribution is contiguous with the distribution of snapper in the western Bay of Plenty, and relative year class strengths match, indicating an association between the northern SNA 2 sub-stock and the SNA 1 Bay of Plenty sub-stock. The southern sub-stock occurs within Hawke Bay, and may be peripheral to the northern stock rather than entirely discrete, although growth rates and relative year classes differ. Most (about 66%) of the SNA 2 catch is taken from the northern sub-stock, and this is assumed to be the primary component of the SNA 2 fishstock.

This analysis is the first full CPUE analysis to examine SNA 2 in separate sub-stocks. Snapper are primarily a bycatch species in FMA 2 trawl fisheries. The majority of the SNA 2 catch comes from tarakihi target trawls in Statistical Areas 011 and 012. There is some snapper targeting in the northern sub-stock and gurnard targeting predominates the southern sub-stock.

For the northern sub-stock, snapper occurred in approximately 70% of vessel-days; occurrence had a generally increasing trend from 2002 to 2008 and then a slightly decreasing trend from 2008 to 2016 (Figure 70). The southern sub-stock had snapper catches in around 50% of vessel-days between 2002 and 2007 then a steady decline to 20% occurrence in 2016 (Figure 70). The decline in snapper occurrence in the SNA 2S sub-stock is thought to be exacerbated by a change in fishing behavour in response to increased SNA 2 deemed values (Figure 70). Trends in occurrence for the tow based series were broadly consistent, taking into account the reporting of the top eight species in the TCER data, as opposed to the top five species in the vessel-day series (Figure 70).

In both the northern and southern sub-stocks CPUE indices were relatively stable between 2002 and 2006. Both sub-stock indices declined after 2006, the decline was more substantial in the southern sub-stock from 2006 to 2009, compared to a more gradual decline from 2006 to 2010 in the northern sub-stock (Figure 71). In the southern sub-stock there was a decline in SNA 2 catch over the same period. Both sub-stocks have been relatively stable between 2010 and 2016, with the southern sub-stock showing more inter-annual variation (Figure 71). Tow based CPUE series for the period 2008 to 2016 closely resemble the mixed form type analysis for corresponding periods in both stocks (Figure 71).

The combined series for the northern sub-stock increased from 2002 to 2006, declined from 2006 to 2010, then gradually increased from 2010 to 2016 (Figure 72). The southern sub-stock also increased from 2002 to 2006, then declined substantially from 2007 to 2010 (Figure 72). There was an uplift in 2012 and 2013 but the index subsequently showed a gradual decrease to 2016.

The most recent catch sampling of the SNA 2 fishery in the 2007/08 and 2008/09 fishing years found that the dominant age classes were 2003 and 2001 (Walsh et al. 2012). The SNA 2N sub-stock had a more uniform distribution of age classes although was dominated by 5–9 year old fish with less recruitment since the 2003 age class. The SNA 2S was dominated by single strong year classes in 2001, 2003 and a 2005 year class that was not significant in SNA 2N. The age composition suggests that snapper recruit infrequently to the SNA 2S sub-stock and the overall SNA 2 fishery was supported by stronger recruitment prior to 2008/09. This provides some explanation for the decline in the SNA 2N CPUE with fewer strong age classes evident after 2003, but is inconsistent with the larger declines in the SNA 2S indices.

The SNA 2 deemed value price increased sharply between the 2006/07 and 2007/08 fishing years (Figure 73, New Zealand Legislation (2015), Ministry for Primary Industries (2017)). The SNA 2S CPUE indices and SNA 2S catch declined sharply in the 2008 fishing year. Prior to the 2008 fishing year the SNA 2 TACC had been consistently exceeded since the introduction of the QMS. Less snapper was caught in the BT-MIX fishery and the overall annual SNA 2 catch has been constrained by the TACC since 2006/07, these changes coincided with a substantial increase in deemed values for SNA 2 (Figure 73). This may indicate that the operation of the SNA 2S fishery changed to reduce snapper catch to avoid or minimise deemed value payments. Consultation with SNA 2 quota holders suggested vessels

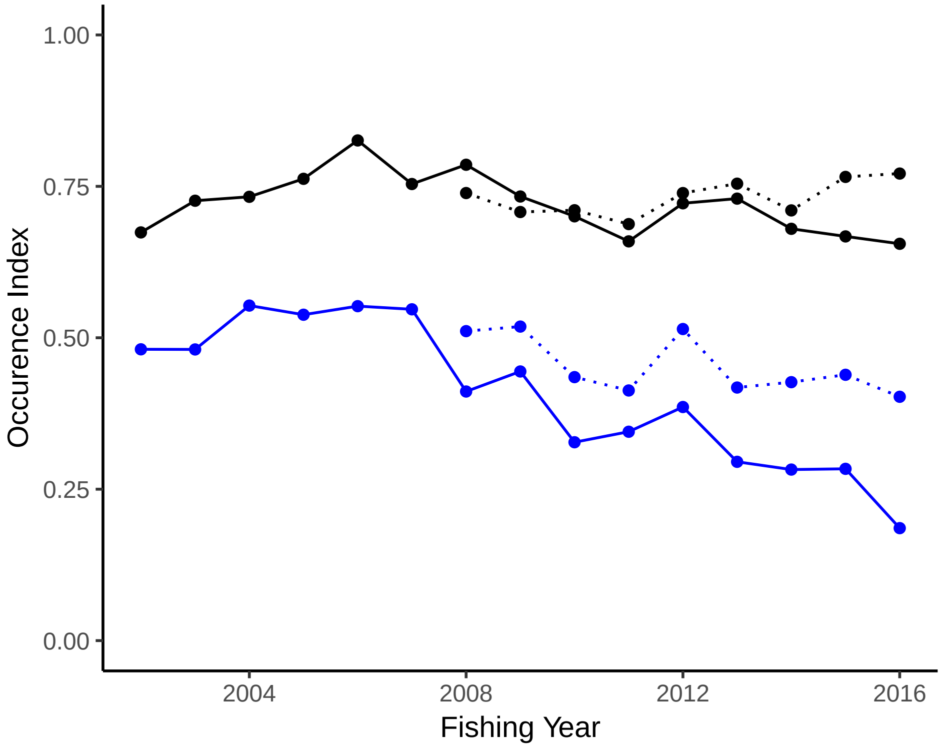

Figure 70: Occurrence (of positive catch) indices for the BT-MIX-N (black) and BT-MIX-S (blue) fisheries, tow by tow series are shown by dotted lines.

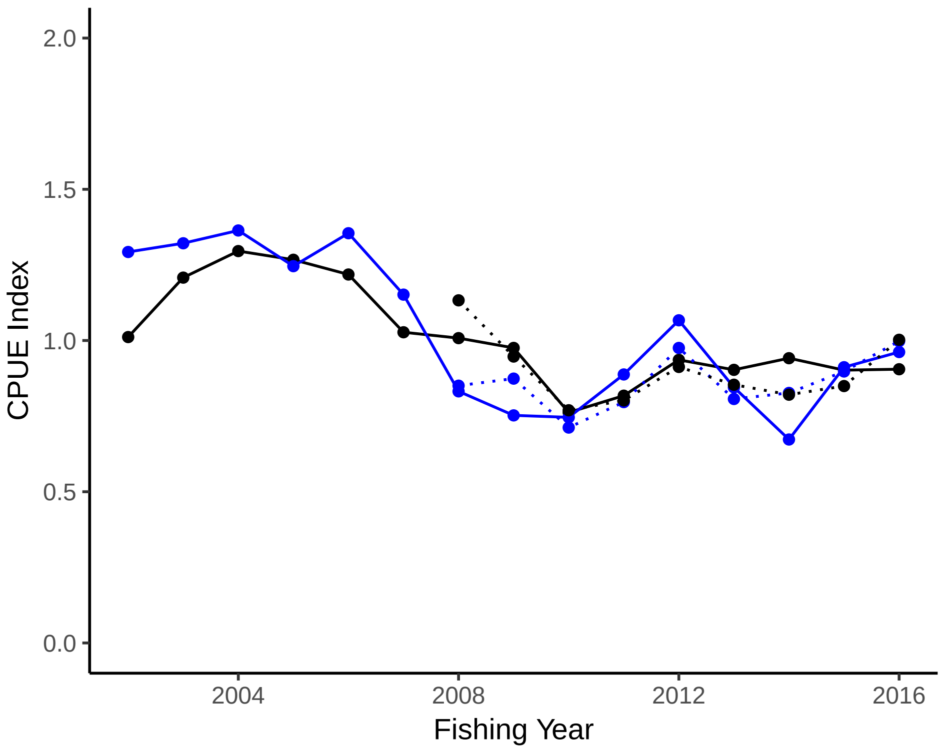

Figure 71: CPUE indices for the BT-MIX-N (black) and BT-MIX-S (blue) fisheries, tow by tow series are shown by dotted lines.

operate to avoid catching snapper in the first half of the fishing year, then will endeavour to catch the remainder of their SNA ACE at the end of the fishing year. This behaviour was likely to be driven by

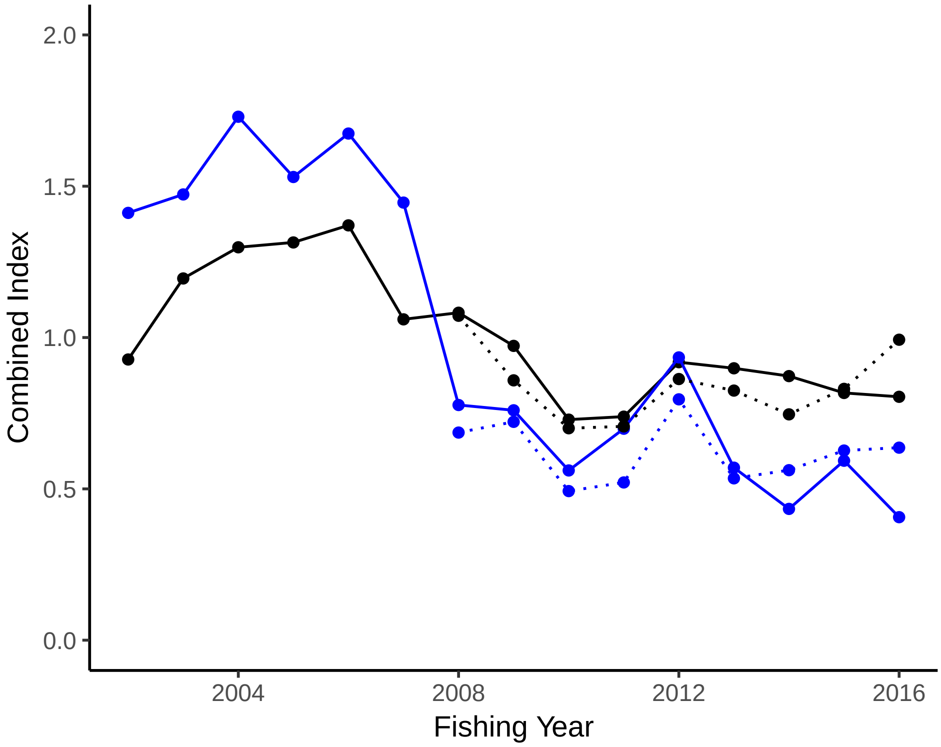

Figure 72: Combined indices for the BT-MIX-N (black) and BT-MIX-S (blue) fisheries, tow by tow series are shown by dotted lines.

the increasing deemed values. Such changes in behaviour may not be adequately accounted for in CPUE standardisation procedures. The influence of the change in deemed values may have negatively biased the SNA 2S CPUE indices from 2007/08 onwards and these indices may not be directly comparable to the indices from the earlier years.

For SNA 2N, the decline in CPUE and snapper catch in 2008 was much less pronounced than for SNA 2S. This may indicate (no analysis of ACE was undertaken) that the vessels that predominantly operate in the SNA 2N fishery had greater access to SNA 2 ACE, consequently, the change in deemed value price structure had less of an impact on the operation of the SNA 2N vessels compared to the vessels operating in the SNA 2S fishery. In that case, the CPUE indices from SNA 2N would be less susceptible to changes in deemed values during the time series.

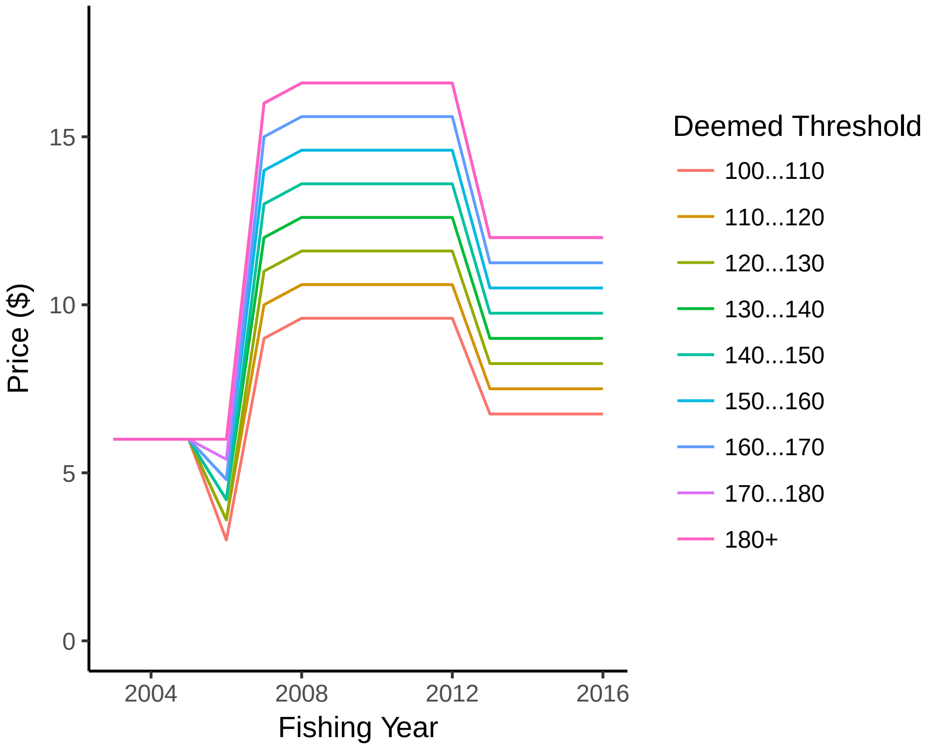

Figure 73: SNA 2 annual deemed values (price/kg) by catch threshold between the 2003 and 2016 fishing years. The threshold represents SNA 2 catch as a percentage of the ACE held by a permit holder (e.g. 110-120 represents a catch 10–20 % higher then the SNA 2 ACE possessed). Sourced from Ministry for Primary Industries (2017), New Zealand Legislation (2015).

8.1 Management Implications

The NINS WG adopted the combined vessel day CPUE indices as indices of abundance for each of the SNA 2 sub-stocks (22 June 2017). The CPUE indices have not been used to define a BMSY proxy for either stock unit. This is primarily due to the short time series of CPUE indices relative to the history of exploitation of the stocks(s). It is unknown how recent CPUE levels correspond to reference levels of stock biomass.

8.2 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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10. APPENDICES

10.1 Appendix 1 Tabulated CPUE indices

Table 24: Annual SNA 2N vessel–day CPUE indices and the lower (LCI) and upper (UCI) bounds of the 95 % confidence intervals.

Fishing Year	Combined Index	LCI	UCI	Binomial Index	LCI	UCI	CPUE index	LCI	UCI
2002	0.928	0.885	0.977	0.674	0.555	0.793	1.012	0.960	1.063
2003	1.195	1.041	1.343	0.726	0.608	0.845	1.208	1.157	1.259
2004	1.298	1.114	1.465	0.733	0.619	0.847	1.296	1.245	1.346
2005	1.314	1.187	1.485	0.762	0.649	0.876	1.267	1.217	1.318
2006	1.371	1.230	1.521	0.826	0.711	0.941	1.218	1.168	1.269
2007	1.060	0.946	1.180	0.754	0.644	0.864	1.027	0.978	1.077
2008	1.082	0.966	1.213	0.786	0.674	0.898	1.008	0.959	1.057
2009	0.973	0.878	1.070	0.733	0.625	0.842	0.976	0.926	1.025
2010	0.729	0.655	0.805	0.701	0.594	0.807	0.762	0.714	0.811
2011	0.739	0.662	0.824	0.659	0.550	0.769	0.818	0.767	0.868
2012	0.919	0.828	1.022	0.722	0.613	0.831	0.936	0.887	0.985
2013	0.898	0.802	0.993	0.730	0.620	0.840	0.903	0.854	0.952
2014	0.873	0.777	0.986	0.680	0.570	0.790	0.942	0.892	0.992
2015	0.817	0.730	0.911	0.667	0.552	0.783	0.902	0.849	0.955
2016	0.804	0.700	0.918	0.655	0.536	0.775	0.905	0.851	0.959

Table 25: Annual SNA 2S vessel-day CPUE indices and the lower (LCI) and upper (UCI) bounds of the 95 % confidence intervals.

Fishing Year	Combined Index	LCI	UCI	Binomial Index	LCI	UCI	CPUE index	LCI	UCI
2002	1.412	1.319	1.507	0.481	0.374	0.588	1.293	1.230	1.356
2003	1.473	1.250	1.734	0.481	0.374	0.588	1.322	1.259	1.385
2004	1.730	1.468	2.005	0.553	0.442	0.664	1.364	1.301	1.427
2005	1.531	1.317	1.779	0.538	0.432	0.644	1.246	1.185	1.307
2006	1.674	1.359	1.998	0.552	0.444	0.661	1.355	1.293	1.417
2007	1.446	1.240	1.668	0.547	0.434	0.660	1.152	1.088	1.216
2008	0.777	0.635	0.926	0.411	0.290	0.533	0.832	0.759	0.905
2009	0.760	0.630	0.894	0.444	0.322	0.567	0.753	0.680	0.825
2010	0.561	0.462	0.676	0.328	0.209	0.446	0.746	0.673	0.819
2011	0.699	0.581	0.849	0.345	0.224	0.466	0.888	0.816	0.959
2012	0.934	0.769	1.132	0.386	0.263	0.508	1.067	0.996	1.138
2013	0.570	0.443	0.725	0.295	0.168	0.422	0.845	0.766	0.925
2014	0.434	0.351	0.527	0.282	0.159	0.406	0.673	0.597	0.749
2015	0.593	0.481	0.719	0.284	0.158	0.410	0.912	0.835	0.989
2016	0.407	0.322	0.551	0.186	0.054	0.318	0.962	0.877	1.047

Table 26: Annual SNA 2N TCER CPUE indices and the lower (LCI) and upper (UCI) bounds of the 95 % confidence intervals.

Fishing Year	Combined Index	LCI	UCI	Binomial Index	LCI	UCI	CPUE index	LCI	UCI
2008	1.270	1.241	1.298	0.739	0.670	0.808	1.269	1.239	1.298
2009	1.017	0.958	1.094	0.708	0.639	0.776	1.061	1.031	1.090
2010	0.830	0.775	0.889	0.711	0.644	0.778	0.862	0.833	0.890
2011	0.837	0.777	0.905	0.688	0.620	0.756	0.898	0.868	0.928
2012	1.023	0.944	1.104	0.739	0.668	0.810	1.022	0.992	1.052
2013	0.977	0.913	1.057	0.754	0.680	0.829	0.956	0.926	0.986
2014	0.884	0.824	0.953	0.710	0.637	0.783	0.919	0.889	0.950
2015	0.984	0.914	1.063	0.766	0.688	0.843	0.951	0.919	0.984
2016	1.177	1.083	1.271	0.771	0.689	0.853	1.123	1.089	1.156

Table 27: Annual SNA 2S TCER CPUE indices and the lower (LCI) and upper (UCI) bounds of the 95 % confidence intervals.

Fishing Year	Combined Index	LCI	UCI	Binomial Index	LCI	UCI	CPUE index	LCI	UCI
2008	1.107	1.070	1.148	0.511	0.442	0.580	0.994	0.942	1.047
2009	1.164	1.039	1.318	0.519	0.450	0.587	1.022	0.969	1.074
2010	0.795	0.697	0.915	0.435	0.369	0.501	0.832	0.781	0.884
2011	0.841	0.759	0.938	0.413	0.347	0.479	0.931	0.881	0.981
2012	1.284	1.144	1.418	0.514	0.444	0.584	1.140	1.088	1.192
2013	0.863	0.758	0.990	0.418	0.347	0.488	0.943	0.886	1.000
2014	0.907	0.792	1.023	0.427	0.357	0.497	0.966	0.911	1.022
2015	1.011	0.899	1.154	0.439	0.367	0.511	1.049	0.993	1.105
2016	1.027	0.882	1.178	0.403	0.327	0.479	1.166	1.107	1.225