Ministry for Primary Industries
Manatū Ahu Matua

Stock assessment of trevally in TRE 7

New Zealand Fisheries Assessment Report 2015/45

A.D. Langley

T.H. Kendrick

N. Bentley

ISSN 1179-5352 (online)

ISBN 978-1-77665-016-3 (online)

August 2015

New Zealand Government

Growing and Protecting New Zealand

Requests for further copies should be directed to:

Publications Logistics Officer
Ministry for Primary Industries
PO Box 2526
WELLINGTON 6140

Email: brand@mpi.govt.nz
Telephone: 0800 00 83 33
Facsimile: 04-894 0300

This publication is also available on the Ministry for Primary Industries websites at:
http://www.mpi.govt.nz/news-resources/publications.aspx
http://fs.fish.govt.nz go to Document library/Research reports

TABLE OF CONTENTS

EXECUTIVE SUMMARY

Langley, A.D.; Kendrick, T.H.; Bentley, N. (2015). Stock assessment of trevally in TRE 7.

***New Zealand Fisheries Assessment Report 2015/45.* 76 p.**

The TRE 7 fishery is dominated by catches from the single trawl method targeting trevally. Prior to 2004/05, a considerable proportion of the trevally catch was also taken as a bycatch of the snapper trawl fishery, but more recently the fishery has been increasingly dominated by the target fishery. This change coincided with a considerable rationalisation of the single trawl fleet, following the reduction in the SNA 8 quota in 2005. Standardised CPUE indices for trevally were derived from catch and effort data from the main trawl fishery.

The TRE 7 stock assessment was revised and updated to include data to the end of the 2013/14 fishing year. The main difference in model structure from the previous (2009) assessment is the spatial domain of the assessment model. Spatial stratification of the TRE 7 fishery age composition and CPUE data sets indicates that there is considerable variability in the population dynamics amongst three main sub-areas of the TRE 7 fishery. Insufficient data were available to develop a spatially structured assessment model for the entire TRE 7 fishstock. Instead, the current assessment was primarily limited to the Kaipara-Manukau-North Taranaki Bight (KM-NTB) sub-area of TRE 7. The KM-NTB area accounted for 69.4% of the total TRE 7 catch during 2011–13, a substantial proportion of the historical TRE 7 catch and the most comprehensive set of fishery age sampling data.

The primary data sets included in the KM-NTB assessment model are the time-series of annual commercial catches and the age composition data and the standardised CPUE indices from the trevally bottom trawl fishery. These data sets were configured to be consistent with the spatial domain of the assessment model. Since the 2009 assessment, two additional years of age composition data are available from the bottom trawl fishery (2009/10 and 2012/13) and the time series of CPUE indices was extended to include 2008/09–2012/13.

The stock assessment was conducted using a statistical, age structured population model implemented in Stock Synthesis. The stock status of the KM-NTB component of TRE 7 was assessed relative to unfished biomass (SB_0) with a default target biomass level of 40% SB_0, a soft limit of 20% SB_0 and a hard limit of 10% SB_0.

The base assessment model estimated that the spawning biomass was reduced considerably during the 1970s and 1980s, although the stock remained above the target biomass level throughout that period. The spawning biomass level stabilised during the late 1990s and 2000s (at about 50% SB_0) and increased during 2010–2014. Current biomass is estimated to be above the target biomass level (SB_{2014}/SB_0 = 0.510, CI 0.393–0.669). The overall level of stock depletion is largely informed by the age composition data collected from the bottom pair trawl fishery during 1998–2001 and the aggregated catch history from the preceding period, especially the 1970s and early 1980s.

The assessment included a range of model sensitivity runs and the overall conclusions regarding stock status were relatively insensitive to the range of assumptions evaluated.

Estimates of equilibrium yield for the KM-NTB sub-area are about 1500 t, although the upper bound of the yield estimates is not well determined (CI 1300–2900 t). The yield estimates are comparable to the recent level of catch from the KM-NTB sub-area (1378 t average 2010/11–2012/13, including non commercial catch).

Five year stock projections were conducted based on the level of catch from the terminal year of the model data period (2013/14). The projected annual catch of 1525 t is slightly higher than the catch from preceding years (2010/11–2012/13) but is below the equilibrium yield estimated for the base model. For the base model, the spawning biomass is projected to decline slightly (by 6%) during the projection period, although there remains a very low probability that the biomass would decline below the target biomass level. The projected stock status is somewhat less optimistic for a model sensitivity analysis that assumed a lower value of natural mortality.

1. INTRODUCTION

Trevally (*Pseudocaranx dentex*) represents a major component of the catch from the inshore fishery off the west coast of the North Island. This area accounts for almost all of the catch from the TRE 7 fishstock. Reported landings from the fishery peaked in the late 1970s and early 1980s at 2500–3000 t. Catches were reduced considerably in the late 1980s, and since the mid-1990s catches have fluctuated about a level slightly below the current TACC of 2153 t (Ministry for Primary Industries 2014).

The first quantitative stock assessment of TRE 7 was conducted by Hanchet (1999) and has been updated and refined in subsequent assessments (Maunder & Langley 2002, McKenzie 2008, Langley & Maunder 2009). The assessments of TRE 7 have been principally based on the time series of annual commercial catches, standardised CPUE indices and age composition data from the commercial trawl fishery. Successive assessments have incorporated the more recent CPUE (Kendrick & Bentley 2010) and age composition data from the fishery.

The ongoing sampling of trevally commercial catches has also revealed considerable differences in the age composition amongst defined sub-areas of TRE 7 (Walsh et al. 2012, Walsh et al. 2014) (Figure 1). There are also differences in the trends in the CPUE indices amongst the sub-areas of TRE 7 (this study). These observations indicate a degree of spatial structure of the trevally population within the TRE 7 fishstock area that has not been accounted for in the previous assessments.

The previous stock assessment of TRE 7 included data to the 2008/09 fishing year (Langley & Maunder 2009) and the current TRE 7 stock assessment extends the model period to the end of the 2013/14 fishing year. The assessment includes a summary of the recent trends in the operation of the commercial fishery and an update of the standardised CPUE indices incorporated in the stock assessment model. The assessment was conducted under the Ministry for Primary Industries (MPI) research project TRE2013-02. The principal objective of the project is "to conduct a stock assessment, including estimating biomass and sustainable yields for trevally in TRE 7".

2. FISHERY CHARACTERISATION

2.1 Characterisation data set

The characterisation of the TRE 7 fishery was based on an extract of commercial catch and effort data that included all fishing trips that landed TRE 7 and/or conducted fishing from within the statistical areas that approximate the TRE 7 fishstock area (Statistical Areas 017 and 032–048) from 1989/90–2012/13. Prior to 1995/96, most of the TRE 7 catch was reported in Catch Effort Landing Return (CELR) format which records aggregated catch and effort data typically summarising the daily fishing activity and catch for a vessel (Figure 2). From 1995/96, most of the catch was reported in either the Trawl Catch Effort Processing Return (TCEPR) or Trawl Catch Effort Return (TCER) formats which record the details of individual fishing events (trawls).

To derive the characterisation data set, the catch and effort records were processed following the approach of Langley (2014). This approach amalgamates records from the event based reporting formats (primarily TCEPR and TCER formats) in a manner that approximates the daily aggregate format of the CELR reporting format. Landed catches of trevally were apportioned to the aggregated fishing effort records based on the distribution of estimated catches of trevally.

The individual fishing event data (TCEPR and TCER data) include detailed information regarding the operation of the fishery, including fishing location, time of day, fishing depth, and trawl speed. These data were utilised to investigate trends in the operation of the main TRE 7 trawl fishery.

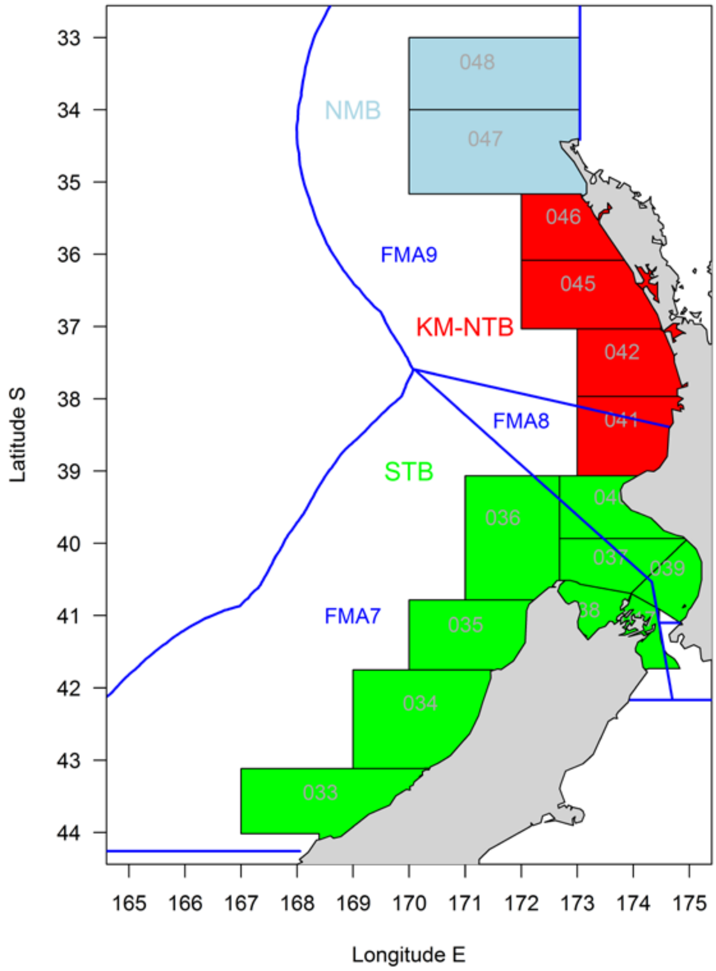


Figure 1: Definition of the three sub-areas of TRE 7 based on Statistical Areas. The Fishery Management Area boundaries are also shown (blue lines).

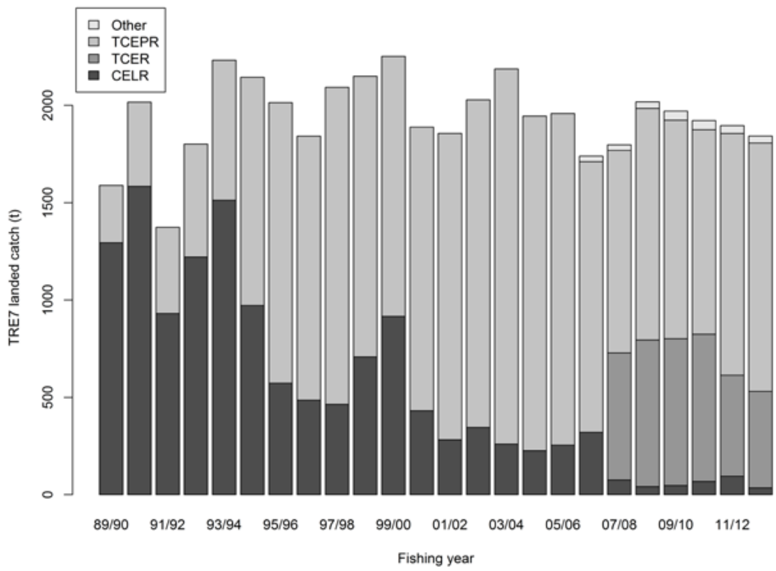


Figure 2: Annual landed TRE 7 catch by reporting form type.

2.2 Characterisation of the TRE 7 fisheries

Since 1989–90, most of the annual TRE7 catch has been taken by single bottom trawl (Table 1). The remainder of the catch was predominantly taken by bottom pair trawl which typically accounted for 20–30% of the annual catch during 1989/90–2010/11, but this fishery did not operate in 2011/12 or 2012/13. The set net fishery accounted for a small proportion of the annual catch (2–7%) and since 2000/01 catches by the set net method have been relatively low (Table 1).

Catches of trevally by the trawl methods (single and pair trawl) were mostly from trawls targeting trevally or snapper, particularly prior to 1998–99 (Table 2, Figure 3 and Figure 4). Trevally is also a bycatch of the red gurnard target single trawl fishery. The barracouta trawl fishery, operating in the southern area of TRE 7, has also accounted for a small and declining proportion of the trevally catch (Figure 3). In recent years, the TRE 7 catch has been increasingly dominated by the target single trawl fishery (Table 2 and Figure 4).

There is considerable overlap in the spatial distribution of trevally catch from the main trawl fisheries with most of the catch taken from the inshore area between Cape Taranaki and Cape Reinga (Figure 5). The red gurnard trawl fishery also extends southward to encompass the South Taranaki Bight. The trevally bycatch from the rig set net fishery is mainly taken in the North and South Taranaki Bights.

Trawl catch rates of trevally tend to increase during November–January and are generally highest north of the Kaipara Harbour (Figure 6). During spring–summer the spatial distribution of the higher catch rates extends southwards to include the North Taranaki Bight and around Cape Taranaki. Catch rates are low during April–October (Figure 6).

Most of the trevally trawl catch is taken from the 25–75 m depth range for the main target fisheries (Figure 7), although trevally catches from the barracouta trawl fishery (included in the “other” category) also extend to deeper water.

Fishing vessels tend to trawl faster when targeting trevally compared to targeting red gurnard and snapper, although there is considerable overlap in the distribution of trawl speed for snapper and trevally target trawls (Figure 8). Average trawl speed among target fisheries has diverged over time especially since 2006/07 which may indicate more selective fishing for the preferred target species (Figure 9).

An analysis of the degree of targeting suggests although there has been an increase in effort targeting trevally, there has been little change in the degree to which those tows fish prime month/location combinations for trevally (Figure 10). These recent trends in the operation of the trawl fishery were increasingly dominated by a single vessel in the main target trevally trawl fishery. In recent years, the number of trawl vessels operating in the fishery has declined and a substantial proportion of the total trevally catch has been taken by this vessel (see Section 3).

Table 1: Distribution of landed trevally from TRE 7 by method and by fishing year in tonnes and in percent of annual landings. Catches are raised to the annual QMR catch; 0 = less than 0.5 t. Percentages sum to 100 by year. BT; bottom trawl, BPT; bottom pair trawl, SN; setnet, PS; Purse seine, RN; Ring net.

Fishing	Fishing method (t)						Fishing method (%)					
year	BT	BPT	SN	PS	RN	Other	BT	BPT	SN	PS	RN	Other
89/90	1 278	467	74	17	2	1	65	29	5	1	0	0
90/91	1 101	851	60	0	3	1	55	42	3	0	0	0
91/92	960	308	94	-	3	10	70	22	7	-	0	1
92/93	1 284	202	121	169	11	15	71	11	7	9	1	1
93/94	1 582	523	96	0	8	23	71	23	4	0	0	1
94/95	1 682	240	131	67	13	12	78	11	6	3	1	1
95/96	1 321	539	111	21	4	18	66	27	6	1	0	1
96/97	1 653	55	118	0	3	12	90	3	6	0	0	1
97/98	1 923	32	122	-	10	7	92	2	6	-	1	0
98/99	1 740	281	97	0	13	18	81	13	5	0	1	1
99/00	1 712	349	75	85	10	20	76	16	3	4	0	1
00/01	1 347	456	55	0	9	22	71	24	3	0	1	1
01/02	1 445	281	59	-	5	66	78	15	3	-	0	4
02/03	1 498	428	43	35	5	19	74	21	2	2	0	1
03/04	1 620	471	46	-	7	43	74	22	2	-	0	2
04/05	1 330	547	56	-	8	4	68	28	3	-	0	0
05/06	1 534	367	40	0	11	5	78	19	2	0	1	0
06/07	1 529	138	56	-	12	4	88	8	3	-	1	0
07/08	1 348	339	49	-	9	53	75	19	3	-	1	3
08/09	1 637	314	47	-	12	9	81	16	2	-	1	1
09/10	1 531	334	70	-	10	27	78	17	4	-	1	1
10/11	1 430	375	65	25	18	8	74	20	3	1	1	0
11/12	1 737	0	56	52	24	27	92	0	3	3	1	1
12/13	1 760	-	52	-	12	18	96	-	3	-	1	1

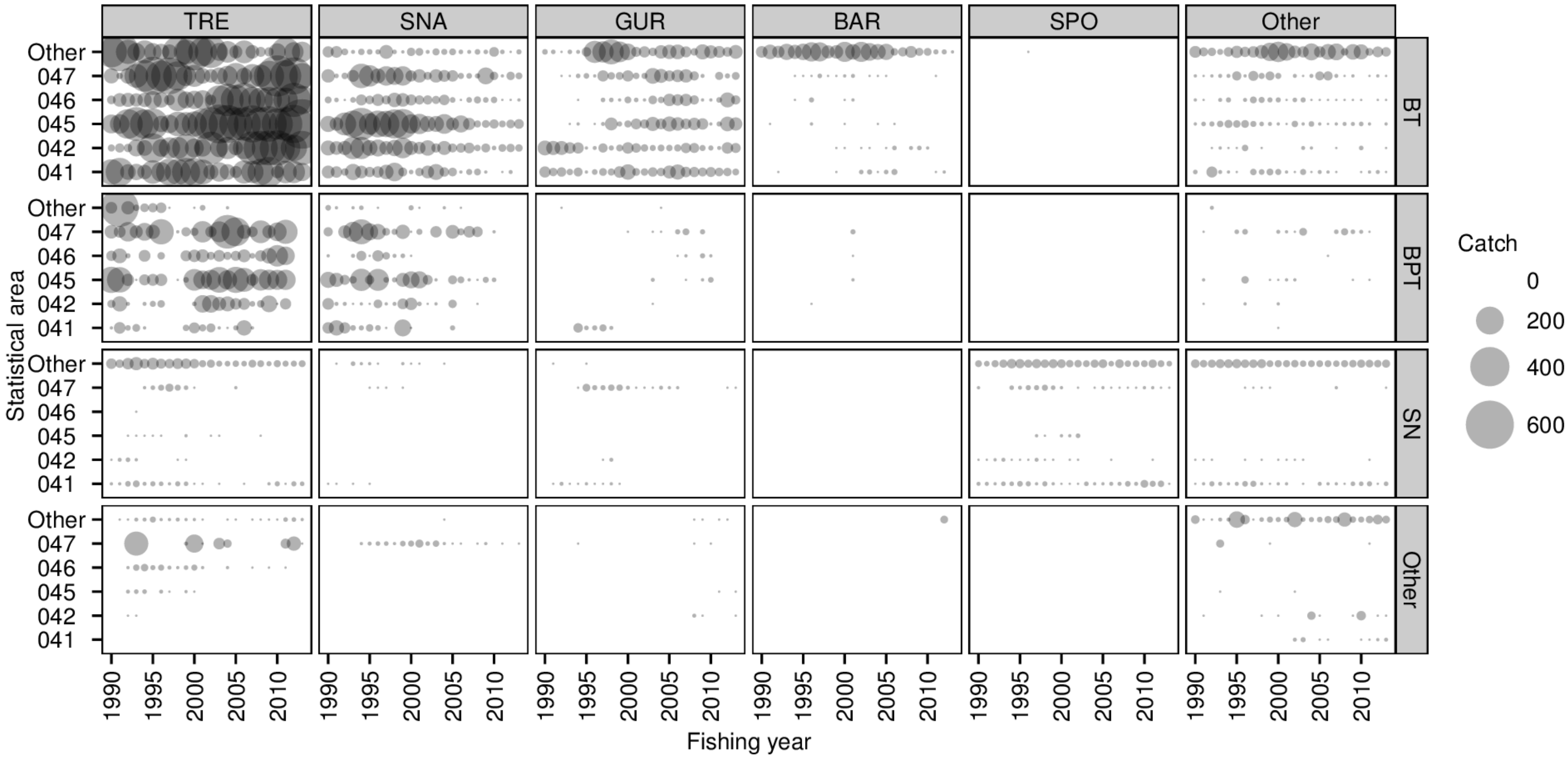


Figure 3: Catch (t) by method, target, and area for each fishing year, 1989–90 to 2012–13.

Table 2: Distribution of landed trevally from TRE 7 by activity (fishing method.target species) and by fishing year in tonnes and in percent of annual landings. Catches are raised to the annual QMR catch (Table 1); 0 = less than 0.5 t. Percentages sum to 100 by year

Fishing year	Fishing activity (t)						Fishing activity (%)					
	BT. TRE	BT. SNA	BPT TRE	BT. GUR	BPT. SNA	Other	BT. TRE	BT. SNA	BPT. TRE	BT. GUR	BPT. SNA	Other
89/90	596	252	302	95	165	178	38	16	19	6	10	11
90/91	772	172	729	73	116	154	38	9	36	4	6	8
91/92	567	221	198	75	105	208	41	16	14	5	8	15
92/93	705	427	70	52	131	416	39	24	4	3	7	23
93/94	782	628	171	65	328	258	35	28	8	3	15	12
94/95	1 147	352	116	36	113	380	53	16	5	2	5	18
95/96	625	390	260	141	247	352	31	19	13	7	12	17
96/97	824	446	1	194	41	335	45	24	0	11	2	18
97/98	1 042	515	4	240	24	268	50	25	0	11	1	13
98/99	876	504	71	179	209	310	41	23	3	8	10	14
99/00	1 019	229	214	219	124	447	45	10	10	10	5	20
00/01	843	242	348	107	91	257	45	13	18	6	5	14
01/02	966	211	251	96	26	306	52	11	14	5	1	16
02/03	947	226	369	182	38	266	47	11	18	9	2	13
03/04	1 056	244	465	162	2	258	48	11	21	7	0	12
04/05	825	133	455	234	92	207	42	7	23	12	5	11
05/06	1 056	114	333	244	26	185	54	6	17	12	1	9
06/07	1 132	95	79	196	36	201	65	5	5	11	2	12
07/08	1 078	61	296	149	29	185	60	3	16	8	2	10
08/09	1 299	121	283	127	9	179	64	6	14	6	0	9
09/10	1 282	77	312	81	7	211	65	4	16	4	0	11
10/11	1 272	37	373	90	0	151	66	2	19	5	0	8
11/12	1 435	60	-	194	0	206	76	3	-	10	0	11
12/13	1 502	58	-	166	-	116	82	3	-	9	-	6

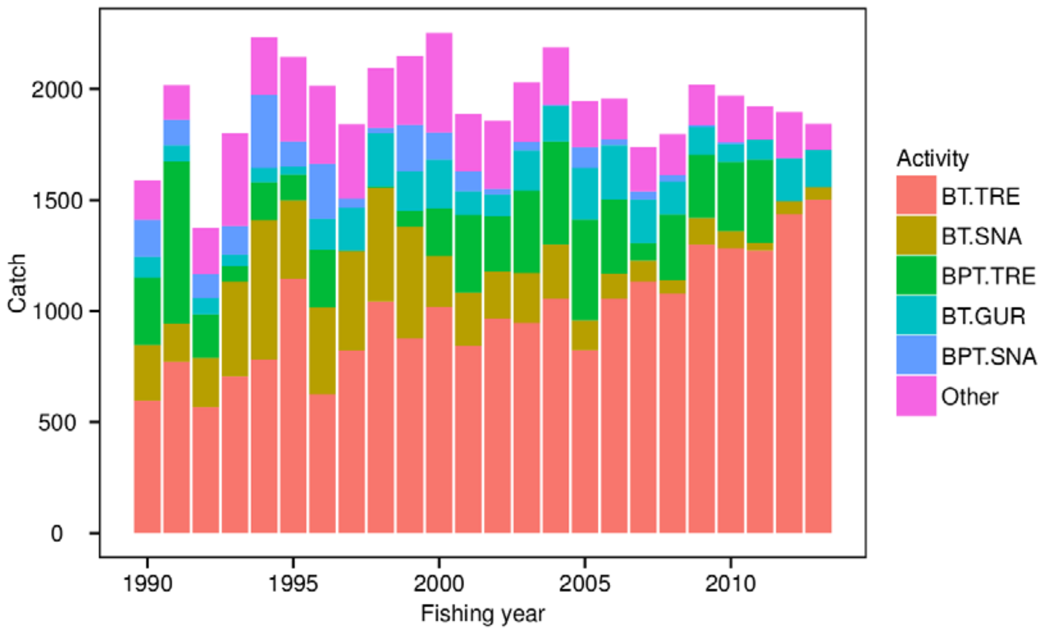


Figure 4: Catch (t) by activity for each fishing year, 1989/90 to 2012/13. The fishing year represents the year at 1 January (e.g. 1990 represents the 1989/90 fishing year).

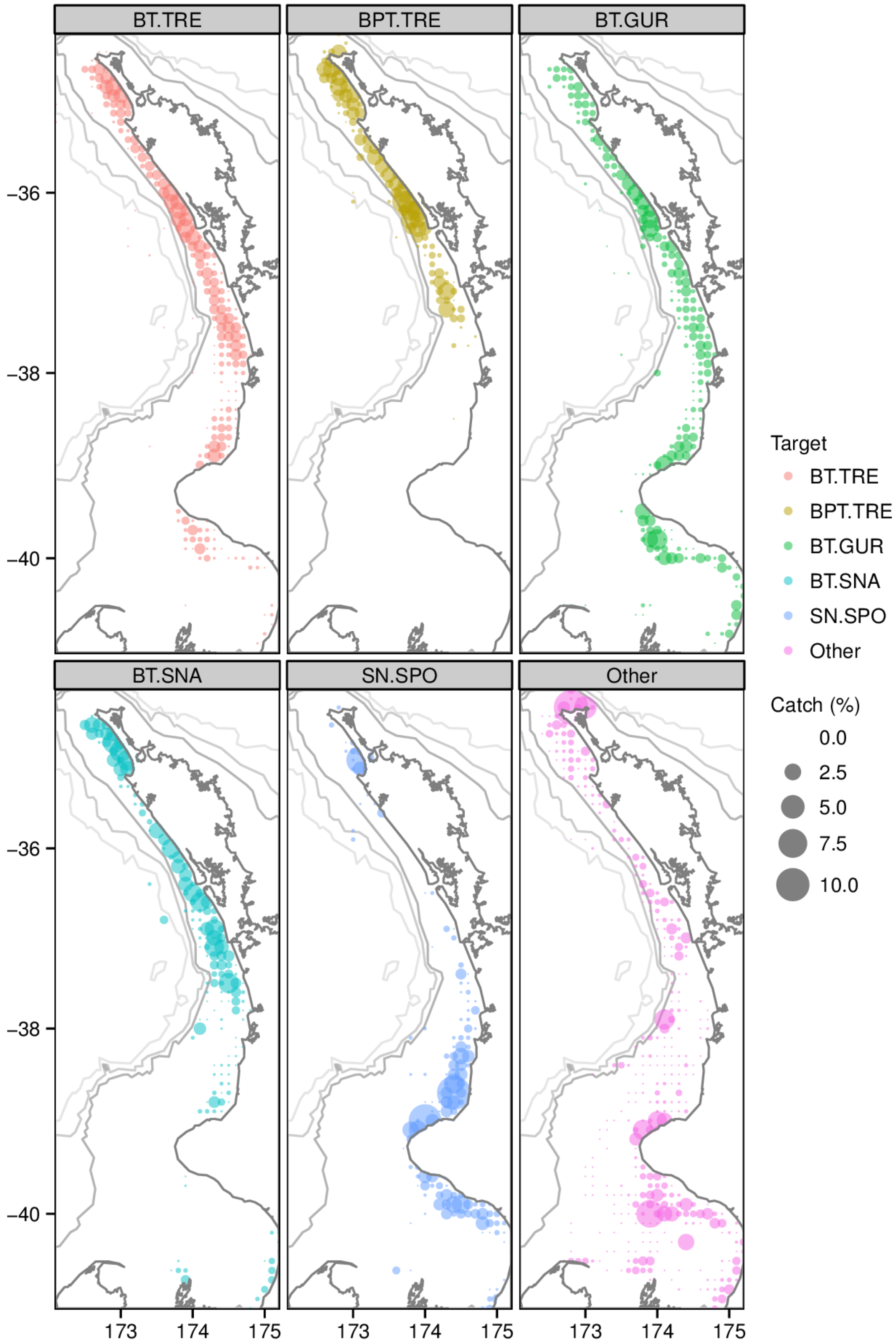


Figure 5: Percentage of catch by 0.1 degree of latitude/longitude for the top five method/target species combinations for the years 2007/08 to 2012/13 (TCEPR, TCE and NCE returns only).

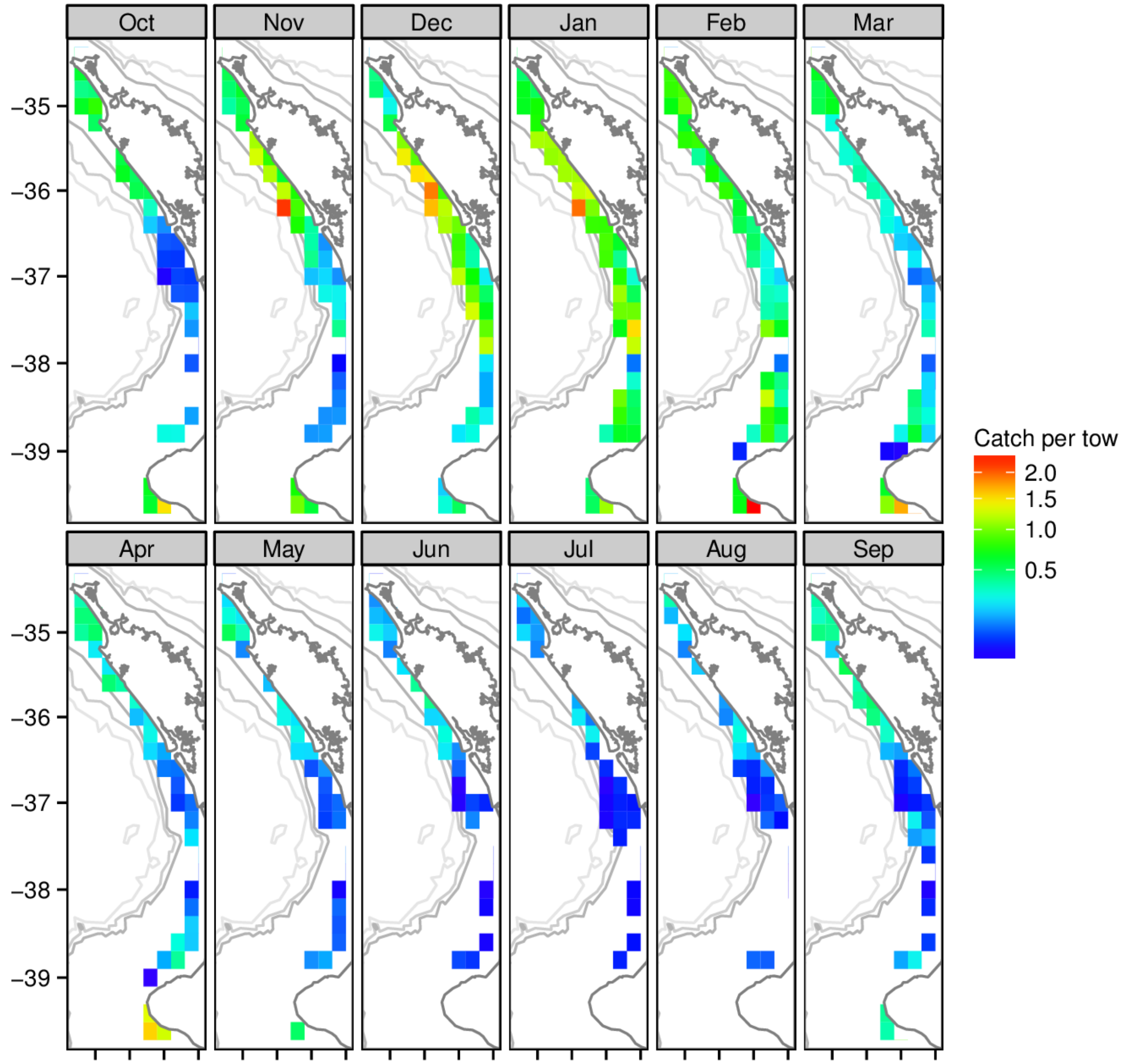


Figure 6: Mean trevally CPUE (tonnes per tow) for bottom trawling targeted at trevally, snapper or gurnard by month and 0.2 degree latitude/longitude cell (TCER and TCEPR forms only, for years 1989/90 to 2012/13).

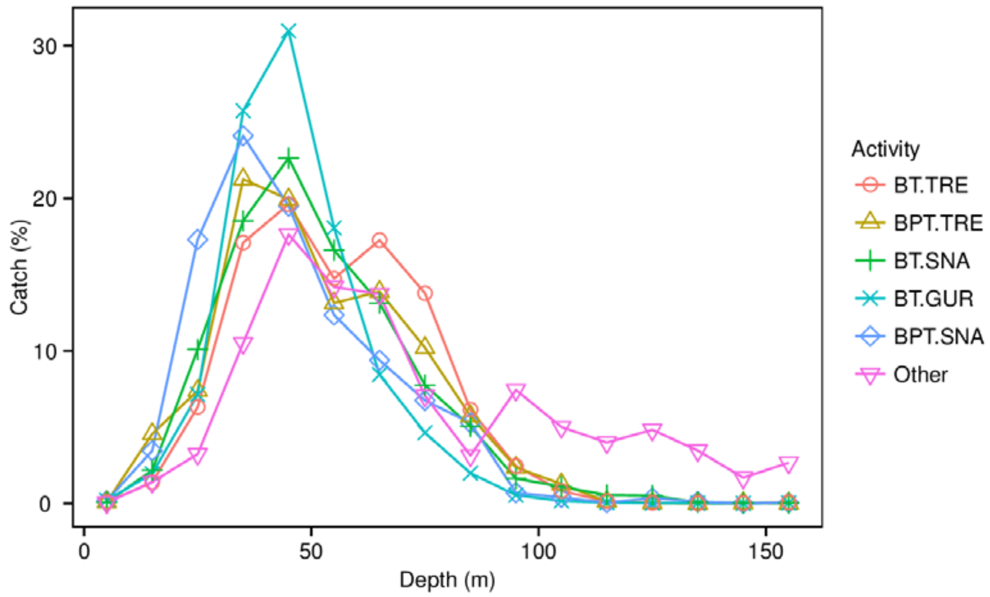


Figure 7: Percentage of catch by depth for each activity (method/target), 1989/90 to 2012/13. Depths are binned by 10 m. The point at 155 m represents all depths greater than or equal to 150 m.

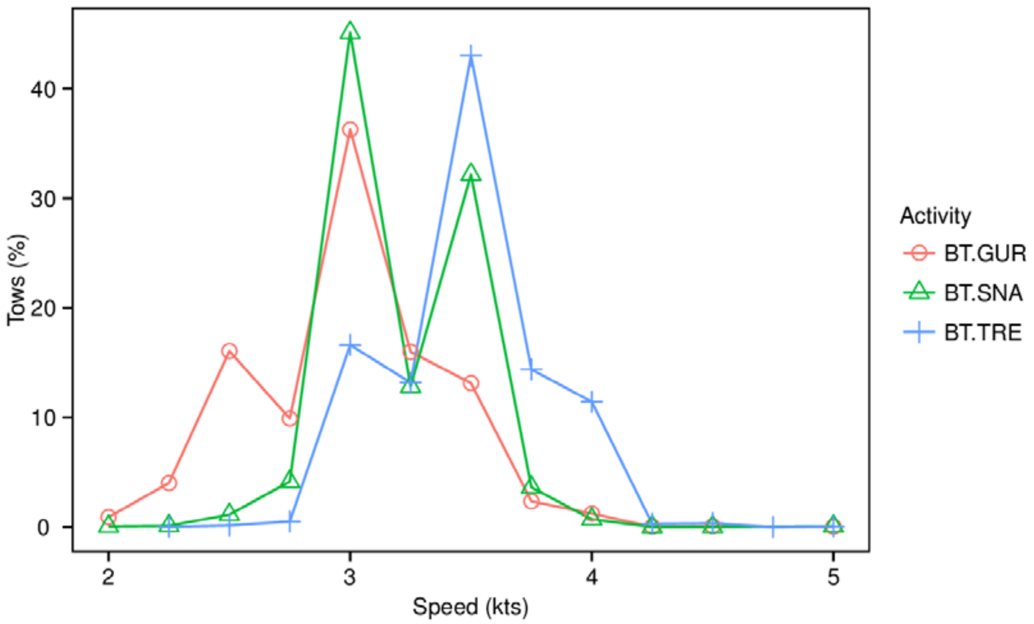


Figure 8: Percentage of tows by speed for bottom trawl targeting trevally, snapper or gurnard, 1989/90 to 2012/13. Speeds are binned by 0.25 knots with 2 knots and 5 knots as 'plus' bins.

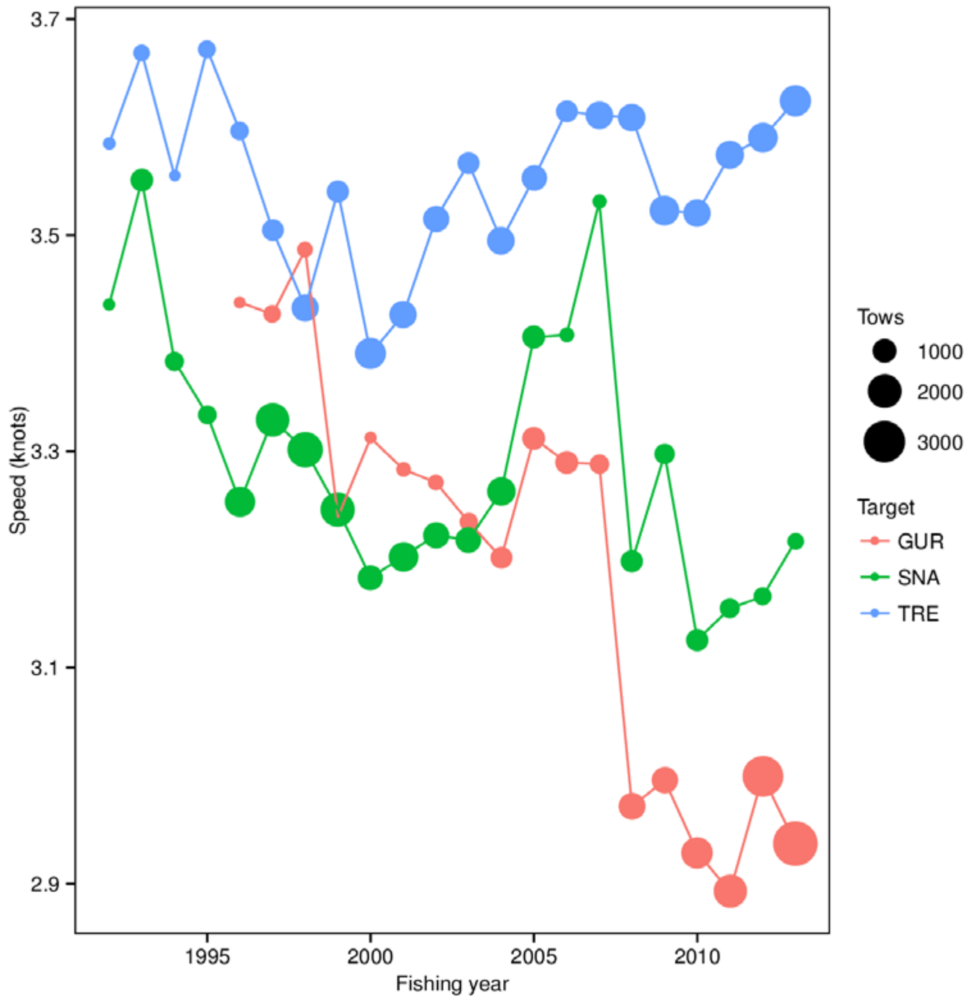


Figure 9: Mean speed of tow and number of tows for bottom trawling targeting trevally, snapper or gurnard (TCER and TCEPR forms only). The area of the symbol is proportional to the number of trawls. The fishing year represents the year at 1 January (e.g. 1990 represents the 1989/90 fishing year).

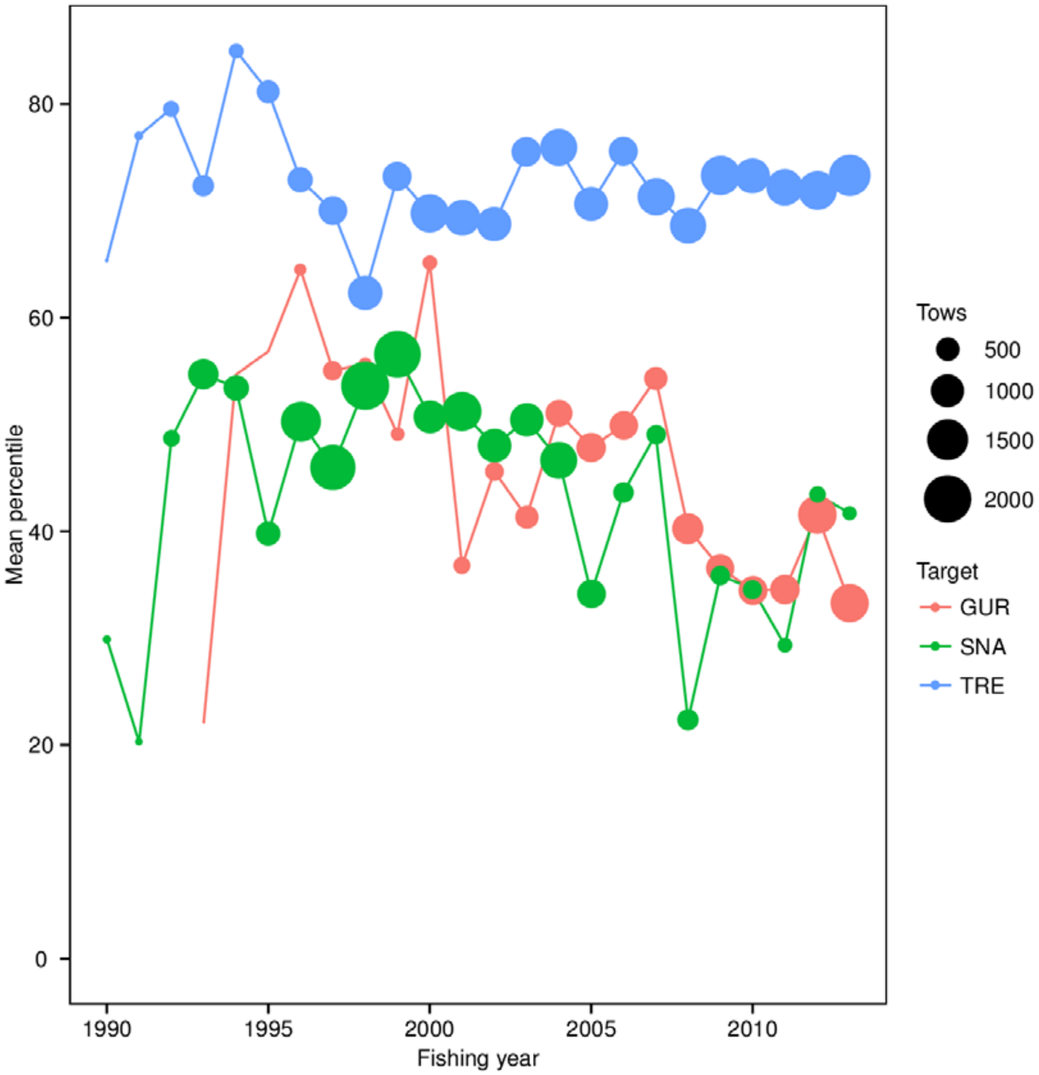


Figure 10: Mean expected catch rate percentile of bottom trawling tows targeting trevally, snapper or gurnard (TCER and TCEPR forms only). The distribution of the mean catch of trevally per tow by month and location was calculated across all years. The mean percentile, on the y-axis of this plot, is the mean percentile with respect to this distribution of tows conducted in each year, for each target species. The fishing year represents the year at 1 January (e.g. 1990 represents the 1989/90 fishing year).

3. STANDARDISED CPUE ANALYSES

The catch and effort data set configured for the TRE 7 fishery characterisation was used to conduct a standardised CPUE analysis for 1989/90–2012/13. Based on the fishery characterisation, the CPUE analysis was limited to single bottom trawl (BT) records that specified trevally (TRE) or snapper (SNA) as the target species. The data set included catch and effort records from the three data reporting formats: CELR, TCEPR and TCER. The effort records from the two latter formats were summarised to approximate the daily aggregate CELR format (following Langley 2014).

Initial CPUE modelling was conducted for the entire TRE 7 fishstock. However, as the preliminary stock assessment modelling progressed, the CPUE analyses were increasingly focussed on the KM-NTB sub area. The final stock assessment models only included the CPUE indices for this sub area of TRE 7 and, hence, considerably more detail is provided for the KM-NTB CPUE analysis in the following sections.

3.1 TRE 7 CPUE analysis

A generalised linear modelling (GLM) approach was applied to calculate standardised CPUE indices for TRE 7 from the daily aggregated catch and effort data set. The data set was limited to a set of core vessels that had fished for at least five trips in at least four years (representing a core fleet of 35 vessels, accounting for 94% of the trevally catch).

Separate models were formulated for the magnitude of the non zero trevally catch and the presence/absence of trevally in the daily vessel catch. A binomial distribution was assumed for the presence/absence model and a lognormal distribution was assumed for the positive catch model. The potential explanatory variables provided to the two models were: the categoric variables FishingYear, Target, Month, StatArea and Vessel, the interaction between StatArea and Month, and the natural logarithm of fishing duration.

The formulation of the two CPUE models was extended to include interaction terms to accommodate potential differences in the seasonal (Month:SubArea) and annual (Year:SubArea) trends among the three sub-areas. For each sub-area, annual CPUE indices were derived from corresponding coefficients from the Year:SubArea interaction term. Combined indices were determined by multiplying the corresponding lognormal and binomial CPUE indices.

The trends in the lognormal and combined CPUE indices differed considerably among the three sub-areas (Figure 11). For the KM-NTB sub-area, the lognormal and combined indices declined during the initial years, remained relatively stable during the mid–late 1990s and fluctuated with an increasing trend from 2000/01 onwards.

The lognormal CPUE indices for the NMB sub-area tended to increase during the early 1990s and then fluctuated throughout the remaining period (Figure 11). The Combined indices for NMB were comparable to the lognormal indices prior to 2001/02 but were considerably higher during 2008/09–2012/13 (Figure 11).

For the STB sub-area, the CPUE indices for 1989/90 and 1990/91 are considerably higher than the two subsequent years. The STB indices varied considerably during the remainder of the period, with relatively high CPUE during 1996/97–2000/01 and relatively low indices during 2002/03–2007/08 (Figure 11). Insufficient data were available to derive a binomial STB index for 2013.

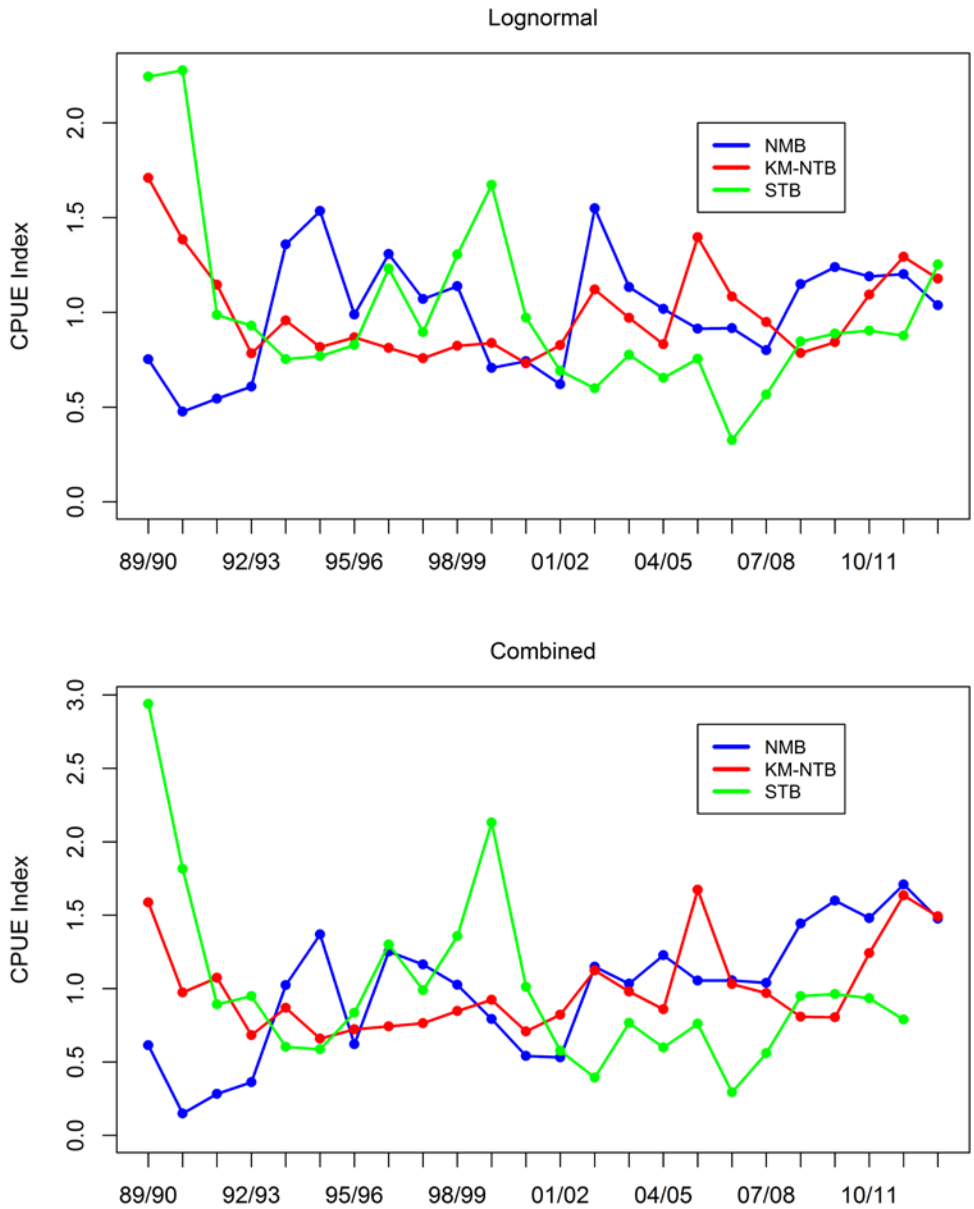


Figure 11: A comparison of the lognormal (top panel) and combined (bottom panel) standardised CPUE indices derived for the bottom trawl (BT) fishery in each of the three sub-areas.

3.2 KM-NTB sub-area CPUE analysis

The SNA/TRE target single trawl fishery accounted for about 70–80% of the annual trevally catch from the KM-NTB sub-area during 1989/90–2012/13 (Figure 12).

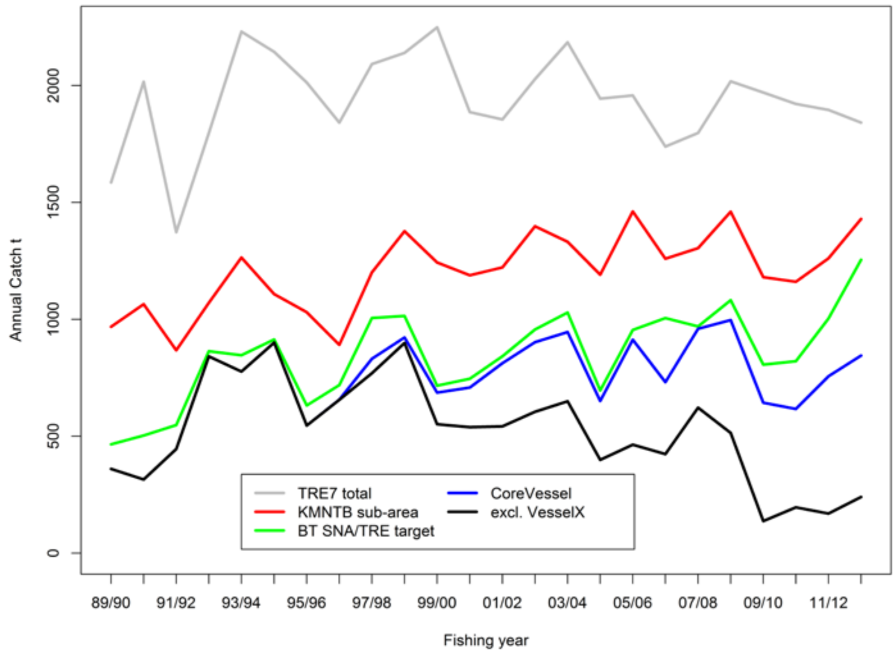


Figure 12: Annual trevally catch included within the catch and effort data subsets configured during the development of the KM-NTB CPUE analysis.

An initial set of core vessels was defined based on a minimum selection criteria of at least 20 trawls in a minimum of 5 years. For most years, the initial set of core vessels accounted for at least 80% of the annual catch from the single trawl SNA/TRE target fishery within the KM-NTB area (Figure 12). During 1989/90–2005/06 there were typically 15–20 core vessels operating in the fishery each year and many of these vessels operated in the fishery throughout that period (Figure 13). In the subsequent years, there was a considerable rationalisation of the fleet and from 2009/10 there were only 4–6 core vessels operating in the fishery. Further, since 1999/2000 the annual catch by the core fleet has been increasingly dominated by a single vessel (vessel key GJLKK denoted VesselX) to the extent that this vessel accounted for about 70% of the annual core vessel catch during 2009/10–2012/13 (Figure 12 and Figure 13).

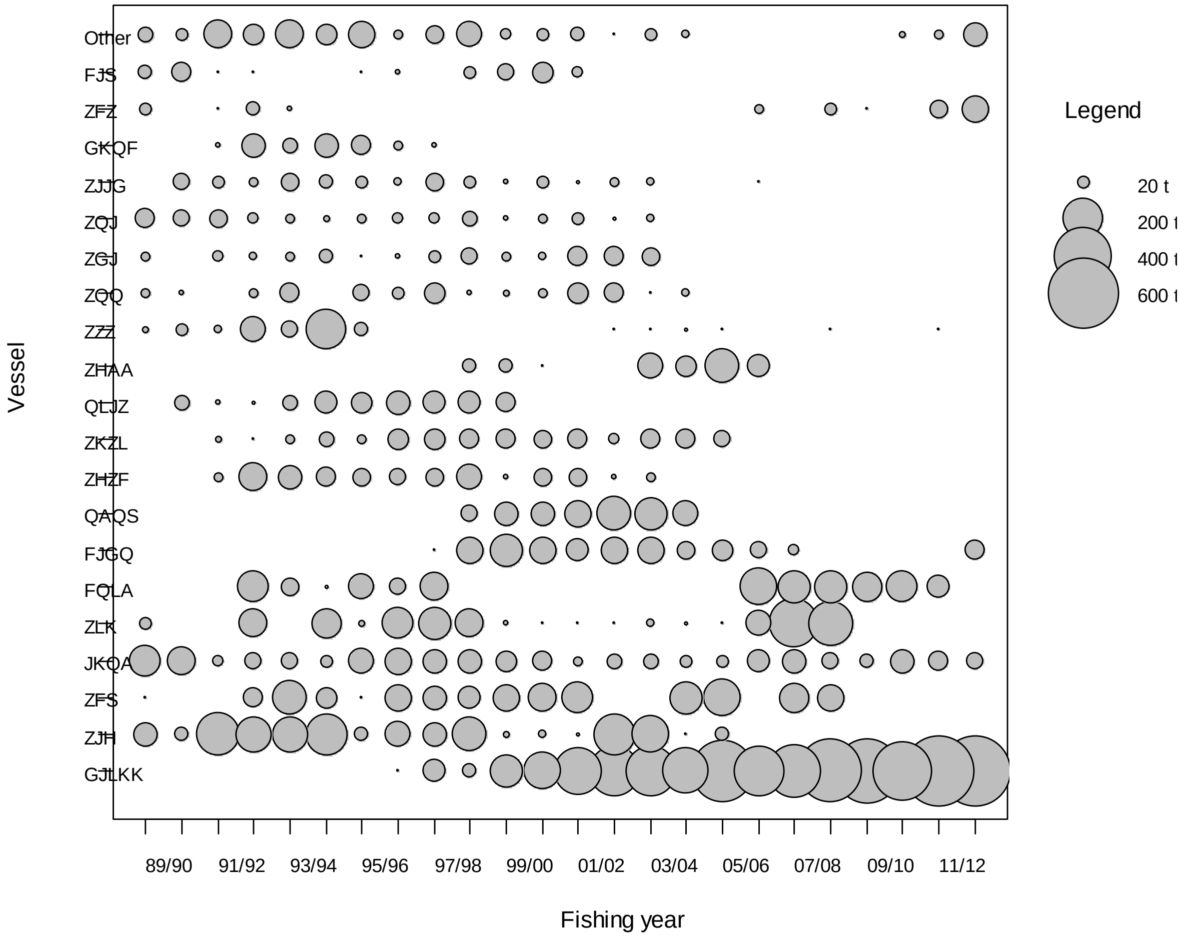


Figure 13: Distribution of annual trevally catch from the KM-NTB SNA/TRE target single trawl fishery by individual vessels included within the initial core vessel set.

The standardised CPUE analysis used a generalised linear modelling (GLM) approach to model the magnitude of the non zero trevally catch and the presence/absence of trevally catch. Preliminary modelling of the magnitude of the non zero catches indicated that the data were more consistent with the Weibull distribution than the other distributional assumptions investigated (lognormal, gamma, log-logistic). The presence/absence of trevally in the reported catch was modelled using a binomial error structure.

For both CPUE models, the potential explanatory variables included the categorical variables FishingYear, StatArea, Month and Vessel and the continuous variable NumTrawl (the natural logarithm of the number of trawls) and trawl duration (Table 3). An interaction term StatArea:Month was offered to the CPUE models to account for seasonal variability in CPUE amongst the Statistical Areas. The models were fitted using a step-wise fitting procedure based on the Akaike Information Criterion (AIC). Terms were only added to the model if they increased the percent deviance explained by 0.5 %. The annual indices derived from each component model were multiplied to derive a Combined CPUE index. The confidence intervals for the Combined indices were derived using a bootstrapping procedure.

Table 3: The variables included in the KM-NTB sub-area CPUE data set.

Variable	Definition	Data type	Range
Vessel	Fishing vessel category	Categoric (26)	
FishingYear	Fishing year	Categoric (24)	
Month	Month	Categoric (12)	1–12
StatArea	Statistical Area fished in fishing day	Categoric (3)	041, 042, 045,046
TargetSpecies	Main species targeted in fishing day	Categoric (2)	TRE, SNA
NumTrawl	Number of trawls conducted	Continuous	1–7
Duration	Total duration of trawling (hrs)	Continuous	1–24
TREcatch	TRE catch (kg)	Continuous	< 50 000

The CPUE modelling approach was initially applied to two data sets: a) the complete core vessel data set and b) a subset of the core vessel data set that excluded VesselX. There were a number of reasons for configuring a CPUE model that excluded VesselX:

- Initial assessment models were configured based on the KM-NTB CPUE indices derived from the entire core vessel data set. These indices increased substantially from 2008/09 to 2012/13. An examination of the resultant model fits highlighted considerable conflict between the CPUE indices and the fishery age composition data from the more recent years.
- An examination of the unstandardized catch and effort data revealed that from 2008/09 onwards there was an increase in the proportion of the total fishing effort occurring in the locations where trevally catch rates were highest, suggesting an increase in the extent of the fishing effort targeting trevally during this period. Most of the increase in target fishing behaviour was attributable to VesselX.
- From 2008/09, there was a southern extension of the area of high trevally catch rates indicating a change in the spatial operation of the target trevally fishery.
- Discussions with the manager of VesselX revealed that one of the most experienced skippers in the fishery has been operating the vessel over about the last five years. There was also a change in the vessel's trawl net in 2009/10; the net used in the latter period had a larger wingspread (14 m compared to 20 m) and lower headline height.
- A re-examination of the age composition data from the recent years suggested that VesselX was catching larger (and older) trevally than the other vessels in the fleet. This suggested that the selectivity for VesselX should be estimated separately from the other vessels in the fleet. Correspondingly, the CPUE indices should also exclude data from VesselX to ensure that the component of the vulnerable biomass monitored by the CPUE indices is consistent with the age-specific selectivity of the remainder of the fleet.
- The increase in the recent CPUE indices derived from the core vessel subset that excluded VesselX is considerably less than for the full entire core vessel data set (Figure 14). When incorporated in the preliminary assessment model, the resultant CPUE indices considerably reduced the magnitude of the conflict with the recent KM-NTB age composition data.

The CPUE indices derived for the KM-NTB area, including all vessels (Figure 14), differ somewhat from the KM-NTB sub-area derived from the composite TRE 7 CPUE models (see Figure 11). The main difference relates to the higher CPUE indices for 2002/03–2007/08 from the composite TRE 7 model. These differences may relate to the different core vessel selection criteria applied at the scale of TRE 7 rather than the KM-NTB sub-area or the differences in the model parameterisation for key variables at the different spatial scales. The KM-NTB indices from the sub-area model tended to be more consistent with the overall CPUE indices derived for TRE 7 in a previous study (Kendrick & Bentley 2010).

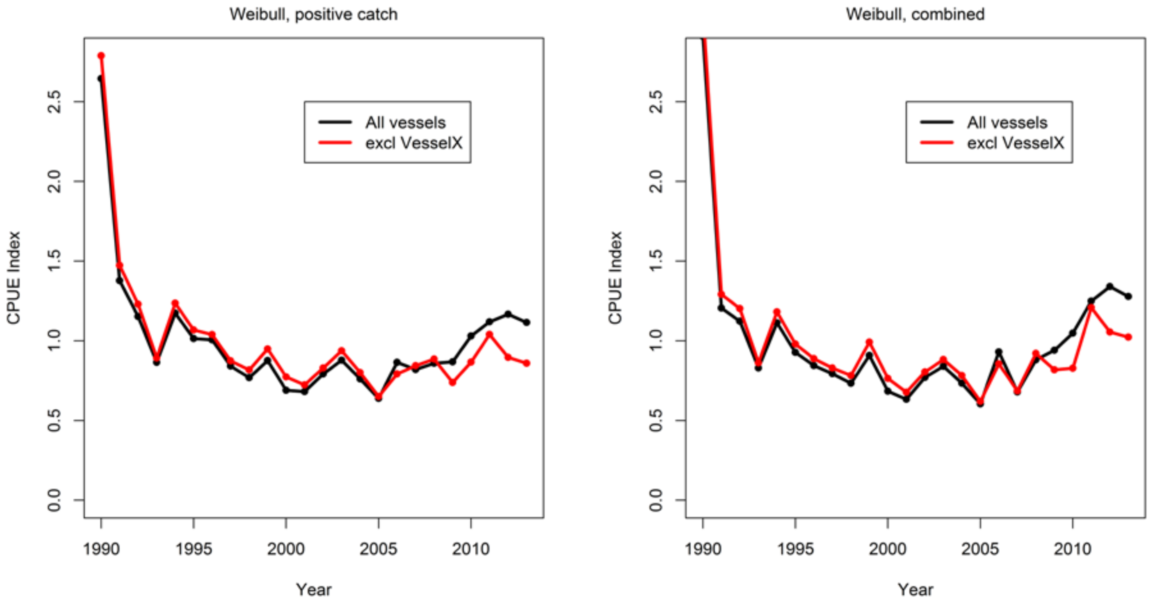


Figure 14: A comparison of the KM-NTB positive catch CPUE indices (left panel) and combined CPUE indices (right panel) based data sets including all vessels and excluding VesselX.

The final KM-NTB data set, excluding VesselX, includes a relatively small proportion of the total KM-NTB trevally catch from 2004/05 onwards, especially since 2009/10 (Table 4 and Figure 12). There was also a substantial decline in the proportion of days when no trevally was caught from 2005/06 onwards (Table 4).

For the positive catch CPUE model, the variables *Month*, *TargetSpecies* and *Vessel* account for a substantial proportion of the variation in trevally catch (Table 5). These three variables are strongly influential in the determination of the annual indices from the CPUE model. The unstandardized catch rates from the fishery reveal a strong increasing trend from 1996/97 to 2012/13, with unstandardized catch rates trebling during the period (Figure 15). The effect of the standardisation procedure is to remove most of the increase in CPUE during that period. Conversely, unstandardized catch rates of trevally were relatively constant from 1990/91 to 1996/97, while the resulting standardised CPUE indices declined during the same period.

Table 4: Summary of the daily aggregated catch and effort data set included in the final KM-NTB CPUE models (excluding data from VesselX).

Fishing year	Number records	Number vessels	Catch (t)	Number trawls	Duration (hr)	Percent zero catch
1989/90	344	13	360.4	849	2 378	11.9
1990/91	502	12	315.0	1 404	3 634	25.7
1991/92	867	16	445.4	1 969	5 244	23.4
1992/93	1 934	20	841.7	3 933	10 564	26.0
1993/94	1 294	18	776.7	3 254	8 828	24.3
1994/95	1 417	18	900.5	3 088	8 730	27.1
1995/96	1 694	21	545.7	2 802	8 367	34.1
1996/97	2 060	20	656.2	2 806	8 045	31.7
1997/98	2 529	20	769.6	3 396	9 828	28.1
1998/99	2 247	18	899.0	3 013	8 056	19.8
1999/00	1 623	17	551.3	1 993	6 057	26.2
2000/01	1 915	16	538.6	2 012	6 589	29.0
2001/02	1 600	14	542.5	1 662	5 503	23.9
2002/03	1 289	13	604.5	1 289	4 605	28.1
2003/04	1 641	14	649.6	1 641	5 742	26.3
2004/05	1 059	11	398.8	1 059	3 814	28.6
2005/06	632	8	463.7	632	2 046	10.8
2006/07	747	7	423.7	768	2 461	26.0
2007/08	952	5	622.3	952	3 097	18.9
2008/09	864	6	514.4	864	2 886	11.6
2009/10	187	3	137.0	187	661	9.6
2010/11	263	4	195.8	263	942	9.1
2011/12	279	5	169.2	279	918	3.2
2012/13	419	4	240.4	419	1 234	2.1

Table 5: Summary of stepwise selection of variables in the positive catch CPUE model (excluding VesselX). Model terms are listed in the order of acceptance to the model. AIC: Akaike Information Criterion; *: Term included in final model.

Term	**DF**	**Log likelihood**	**AIC**	**Nagelkerke pseudo-R^2**
FishingYear	23	-6 236	12 522	7.69 *
Month	11	-4 895	9 863	32.32 *
TargetSpecies	1	-3 909	7 893	48.56 *
Vessel	24	-3 327	6 776	57.46 *
poly(log(NumTrawls), 3)	3	-2 980	6 088	62.54 *
StatArea	3	-2 821	5 776	64.82 *
StatArea:Month	33	-2 623	5 447	67.59 *

The annual indices derived from the positive catch CPUE model are strongly influenced by a strong trend in the composition of the fishing fleet over the time-series shifting towards more efficient vessels from 1989/90 to 2009/10 (Figure 16). Similarly, there was a strong increase in the proportion of the trawls targeting trevally (TRE) as opposed to snapper from 2003/04 to 2012/13 (Figure 17) and an increase in the proportion of the effort in the months with higher catch rates of trevally (December-

February) (Figure 18). Collectively, these three factors had a strong moderating effect on the trend in the unstandardized trevally catch rates.

Relatively high catch rates were reported from 1989/90 and this resulted in the estimation of an exceptionally high annual index from the positive catch CPUE model (Figure 15). An examination of the data records from 1989/90 did not identify any marked differences in the distribution of the catch and effort data compared to the subsequent years. A possible explanation for the exceptionally high CPUE in 1989/90 was that the year represented the first year of implementation of the new CELR reporting forms and there may have been some transition in the reporting of catch and fishing effort during that period. The large decline in the CPUE indices between 1989/90 and 1990/91 is not consistent with the underlying stock dynamics of the species and, on that basis, the 1989/90 CPUE index was excluded from the stock assessment models.

Trevally was caught in a relatively high proportion (approximately 70–80%) of the fishing days included in the CPUE data set during 1990/91–2004/05 (Figure 15). From 2004/05, the proportion of positive catch records increased steadily and approached 100% in 2012/13. The binomial model of the presence/absence of trevally catch also included *Month*, *Vessel* and *TargetSpecies* as the main explanatory variables (Table 6), although the annual indices derived from the CPUE model were generally consistent with the unstandardized proportion of trevally catches (Figure 15).

Table 6: Summary of stepwise selection of variables in the binomial presence/absence CPUE model (excluding VesselX). Model terms are listed in the order of acceptance to the model. AIC: Akaike Information Criterion; *: Term included in final model.

Term	DF	Log likelihood	AIC	Nagelkerke pseudo-R^2
FishingYear	23	-15 478	31 004	4.05 *
Month	11	-14 406	28 882	14.56 *
Vessel	24	-13 348	26 813	24.20 *
TargetSpecies	1	-12 985	26 091	27.33 *
poly(log(NumTrawls), 3)	3	-12 922	25 970	27.87 *
StatArea	3	-12 877	25 886	28.25
StatArea:Month	33	-12 787	25 772	29.01

The Combined standardised CPUE indices generally decline from 1990/91 to 1999/2000, remain relatively stable during 1999/2000–2006/07 and then increase in the subsequent years, with relatively high indices for 2010/11–2012/13 (Figure 15). The trend in the Combined CPUE indices is generally consistent with the corresponding annual indices from the previous TRE 7 CPUE analysis (Kendrick & Bentley 2010) (Figure 15).

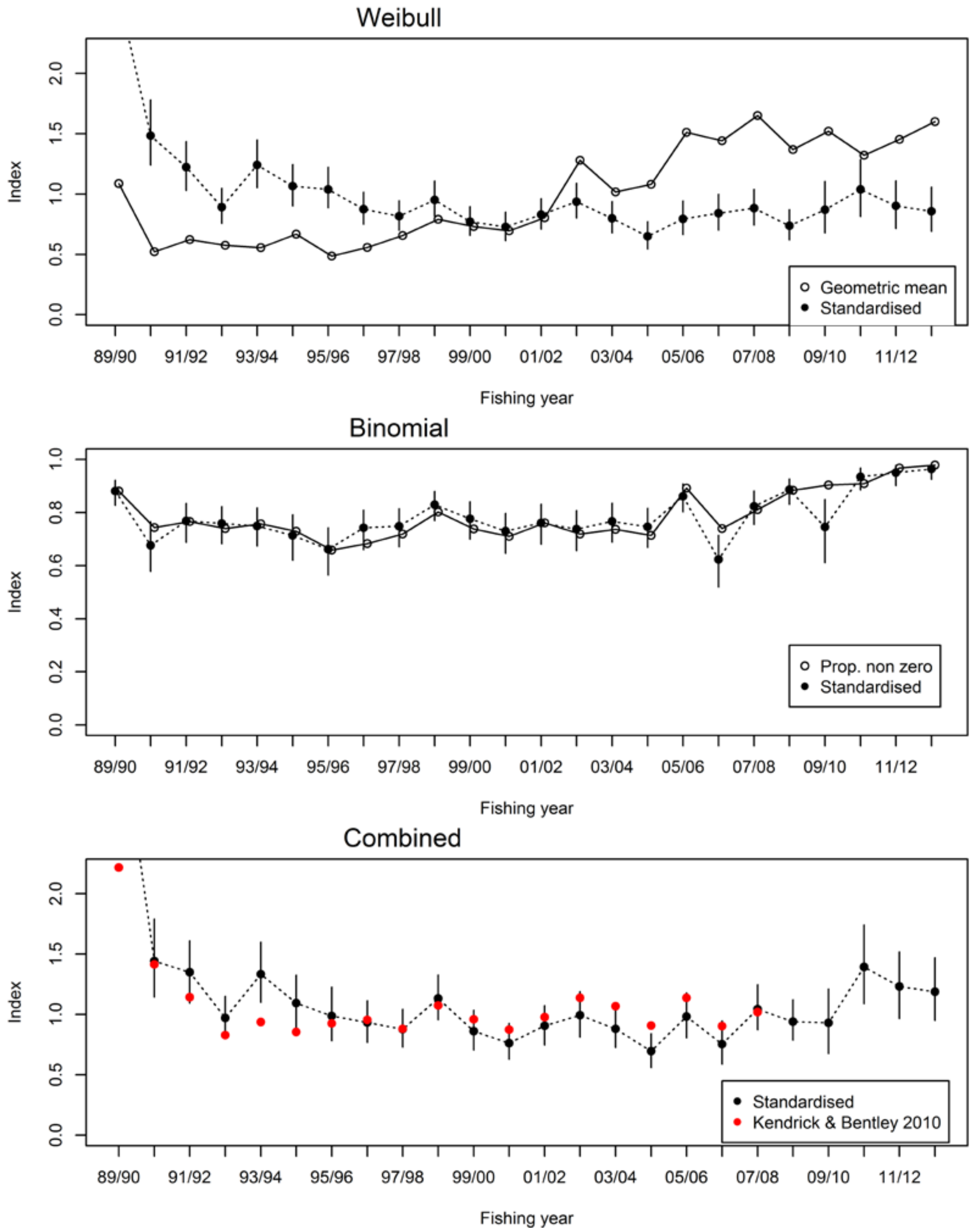


Figure 15: A comparison of the standardised CPUE indices (excluding VesselX) and the geometric mean of the positive catch per trawl (unstandardised) (top panel), a comparison of the binomial indices and the annual proportion of positive catch records in the data set (middle panel) and the combined index (bottom panel) . The error bars represent the 95% confidence intervals associated with each index.

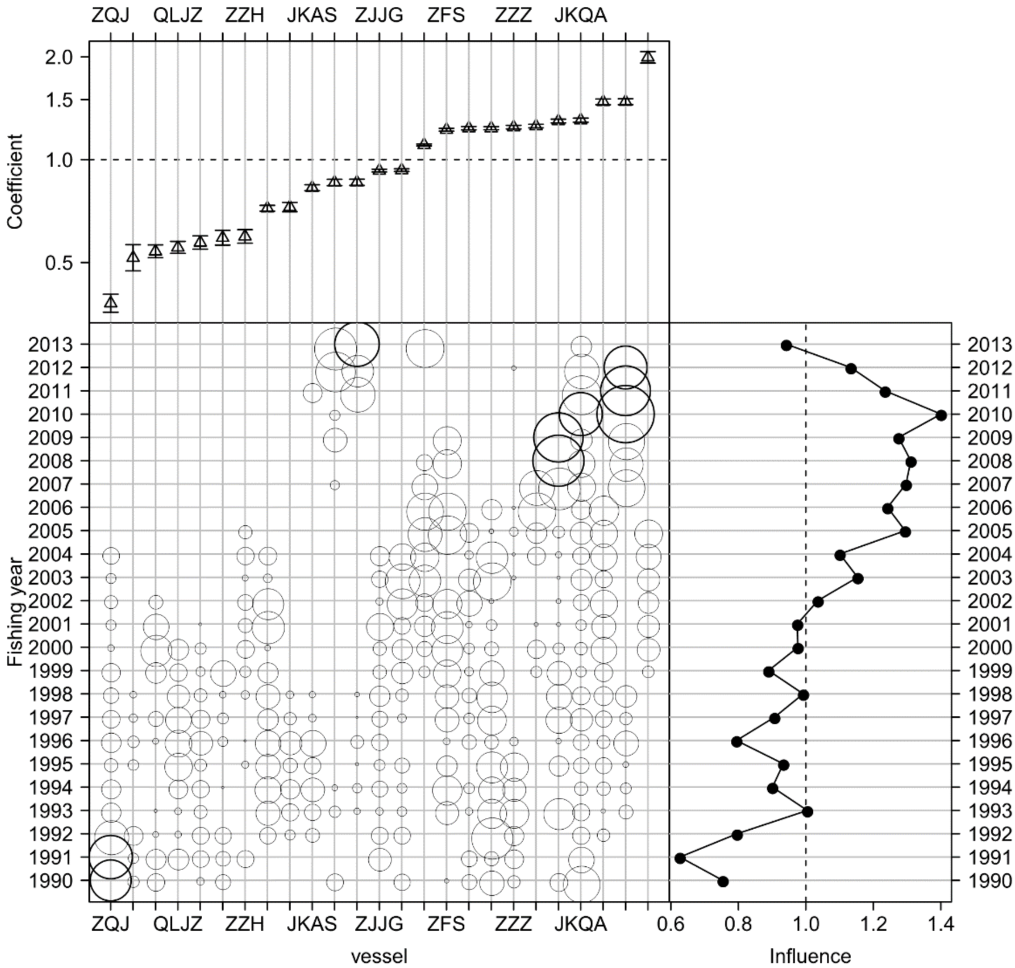


Figure 16: Coefficient-distribution-influence plot for the *Vessel* variable in the Weibull positive catch CPUE model (excluding VesselX). The fishing year is denoted by the calendar year for January-September (e.g. 1990 represents the 1989/90 fishing year).

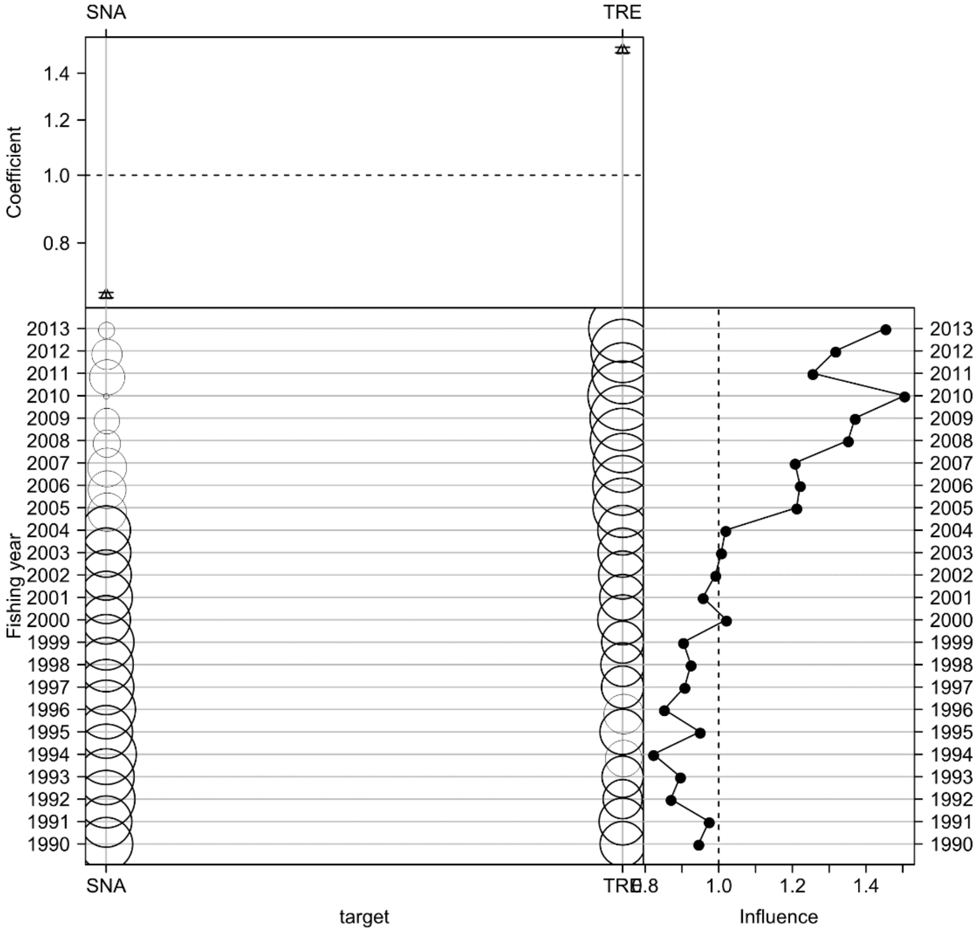


Figure 17: Coefficient-distribution-influence plot for the *TargetSpecies* variable in the Weibull positive catch CPUE model (excluding VesselX). The fishing year is denoted by the calendar year for January-September (e.g. 1990 represents the 1989/90 fishing year).

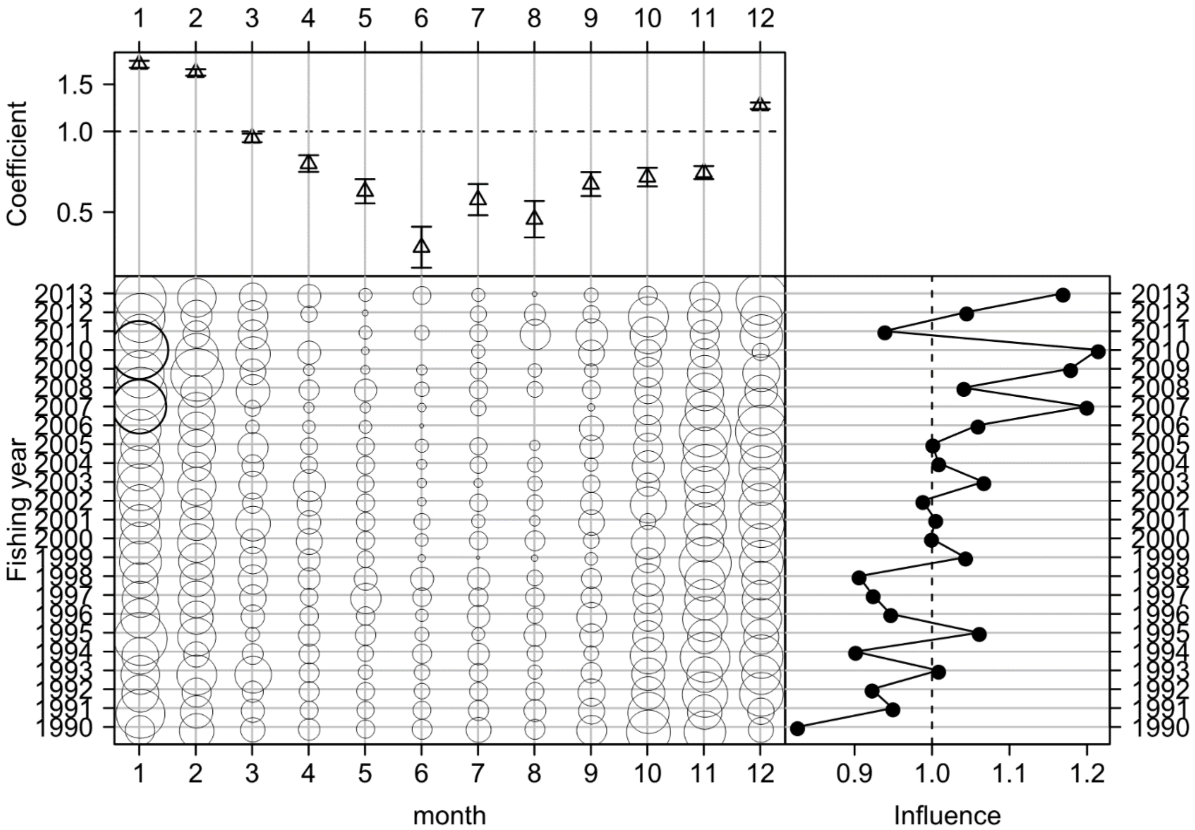


Figure 18: Coefficient-distribution-influence plot for the *Month* variable in the Weibull positive catch CPUE model (excluding VesselX). The fishing year is denoted by the calendar year for January-September (e.g. 1990 represents the 1989/90 fishing year).

The base Combined CPUE indices were compared to alternative CPUE indices derived from trawl based catch and effort records (TCEPR and TCER format). The trawl-based data set was configured using the same selection criteria as the base CPUE models and excluded records from VesselX. The CPUE models of the magnitude of the trevally catch and presence/absence of trevally catch included the additional potential explanatory variables trawl speed, fishing depth, start time, and location (latitude) of the trawl in addition to the fishing year, month, vessel and trawl duration. Two sets of trawl-based Combined CPUE indices were derived that either included or excluded the declared target species (TRE or SNA).

The trawl-based Combined CPUE indices derived from the standardised CPUE models that included the declared target species in the formulation are very similar to the base Combined CPUE indices (Figure 19).

The two sets of trawl-based CPUE indices (with and without target species) exhibit similar temporal trends, although the extent of the recent increase in CPUE indices is considerably higher for the model that excluded the target species variable (Figure 19). For the latter model, the parameterisation of several key variables, most notably trawl speed and month, accounted for some of the variance in catch rate associated with the declared target species.

These results indicate that the base CPUE indices are likely to be somewhat sensitive to the consistency in the declaration of target species (SNA or TRE) by the individual vessels operating in the fishery. A more thorough investigation of the partitioning of SNA and TRE target trawls should be conducted in future CPUE analyses.

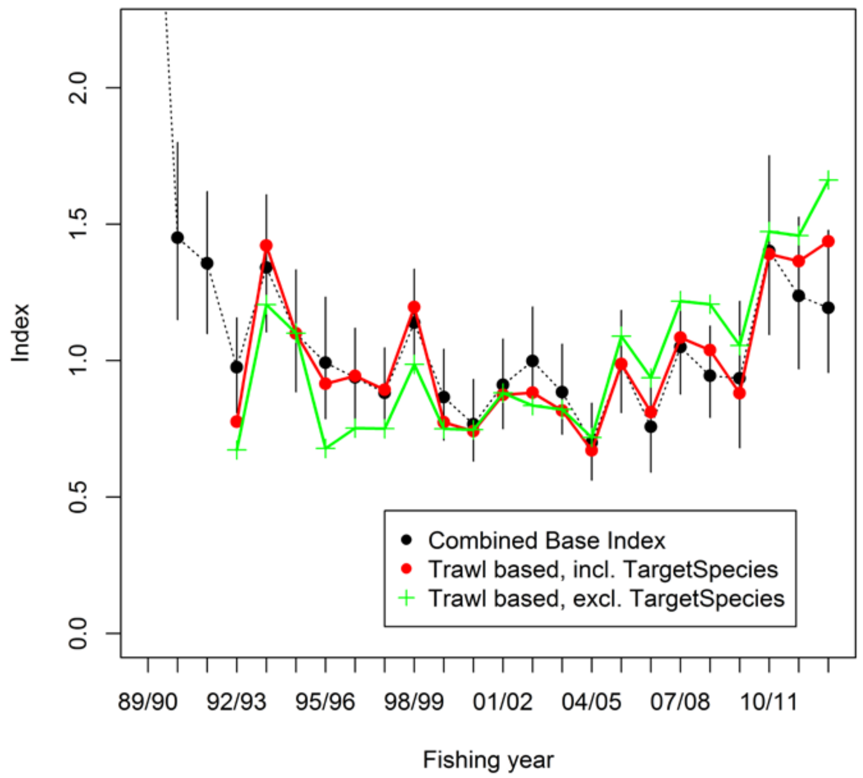


Figure 19: A comparison of annual CPUE indices for the KM-NTB (excluding VesselX) from the base CPUE analysis and the combined indices derived from the standardised CPUE analysis of individual trawl based data either including or excluding the declared target species.

4. STOCK ASSESSMENT DATA SETS

4.1 Overview

The analysis of recent catch sampling data from the TRE 7 commercial fishery has identified spatial variation in the age composition of the commercial catch, including some differences in the relative strength of individual year classes and differences in the proportion of older fish in the age composition (Walsh et al. 2014). These differences exist amongst three main sub-areas of the TRE 7 trawl fishery: Ninety Mile Beach (NMB), Kaipara-Manukau-North Taranaki Bight (KM-NTB) and South Taranaki Bight (STB) (Figure 1). These sub area definitions tend to correspond to the operational range of some of the main vessels operating in the fishery enabling the landing based sampling data to be assigned to a specific sub-area.

There are also differences in the recent CPUE trends from the trawl fisheries in the three sub-areas that may indicate different trends in stock abundance among the areas.

The spatial heterogeneity evident in the age composition and CPUE indices suggests that TRE 7 may not be a single, homogeneous stock. Rather, the fishstock may be comprised of a number of relatively discrete geographic sub-populations with variable recruitment processes and/or differential patterns of fishing mortality. The apparent differences in the age composition and CPUE data sets suggest that the movement rates of fish between adjacent sub-areas may be relatively low. Based on these observations, the NINS WG recommended that the TRE 7 stock assessment should be structured to incorporate a degree of spatial stratification. Thus, the various model data sets were configured based on the three spatial strata defined above.

4.2 Catch history

Francis & Paul (2013) tabulate annual reported commercial catches (domestic and foreign) of trevally by Fishery Management Area (FMA) for 1931–1982. For this period, annual catches for TRE 7 were determined from the combined catches from FMAs 7, 8 and 9 (Figure 20). Annual reported TRE 7 commercial catches from the more recent years (1983–2013) were sourced from Ministry for Primary Industries (2014) (Figure 20). Annual catches by fishing year were assigned to the calendar year of the January–September period (e.g. catches from 2012/13 were assigned to the 2013 year in the assessment model). Annual commercial catches from 2014 were assumed to be equivalent to 2013.

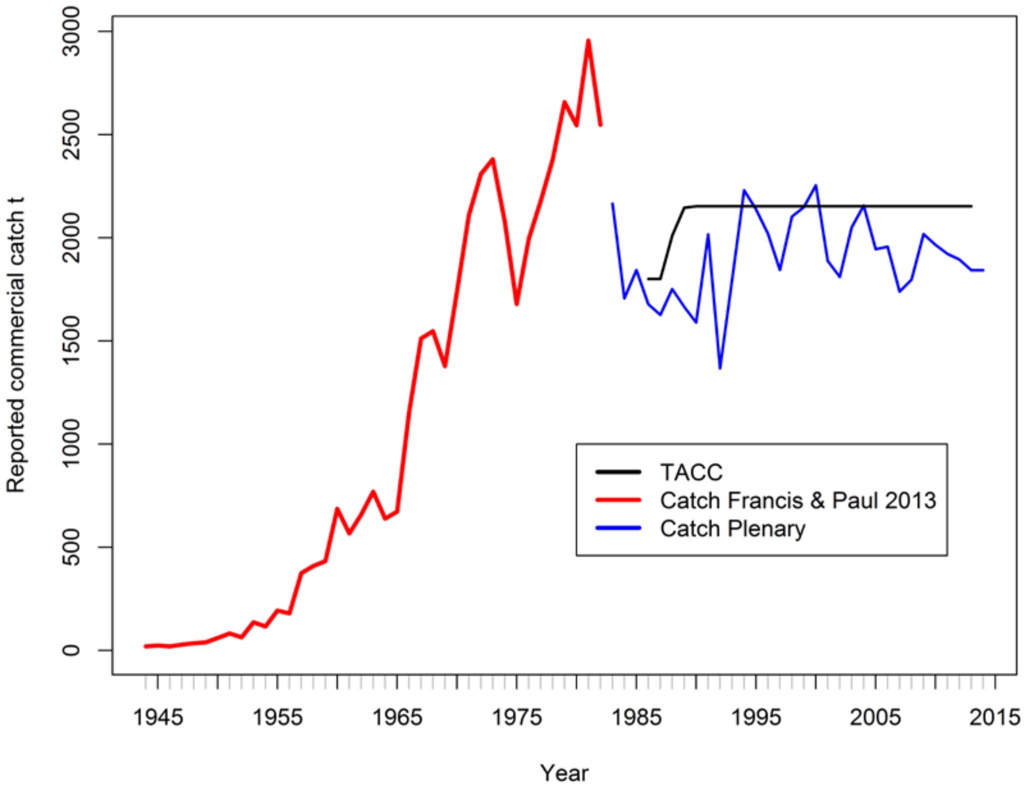


Figure 20: Annual reported commercial catch from the TRE 7 fishery and the TACC.

Previous TRE 7 stock assessments have included an allowance for the discard of trevally catches prior to 1970 (MPI 2014). The discarded catch component was specified as a percentage of the annual reported commercial catch; 50% during 1944–59, 20% during 1960–65 and 5% during 1966–69. Similarly, previous assessments have included an allowance for unreported commercial catch expressed as a percentage of the annual reported commercial catch; 20% during 1944–1986, 10% in 1987 and then decreasing by 1% per annum to prior to 1997 and remaining at 1% during 1997–2014 (MPI 2014). The total TRE 7 commercial catch was determined from the addition of the reported catch and the allowances for discards and unreported catch (Figure 21).

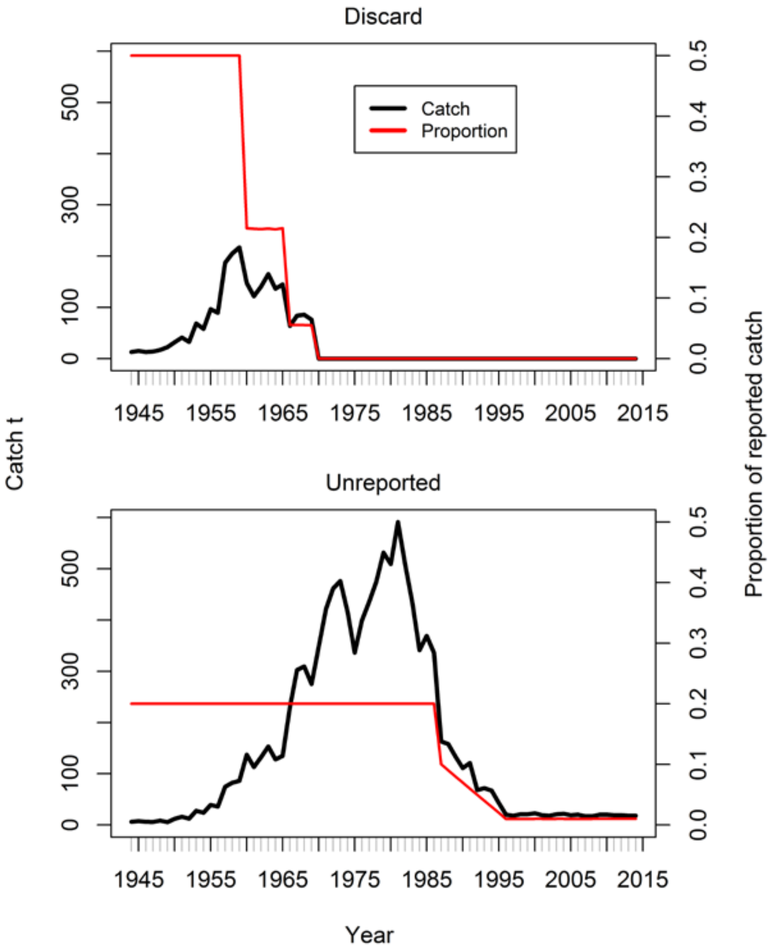


Figure 21: Annual discarded and unreported trevally catches assumed for the stock assessment.

The model catch data sets were configured to include six commercial fisheries with a single trawl and a pair trawl fishery in each of the three sub-areas. The current catch and effort reporting regime provides sufficient information to determine the proportion of the total catch from each area/method fishery from 1990–2013 (Figure 22). For the preceding period, limited catch and effort data are available and it was necessary to apportion the annual total TRE 7 commercial catch among fishing methods and sub-areas based on the following assumptions.

i. For 1944–82, the total annual catch was apportioned among sub-areas based on the FMA catches from Francis & Paul (2013). The combined FMA 7 and 8 areas approximate the STB subarea, although there is some overlap of FMA 8 and the KM-NTB sub-area (Figure 1). On that basis, the entire catch from FMA 7 and 80% of the catch from FMA 8 was allocated to the STB sub-area.

ii. For 1944–82, the combined KM-NTB and NMB catch was determined from the entire FMA 9 catch and the remaining 20% of the catch taken from FMA 8. The combined catch was then apportioned between the two subareas based on the average annual proportion of the catch taken from the two areas (77% KM-NTB, 23% NMB) in the recent period (1990–2013). It is worth noting that these percentages were quite variable amongst years (standard deviation 9.2%) although there was no strong temporal trend from 1990 to 2013.

iii. For 1983–89, total annual catches were allocated amongst the three sub-areas based on the average of the annual proportion of the total catch from the period immediately preceding 1983 (1978–82) and immediately following 1989 (1990–95) (i.e. NMB 22%, KM-NTB 57% and STB 21%).

iv. Pair trawling commenced in the TRE 7 fishery in about 1974. For the preceding period, the total sub-area commercial catch was assigned to the single trawl fishery.

v. Francis et al. (1999) provides a summary of the monthly catches of trevally by vessel type (single trawlers, small pair trawlers and large pair trawlers) based on the catch landed at Onehunga (predominantly TRE 7 catches). This catch was assumed to be representative of the combined KM-NTB and NMB catch. The annual proportion of the catch taken by the single trawl and pair trawl methods was used to apportion the sub area commercial catches amongst the two fishing methods from 1974 to 1986. The gear specific catch data were not available for the STB area and catches were split equally between the two fishing methods from 1974 to 1986 (Figure 22).

vi. For the three areas, the subarea catches from 1987–89 were allocated between fishing methods based on the average annual proportional split of the catch from the specific sub-area during 1990–93.

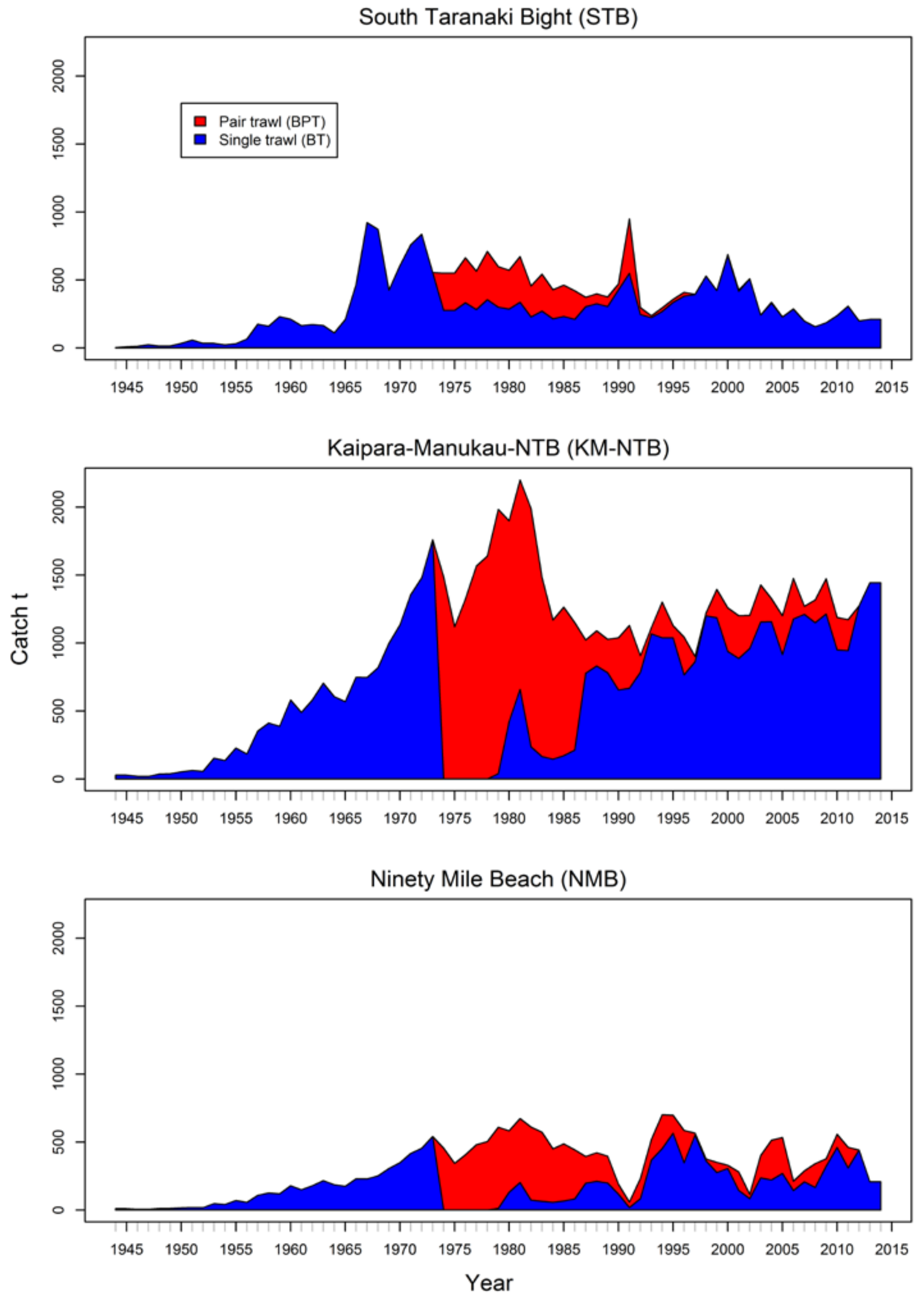


Figure 22: Annual total commercial TRE 7 catches apportioned among fishery areas and between fishing methods, includes allowances for discards and under reporting of catch.

The TRE 7 catch data set also included a non-commercial fishery that encompassed catches from the customary and recreational sectors. The annual catches were equivalent to the catch history included in the previous TRE 7 stock assessments (MPI 2014) extended to include the more recent years (to 2014). Following previous assessments, recreational and customary catches were assumed to be 70 t and 12 t per annum, respectively, since 1980. The recreational catch history is based on a telephone/diary estimate of TRE 7 catch in 1996. The estimates of recreational catch derived using the telephone/diary methodology are no longer considered to be reliable and probably represent an over-estimate of actual level of catch (MPI 2014). Nonetheless, the catch estimate has been maintained in the current assessment as the level of catch is very low relative to the commercial catches and further refinement of the recreational catch history was not expected to have any influence on the overall assessment. The non-commercial component of the catch was assumed to be taken entirely within the KM-NTB sub-area.

4.3 CPUE indices

The derivation of the standardised bottom trawl CPUE indices is detailed in Section 3. Preliminary, spatial stratified assessment models incorporated the three area specific CPUE indices, whereas the final assessment models included the CPUE indices from the KM-NTB sub-area only (combined indices, excluding VesselX).

The KM-NTB CPUE indices are characterised by a very high index for 1990. Data from that year were examined in detail to investigate potential reasons for the exceptionally high CPUE; however, there was no information to suggest that the high CPUE index was attributable to errors and/or inconsistencies in the catch and effort data and CPUE was consistently high for most of the vessels operating in the fishery in that year. Preliminary assessment models indicated that the large decline in CPUE from 1990 to 1991 is not compatible with the underlying population dynamics of TRE 7. On that basis, the NINS WG (17/9/2014) recommended that the 1990 CPUE index be excluded from the CPUE time series incorporated in the final assessment model.

Francis et al. (1999) derived annual CPUE indices from the pair trawl fishery (LPT) for 1977–1985. These CPUE indices had been excluded from the previous TRE 7 stock assessments on the basis that the indices were not considered to provide a reliable index of stock abundance. This conclusion was reaffirmed by the results of the preliminary phase of model development conducted during the current assessment. The Francis et al. (1999) CPUE indices remained relatively stable throughout the period of highest annual catch from the TRE 7 fishery. The preliminary assessment models were only able to fit these CPUE indices by substantially increasing recruitment in the period immediately prior to the increased catch. This result was not considered credible and was not supported by any available age composition data.

4.4 Age composition data

Previous TRE 7 stock assessments have included three main sets of age composition data:

i. Age compositions derived from trawl surveys conducted by the *James Cook* in the early 1970s (James 1984),
ii. Age compositions of the sampled catch from the pair trawl fishery (BPT) from two periods (1974–79 and 1998–2001), and
iii. Age compositions of the sampled catch from the single trawl fishery from 1998 onwards.

Previous studies have concluded that there is no sexual dimorphism in the growth of trevally in TRE 7. There is also no indication of sex-specific differences in fishery selectivity. On that basis, the fishery age composition data have been routinely configured as a composite age composition (both sexes combined).

For the current assessment, it was necessary to restructure the age composition data by sub-area. For the *James Cook* trawl survey, a combined age composition was determined from the separate age compositions from the Kaipara (Area A) and North Taranaki Bight (Area B) areas of the trawl survey within the 0–50 m depth range (James 1984). The resultant age compositions were associated with the KM-NTB model area (Table 7 and Appendix 3).

The derivation of the early (1974–79) BPT age compositions is documented in McKenzie (2008, see Appendix A2.2). No information is available that details the location of the catch from the individual sampled landings. However, most of the total TRE 7 catch from 1974–79 was taken from the KM-NTB area and, on that basis, the 1974–79 BPT age compositions were assigned to that sub-area (Table 7).

For the more recent period, the catch statistics indicate that most of the TRE 7 BPT catch was taken from the KM-NTB areas. This is consistent with the spatial distribution of the trevally catch from the individual landings sampled during 2000/01 (Langley 2002). The distribution of the sampled catch was not documented for the preceding years (1997/98 and 1998/99). Nonetheless, based on the overall distribution of BPT catch, it was assumed that all three age compositions represented the age composition of the BPT catch from the KM-NTB area (Table 7).

Since the last stock assessment, additional age composition data were collected from the TRE 7 single trawl fishery in 2009/10 (Walsh et al. 2012) and 2012/13 (Walsh et al. 2014). The recent sampling has attempted to determine the age composition of the catch from each of the fishery sub areas. Thus, specific age compositions were available for the single trawl fishery from the three sub-areas in recent years. Age composition data from 2006/07 and 2007/08 was also reanalysed to derive spatially structured age compositions for those years also (Walsh et al. 2012).

During the formulation of the model input data sets for the current assessment, NIWA reanalysed the single trawl age composition data from 1997/98 to 2005/06 to determine separate age compositions for the KM-NTB and NMB areas. In addition, all single trawl age compositions were reanalysed to extend the age range from 1–19 to 1–29 years, increasing the terminal age class (plus group) from 20+ years to 30+ years (Table 7 and Appendix 5).

Table 7: A summary of individual TRE 7 age samples included in the stock assessment models.

Sub area	Fishery /survey	Fishing year	Model Year	Max age	MW CV %	Source
KM-NTB	BT	1997/98	1998	30	41.5	Walsh & McKenzie 2009, see Appendix 5
KM-NTB	BT	1998/99	1999	20	18	Walsh & McKenzie 2009
KM-NTB	BT	1999/00	2000	30	31.1	Walsh & McKenzie 2009, see Appendix 5
KM-NTB	BT	2000/01	2001	30	29.0	Walsh & McKenzie 2009, see Appendix 5
KM-NTB	BT	2005/06	2006	30	34.7	Langley 2009, see Appendix 5
KM-NTB	BT	2006/07	2007	30	24.1	Walsh et al. 2012, see Appendix 5
KM-NTB	BT	2007/08	2008	30	23.9	Walsh et al. 2012, see Appendix 5
KM-NTB	BT	2009/10	2010	30	39.9	Walsh et al. 2012, see Appendix 5
KM-NTB	BT	2012/13	2013	30	37.9	Walsh et al. 2014
KM-NTB	BPT		1974	13	Na	McKenzie 2008
KM-NTB	BPT		1975	13	Na	McKenzie 2008
KM-NTB	BPT		1976	13	Na	McKenzie 2008
KM-NTB	BPT		1978	40	Na	McKenzie 2008
KM-NTB	BPT		1979	40	Na	McKenzie 2008
KM-NTB	BPT	1997/98	1998	20	23	Walsh & McKenzie 2009
KM-NTB	BPT	1998/99	1999	20	18	Walsh & McKenzie 2009
KM-NTB	BPT	2000/01	2001	20	Na	Langley 2002
KM-NTB	Survey		1971	30	Na	James 1984, McKenzie 2008
KM-NTB	Survey		1972	30	Na	James 1984, McKenzie 2008
KM-NTB	Survey		1974	30	Na	James 1984, McKenzie 2008
NMB	BT	1997/98	1998	30	67.2	Walsh & McKenzie 2009, see Appendix 5
NMB	BT	1998/99	1999	20	42.9	Walsh & McKenzie 2009, see Appendix 5
NMB	BT	1999/00	2000	30	38.3	Walsh & McKenzie 2009, see Appendix 5
NMB	BT	2000/01	2001	20	Na	Langley 2002
NMB	BT	2006/07	2007	30	43.0	Walsh et al. 2012, see Appendix 5
NMB	BT	2007/08	2008	30	31.6	Walsh et al. 2012, see Appendix 5
NMB	BT	2009/10	2010	30	25.0	Walsh et al. 2012, see Appendix 5
NMB	BT	2012/13	2013	30	30.2	Walsh et al. 2014
STB	BT	2006/07	2007	30	39.3	Walsh et al. 2012, see Appendix 5
STB	BT	2007/08	2008	30	38.6	Walsh et al. 2012, see Appendix 5
STB	BT	2009/10	2010	30	45.2	Walsh et al. 2012, see Appendix 5
STB	BT	2012/13	2013	30	40.0	Walsh et al. 2014
STB	Survey		1971	30	Na	James 1984, McKenzie 2008

The two most recent age compositions from the KM-NTB single trawl fishery (2009/10 and 2012/13) included a higher proportion of fish in the older age classes (15 years and older) compared to the previous sampled years (Figure 23). As previously discussed, preliminary assessment modelling indicated that the age composition data were inconsistent with the CPUE indices and, as a result the CPUE indices were revised to exclude data from a specific vessel (VesselX) (see Section 4.3).

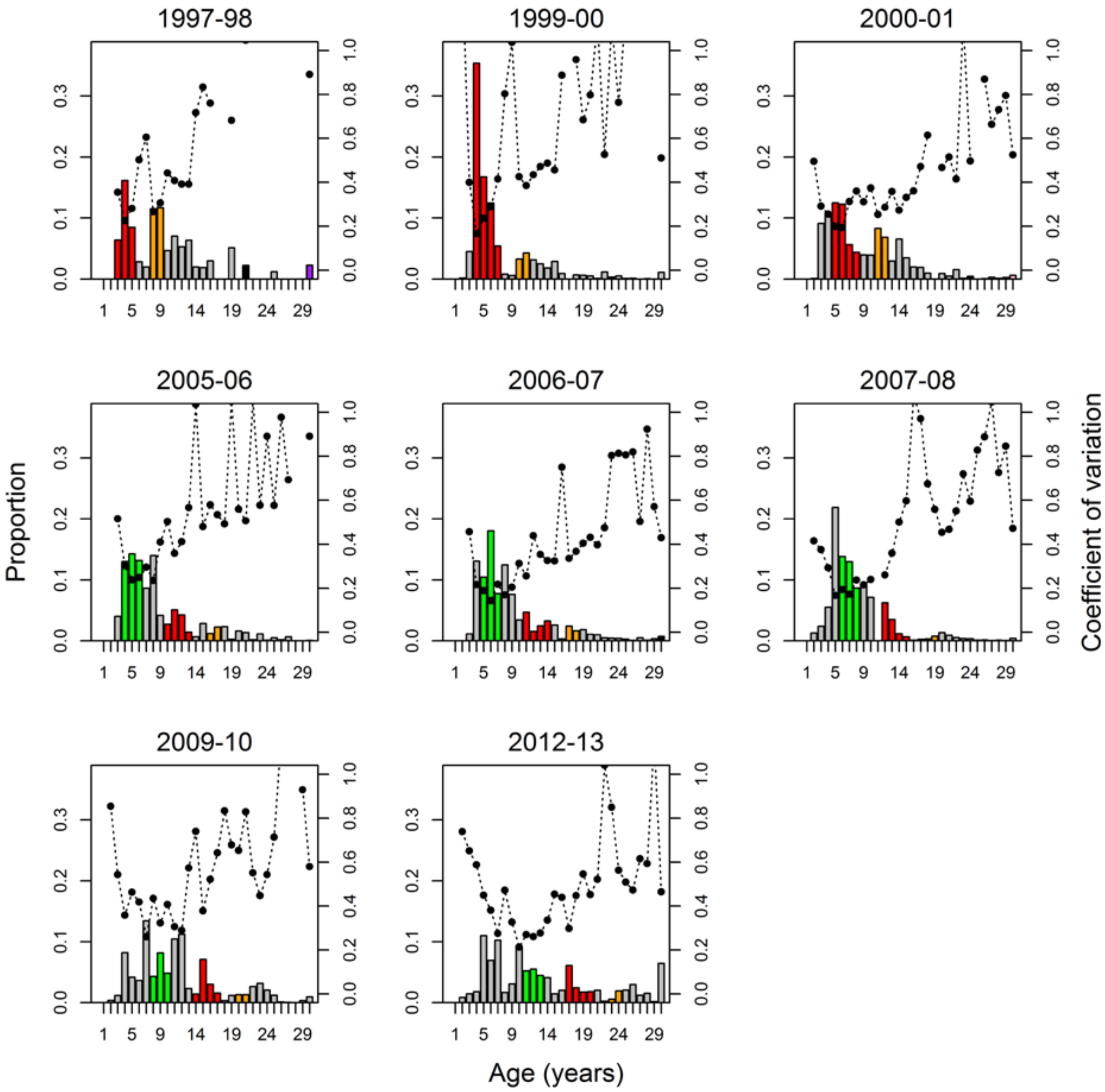


Figure 23: Proportional age compositions of the commercial catch from the KM-NTB bottom trawl (BT) fishery, all vessels combined. The points represent the coefficient of variation associated with the estimates of proportion at age. The different colours represent periods of relatively strong recruitment (from qualitative interpretation of the age composition data).

The age composition data were also investigated to determine whether there were any marked differences in the age composition of the sampled catches amongst the fleet. The results did not reveal a consistent difference in the length composition of the catch from VesselX compared to the remainder of the fleet. However, in both years the overall age compositions were dominated by samples from large (exceeding 80 t) landings of trevally from VesselX that were comprised of trevally that were considerably larger than the fish sampled from other landings.

To ensure that the recent age compositions from the KM-NTB single trawl fishery were consistent with the corresponding CPUE indices, the 2009/10 and 2012/13 age composition data were reconfigured to exclude the sampling data from VesselX. This resulted in a considerable change in the 2012/13 age composition of the KM-NTB single trawl fishery, reducing the proportion of older (greater than 15 years) fish in the revised age composition (Figure 24). The annual catch sampling data from VesselX were combined to represent the age composition of the catches for the vessel in 2009/10 and 2012/13 (enabling the estimation of a separate selectivity function for the vessel).

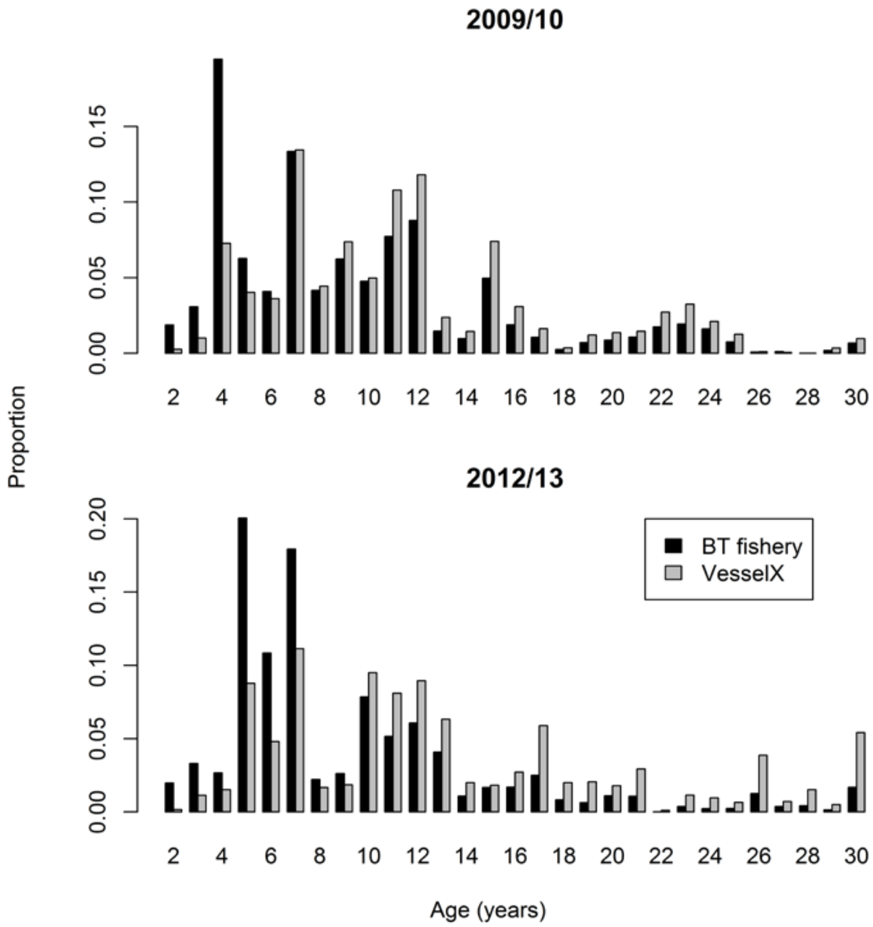


Figure 24: A comparison of the KM-NTB age compositions for 2009/10 and 2012/13 for bottom trawl (BT) excluding data from VesselX (BT fishery) and for VesselX only.

The cumulative set of age composition data from KM-NTB provide information on the relative strength of individual year classes from about 1955 to 2008 (Figure 25). However, the lack of sampling data from the 1980s and early-mid 1990s means that observations are limited for the 1973–1985 year classes. There is very limited overlap in the year classes sampled from the two periods (1976 and 1977 year classes only) and no relative abundance indices (e.g. CPUE indices) spanning the two sampling periods.

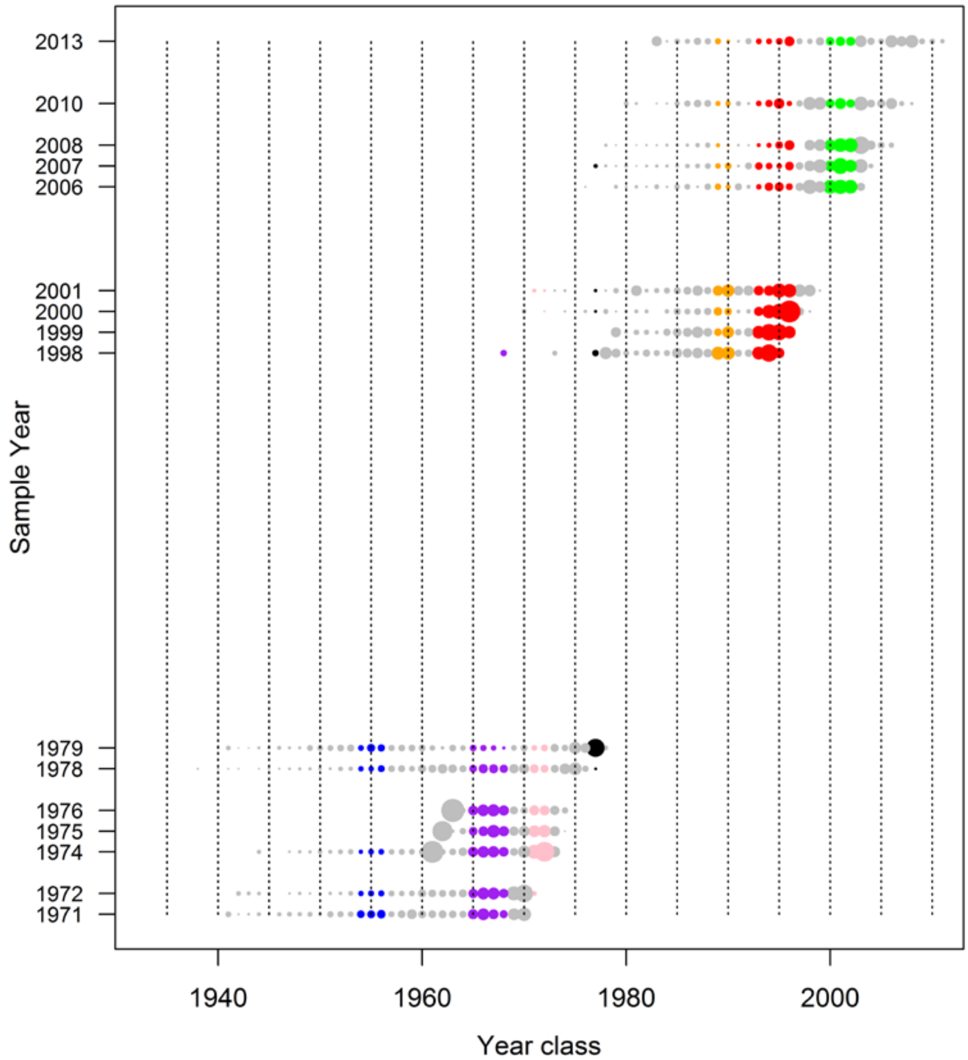


Figure 25: Proportional age compositions from the range of age samples (*James Cook* trawl survey, BPT fishery and BT fishery) from the KM-NTB area. The area of the bubble represents the proportion of the sample within each age class, including plus groups. The colour correspond to apparent strong year classes based on a qualitative examination of the individual age compositions.

5. MODEL CONFIGURATION

Stock assessment modelling was conducted using the Stock Synthesis software (version 3.24) (Methot 2013, Methot & Wetzell 2013). Stock Synthesis (SS) is a platform for implementing statistical, age structured population models and is sufficiently flexible to enable the investigation of spatial stratification in the stock dynamics, including spatial variation in recruitment processes and movement dynamics. On that basis, SS was considered suitable for the development of spatially discrete and spatially stratified assessment models for TRE 7.

5.1 Spatial structure

Initial modelling was primarily focussed on developing an assessment model for the KM-NTB area of the TRE 7 fishery. This area accounted for 68% of the recent (2003/04–2012/13) catch from the TRE 7 fishery. Consequently, trends in this fishery area will strongly influence the overall assessment and management of the overall TRE 7 fishstock.

Two alternative spatially disaggregated models were also investigated during the preliminary modelling phase: a model including all three sub-areas (STB, KM-NTB and NMB) and a model including the two northern sub-areas (KM-NTB and NMB) only. The sub-area models were configured to include the estimation of the overall distribution of recruitment amongst sub-areas, age-specific movement of fish between adjacent sub-areas and temporal variation in the distribution of recruitment amongst sub-areas. The three sub-area model was rejected at an early stage as there are limited age composition data available from the STB sub-area and substantial differences in both the CPUE indices and age composition data between the STB sub-area and the other two areas. The available data were inadequate to enable the estimation of key area specific parameters (recruitment distribution and movement parameters).

Further progress was made in the development of the two sub-area (KM-NTB and NMB) model. However, it was necessary to impose a number of highly informative structural assumptions to produce credible results from the two sub-area model. There remained a number of outstanding issues that could not be addressed with the relatively limited data sets available from each fishery area, particularly the NMB sub-area. Consequently, the resulting model was not considered to be sufficiently reliable for the provision of management advice. A more detailed description of the two sub-area model is provided in Appendix 2.

The final assessment of TRE 7 is primarily based on the single sub-area KM-NTB model. The configuration of the KM-NTB model is described in detail in Section 5.3.

5.2 Biological parameters

The key biological parameters for the TRE 7 stock assessment are presented in Table 8. Following previous assessments, natural mortality (*M*) was assumed to be 0.1 for the base model options. The value of *M* was derived from the equation $M = \log_e 100/\text{maximum age}$, assuming a maximum age of 45 years for trevally (Hanchet 1999). The previous assessments have recognised the uncertainty associated with the parameter and conducted sensitivity analyses using alternative values for *M*, ranging from 0.05 to 0.15 (McKenzie 2008). Langley & Maunder (2009) conducted a likelihood profile of *M* that yielded a maximum likelihood at 0.087 and a lower bound of 0.075.

Growth parameters for TRE 7 are provided in Walsh et al. (1999). There is no evidence of sexual dimorphism in trevally growth and the growth parameters have been estimated for both sexes combined. There is also no indication that the growth of trevally varies among the three sub areas of TRE 7 (Walsh et al. 2012). Maturity was assumed to be age-specific with 50% of fish reaching maturity at age 4 years and full maturity at 5 years.

A Beverton-Holt spawning stock-recruitment relationship (SRR) was assumed with steepness (*h*) fixed at 0.85 for the base assessment model. The value of steepness is higher than the value of 0.75 assumed in the previous assessment (Langley & Maunder 2009). Preliminary assessment models did not provide any indication that levels of recruitment were depressed following the substantial reduction in spawning stock biomass during the 1960s and 1970s. However, these model based estimates of recruitment and biomass are not informative regarding the actual level of steepness for the TRE 7 stock. Thus, the sensitivity of the stock assessment results to a lower value of steepness (0.70) was evaluated. Recruitment deviates from the SRR were estimated assuming a standard deviation of the natural logarithm of recruitment (σ_R) of 0.6.

Table 8: A description of the model parameters included in the KM-NTB base assessment model.

Parameters	Value, Priors (mean, sd)
Biology	
Natural mortality (*M*)	0.10, fixed
Growth (Von Bertalanffy)	*k* = 0.28
	Lmax = 46.21
Length-wt relationship	*a* = 1.6e-005
	b = 3.064
Recruitment	
R_0	Normal (8.0, 4)
B-H steepness	0.85, fixed
SigmaR	0.6, fixed
Log Rec deviates (1970–2008)	Normal (0, SigmaR) [-5 to +5]
Selectivity	
BT fishery Double normal	
p1 – *peak*: beginning age for the plateau	Normal (5,1)
p2 – *top*: width of plateau	Normal (-3,2)
p3 – *asc-width*	Normal (1,2)
p4 – *desc-width*	Normal (5,2)
p5 – *init*: selectivity at first bin	-6, fixed
p6 – *final*: selectivity at last bin	Normal (0,1.5)
Trawl survey Double normal	
p1 – *peak*: beginning age for the plateau	Normal (2,0.5)
p2 – *top*: width of plateau	Normal (-5,1)
p3 – *asc-width*	Normal (-1,1)
p4 – *desc-width*	Normal (5,1)
p5 – *init*: selectivity at first bin	-6, fixed
p6 – *final*: selectivity at last bin	Normal (-1.5,2)
BPT fishery Logistic	
p1 – age at inflection	Normal (3,2)
p2 – width for 95% selection	Normal (2,2)
VesselX, BT fishery Logistic	
p1 – age at inflection	Normal (3,2)
p2 – width for 95% selection	Normal (2,2)
Non comm fishery	Equivalent to BT fishery
Log CPUE q	Uniform, nuisance parameter

5.3 KM-NTB model

The model included the entire catch history (from 1944) and assumes that the initial population age structure is in an equilibrium, unexploited state. The population is structured by sex and includes 40 age classes, the oldest age class representing an aggregated "plus" group (40 years and over). The model data period extends to the 2014 year (2013/14 fishing year).

The model was structured with a single annual time-step. Spawning is assumed to occur instantaneously at the start of the year and recruitment is a function of the spawning biomass at the start of the year. Recruitment deviates from the Beverton-Holt stock-recruitment relationship were estimated for the range of years with sufficient age frequency observations to inform estimates of year class strength (see following paragraph). Recruitment deviates were assumed to have a lognormal distribution with a standard deviation of 0.6 (Table 8).

The KM-NTB model was configured to encompass four fisheries: single trawl (BT), pair trawl (BPT), VesselX single trawl and non commercial. Age composition data are available from the single trawl fishery (9 observations), pair trawl fishery (8 observations), the *James Cook* trawl survey (3 observations) and the VesselX single trawl fishery (2 observations). The single trawl CPUE indices represented the principal index of stock abundance (1991–2013, 23 observations).

During the preliminary modelling phase, the precision of the estimates of the time-series of recruitment deviates was investigated for a model that estimated annual recruitment deviates for 1955–2008. The parameter estimates derived from individual Markov chain Monte Carlo (McMC) draws revealed that individual recruitment deviates from the 1955–69 period tended to be negatively correlated with the *R0* parameter estimates. The performance of the parameter estimates from the McMCs improved considerably when the period of estimation of the recruitment deviates was restricted to 1970–2008. The latter model option was selected as the preferred (base) model, although other model options with different recruitment deviate periods were considered for comparative purposes (1955–2008 and 1980–2008).

Each fishery and survey was associated with an age-specific, sex invariant selectivity function. The recent age composition data from the BT fishery indicates that the older age classes may not be fully vulnerable to the main BT fleet (excluding VesselX). On that basis, the fishery selectivity was parameterised using a double normal function, enabling considerable flexibility in the estimation of the selectivity function (Table 8). Similarly, the selectivity of the *James Cook* trawl survey was also parameterised using a double normal function.

The dominant vessel in the BT fishery in recent years (VesselX) tends to catch larger (and older) fish than the remainder of the BT fleet. For the VesselX model fishery, it was assumed that the older age classes in the population were fully vulnerable and the selectivity was parameterised using a logistic selectivity function. Similarly, the BPT fishing method also tends to catch larger fish than the single BT fishing method and a separate logistic selectivity function was estimated for the BPT fishery (Table 8).

No age composition data are available from the non commercial fishery and the fishery was assumed to have a selectivity equivalent to the BT fishery.

The CPUE indices are assumed to have a lognormal distribution and represent the relative abundance of the biomass of trevally vulnerable to the BT fishery.

Fishing mortality was modelled using a hybrid method that calculates the harvest rate using Pope's approximation then converts it to an approximation of the corresponding fishery specific *F* (see Methot & Wetzell 2013 for details). The timing of the fisheries and CPUE indices within the year was specified so that annual catches were instantaneously taken a third of the way through the year. This corresponds to the actual mid-season of the main fishery occurring during January.

There are four components to the model composite likelihood:

i. Survey. The fit to the CPUE indices assuming a lognormal error structure.
ii. Age composition. The fit to the age composition data assuming a multinomial error structure.
iii. Recruitment deviations. The likelihood is formulated to constrain lognormal recruitment deviations relative to the (assumed) standard deviation (sigmaR).
iv. Parameter priors. Deviation of estimated parameter(s) from assumed prior distribution(s).

The formulation of the individual likelihood components is documented in Methot & Wetzell (2013). Model uncertainty was determined using Markov chain Monte Carlo (McMC) implemented using the Metropolis-Hastings algorithm. For each model option, 1000 McMC samples were drawn at 1000 intervals from a chain of 1.1 million following an initial burn-in of 100 000. The performance of the McMC sample was evaluated using a range of diagnostics, including Heidelberg and Welch and Geweke test statistics.

5.4 Data weighting

The main data inputs were assigned relative weightings based on the approach of Francis (2011). This followed a two-step procedure: the first step was to fit the single trawl CPUE indices in the assessment model with all the age composition data down-weighted (Effective Sample Size ESS of 1). The resultant SDNR of the fit to the CPUE observations was adopted as the CV for all the individual CPUE observations (CV 16%).

The second step of the fitting procedure was to rerun the model with the revised CPUE CV and determine the fleet/fishery specific ESS for the age composition data sets. The approach used Method TA1.8 of Francis (2011) to provide an indicative overall ESS for each fleet. The fleet specific ESSs were 31.3, 24.6, 48.7 and 13.9 for the BT, BPT, trawl survey and VesselX age composition data sets, respectively.

An examination of the fits to the 1970s BPT age composition data indicate that the data are not particularly informative regarding the age composition of the BPT catch; the data from 1974–76 have an aggregate age class of 13+ years and there is a marked difference in the age structure between the 1978 and 1979 samples. The relatively high ESS (of 24.6) obtained for the BPT fishery during the weighting procedure may be partly attributable to the lack of a corresponding series of abundance indices in the earlier period. Given the issues identified with these age observations, it was decided to down-weight the data from the 1970s and assign an ESS of 5 to those age samples. The three later BPT age samples were assigned an ESS of 20.

For the BT age composition data, coefficients of variation were available for the estimates of the proportion at age for most of the age samples. A relative weighting of the individual samples was determined based on a nonlinear regression of CV on proportion as described in Francis (2011). This resulted in ESSs for the individual BT age samples ranging from 11 to 52.

For all age compositions there was assumed to be no error associated with the age determination. This assumption is not consistent with the results from trevally ageing studies (Walsh & McKenzie 2009, Walsh et al. 2012). However, initial model trials indicated that the assessment model was relatively insensitive to the inclusion of a relatively large ageing error for all age compositions (equivalent to a CV of 15% for each age). The introduction of ageing error resulted in a smoothing of the estimates of year class strength but did not affect the biomass trajectory or estimates of stock status and yield.

5.5 Stock status

Stock status was determined relative to the equilibrium, unexploited spawning (mature) biomass of female fish (SB_0). Current biomass was defined as the spawning biomass in the 2014 model year (2013/14 fishing year) ($SB_{current}$ or SB_{2014}).

Following the MPI Harvest Strategy Standard (HSS), current biomass was assessed relative to the default soft limit of 20% SB_0 and hard limit of 10% SB_0 (Ministry of Fisheries 2008). The HSS also defines a default target biomass level of 40% SB_0 for stocks where SB_{MSY} has not been fully evaluated. Current stock biomass is reported relative to the default target biomass level ($SB_{40\%}$) and current levels of fishing mortality are reported relative to the level of fishing mortality that result in $SB_{40\%}$ under equilibrium conditions (i.e. $F_{SB40\%}$). The reference level of age specific fishing mortality is determined from the composite age specific fishing mortality from the last year of the model data period (2014). Estimates of equilibrium yield are determined from the level of fishing mortality that produces the target biomass level ($F_{SB40\%}$)

For the main model options, stock projections were conducted for a 5 year period (2015–2019) assuming the current (2014) level of catch for each fishery. The stock status in the terminal year of the projection period (2019) is reported relative to the target and limit biomass reference points. During the projection period, uncertainty in annual recruitment is incorporated by drawing recruitment deviation values from the lognormal distribution.

6. MODEL RESULTS

During model development, a wide range of model options were investigated to examine key structural assumptions, including parameterisation of model priors (especially fishery selectivity), the relative weighting of different data sets and the estimation period for recruitment deviates. Overall, the stock assessment model was relatively insensitive to these assumptions. A base assessment model was chosen that provided a reasonable fit to all the main data inputs and the estimated key parameters that were consistent with the general understanding of the operation and performance of the fishery. The following sections primarily report the results from the base model. In addition, a number of model sensitivity analyses were formulated to encompass the main sources of uncertainty in the stock assessment.

6.1 Base model

6.1.1 Parameter estimation

Priors were formulated for fishery selectivity parameters based on a qualitative examination of the age composition data (i.e. age at recruitment and the proportion of older fish in the samples). Relatively uninformative, normally distributed priors were adopted for all the fishery selectivity parameters (Figure 26). For the fisheries with logistic selectivity (BPT and VesselX), the data were relatively informative regarding the corresponding selectivity parameters as evident from the posterior distributions of the estimated parameters derived from McMC (Figure 26).

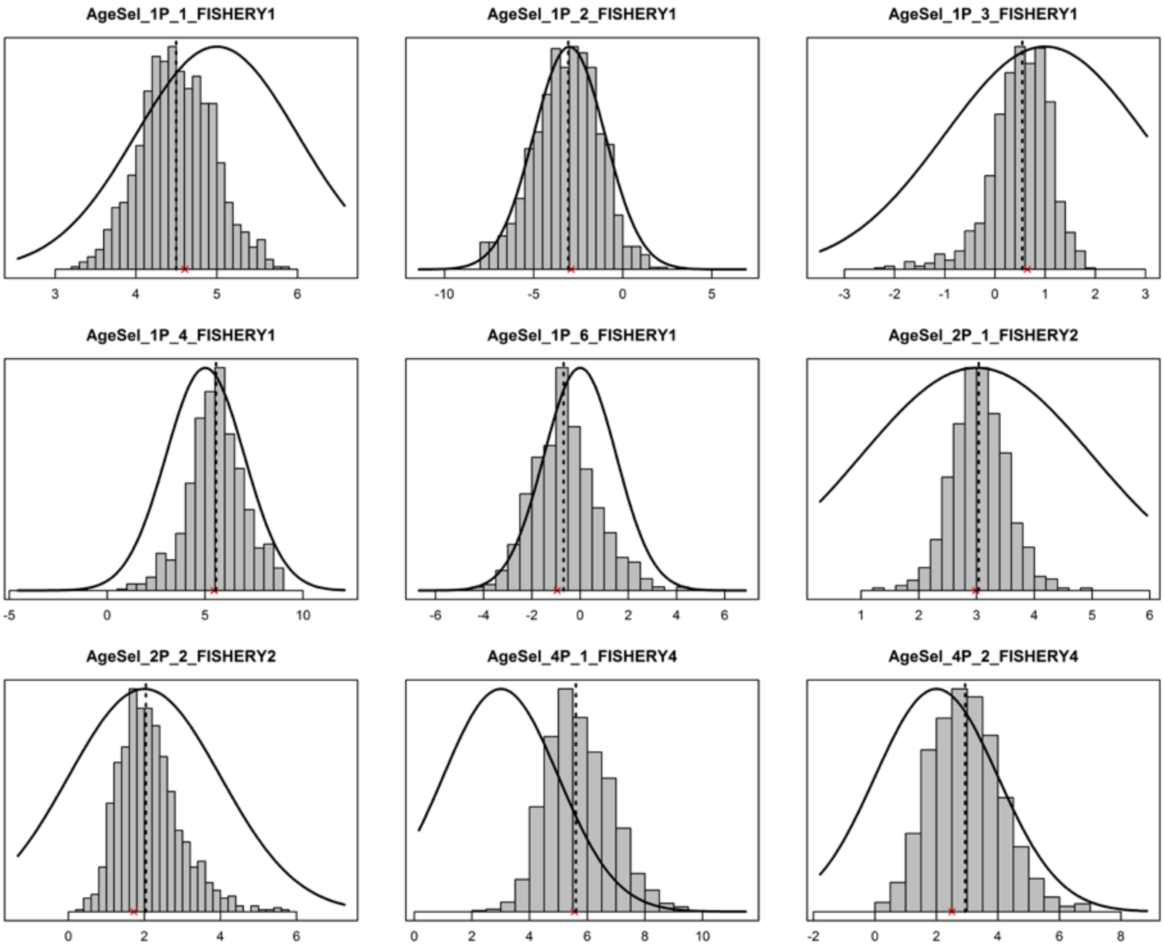


Figure 26: Prior distributions (solid line) and estimated probability distributions derived from McMC (histograms) for the estimated selectivity parameters of the base KM-NTB model (Fishery1, BT; Fishery2, BPT; Fishery4, VesselX). The median of the McMCs (dashed vertical lines) and MPD estimates (red crosses) are also presented.

The double-normal selectivity function of the BT fishery has five estimated parameters. The initial parameter values corresponded to a selectivity function that had a relatively low selectivity for the oldest age classes, based on the observation that the proportion of older fish in the observations are considerably lower than for either the BPT fishery or VesselX. These data are relatively informative regarding the parameters that determine the age at recruitment to the fishery (p1 and p3) but are relatively uninformative regarding the parameterisation of the right-hand limb of the selectivity function (p2, p4 and p6) (Figure 26). During the initial model development, a range of different starting values were tested for the p4 and p6 parameters of the BT selectivity. The relative selectivity of the older age classes was sensitive to the starting values, although the overall model results were relatively insensitive to the BT selectivity parameters. This issue is further examined in the range of model sensitivity analyses investigated (see Section 4.2).

6.1.2 Fit to observational data

The KM-NTB BT CPUE indices are characterised by a general decline during the 1990s and a general increase from the mid 2000s. The assessment model fits this general trend in the CPUE indices although the scale of the temporal variation in the CPUE indices is under-estimated by the model (Figure 27). There is a corresponding trend in the model residuals with positive residuals at the beginning and end of the CPUE time-series and a preponderance of negative residuals in the middle of the series (Figure 27). This observation suggests that the scale of variation observed in the CPUE indices is not entirely consistent with the age composition data from the BT fishery.

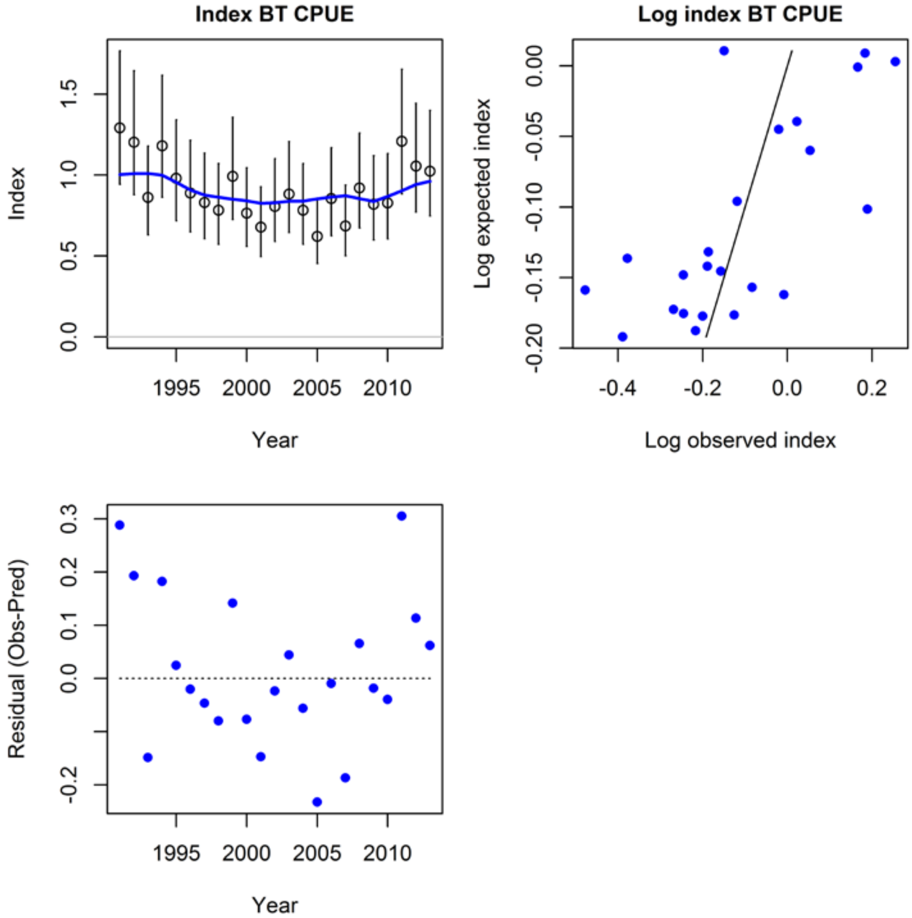


Figure 27: Fit to the CPUE indices and associated diagnostics for the KM-NTB base model. The year represents the model year denoted by the calendar year at 1 January (e.g. 1995 denotes the 1994/95 fishing year).

Overall, the model represents a good fit to the time-series of BT age composition data (Figure 28). The model estimates considerable variability in recruitment with relatively strong recruitment for the 1985–87 and 1990 year classes corresponding to the higher proportion of fish in the respective age classes from 1998 to 2001 in the age compositions (age classes 8 and 11–13 yr in 1998) (Figure 28). There is a weaker fit to the 2010 year class as the model considerably under-estimates the proportion of fish observed in the 11, 12 and 15 year age classes. Conversely, the model over-estimations the proportion of older fish in the 2000 age composition (Figure 28).

There is no trend in the standardised residuals by age class that would indicate a systematic lack of fit through the age range for all years combined. However, there is a declining temporal trend in the standardized residuals of the youngest age classes (3 and 4 year) in the BT age composition (Figure 29).

This may indicate a shift in the selectivity of the trevally fishery towards older fish during the period, although the overall magnitude of the change in selectivity appears to be relatively small as there is no fundamental change in the age composition of the fishery as the average age of fish in the sampled catch has remained relatively constant (Figure 30). In general, the model yields a reasonable prediction of the average age of fish in the BT catch for 1998–2008, with the exception of the 2000 age sample. However, the model substantially under-estimates the age of fish in the BT fishery catch-at-age in the two most recent years (2010 and 2013) (Figure 30).

The younger average age in the predicted fishery age composition in the more recent years is related to estimates of higher recruitment for the 2006–2008 year classes, influenced by the higher CPUE in the latter period of the model. The influence of the CPUE data on the age composition may also be the main factor causing the trend in the residuals for the age 3 and 4 year classes (i.e. the younger age classes may be over-estimated and hence predicted catches of younger fish are higher than observed).

These trends indicate a degree of inconsistency in the two main data sets during the more recent period. This discrepancy was much more pronounced in earlier exploratory models that did not explicitly account for the data (CPUE and age composition) from the single, dominant vessel that has operated in the fishery over recent years (Vessel X).

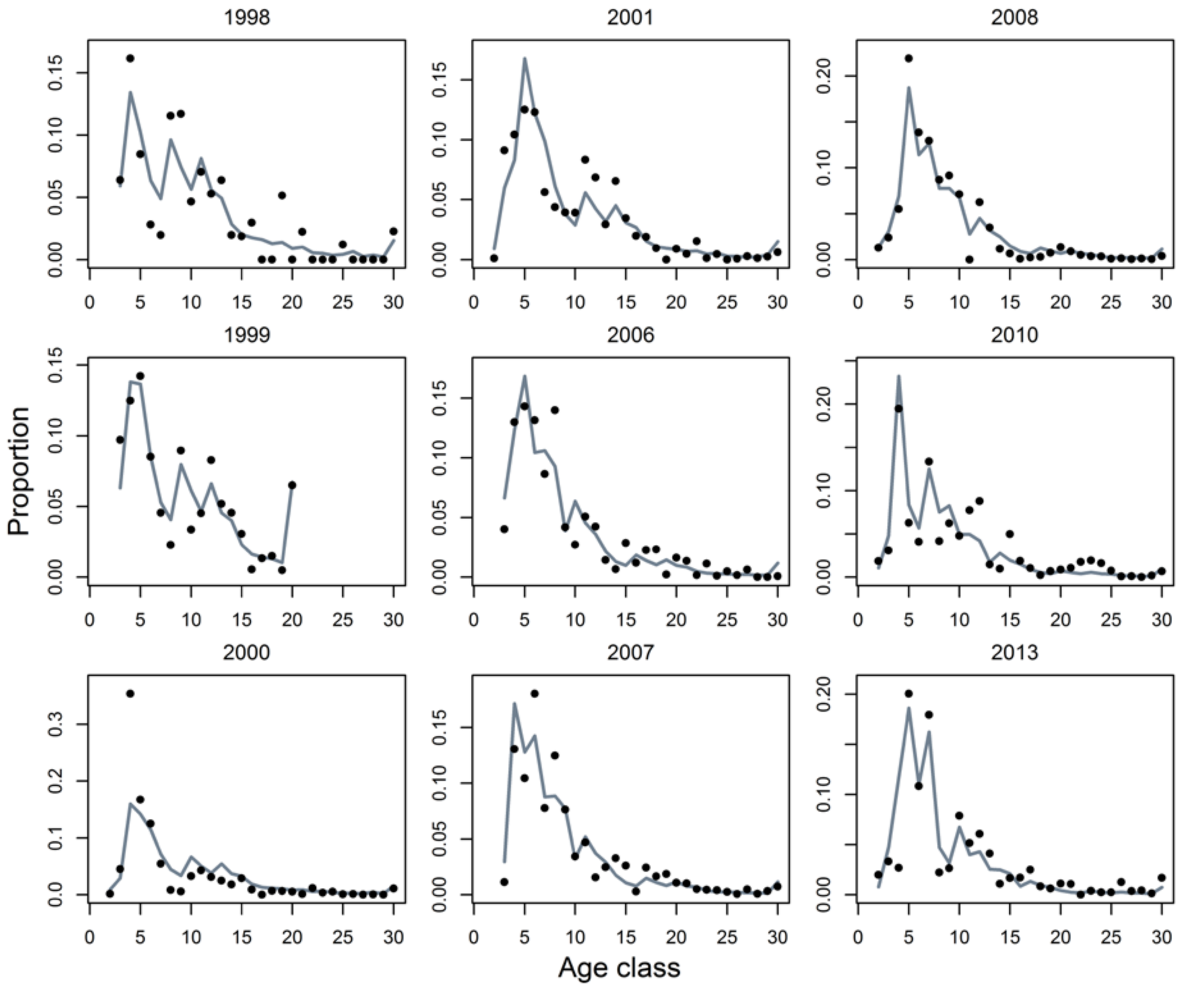
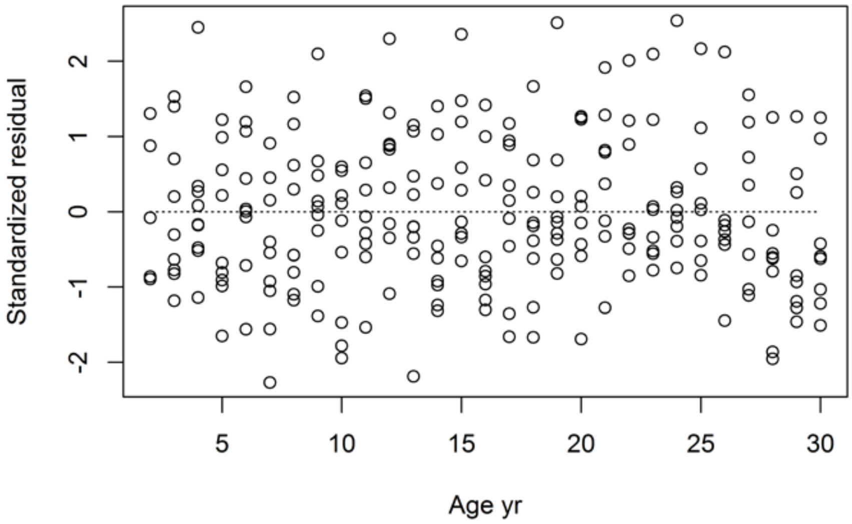


Figure 28: Observed (points) and predicted (line) proportions at age for the bottom trawl catch-at-age data included in the KM-NTB base model.



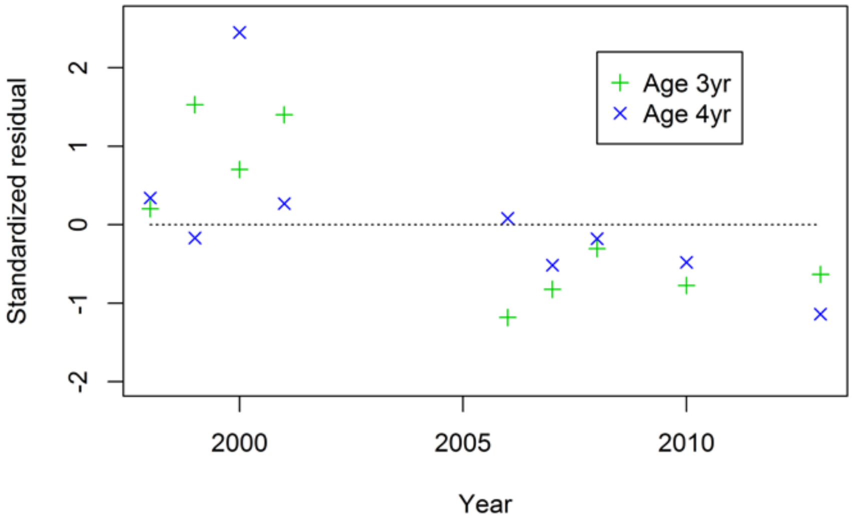


Figure 29: Standardized residuals by age class for all KM-NTB bottom trawl (BT) age compositions combined (top panel) and the standardized residuals of the 3 and 4 year age classes from the KM-NTB BT age compositions by sample year (bottom panel). Residuals are from the KM-NTB base model.

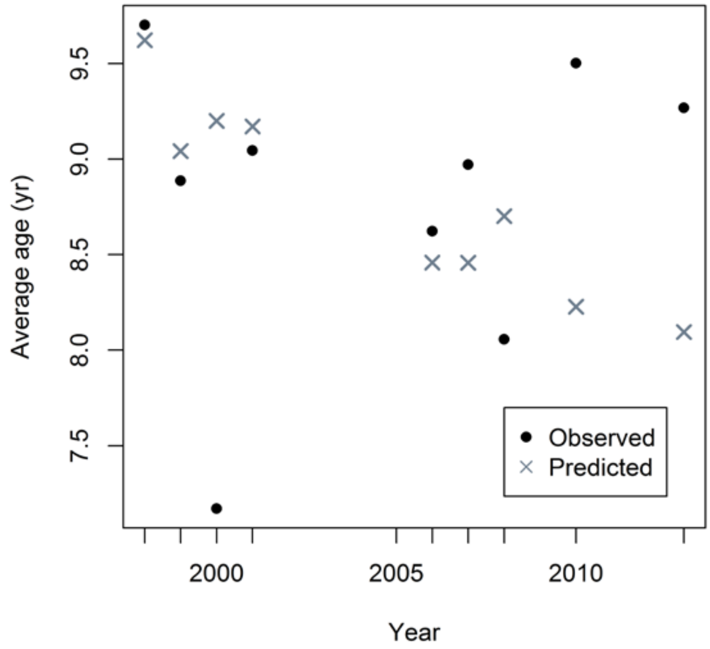


Figure 30: Comparison of the observed average age from the KM-NTB BT age compositions and the predicted average age by year of sampling (base assessment model).

The base model partitions the recent age composition data from the dominant vessel (VesselX) in a separate fishery. The data from the vessel are quite variable between the two years (Figure 31). Consequently, while the model provides a reasonable fit to the underlying age composition from the fishery, the fit to the individual age compositions is quite poor.

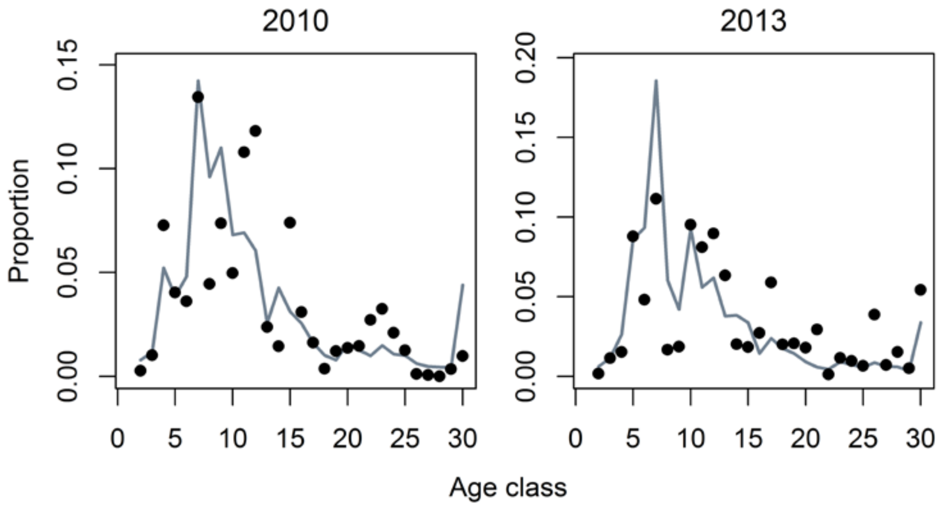


Figure 31: Observed (points) and predicted (line) proportions at age for the VesselX bottom trawl catch-at-age data included in the KM-NTB base model.

The age composition data from the early BPT fishery are not particularly informative; age samples from 1974–76 were only aged to 13 years and consequently there is a very large aggregated age class of older fish (13 years or more) (Figure 32). Further, there is a marked difference in the age structure between the 1978 and 1979 samples that is not consistent with the assumption of time invariant selectivity and may indicate inconsistency in the sampling approach between years. Recruitment deviates were not estimated for the years before 1970 and, hence, predicted 1978 and 1979 age compositions are primarily based on the equilibrium age structure. Overall, the resulting fit to both age samples is very poor (Figure 32).

The BPT age compositions from 1998, 1999 and 2001 are also quite variable, particularly the relative proportion of young (3–5 year) and older (20+ year) fish in the sampled catch among years (Figure 32). Consequently, while the model approximates the general age structure the individual fits to the observed age compositions are quite poor.

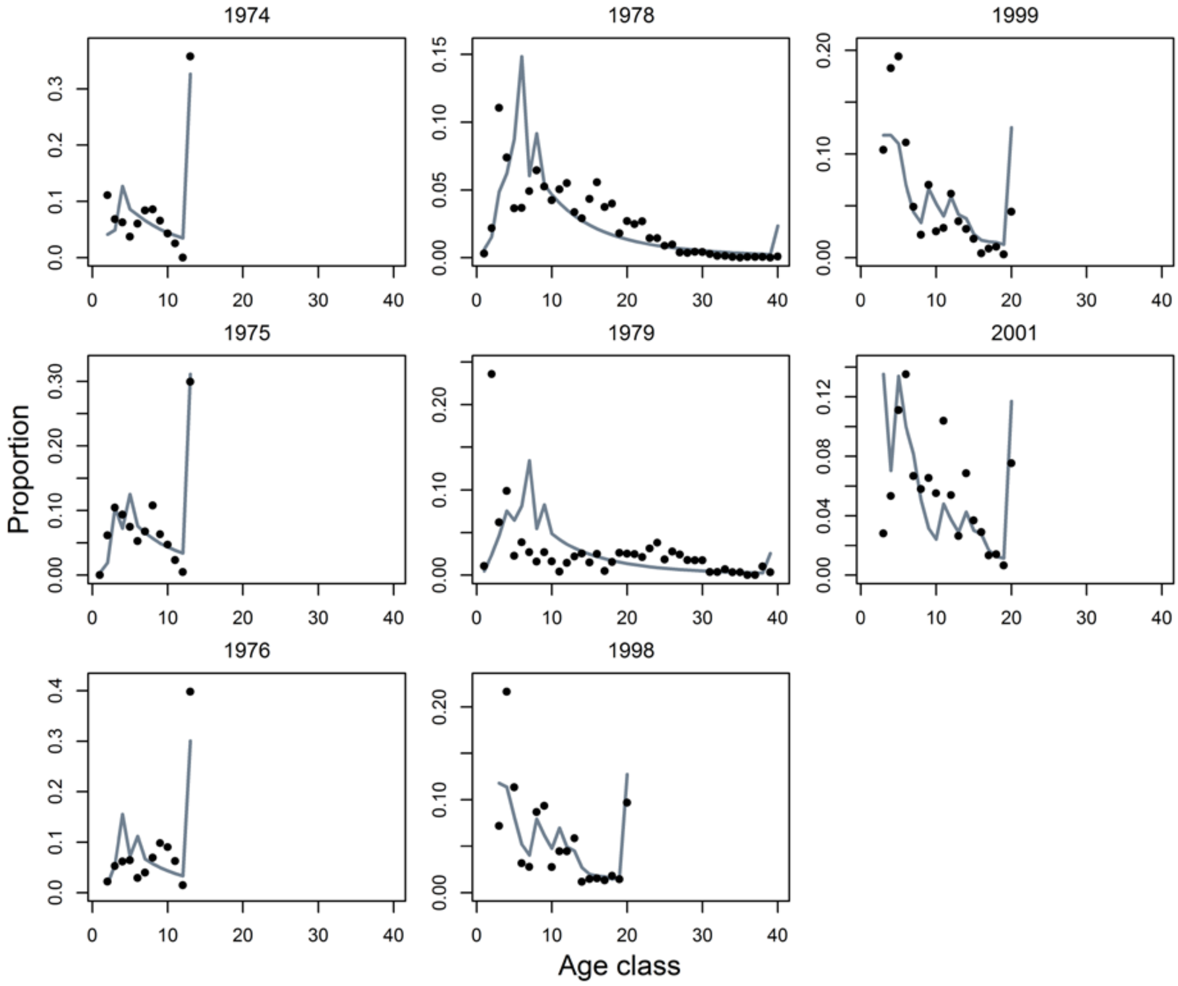


Figure 32: Observed (points) and predicted (line) proportions at age for the bottom pair trawl (BPT) catch-at-age data included in the KM-NTB base model.

The predicted age compositions for the *James Cook* trawl surveys are primarily based on the equilibrium age structure of the model population prior to 1970. Consequently, the model does not estimate the variability in the individual age classes included within the age compositions (Figure 33). Nonetheless, the model provides a reasonable fit to the underlying age structure of the three age frequency distributions.

Figure 33: Observed (points) and predicted (line) proportions at age from the *James Cook* trawl survey data set included in the KM-NTB base model.

6.1.3 Stock dynamics – base model results

The McMCs provide estimates of the central tendency and uncertainty associated with the main model parameters and derived parameters (annual recruitment, spawning biomass and stock status). For the base model, diagnostic plots for the McMC sample are presented in Appendix 1. The plots are presented for three key model parameters only: lognormal equilibrium recruitment R_0, the terminal (2008) recruitment deviate and a key selectivity parameter of the BT trawl fishery (p6 final selectivity). The McMC results for the range of other model parameters were also examined but are not presented. There was no indication of strong autocorrelation amongst successive McMC draws and the Heidelberg and Welch and Geweke statistics did not detect a significant deviation from the assumption that the Markov chain is from a stationary distribution.

The estimated selectivity functions for the fisheries and trawl survey are presented in Figure 34. The selectivity functions are consistent with the model parameterisation and the comparative age compositions. For the BT fishery, there is a high level of uncertainty associated with the selectivity of the older age classes (20 years or more). This is of particular significance given that the fishery selectivity is linked to the only series of abundance indices included in the assessment model (BT CPUE indices).

There is also considerable uncertainty regarding the selectivity of the older age classes in the *James Cook* trawl survey (Figure 34). Consequently, these data are unlikely to be very informative regarding the level of exploitation of the fishery prior to the period of the trawl survey (early 1970s) and, hence are unlikely to be informative regarding the magnitude of the initial biomass (SB_0).

The BPT fishery selectivity is constrained by the logistic parameterisation (Figure 34). Therefore, the age composition data from the fishery may be informative regarding the age structure of the population and the overall magnitude of fishing mortality in the period preceding the sampling. The sensitivity of the assessment model to the BPT age composition data set is investigated in Section 6.2.3.

The ascending limb of the logistic selectivity of the VesselX fishery is relatively uncertain, reflecting the variability in the age compositions from the two age samples (Figure 34).

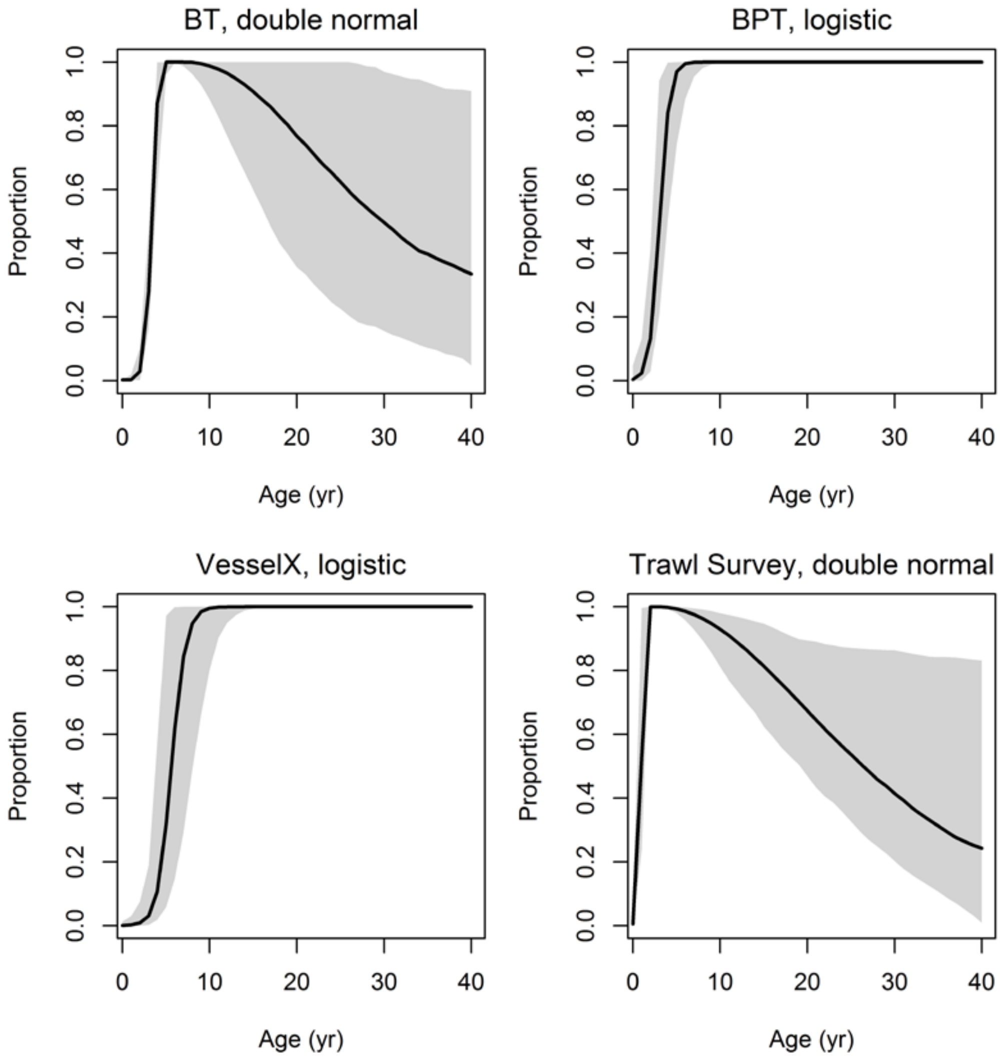


Figure 34: Age specific selectivity functions estimated for each fishery and trawl survey from the KM-NTB base assessment model. The lines represent the median of the McMC samples and the grey shaded area represents the 95% confidence interval.

For the base model, recruitment deviates were estimated for the 1970–2008 years only (Figure 35). A period of low recruitment was estimated for 1974–84. Recruitment was also estimated to be low for the 1991–93, 1997 and 2004–05 year classes and high for the 1985–87 and 2006–08 year classes. The recruitment estimates for the 2006–08 year classes were poorly determined.

For the base model, the variation in the estimated recruitment deviates (std. dev = 0.33) is considerably less than the assumed variation (*SigmaR* 0.6). The input data are uninformative regarding the value of *SigmaR* and attempts to estimate the parameter were unsuccessful, i.e. the models failed to converge.

Spawning biomass was estimated to have declined from 1960 to 2000, remained relatively stable during the 2000s and then increased slightly from 2010 to 2014 (Figure 36). The upper bound of the spawning biomass level is relatively poorly determined.

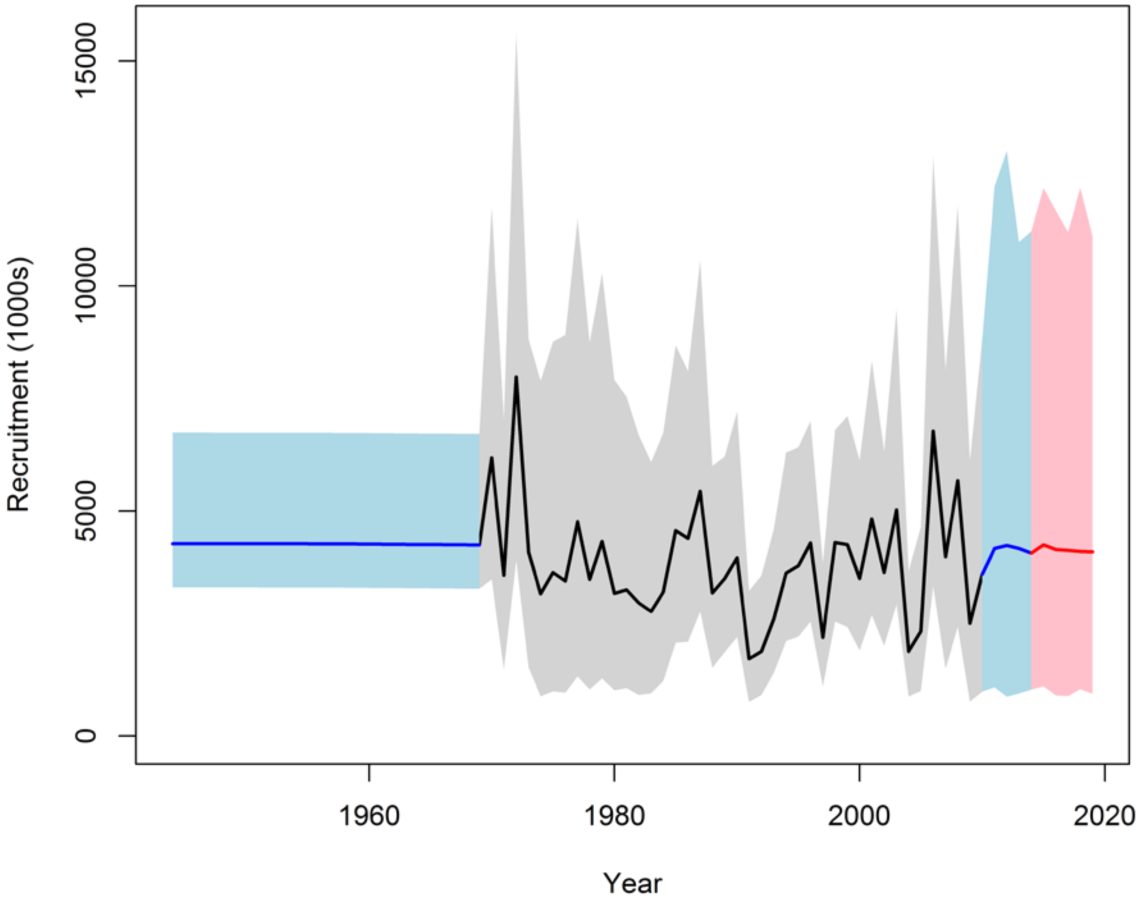


Figure 35: Estimates of annual recruitment (numbers of fish) from the KM-NTB base assessment model. The line represents the median of the McMC samples and the shaded area represents the 95% confidence interval. The grey time block represents the period for which recruitment deviates are estimated. The blue time blocks correspond to years within the model period for which recruitment deviates were not estimated. The red time block represents the 5-year forecast (projection) period.

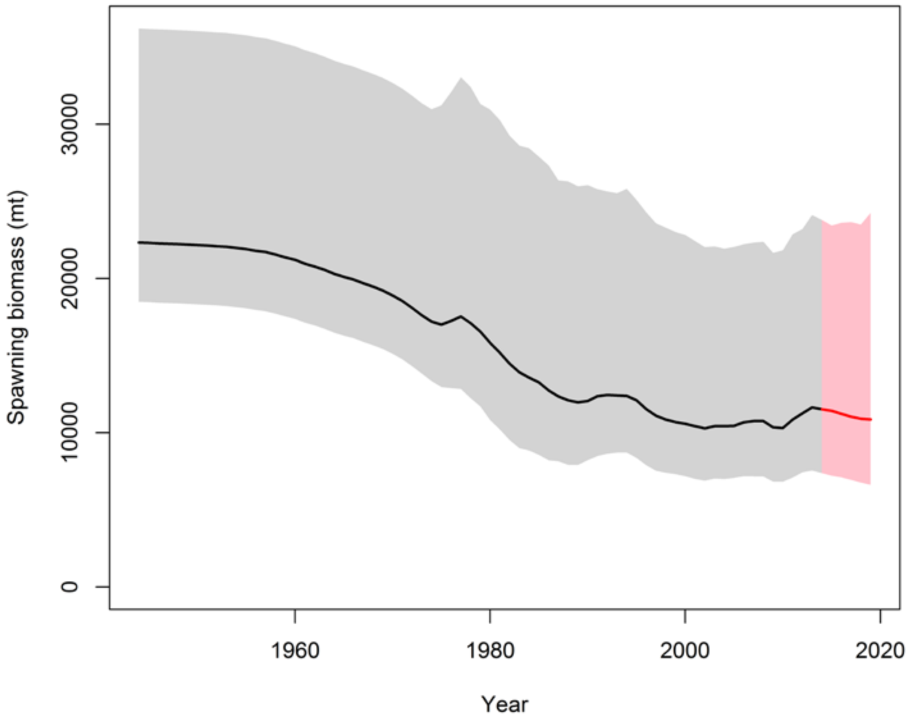


Figure 36: Estimates of female spawning biomass (t) from the KM-NTB base assessment model. The line represents the median of the McMC samples and the shaded area represents the 95% confidence interval. The red time block represents the 5-year forecast (projection) period.

6.2 Model sensitivity analyses

6.2.1 Natural mortality

Previous assessments of TRE 7 have highlighted the value of natural mortality (*M*) as a key source of uncertainty. For the current assessment, the equation of Hoenig (1983) was used to derive an alternative value of *M* of 0.083 based on an inflated maximum age of 50 years (from a maximum age of 45 years used by Hanchet 1999) (*Low M* sensitivity run). The lower value of *M* resulted in a slight deterioration in the fit to both the CPUE indices and the age composition data compared to the base assessment model (Table 9).

The lower value of natural mortality resulted in a slightly lower estimate of SB_0 and a somewhat higher level of stock depletion compared to the base assessment model (Figure 37).

Table 9: Model log likelihoods for the base model and selected sensitivity runs.

Model	Likelihood component		
	Total	CPUE indices	Age comp
Base	28.61	-32.16	60.62
Low *M*	30.39	-31.79	61.57
Steepness 0.70	28.91	-32.18	60.83
BT selectivity	29.75	-31.86	61.23
AllCatch	27.19	-32.78	59.96

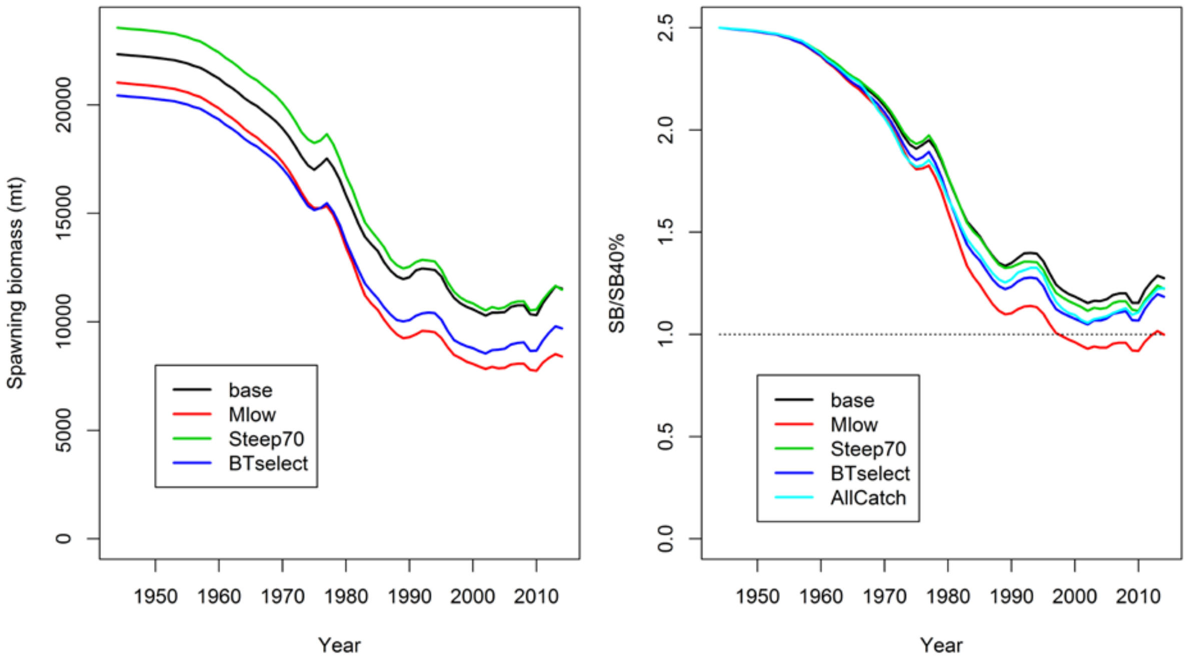


Figure 37: A comparison of the biomass trajectories from the KM-NTB base assessment model and the main model sensitivity runs (median of McMCs). The dashed horizontal line in the right panel represents the default target biomass level.

For comparative purposes, the base assessment model was applied to determine a likelihood profile for natural mortality (with intervals of 0.05). The probability distribution derived from the likelihood profile has a mode of 0.120 and an approximate 95% confidence interval of 0.085–0.145 (Figure 38).

This point estimate of *M* is considerably higher than estimates of *M* derived from previous assessment models (McKenzie 2008, Langley & Maunder 2009). The variation in estimates of *M* from different assessments probably indicates that the estimates of *M* are sensitive to the structural assumptions of the individual models, especially selectivity and relative weighting of the individual data sets.

An examination of the various components of the model likelihood obtained from the *M* likelihood profile (Figure 39) indicates that the estimate of the higher value of *M* (0.120) is being informed by the recent CPUE indices. The lower bound of the *M* probability distribution is essentially constrained by the BPT age composition data. The upper bound of the probability distribution of *M* is constrained by the trawl survey age composition data; however, given that these data are from a limited time period and are fitted in the model with a relatively flexible selectivity function it seems unlikely that these data have any information regarding natural mortality. On that basis, it appears likely that the likelihood profile is being influenced by the initial parameterisation (priors) of the selectivity function of the trawl survey. The CPUE indices are more consistent with higher values of natural mortality (Figure 39), skewing the likelihood profile towards higher values of *M*.

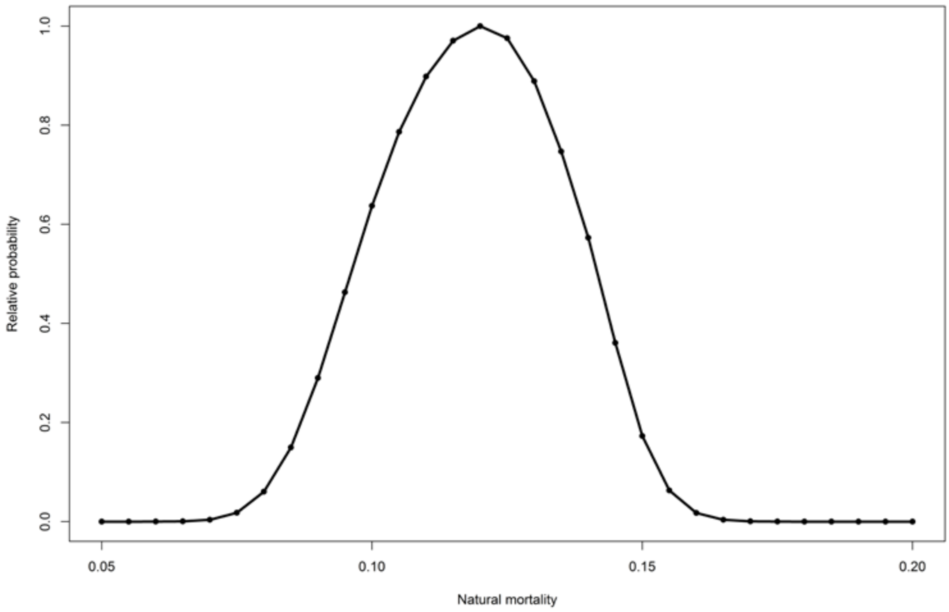


Figure 38: Probability density for natural mortality (M) determined from a likelihood profile using the base assessment model.

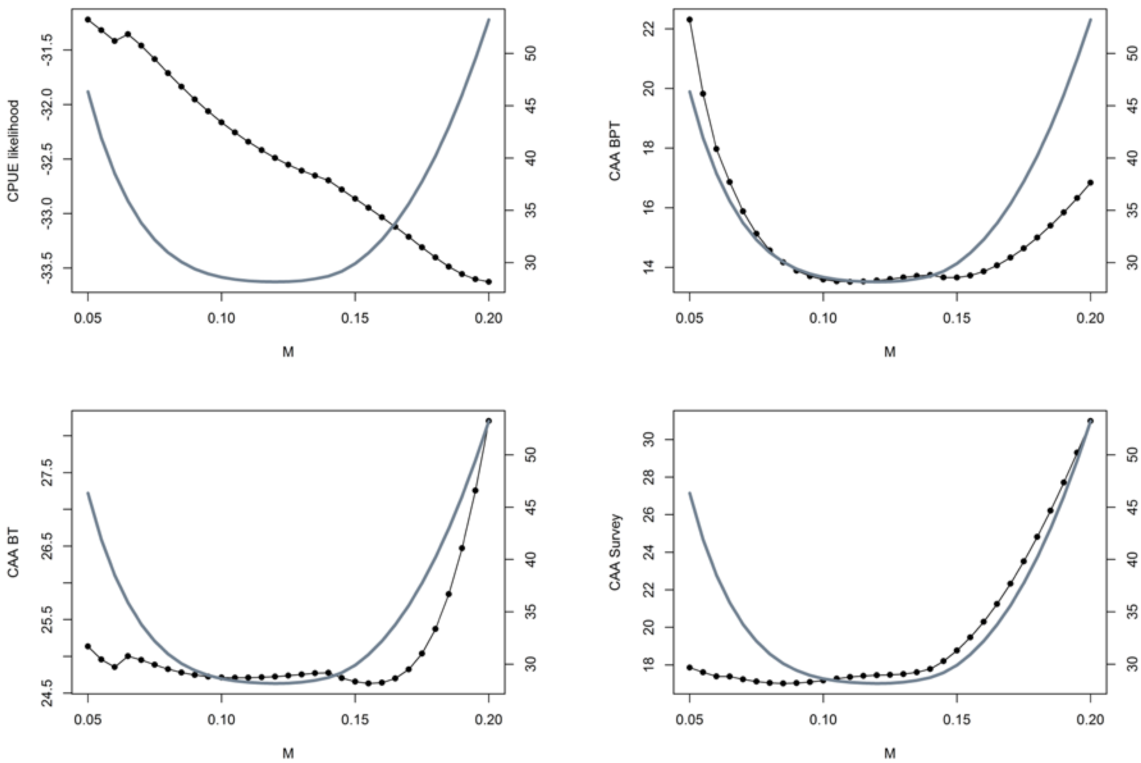


Figure 39: Model likelihood profiles of natural mortality for the individual components of the likelihood (points) and the overall (total) likelihood (grey line).

6.2.2 SRR Steepness

An additional sensitivity run was conducted that assumed a lower value of steepness (h = 0.70) of the SRR than the base assessment model (h = 0.85). There was no appreciable difference in the fit to the CPUE indices and age composition data with the alternative value of steepness (Table 9). The biomass trajectory from the steepness sensitivity run is comparable to the base model (Figure 37).

6.2.3 BT fishery selectivity

As noted in Section 6.1.1, the estimated selectivity function for the BT fishery is sensitive to the initial values of the parameters that determine the relative selectivity of the older age classes (p4 and p6). The sensitivity of the model results to the BT selectivity parameters was investigated by setting the initial prior values to correspond to a relatively high (80%) selectivity for the oldest age classes (i.e. p4=Norm(7,2), p6=Norm(2,1.5)) (*BTselect*).

This estimated BT selectivity for the *BTselect* model was consistent with the new prior values and resulted in a slight deterioration in the fit to the CPUE indices and the age composition data sets (Table 9) with the model tending to slightly over-estimate the proportion of fish in the oldest age classes from the BT fishery. The high selectivity of the older age classes resulted in a reduction in the overall magnitude of the virgin and current stock biomass (Figure 37).

6.2.4 Relative weighting of key data sets

The influence of the various data sets was examined by varying the relative weighting of various data components in turn. The model was relatively insensitive to the weighting of the recent BT age composition data; reducing the ESS by an order of magnitude (ESS/10) resulted in minimal change to the biomass trajectory (Figure 40). By contrast, the model was relatively sensitive to the weighting assigned to the three BPT age compositions sampled from the fishery in 1998, 1999 and 2001. In the base model, these observations were assigned an ESS of 20. Down-weighting these data by assigning an ESS of 2 resulted in a substantial increase in virgin biomass (SB_0) and reduced the overall level of depletion of the stock (from about 50% to about 30%) (Figure 40). Conversely, increasing the weighting of these three observations (ESS 200) resulted in a smaller decrease in the overall biomass level compared to the base model (*UpWtAgeBPT* model option).

The fishery has an associated logistic selectivity function and, consequently, the proportion of fish in the accumulated (20+) age class is informing the model regarding the level of fishing mortality in the period prior to 1998–2001, given the specified value of natural mortality (0.1).

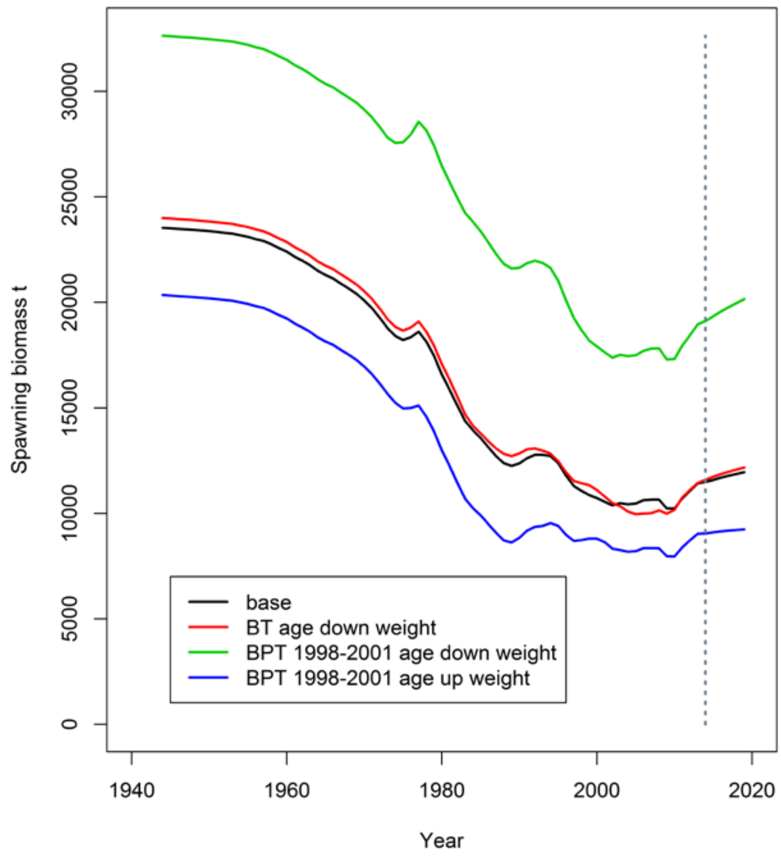


Figure 40: A comparison of the biomass trajectories from the KM-NTB base assessment model (base) and model options with different weightings associated with key data components (MPD fits). The dashed vertical line represents the start of the five year forecast period.

6.2.5 Additional sensitivity runs

There is some concern regarding the reliability of the recent CPUE indices. The CPUE indices increased from about 2006/07 and there is some indication that the operation of the fishery changed at that time with an increase in the degree of targeting of trevally. These operational changes may be related to the reduction in the SNA 8 TACC in 2005/06. It is unknown whether the CPUE standardisation has adequately accounted for the changes in the operation of the SNA/TRE trawl fishery. The sensitivity of the model results to the recent CPUE indices was investigated by increasing the CV associated with the 2007–2013 indices from 16% to 30%, essentially down weighting the influence of these observations (*CPUEcv2007*).

The *CPUEcv2007* model sensitivity run did not estimate a recent increase in stock biomass to attempt to fit the higher CPUE indices from 2011–2013. Consequently, current (2014) biomass was estimated to be lower than for the base assessment model. The biomass trajectory for the period prior to 2005 was comparable to the base assessment model.

The base model encompasses the KM-NTB sub-area only. The spatial partitioning of the sub-areas within TRE7 was based on the observed differences in the spatially stratified CPUE indices and age composition data from the bottom trawl fisheries. However, it is conceivable that the observed differences in the age compositions among the three areas are at least partly attributable to sampling variability in each area; this may be particularly the case for the STB sub-area as indicated by the low precision associated with the age composition data (see Appendix 3). In general, strong year classes identified in the KM-NTB age compositions were typically also evident in the age compositions from the other two areas. The lower proportion of younger fish in the NMB age compositions could indicate a difference in the selectivity of the bottom trawl fishery between the two areas which could also account for the higher variability in the CPUE indices from NMB compared to KM-NTB. CPUE indices from STB differ considerably from the other two areas from 2005/06 onwards, although fishing effort was relatively low during that period and, consequently, the reliability of the CPUE indices for the STB area is probably quite low.

Therefore, it is conceivable that the spatial partitioning of the base assessment model (i.e. KM-NTB area only) may be overly restrictive and not adequately represent the spatial domain of the main TRE 7 stock. Thus, an additional model option was configured that included the additional catch from the NMB and STB sub-areas within the base model (*AllCatch*). The *AllCatch* model was equivalent in structure in all other respects to the KM-NTB base model (i.e. CPUE indices and age composition data from the KM-NTB area only). The main utility of the *AllCatch* model is to provide estimates of yield that are consistent with the wider TRE 7 fishstock, rather than just the KM-NTB area. Yield estimates are approximately 50% higher for the *AllCatch* model which is consistent with the historical catch history from the TRE 7 fishery; i.e. approximately two thirds (62%) of the entire TRE 7 catch was taken in the KM-NTB area.

6.3 Stock status

The stock status of the KM-NTB component of TRE 7 has been assessed relative to a default target biomass level of 40% SB_0 and associated soft limit and hard limit of 20% and 10% of SB_0 (Ministry of Fisheries 2008). Stock status conclusions are informed by the assessment results from models that are primarily based on the core area of the TRE 7 fishstock i.e. the KM-NTB subarea.

The base assessment model estimated that the spawning biomass was reduced considerably during the 1970s and 1980s although the stock remained above the target biomass level throughout that period (Figure 41). The spawning biomass level stabilised during the late 1990s and 2000s (at about 50% SB_0) and there is a low probability that the biomass declined below the target biomass during that period. The spawning biomass is estimated to have increased from 2010 to 2014 and the base model estimates that current biomass (SB_{2014}) is above the target biomass level. Correspondingly, there is no risk that the stock has approached either the soft or hard biomass limit (Table 10).

The overall stock status from the main model sensitivity analyses is comparable to the base model, although the status is somewhat less optimistic for the *Low M* sensitivity run (Table 10). For the *Low M* sensitivity run, current biomass was estimated to be at about the target biomass level with no associated risk that the stock biomass has approached the biomass limit reference points.

Estimates of equilibrium yield for the KM-NTB sub-area are about 1500 t, although the upper bound of the yield estimates are not well determined (range 1300–2900 t) (Table 10). The yield estimates are generally comparable to the recent level of catch from the KM-NTB sub-area (1378 t average 2011–13, including non commercial catch).

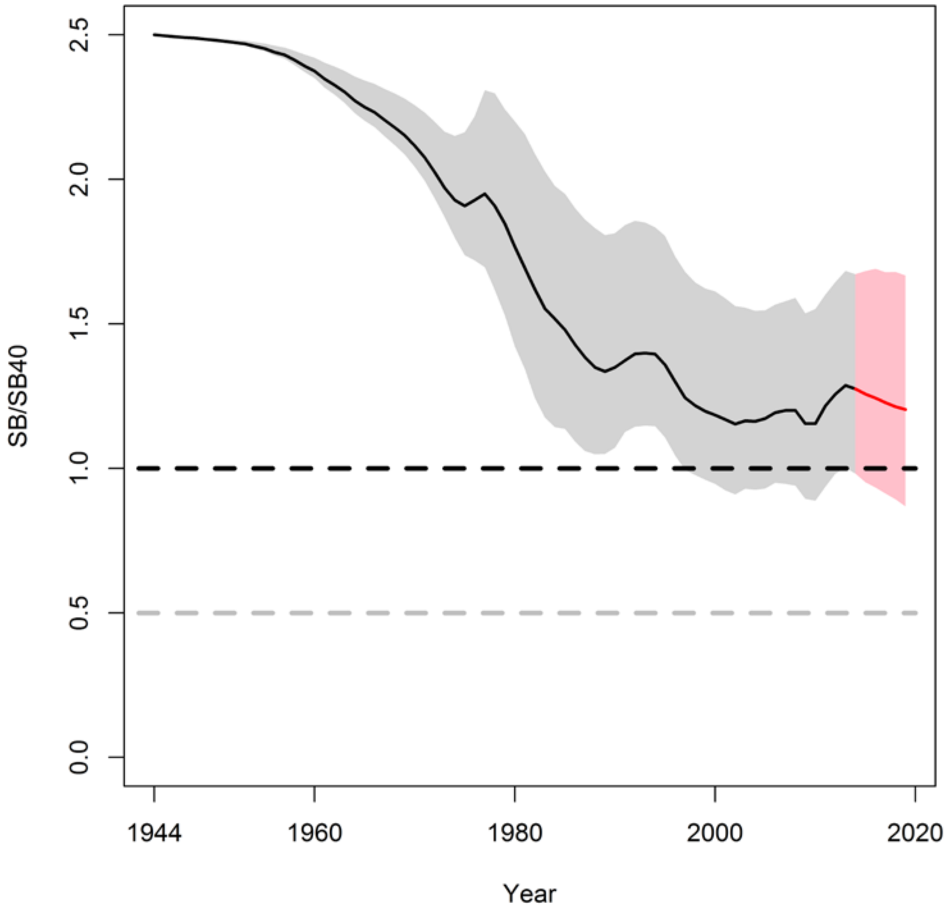


Figure 41: Spawning biomass relative to the default target spawning biomass reference point from the KM-NTB base assessment model. The solid line represents the median of the McMC samples and the shaded area represents the 95% confidence interval. The red time block represents the 5-year forecast (projection) period. The black and grey dashed lines represents the default target and soft limit biomass reference point, respectively.

The trends in fishing mortality for the base assessment model generally reflect the spawning biomass trajectory. Fishing mortality rates increased from 1960 and reached a peak in 1981–82 (Figure 42). Fishing mortality rates were lower during the mid-late 1980s and 1990s and then returned to approach the higher level during the 2000s. Nonetheless, fishing mortality rates are estimated to have remained below the fishing mortality rate that corresponds to the target biomass level (i.e. $F_{SB40\%}$) throughout the model period (Figure 42). Current fishing mortality levels are estimated to be below the $F_{SB40\%}$ level for all model options, with the exception of the Low *M* sensitivity run which estimates that current fishing mortality is at approximately the reference level (Table 11).

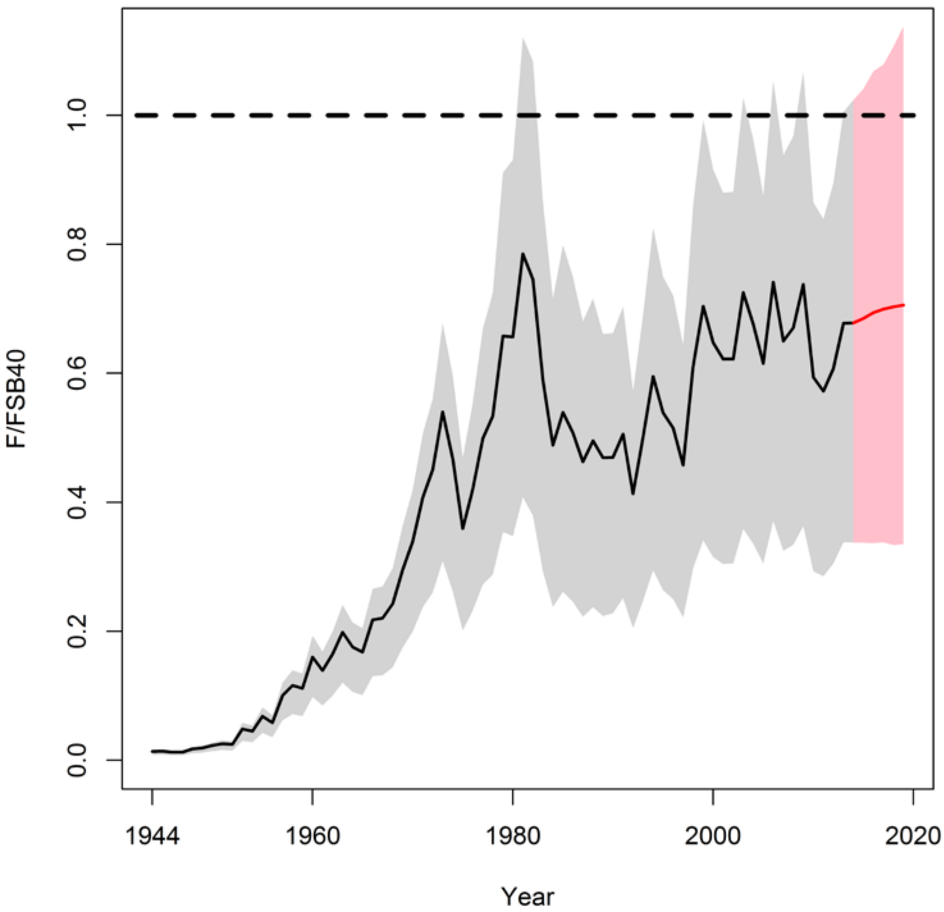


Figure 42: Annual fishing mortality relative to the level of fishing mortality that corresponds to the default target spawning biomass from the KM-NTB base assessment model. The line represents the median of the McMC samples and the shaded area represents the 95% confidence interval. The red time block represents the 5-year forecast (projection) period.

Five year stock projections were conducted using the catch from the terminal year of the model data period (2014). The projected annual catch of 1525 t is slightly higher than the catch from the preceding years (2010–12) but is below the equilibrium yield estimated for the base model. For the base model, the spawning biomass is projected to decline (by 6%) during the projection period, although there remains a very low probability that the biomass would decline below the target biomass level (Figure 41 and Table 12). There is a corresponding small increase in the fishing mortality rate during the projection period (Figure 42).

The stock forecast is very similar for the lower SRR steepness and BT select model sensitivity runs. Projected stock status is somewhat less optimistic for the Low M sensitivity run with a higher probability that the stock would decline below the target biomass level while still remaining well above the biomass soft limit at the end of the projection period (2019) (Table 12).

Projections were also conducted for the entire TRE 7 fishstock using the *AllCatch* model. In this case, two options were considered for catches during the projection period 1) annual catches equivalent to the catch from the total catch in the terminal year of the model data period (1942 t) and 2) annual catches equivalent to the current TACC (2153 t) with an additional allowance for non commercial catch (2235 t). For both levels of catch, the stock is maintained above the target biomass level throughout the projection period (Table 12).

Table 10: Current (2014/15) stock status relative to default target ($SB_{40\%}$) and probability of current biomass being above default limit biomass reference levels for the base model and model sensitivity runs. Model results are limited to the KMNTB area of TRE 7, except for the *AllCatch* sensitivity run which represents the entire TRE 7 area.

Model run	SB_0	SB_{2014}	$SB_{40\%}$	$SB_{40\%}$ Yield	SB_{2014}/SB_0	$SB_{2014}/SB_{40\%}$	Pr(SB_{2014} > X%SB_0)		
							10%	20%	40%
Base	22 339	11 526	8 935	1 818	0.510	1.275	1.000	1.000	0.961
	(18 493–36 213)	(73 84–23 808)	(7 397–14 485)	(1 523–2 910)	(0.393–0.669)	(0.982–1.672)			
M low	21 026	8 399	8 410	1 455	0.399	0.998	1.000	1.000	0.492
	(18 692–26 268)	(5 774–13 446)	(7 477–10 507)	(1 296–1 773)	(0.305–0.525)	(0.762–1.313)			
Steep70	23 557	11 483	9 423	1 666	0.489	1.224	1.000	1.000	0.899
	(19 723–39 933)	(7 384–26 688)	(7 889–15 973)	(1 402–2 743)	(0.368–0.682)	(0.92–1.704)			
BTselect	20 436	9 698	8 174	1 678	0.474	1.184	1.000	1.000	0.909
	(17 787–27 121)	(6 708–16 116)	(7 115–10 848)	(1 465–2 182)	(0.371–0.619)	(0.927–1.549)			
AllCatch	34 363	16 873	13 745	2 782	0.49	1.226	1.000	1.000	0.931
	(29 348–50 375)	(11 247–32 361)	(11 739–20 150)	(2 384–4 008)	(0.381–0.66)	(0.951–1.649)			

Table 11: Estimates of target fishing mortality ($F_{SB40\%}$) and current fishing mortality (F_{2014}) relative to the target level (medians, with 95% confidence intervals in parentheses) for the base model and sensitivity runs. Estimates are derived from MCMC analysis. Model results are limited to the KMNTB area of TRE 7, except for the *AllCatch* sensitivity run which represents the entire TRE 7 area.

Model run	$F_{SB40\%}$	$F_{2014}/F_{SB40\%}$	$Pr\ (F_{2014}<F_{SB40\%})$
Base	0.088 (0.084–0.090)	0.678 (0.338–1.024)	0.969
M low	0.077 (0.074–0.079)	1.067 (0.690–1.517)	0.365
Steep70	0.077 (0.074–0.080)	0.776 (0.351–1.183)	0.851
BTselect	0.089 (0.086–0.091)	0.796 (0.490–1.120)	0.902
AllCatch	0.087 (0.084–0.090)	0.591 (0.319–0.862)	0.999

Table 12: Stock status in the terminal year (2018/19) of the five year forecast period for the base model and main model sensitivity runs. For each option, the total annual projected catch (t), including an allowance for non commercial catch, is also presented.

Model option	Projected catch (t)	SB_{2019}/SB_0	Pr(SB_{2019} > X%SB_0)		
			10%	20%	40%
Base	1 525	0.481 (0.347–0.667)	1.000	1.000	0.851
M low	1 525	0.363 (0.253–0.508)	1.000	0.997	0.308
Steep70	1 525	0.456 (0.314–0.669)	1.000	1.000	0.765
BTselect	1 525	0.445 (0.324–0.605)	1.000	1.000	0.746
AllCatch (TACC projection)	2 235	0.478 (0.355–0.659)	1.000	1.000	0.863
AllCatch (2013 catch projection)	1 942	0.494 (0.374–0.671)	1.000	1.000	0.924

7. DISCUSSION AND MANAGEMENT IMPLICATIONS

The current assessment model is similar in structure to the previous TRE 7 assessment (Langley & Maunder 2009). The main differences are the addition of two years of age composition data from the bottom trawl fishery (2010 and 2013) and the extension of the time series of CPUE indices (to include 2009–13). The new model also restricts the spatial domain of the assessment to encompass the KM-NTB sub-area only, whereas the previous assessments encompassed the entire area of TRE 7. Correspondingly, estimates of virgin biomass (SB_0) from the current assessment model are somewhat lower (approximately 30% less) than for the previous (2009) assessment model. Nonetheless, estimates of recent biomass relative to SB_0 are very similar for the two assessments (about 50% SB_0). Equilibrium yield estimates for the current assessment (about 1500 t) are lower than the previous assessment (about 2500 t) reflecting the reduced spatial domain of the current assessment (and correspondingly lower historical catches).

As mentioned, the current assessment model is limited to the KM-NTB sub-area of TRE 7. The available CPUE indices and age composition data sets reveal considerable variability amongst the defined sub-areas of TRE 7. These differences may be attributable to different processes influencing the stock dynamics in the individual sub areas and limited mixing of the population amongst sub-areas. An assessment model encompassing the entire area of TRE 7 assumes a single homogeneous stock. The observed spatial heterogeneity in stock structure has the potential to introduce biases in a stock-wide assessment if there are temporal trends in the distribution of catch, fishing effort and/or the collection of age sampling data. There is potential to account for some of the spatial processes in a spatially stratified assessment model. However, exploratory modelling revealed that there are insufficient data available from across the TRE 7 sub-areas to reliably estimate key model parameters to inform a spatially stratified model (e.g. recruitment distribution and movement parameters).

The KM-NTB sub-area accounted for 69.4% of the total TRE 7 catch from 2011–13 and a substantial proportion of the historical TRE 7 catch. Given the high proportion of the total TRE 7 catch taken within the KM-NTB sub-area, it is reasonable to base management advice for the overall TRE 7 stock on the KM-NTB assessment model. The primary purpose of the *AllCatch* model, including the entire catch from TRE 7, was to provide a relatively simple model option to evaluate the sustainability of the overall level of TRE 7 catch and the current TACC. The model is primarily informed by the abundance trend within the KM-NTB sub-area. It is important to continue to monitor the proportion of the catch taken from each of the three sub-areas to ensure that current assumptions regarding stock status remain valid.

The TRE 7 stock assessment is highly dependent on the reliability of the CPUE as an index of stock abundance. Analyses of the detailed location-based catch and effort data revealed an apparent increase in the directed targeting of trevally from about 2006. This effect was partially removed from the KM-NTB standardised CPUE indices by excluding the dominant fishing vessel from the final analysis. However, in recent years the single vessel has accounted for a substantial proportion of the TRE 7 catch from KM-NTB and the amount of catch and effort data from the remainder of the fleet has also reduced. Future development of the TRE 7 stock assessment should further refine the standardised CPUE analysis to account for changes in targeting behaviour. It may also be necessary to partition the CPUE indices by time period to account for recent changes in the overall operation of the fishery.

Despite refinements to the CPUE indices and age composition data included in the final assessment model, there remains some indication of a conflict between the two main data sources, particularly in the latter years (2010 and 2013). This may indicate that apparent changes in targeting behaviour were not adequately accounted for in the standardised CPUE analysis and/or there has been a shift in fishery selectivity towards older fish. The triennial frequency of the age sampling means that it is difficult to make strong inferences regarding changes in the age composition of the catches, particularly given the relatively low precision of the estimates of proportion at age for the KM-NTB fishery (MWCVs approximately 40% for 2010 and 2013). Improving the precision of the age composition data may require an increase in sampling intensity within the KM-NTB area and/or a more structured approach to the sampling amongst the fleet (e.g. VesselX and other vessels). Nonetheless, it is crucial that routine age sampling of the commercial catch is maintained to determine the sensitivity of the assessment model to different assumptions regarding the reliability of the two main data sets (CPUE indices and age compositions).

The age composition data from the BPT fishery from 1998–2001 are relatively influential in determining the overall level of stock depletion and, correspondingly, estimates of SB_0 and current stock status. These data have relatively limited information regarding the age structure of the oldest fish in the population as the age compositions have been derived with an aggregating age class (“plus group”) of 20 years. Future assessments should review the age sampling data and endeavour to extend the range of age classes included in the age compositions (to at least 30 years).

Further, the age composition data from the earlier BPT sampling should also be reviewed. Comprehensive sampling was conducted in 1978 and 1979. However, the age compositions from the two years are inconsistent with each other and, consequently, the assessment models were not able to adequately fit these observations and these data were substantially down-weighted in the final model runs. It may be possible to account for some of the differences between the two age compositions by examining the variation in the length/age structure amongst the individual sampled landings, particularly in relation to the seasonal and/or spatial distribution of the sampled landings.

The assessment was reviewed and accepted by the Fishery Assessment Plenary in May 2015.

8. ACKNOWLEDGMENTS

This study was funded by the Ministry for Primary Industries under research project TRE2013-02. Cameron Walsh (Stock Monitoring Services) working in conjunction with NIWA provided a time-series of revised age composition data from the commercial fishery. This additional ageing work was conducted under funding from MPI. Members of the Northern Inshore Fishery Assessment Working Group provided input during the development of the standardised CPUE indices and assessment modelling.

9. REFERENCES

Francis, M.P.; Bradford, E.; Paul, L.J. (1999). Trevally catch per unit effort in TRE 7. New Zealand Fisheries Assessment Research Document 99/13. 28 p. (Unpublished document held by NIWA library, Wellington.)

Francis, M.P.; Paul, L.J. (2013). New Zealand inshore finfish and shellfish commercial landings, 1931–82. *New Zealand Fisheries Assessment Report 2013/55.* 140 p.

Francis, R.I.C.C. (2011). Data weighting in statistical fisheries stock assessment models. *Canadian Journal of Fisheries and Aquatic Sciences* 68: 1124–1138.

Hanchet, S.M. (1999). Stock assessment of trevally *(Caranx georgianus)* in TRE 7. New Zealand Fisheries Assessment Research Document 99/55. 27 p. (Unpublished report held in NIWA library, Wellington.)

Hoenig, J.M. (1983). Empirical use of longevity data to estimate mortality rates. *Fishery Bulletin* 82: 898–903.

James, G.D. (1984). Trevally, *Caranx georgianus* Cuvier: age determination, population biology, and the fishery. *Fisheries Research Bulletin 25.* 52 p.

Kendrick, T.H.; Bentley, N. (2010) Fishery characterisation and catch-per-unit-effort indices for trevally in TRE 7; 1989–90 to 2007–08. *New Zealand Fisheries Assessment Report 2010/41.* 58 p.

Langley, A.D. (2002). Length and age composition of trevally in commercial landings from TRE 1 and TRE 7, 2000–01. *New Zealand Fisheries Assessment Report 2002/19.* 34 p.

Langley, A.D. (2009). Length and age composition of trevally in commercial landings from TRE 1 and TRE 7, 2005–06. *New Zealand Fisheries Assessment Report 2009/31.* 23 p.

Langley. A.D. (2014). Updated CPUE analyses for selected South Island inshore finfish stocks. *New Zealand Fisheries Assessment Report 2014/40*. 116 p.

Langley, A.D.; Maunder, M. (2009). Stock assessment of TRE 7. *New Zealand Fisheries Assessment Report 2009/49.* 42 p.

McKenzie, A. (2008). Standardised CPUE analysis and stock assessment of the west coast trevally fishery (TRE 7). *New Zealand Fisheries Assessment Report 2008/44*. 74 p.

Maunder, M.N.; Langley, A.D. (2002). Stock assessment of trevally *(Pseudocaranx dentex)* in the TRE 7 fishery. (Unpublished report held by Ministry for Primary Industries, Wellington.)

Methot, R.D. (2013). User manual for Stock Synthesis, model version 3.24f.

Methot, R.D.; Wetzel, C.R. (2013). Stock synthesis: A biological and statistical framework for fish stock assessment and fishery management. *Fisheries Research 142:* 86–99.

Ministry of Fisheries (2008). Harvest Strategy Standard for New Zealand Fisheries. October 2008. http://fs.fish.govt.nz/Doc/16543/harveststrategyfinal.pdf.ashx

Ministry for Primary Industries (2014). Fisheries Assessment Plenary, May 2014: stock assessments and stock status. Compiled by the Fisheries Science Group, Ministry for Primary Industries, Wellington, New Zealand. 1381 p.

Walsh, C.; McKenzie, J.M. (2009). Review of length and age sampling for trevally in TRE 1 and TRE 7 from 1997–98 to 2002–03. *New Zealand Fisheries Assessment Report 2009/14.* 56 p.

Walsh, C.; McKenzie, J.M.; Bian, R.; Buckthought, D.; Armiger, H.; Ó Maolagáin, C. (2014). Length and age composition of commercial trevally landings in TRE 7, 2012–13. *New Zealand Fisheries Assessment Report 2014/66.* 51 p.

Walsh, C.; McKenzie, J.M.; Buckthought, D.; O Maolagain, C.; Bian, R. (2012). Length and age composition of commercial trevally landings in TRE 7, 2009–10. *New Zealand Fisheries Assessment Report 2012/41*. 51 p.

Walsh, C; McKenzie, J; Ó Maolagáin, C; Stevens, D (1999) Length and age composition of trevally in commercial landings from TRE 1 and TRE 7, 1997–98. *NIWA Technical Report* 66.

APPENDIX 1. STANDARDISED CPUE INDICES FOR THE KM-NTB FISHERY SUB-AREA

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

Fishing	Weibull			Binomial			Combined		
year	Index	LCI	UCI	Index	LCI	UCI	Index	LCI	UCI
89/90	2.777	2.304	3.337	1.123	1.054	1.174	3.106	2.557	3.738
90/91	1.484	1.240	1.780	0.862	0.737	0.975	1.273	1.010	1.579
91/92	1.223	1.031	1.435	0.979	0.876	1.063	1.191	0.965	1.421
92/93	0.891	0.757	1.049	0.966	0.870	1.047	0.856	0.710	1.015
93/94	1.240	1.053	1.447	0.954	0.859	1.042	1.177	0.970	1.411
94/95	1.066	0.902	1.245	0.910	0.791	1.009	0.965	0.777	1.169
95/96	1.039	0.886	1.222	0.843	0.719	0.946	0.871	0.691	1.082
96/97	0.875	0.751	1.016	0.946	0.842	1.032	0.823	0.679	0.982
97/98	0.816	0.700	0.944	0.954	0.855	1.038	0.774	0.644	0.919
98/99	0.951	0.816	1.108	1.057	0.980	1.120	0.999	0.844	1.172
99/00	0.772	0.659	0.896	0.989	0.892	1.071	0.760	0.622	0.914
00/01	0.727	0.614	0.850	0.930	0.824	1.016	0.673	0.555	0.817
01/02	0.829	0.710	0.963	0.970	0.868	1.060	0.799	0.659	0.947
02/03	0.937	0.801	1.091	0.940	0.836	1.029	0.876	0.717	1.050
03/04	0.799	0.679	0.938	0.977	0.878	1.064	0.777	0.641	0.930
04/05	0.649	0.545	0.771	0.951	0.853	1.040	0.614	0.493	0.741
05/06	0.794	0.665	0.943	1.097	1.023	1.157	0.866	0.711	1.039
06/07	0.842	0.701	0.998	0.795	0.662	0.911	0.665	0.519	0.836
07/08	0.883	0.745	1.039	1.050	0.962	1.123	0.921	0.771	1.100
08/09	0.738	0.621	0.870	1.129	1.059	1.180	0.829	0.695	0.989
09/10	0.870	0.678	1.104	0.950	0.779	1.082	0.821	0.597	1.068
10/11	1.038	0.815	1.286	1.191	1.128	1.233	1.230	0.961	1.537
11/12	0.902	0.715	1.109	1.211	1.149	1.247	1.086	0.852	1.339
12/13	0.858	0.692	1.058	1.228	1.178	1.257	1.047	0.840	1.297

APPENDIX 2. MCMC DIAGNOSTICS FOR BASE MODEL

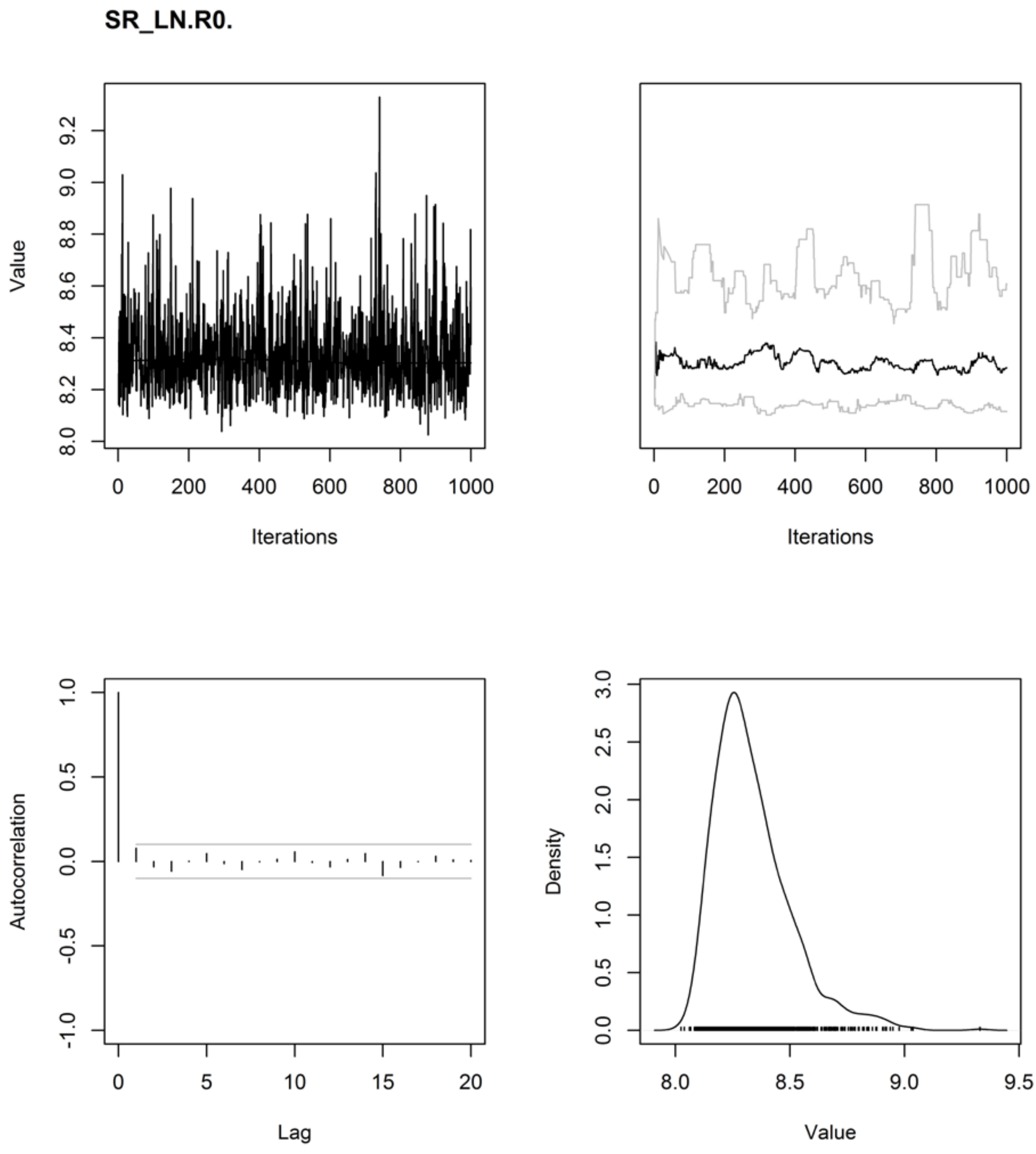


Figure A1: Diagnostic plots for the McMC draws for the Ln*R0* parameter of the base KM-NTB assessment model.

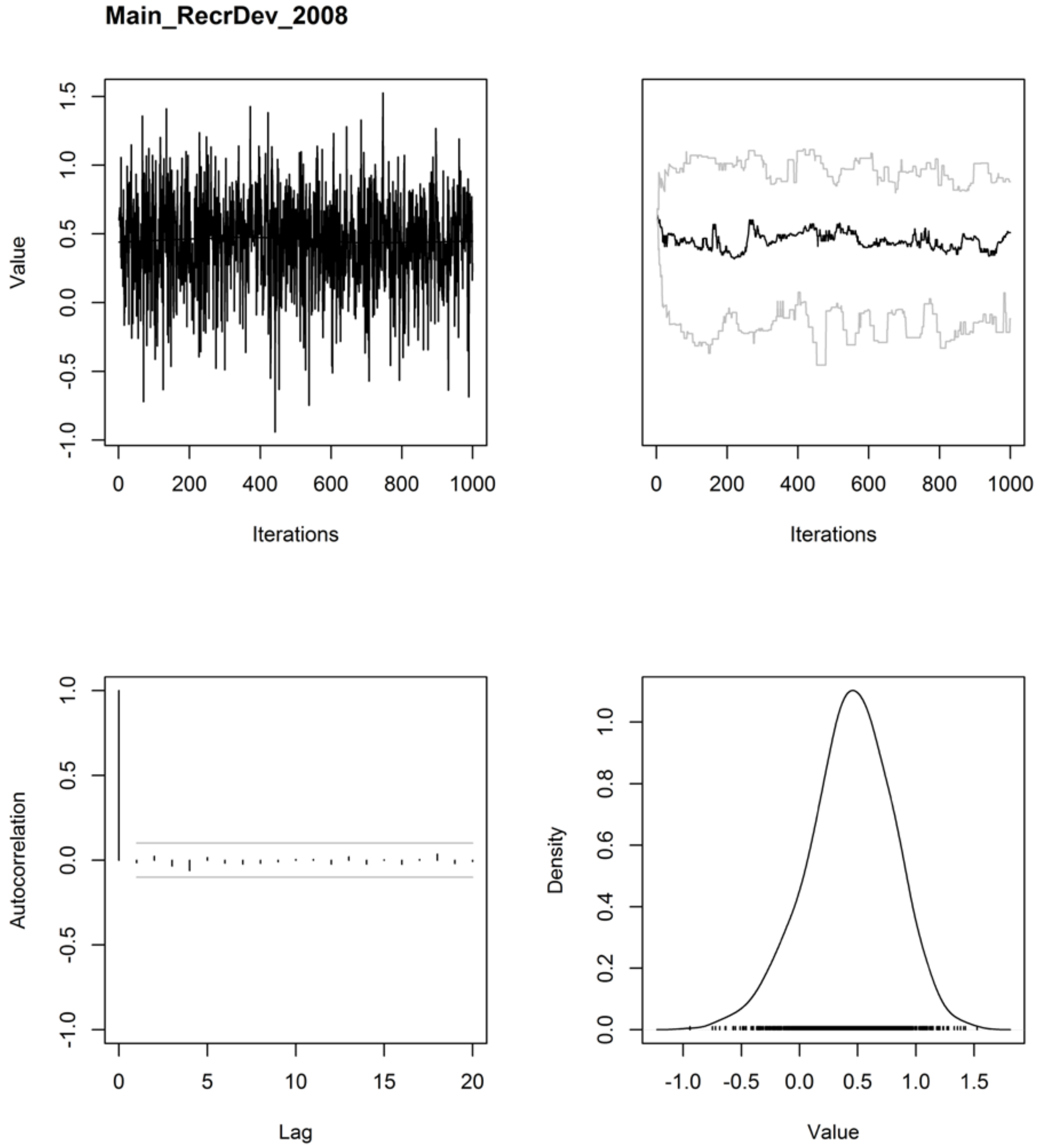


Figure A2: Diagnostic plots for the McMC draws for the 2008 recruitment deviate parameter of the base KM-NTB assessment model.

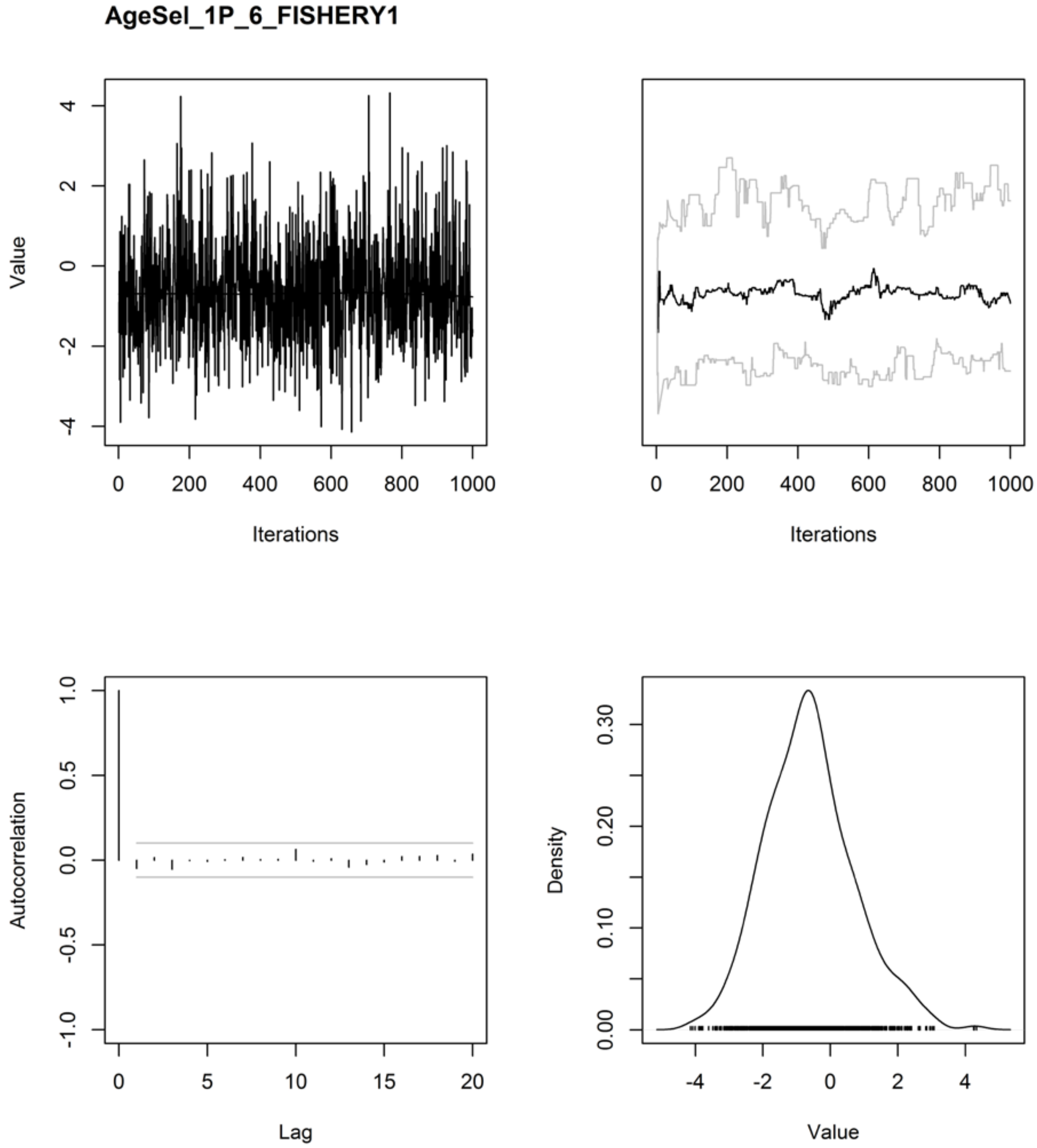


Figure A3: Diagnostic plots for the McMC draws for the key BT selectivity parameter of the base KM-NTB assessment model. The selectivity parameter determines the proportion selected for the oldest age class.

APPENDIX 3. ADDITIONAL AGE COMPOSITION DATA FROM THE TRE 7 FISHERY

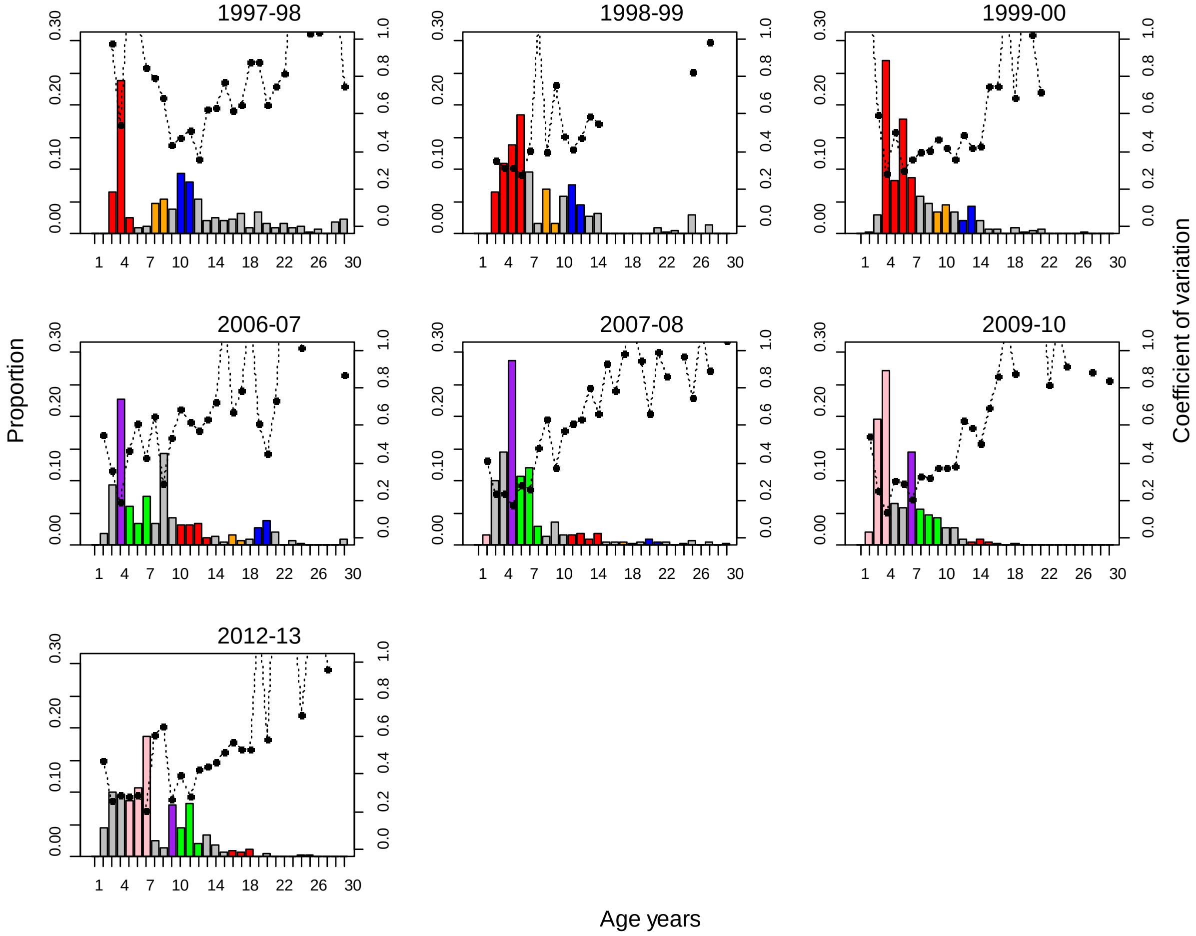


Figure A4: Proportional age compositions of the commercial catch from the Ninety Mile Beach (NMB) bottom trawl (BT) fishery. The points represent the coefficient of variation associated with the estimates of proportion at age. The different colours represent periods of relatively strong recruitment inferred from the KM-NTB age composition data.

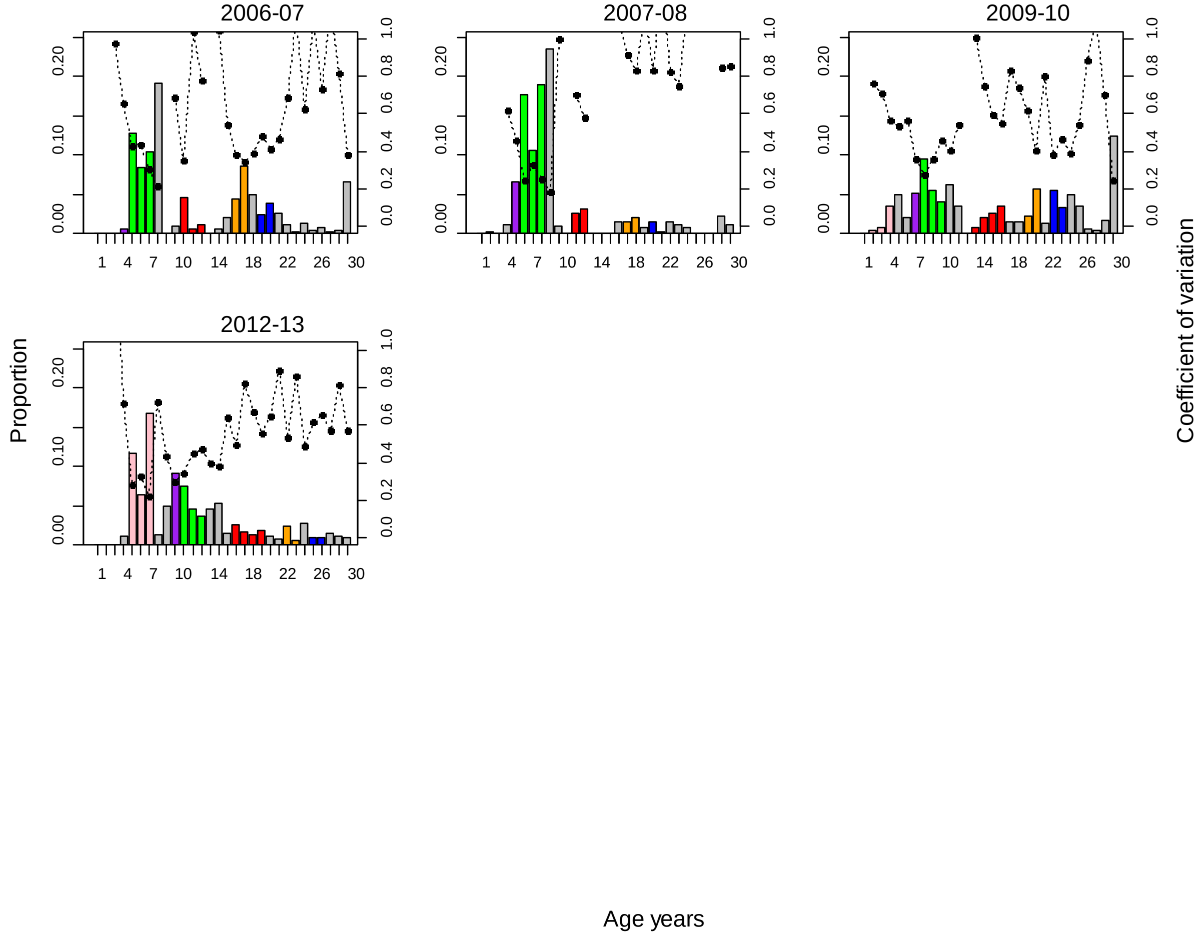


Figure A5: Proportional age compositions of the commercial catch from the South Taranaki Bight (STB) bottom trawl (BT) fishery. The points represent the coefficient of variation associated with the estimates of proportion at age. The different colours represent periods of relatively strong recruitment inferred from the KM-NTB age composition data.

APPENDIX 4. SPATIALLY DISSAGGREGATED MODEL FOR TRE 7

Stock Synthesis has the flexibility to implement spatially stratified population models. The spatial dynamics are parameterised by defining separate model regions and assigning specific fisheries to the relevant model region. The proportion of the annual recruitment that is apportioned to each region is determined and movement parameters are configured to allow age-specific movement amongst the model regions. There is also flexibility in the parameter estimation to enable temporal variation in the regional processes. A two region model was formulated for the two northern sub-areas in TRE 7 (KM-NTB and NMB).

The proportion of fish moving between two specified areas is parameterised as an age-specific function with differential movement for younger and older fish and a linear transition between the respective ages. The exploratory spatial models developed for TRE 7 assumed inflection points of the age specific movement at ages 4 and 8 years. No movement was assumed to occur until the age of 3 years. The ages were chosen to correspond to the approximate age of maturity for trevally. Initial model options included non informative prior constraints on the movement parameters.

The spatial distribution of the total recruitment is estimated as a separate parameter for each model area ($RecrDist\_Area_x$). Temporal variation in the relative proportion of the total recruitment in each area is estimated using temporal deviates about the $RecrDist\_Area_x$ parameter (Methot 2013). For the exploratory models, temporal deviates for the $RecrDist\_Area_x$ parameters were estimated for the period that encompassed the year classes included in the recent BT age samples from the two sub-areas (NMB and KM-NTB) (1975–2010).

The selectivity of the BT fishery was assumed to be equivalent between the two model areas. Similarly, the BPT fishery selectivity was assumed to be equivalent amongst the areas.

There are no data available to explicitly estimate the movement dynamics amongst the model areas (such as tagging data). The resultant estimates of movement and the spatial recruitment distribution simply represent the best overall fit to the range of data included in the model, primarily the CPUE indices and age composition data. Consequently, the resultant models frequently produced stock dynamics that were unrealistic compared to our understanding of the biology of the species.

No data were available to formulate priors for the individual movement parameters or the proportion of recruitment in each area. Instead, the distribution of commercial catch was used to inform the model regarding the relative distribution of biomass in each area. This was implemented by scaling the area specific CPUE indices by the proportion of the total TRE 7 catch taken in the area during 1970–1982 (NMB 28%, KM-NTB 50%). This period was selected on the basis that it encompassed the peak in the fishery catch and it occurred prior to the introduction of the QMS. The catchability (q) parameter of the CPUE indices was shared amongst the model areas. This has the effect of constraining the recent (1990–2013) level of recruited biomass in each area by the relative proportion of the catch (during an earlier period). Not surprisingly, the resultant population dynamics, particularly the recruitment distributions, were much more consistent with the assumed distribution of the stock.

The parameterisation of the model was equivalent to the single region KM-NTB model, with the addition of the parameters specified in Table A2. The selectivity of the single trawl and pair trawl fisheries were equivalent between the two regions. The area specific CPUE indices, scaled by historical catch, shared a common catchability coefficient.

Table A2: Region specific model parameters included in the two area model.

Component	Parameter	Value, Priors	
Recruitment	RecrDist-NMB	0	Fixed
	RecrDist-KMNTB	unconstrained	Estimated (1)
	Dist-KMNTB temporal deviates	Deviates, 1975–2010	Estimated (36)
Movement			
NMB to KMNTB	Move_Age1 (≤4yr)		Estimated (1)
	Move_Age2 (≥8yr)		Estimated (1)
KMNTB to NMB	Move_Age1 (≤4yr)		Estimated (1)
	Move_Age2 (≥8yr)		Estimated (1)

Detailed model results are not presented for the two area model as the model is not considered sufficiently reliable to be considered to provide an assessment that is sufficiently robust to inform the management of the northern areas of the TRE 7 fishery. The main model observations are as follows.

- The trend in the CPUE indices from the two areas is comparable from the mid 1990s to the end of the series. There is a declining trend in CPUE from the mid 1990s to the early 2000s followed by an increasing trend in CPUE. The two sets of CPUE indices differ considerably during 1991–95; the CPUE indices from NMB area increase from a relatively low level in 1991–92, while the indices for KM-NTB were relatively high during the period.
- Fishery selectivities estimated for the BT and BPT fleets are very similar to the selectivities estimated for the KM-NTB model.
- A high proportion of the recruitment is estimated to occur in the KM-NTB area (72% of total recruitment). McMCs indicate that this parameter (*RecrDist-KMNTB*) is well determined. This is likely to be due to the effect of scaling the relative magnitude of the CPUE indices from the two areas (and the shared catchability parameter).
- Movement rates are estimated to be negligible for younger fish (4 years and under) and very high for older fish (8 years and over); in each annual time step approximately 70% of the older fish move from NMB to KM-NTB, while 40% of the older fish move from KM-NTB to NMB. The scale of the movement parameter results in virtually complete mixing of the older fish in the population. However, McMCs indicate that the movement rates for the older fish are poorly determined.
- For the 1975–2010 years, trends in annual recruitment are similar for both areas; i.e., the temporal deviates in the spatial distribution of recruitment (*RecrDist-KMNTB* deviates) approximate zero in most years. However, for the 1985–87 period a series of strong positive annual deviates was estimated resulting in a high proportion of the annual recruitment being associated with the KM-NTB area. The overall recruitment deviates (Rec devs) were also high for those three years, resulting in very high recruitment in the KM-NTB area.
- The temporal deviates in the spatial distribution of recruitment (*RecrDist-KMNTB* deviates) are poorly determined and are probably strongly correlated with the movement parameters for fish in the older age classes.
- The temporal trends in the region specific recruitment (and the movement parameters) result in divergent trends in regional biomass during the early 1990s; adult biomass in the KMB-NTB area increases sharply from 1989 to 1991 and then declines during the remainder of the 1990s. In contrast, the low recruitment in the NMB area in 1985–87 means that recruited biomass in the area is low in 1991 and 1992, but then increases to reach a peak in 1995 through the transfer of fish (belonging to the strong 1985–87 year classes) from KMB-NTB.
- The movement parameters and recruitment dynamics (especially the 1985–87 year classes) enable the divergent trends in region specific CPUE indices to be fitted reasonably well by the model. There is also a reasonable fit to the CPUE indices during the subsequent years.
- Overall, there is a reasonable fit to the time-series of age compositions from the NMB and KM-NTB BT fisheries. The BT age compositions from NMB and KMB-NTB have some information to support the presence of strong recruitment of the 1985–87 years classes. However, the year classes

were first sampled in 1998 at age 11–13 years and, hence, the sampling does not span the period when the model predicts the delayed recruitment of these year classes to the NMB fishery (i.e. late 1980s and early 1990s).

- The diagnostics of the sampled McMC chain indicate poor convergence. For key parameters (e.g. *R0*), there is considerable autocorrelation between successive (thinned) values from chain and trends in the running average of the parameters values.
- An additional model option was examined for the two area model that limited the estimation of annual recruitment deviations to 1970–2008 and limited the estimation of the spatial recruitment deviates to 1990–2010. This improved the convergence of the McMC; however, the fit to the CPUE indices was substantially degraded due to the lack of flexibility to estimate differential recruitment between the two areas in the mid 1980s.
- There are a range of limitations of the two region model that mean that it is not sufficiently reliable for the provision of management advice. Nonetheless, the estimates of stock status do not differ substantially from the base KM-NTB model; current (2014) biomass for the two region model was estimated at about 55% of SB_0.

APPENDIX 5. STOCK ASSESSMENT MODEL DATA SETS

Table A3: Annual trevally catch (t) by sub-area (NMB, Ninety Mile Beach; KM-NTB, Kaipara-Manukau-North Taranaki Bight; STB, South Taranaki Bight) and fishing method/fishery (BT, bottom trawl, BPT, bottom pair trawl; Non Comm, non commercial), including unreported and discarded catch. The year represents the fishing year denoted by the year at 1 January (e.g. 2014 represents the 2013/14 fishing year).

Year	NMB		KM-NTB				STB	
	BT	BPT	BT	BPT	VesselX	Non Comm	BT	BPT
1944	9	0	28	0	0	29	2	0
1945	9	0	29	0	0	31	8	0
1946	6	0	20	0	0	33	12	0
1947	6	0	18	0	0	35	24	0
1948	11	0	36	0	0	38	13	0
1949	12	0	39	0	0	40	15	0
1950	16	0	53	0	0	42	34	0
1951	19	0	63	0	0	44	57	0
1952	17	0	56	0	0	46	34	0
1953	47	0	153	0	0	48	33	0
1954	41	0	135	0	0	51	22	0
1955	70	0	228	0	0	53	31	0
1956	56	0	183	0	0	55	65	0
1957	108	0	352	0	0	57	175	0
1958	126	0	411	0	0	59	159	0
1959	119	0	388	0	0	61	230	0
1960	178	0	581	0	0	58	211	0
1961	150	0	489	0	0	61	163	0
1962	178	0	581	0	0	63	172	0
1963	216	0	705	0	0	65	165	0
1964	186	0	606	0	0	67	111	0
1965	175	0	569	0	0	69	209	0
1966	230	0	749	0	0	71	466	0
1967	229	0	747	0	0	74	922	0
1968	251	0	818	0	0	76	873	0
1969	306	0	998	0	0	78	425	0
1970	348	0	1 134	0	0	80	606	0
1971	416	0	1 356	0	0	80	759	0
1972	454	0	1 480	0	0	80	836	0
1973	541	0	1 761	0	0	80	555	0
1974	0	456	0	1 487	0	80	275	275
1975	0	344	0	1 120	0	80	275	275
1976	0	406	0	1 323	0	80	332	332
1977	0	481	0	1 567	0	80	282	282
1978	0	503	0	1 640	0	80	355	355
1979	12	597	39	1 945	0	80	299	299

Table A3 continued.

Year	NMB		KM-NTB				STB	
	BT	BPT	BT	BPT	VesselX	Non Comm	BT	BPT
1980	130	453	422	1 477	0	82	286	286
1981	202	472	660	1 540	0	82	336	336
1982	73	538	237	1 753	0	82	228	228
1983	64	509	165	1 319	0	82	271	271
1984	56	395	146	1 024	0	82	214	214
1985	66	421	171	1 093	0	82	231	231
1986	82	361	213	938	0	82	210	210
1987	197	197	778	244	0	82	303	70
1988	211	210	831	260	0	82	324	74
1989	198	198	782	245	0	82	305	70
1990	117	73	655	384	0	82	427	44
1991	19	40	667	462	0	82	549	400
1992	83	148	784	122	0	82	245	52
1993	367	152	1 068	45	0	82	223	13
1994	452	249	1 039	263	0	82	268	26
1995	565	132	1 038	90	0	82	335	22
1996	347	238	766	278	0	82	380	29
1997	551	15	862	39	0	82	393	1
1998	363	13	1 200	20	0	82	529	0
1999	276	75	1 186	210	0	82	422	0
2000	306	24	938	321	0	82	679	9
2001	145	136	886	315	0	82	416	9
2002	84	32	959	245	0	82	508	0
2003	237	164	1 155	273	0	82	241	0
2004	221	293	1 157	170	0	82	330	6
2005	269	265	915	287	0	82	227	0
2006	143	70	728	299	449	82	286	1
2007	208	80	904	59	308	82	197	0
2008	166	175	813	167	337	82	156	0
2009	322	56	731	260	483	82	185	0
2010	461	97	443	239	507	82	238	0
2011	310	152	524	227	421	82	307	0
2012	442	0	686	0	587	82	199	0
2013	207	0	838	0	605	82	210	0
2014	207	0	838	0	605	82	210	0

APPENDIX 5 contd.

Table A4: Proportional age compositions for KM-NTB bottom trawl (BT) fishery for the main fleet (excluding VesselX). The oldest age class represents an accumulated age class (plus group).

Age (yr)	Fishing year								
	1997/98	1998/99	1999/00	2000/01	2005/06	2006/07	2007/08	2009/10	2012/13
1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2	0.0000	0.0000	0.0014	0.0011	0.0000	0.0000	0.0128	0.0186	0.0198
3	0.0639	0.0971	0.0450	0.0910	0.0402	0.0112	0.0240	0.0307	0.0330
4	0.1614	0.1247	0.3538	0.1044	0.1298	0.1306	0.0550	0.1945	0.0267
5	0.0845	0.1422	0.1672	0.1250	0.1430	0.1045	0.2189	0.0627	0.2006
6	0.0281	0.0851	0.1247	0.1228	0.1315	0.1804	0.1385	0.0408	0.1084
7	0.0197	0.0454	0.0541	0.0564	0.0864	0.0776	0.1295	0.1335	0.1793
8	0.1154	0.0228	0.0081	0.0436	0.1399	0.1246	0.0868	0.0415	0.0221
9	0.1170	0.0895	0.0057	0.0393	0.0417	0.0762	0.0915	0.0623	0.0262
10	0.0465	0.0336	0.0327	0.0390	0.0271	0.0342	0.0712	0.0476	0.0786
11	0.0703	0.0452	0.0427	0.0831	0.0507	0.0470	0.0000	0.0773	0.0516
12	0.0529	0.0827	0.0311	0.0685	0.0423	0.0154	0.0624	0.0878	0.0606
13	0.0637	0.0518	0.0249	0.0293	0.0143	0.0246	0.0349	0.0146	0.0409
14	0.0197	0.0454	0.0180	0.0655	0.0066	0.0326	0.0116	0.0098	0.0107
15	0.0186	0.0306	0.0288	0.0345	0.0286	0.0259	0.0067	0.0496	0.0166
16	0.0296	0.0054	0.0089	0.0197	0.0120	0.0028	0.0009	0.0187	0.0169
17	0.0000	0.0133	0.0000	0.0189	0.0226	0.0241	0.0022	0.0105	0.0249
18	0.0000	0.0150	0.0067	0.0095	0.0232	0.0165	0.0028	0.0024	0.0082
19	0.0515	0.0048	0.0062	0.0000	0.0022	0.0185	0.0074	0.0070	0.0062
20	0.0000	0.0649	0.0052	0.0091	0.0163	0.0108	0.0136	0.0086	0.0110
21	0.0224		0.0010	0.0048	0.0137	0.0102	0.0090	0.0106	0.0107
22	0.0000		0.0117	0.0154	0.0017	0.0049	0.0051	0.0174	0.0000
23	0.0000		0.0033	0.0012	0.0114	0.0044	0.0036	0.0193	0.0037
24	0.0000		0.0052	0.0046	0.0011	0.0040	0.0034	0.0161	0.0023
25	0.0120		0.0010	0.0000	0.0049	0.0025	0.0010	0.0075	0.0024
26	0.0000		0.0011	0.0007	0.0017	0.0005	0.0012	0.0008	0.0125
27	0.0000		0.0000	0.0029	0.0064	0.0048	0.0005	0.0011	0.0037
28	0.0000		0.0005	0.0011	0.0000	0.0009	0.0011	0.0000	0.0042
29	0.0000		0.0000	0.0024	0.0000	0.0032	0.0005	0.0019	0.0014
30	0.0227		0.0110	0.0062	0.0008	0.0073	0.0040	0.0067	0.0167

APPENDIX 5 contd.

Table A5: Proportional age compositions for KM-NTB bottom trawl VesselX fishery. The oldest age class represents an accumulated age class (plus group).

Age (yr)	Fishing year	
	2009/10	2012/13
1	0.0000	0.0000
2	0.0026	0.0016
3	0.0101	0.0114
4	0.0726	0.0152
5	0.0403	0.0878
6	0.0361	0.0480
7	0.1344	0.1114
8	0.0444	0.0167
9	0.0736	0.0185
10	0.0497	0.0951
11	0.1079	0.0810
12	0.1181	0.0895
13	0.0237	0.0633
14	0.0144	0.0200
15	0.0739	0.0182
16	0.0309	0.0272
17	0.0161	0.0588
18	0.0036	0.0199
19	0.0121	0.0206
20	0.0136	0.0179
21	0.0145	0.0293
22	0.0271	0.0011
23	0.0324	0.0115
24	0.0209	0.0096
25	0.0125	0.0065
26	0.0010	0.0387
27	0.0005	0.0071
28	0.0000	0.0152
29	0.0034	0.0050
30	0.0097	0.0542

APPENDIX 5 contd.

Table A6: Proportional age compositions for KM-NTB bottom pair trawl (BPT) fishery. The oldest age class represents an accumulated age class (plus group).

Age (yr)	Fishing year							
	1973/74	1974/75	1975/76	1977/78	1978/79	1997/98	1998/99	2000/01
1	0.0000	0.0002	0.0000	0.0029	0.0105	0.0000	0.0000	0.0000
2	0.1110	0.0616	0.0217	0.0217	0.2358	0.0000	0.0000	0.0000
3	0.0683	0.1045	0.0525	0.1105	0.0618	0.0719	0.1040	0.0282
4	0.0627	0.0936	0.0616	0.0738	0.0988	0.2165	0.1829	0.0534
5	0.0374	0.0749	0.0639	0.0363	0.0224	0.1135	0.1940	0.1113
6	0.0602	0.0528	0.0289	0.0366	0.0384	0.0315	0.1111	0.1356
7	0.0838	0.0674	0.0394	0.0490	0.0267	0.0276	0.0489	0.0669
8	0.0856	0.1076	0.0692	0.0644	0.0157	0.0866	0.0221	0.0581
9	0.0655	0.0631	0.0981	0.0525	0.0267	0.0934	0.0703	0.0656
10	0.0429	0.0470	0.0900	0.0422	0.0161	0.0275	0.0254	0.0552
11	0.0252	0.0233	0.0621	0.0504	0.0042	0.0443	0.0287	0.1042
12	0.0000	0.0047	0.0147	0.0549	0.0142	0.0444	0.0616	0.0539
13	0.3574	0.2993	0.3980	0.0335	0.0217	0.0585	0.0350	0.0264
14				0.0290	0.0252	0.0118	0.0277	0.0687
15				0.0432	0.0149	0.0146	0.0181	0.0368
16				0.0556	0.0248	0.0154	0.0040	0.0290
17				0.0372	0.0049	0.0134	0.0085	0.0133
18				0.0398	0.0152	0.0180	0.0103	0.0139
19				0.0180	0.0260	0.0145	0.0030	0.0065
20				0.0269	0.0250	0.0967	0.0443	0.0755
21				0.0247	0.0245			
22				0.0268	0.0211			
23				0.0144	0.0312			
24				0.0144	0.0381			
25				0.0088	0.0182			
26				0.0097	0.0276			
27				0.0037	0.0240			
28				0.0034	0.0175			
29				0.0042	0.0174			
30				0.0041	0.0172			
31				0.0026	0.0036			
32				0.0011	0.0037			
33				0.0011	0.0068			
34				0.0004	0.0034			
35				0.0000	0.0034			
36				0.0004	0.0000			
37				0.0004	0.0000			
38				0.0004	0.0101			
39				0.0000	0.0034			
40				0.0008	0.0000			

APPENDIX 5 contd.

Table A7:Proportional age compositions for KM-NTB James Cook trawl surveys. The oldest age class represents an accumulated age class (plus group).

Age (yr)	Fishing year		
	1970/71	1971/72	1973/74
1	0.1245	0.0102	0.0789
2	0.0960	0.2221	0.2830
3	0.0379	0.1373	0.1374
4	0.0614	0.0544	0.0988
5	0.0944	0.0956	0.0161
6	0.0643	0.0951	0.0114
7	0.0286	0.0571	0.0496
8	0.0317	0.0396	0.0583
9	0.0357	0.0295	0.0336
10	0.0342	0.0278	0.0248
11	0.0371	0.0340	0.0115
12	0.0588	0.0379	0.0180
13	0.0349	0.0161	0.0066
14	0.0198	0.0145	0.0227
15	0.0432	0.0177	0.0161
16	0.0356	0.0190	0.0181
17	0.0341	0.0198	0.0153
18	0.0164	0.0145	0.0160
19	0.0192	0.0112	0.0155
20	0.0208	0.0047	0.0087
21	0.0061	0.0047	0.0135
22	0.0116	0.0031	0.0113
23	0.0082	0.0015	0.0066
24	0.0104	0.0047	0.0087
25	0.0072	0.0015	0.0041
26	0.0017	0.0000	0.0052
27	0.0063	0.0047	0.0021
28	0.0019	0.0059	0.0000
29	0.0009	0.0064	0.0000
30	0.0171	0.0094	0.0080

APPENDIX 5 contd

Table A8:Proportional age compositions for Ninety Mile Beach (NMB) bottom trawl (BT) fishery. The oldest age class represents an accumulated age class (plus group).

Age (yr)	Fishing year							
	1997/98	1998/99	1999/00	2000/01	2006/07	2007/08	2009/10	2012/13
1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2	0.0000	0.0000	0.0039	0.0000	0.0192	0.0157	0.0216	0.0455
3	0.0651	0.0662	0.0297	0.0789	0.0939	0.0998	0.1955	0.1015
4	0.2379	0.1098	0.2702	0.1361	0.2264	0.1457	0.2707	0.0961
5	0.0245	0.1384	0.0831	0.1595	0.0600	0.2863	0.0659	0.0869
6	0.0092	0.1858	0.1777	0.1507	0.0336	0.1081	0.0588	0.1069
7	0.0110	0.0957	0.0870	0.0608	0.0757	0.1203	0.1458	0.1881
8	0.0468	0.0156	0.0581	0.0419	0.0340	0.0291	0.0562	0.0252
9	0.0532	0.0704	0.0479	0.0636	0.1419	0.0138	0.0467	0.0150
10	0.0377	0.0175	0.0332	0.0380	0.0429	0.0373	0.0435	0.0807
11	0.0939	0.0592	0.0461	0.0697	0.0320	0.0168	0.0273	0.0452
12	0.0819	0.0759	0.0344	0.0327	0.0324	0.0160	0.0278	0.0821
13	0.0545	0.0447	0.0210	0.0150	0.0349	0.0179	0.0086	0.0207
14	0.0212	0.0278	0.0436	0.0440	0.0127	0.0093	0.0060	0.0346
15	0.0260	0.0313	0.0216	0.0211	0.0131	0.0174	0.0094	0.0191
16	0.0218	0.0000	0.0066	0.0187	0.0043	0.0050	0.0043	0.0082
17	0.0220	0.0000	0.0066	0.0096	0.0157	0.0048	0.0031	0.0104
18	0.0324	0.0000	0.0010	0.0093	0.0069	0.0052	0.0011	0.0074
19	0.0090	0.0000	0.0089	0.0033	0.0101	0.0038	0.0023	0.0107
20	0.0344	0.0000	0.0023	0.0503	0.0284	0.0062	0.0000	0.0007
21	0.0174	0.0000	0.0057		0.0380	0.0097	0.0000	0.0057
22	0.0088	0.0096	0.0080		0.0208	0.0055	0.0003	0.0004
23	0.0169	0.0026	0.0000		0.0015	0.0057	0.0013	0.0010
24	0.0105	0.0064	0.0000		0.0077	0.0000	0.0007	0.0004
25	0.0118	0.0000	0.0000		0.0030	0.0033	0.0010	0.0030
26	0.0041	0.0294	0.0000		0.0000	0.0081	0.0000	0.0023
27	0.0078	0.0000	0.0023		0.0015	0.0016	0.0000	0.0004
28	0.0000	0.0134	0.0011		0.0000	0.0046	0.0011	0.0013
29	0.0183	0.0000	0.0000		0.0000	0.0000	0.0000	0.0000
30	0.0221	0.0004	0.0000		0.0094	0.0029	0.0010	0.0006