Ministry for Primary Industries
Manatū Ahu Matua

Assessment of the TRE 1 stocks in 2015

New Zealand Fisheries Assessment Report 2016/48

J.R. McKenzie,
D.M. Parsons,
R. Bian
I. Doonan

ISSN 1179-5352 (online)
ISBN 978-1-77665-361-4 (online)

August 2016

New Zealand Government

Growing and Protecting New Zealand

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EXECUTIVE SUMMARY

McKenzie, J.R.; Parsons, D.M.; Bian, R.; Doonan, I. (2016). Assessment of the TRE 1 stocks in 2015.

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Patterns seen in the time-series of catch at-age data from TRE 1 suggest that the Bay of Plenty and East Northland regions of TRE 1 constitute two biological stocks. Correspondence between strong and weak year classes also suggests that the East Northland area of TRE 1 and the northern Ninety Mile Beach area of TRE 7 are likely to be part of the same biological stock.

A catch-per-unit-effort (CPUE) analyses of Bay of Plenty and East Northland trevally bottom trawl fisheries produced contrasting trends for the log-normal (positive catch) and binomial (presence-absence) abundance indices for both stock areas. The likely cause of the disparity was subsequently shown to be a systematic change in the fisher-reporting of small trevally catches over the 20 year series. The Northern Inshore Working Group believed that the potential for bias in the TRE 1 CPUE analyses due to this reporting trend could be mitigated by aggregating the catch and effort data at the trip level; subsequently accepting trip-level CPUE standardised indices for Bay of Plenty and East Northland as being proportional to abundance. An abundance index based on aerial sightings data from the purse seine fishery was derived for the Bay of Plenty. Although this index correlated poorly with the Bay of Plenty trawl index, it was initially believed that this difference may have been due to selectivity differences between purse seine and trawl capture methods.

An age-based total catch-history assessment model for the Bay of Plenty trevally stock was unable to achieve "plausible" assessment results when both the aerial sightings and bottom trawl CPUE abundance indices were fitted or when the model was fitted to the aerial sightings index on its own. The main issue with the aerial sightings index was that it shows a significant drop in Bay of Plenty trevally abundance during the 1980s; however, as this is during a period of relatively low catches compared to the 1970s, the assessment model has difficultly tracking the decline. Without the aerial sightings index the model predicts the Bay of Plenty stock to have steadily rebuilt through the 1980s and beyond to the present day (2013). The Working Group accepted the bottom-trawl-index-only model run as being the most "plausible" but did not endorse this model's stock-status predictions because there had been insufficient time for a thorough exploration of model performance; instead recommending that this be done in a future assessment. The Working Group also recommended that an assessment of the East Northland trevally stock be undertaken the next time TRE 1 is assessed. The working group accepted the trip-based standardised bottom trawl CPUE series as an index of abundance for this stock.

1 INTRODUCTION

Trevally (*Pseudocaranx georgianus* (*formerly dentax*)) is a common coastal species that occurs around the North Island and the north of the South Island. Trevally has a wide disjunct Indo-West Pacific sub-tropical and temperate geographic distribution and is an important commercial fish species in New Zealand and Australia. In New Zealand approximately 3500 t of trevally are commercially harvested each year, mostly by bottom trawl and purse seine methods; estimates of recreational harvest are in the order of 500 t (Ministry for Primary Industries 2015). Trevally fisheries are divided into five Quota Management Areas (QMAs) for fishery management purposes (Figure 1). Virtually all trevally is taken from the three northern QMAs (TRE 1, 2 & 7): with approximately 60% of the annual trevally harvest taken from TRE 7, 30% from TRE 1 and the remaining 10% from TRE 2 (Ministry for Primary Industries 2015.

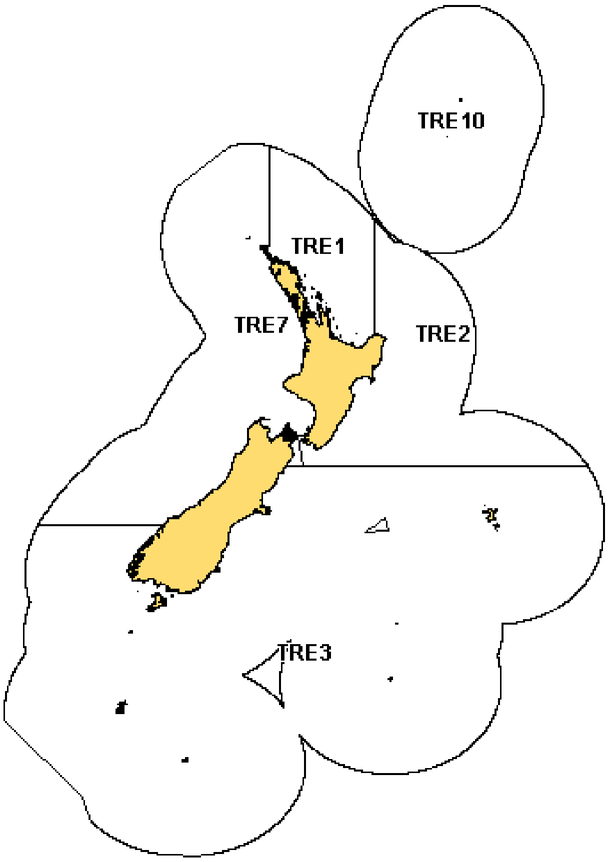


Figure 1: Trevally QMA administrative boundaries.

A commercial harvest limit of 1200 t was established for TRE 1 in 1986 on the basis of two assessments: a stock reduction analysis for the Bay of Plenty trevally fishery in 1984 (Gilbert 1988) which produced Current Surplus Production (CSP) estimates corresponding with a Maximum Constant Yield (MCY) of 400 t; and a MCY estimate of 830 t for East Northland and the Hauraki Gulf derived from average annual commercial catches between 1973 and 1983. By 1993 commercial TRE 1 quotas had increased to 1500 t due to a number of successful quota appeals. An assessment of TRE 1 was attempted in 2006 using an age-based total catch history model (McKenzie 2007). Model inputs were commercial purse seine and single trawl proportion-at-age data and a purse seine aerial sightings abundance index. Although there were issues in fitting the model, the assessment was primarily rejected because of a lack of confidence that the aerial sightings index reflected abundance. Since this rejected assessment there has been concern that the current TRE 1 catch limits are not sustainable as evidenced by falling catches, the progressive loss of older fish from trawl catches over the last 12 years, and a declining trend in aerial sightings of trevally associated with the Bay of Plenty purse seine fishery (Walsh et al. 2012a; Taylor & Doonan 2014b; Ministry for Primary Industries 2015). Further work on the Aerial Sightings index resulted in the revised series being tentatively accepted by the NINSWG as an index of abundance for trevally in the Bay of Plenty in 2012 (Taylor & Doonan 2014b). Recent progress made with methods for deriving indices of abundance from bottom trawl catch and effort data also suggested that it may be possible to derive an accepted index of abundance for TRE 1 stocks from the bottom trawl fisheries.

As such, an assessment of the TRE 1 fishery was commissioned with the specific objective to conduct a stock assessment, including estimating biomass and sustainable yields for trevally in TRE 1. In this document we present: stock definitions for TRE 1 based on catch sampling; a characterisation of the TRE 1 fishery; a Catch per Unit Effort (CPUE) analysis of the commercial bottom trawl fishery; and stock assessments for the component sub-stocks within TRE 1 (including summaries of all the data inputs that went into these assessments such as catch histories and catch at age).

This report meets the final reporting requirement for MPI project TRE2013/01 (Objectives 1–2) as follows:

Objective 1: To collate and update catch histories through to 2012–13 and all observational data series required for the TRE 1 stock assessment;

Objective 2: To conduct a stock assessment, including estimating biomass and sustainable yields for trevally in TRE 1.

2 EVIDENCE OF STOCK SEPARATION IN TRE 1 & 7 FROM CATCH SAMPLING

2.1 Introduction

In this section we review evidence from catch at-age sampling that the TRE 1 & TRE 7 QMAs comprise more than two biological stocks. Catch at-age sampling data from bottom trawl and purse seine methods are available for TRE 1 back to 1998 (see also Section 7). Catch at-age estimates for the 1970s Bay of Plenty purse seine fishery also exist but only as published figures in James (1984) (see also Section 7).

A review of trevally ageing protocols by Walsh & McKenzie (2009) identified inconsistences in the relative year class strength (YCS) in trevally catch at-age data collected prior to 2006–07, and concluded that these inconsistencies were most likely due to ageing error. A more rigorous approach to ageing trevally was adopted in 2006–07 to improve reader accuracy (Walsh et al. 2014d); however, the trevally age material collected prior to 2006–07 has yet to be re-aged, and inconsistences in YCS between these and the later data series are still likely to remain.

In addition to considerations of ageing error, catch-at-age data collected at sufficient spatial resolution to investigate TRE 1 stock structure hypotheses were only collected after 2006. The need to investigate spatial stock structure was a specific factor in the design of the recent programmes (Walsh et al. 2014a & b; Figure 2). Based on four years of catch at-age observations from TRE 7 subareas and three-four from TRE 1 sub-areas, we have investigated the number and likely spatial extent of TRE 1 & 7 sub-stocks. This section presents a stock structure analyses of the post 2006 TRE 1 & 7 catch data series.

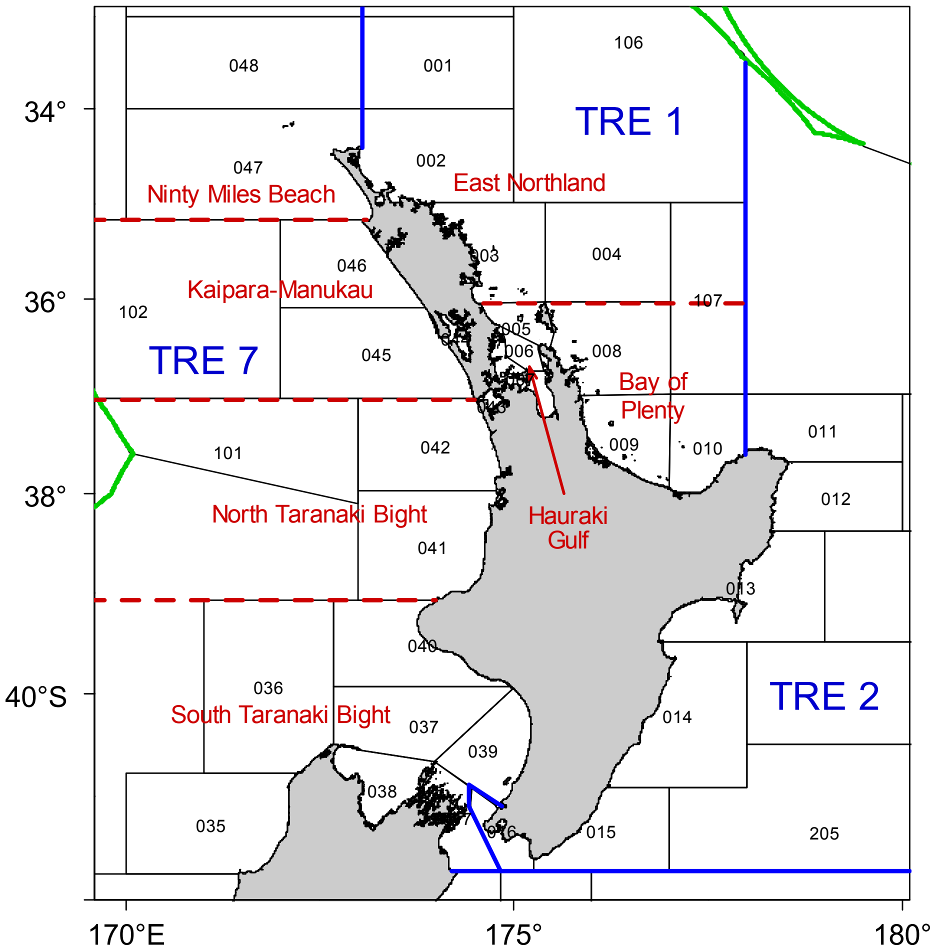


Figure 2: **TRE 1 & 7 catch sampling spatial areas adopted post 2006 (highlighted in red).**

2.2 Methods

2.2.1 TRE 1 and 7 post 2006 catch sampling areas

In TRE 7 four spatial strata are recognised for sampling purpose: Ninety Mile beach (NMB); Kaipara-Manukau (KM); North Taranaki Bight (NTB); and South Taranaki Bight (STB) (Figure 2). Due to difficulties obtaining "clean" area landing samples from KM and NTB areas prior to 2012–2013 (Walsh et al. 2014b), data from these two areas were combined into a broader Kaipara to North Taranaki spatial area (KMNT).

In TRE 1 three spatial areas were recognised: East Northland (ENLD); Hauraki Gulf (HAGU); and Bay of Plenty (BPLE); (Figure 2; Walsh et al. 2014b). Relative to the other two areas, very little trevally catch is taken from the Hauraki Gulf, and it has not been possible to exclusively sample this area. In 2013 a small proportion of East Northland landings had also fished in the Hauraki Gulf, with these trips classified as East Northland. The number of fishing years where area-specific catch at-age data is available from each trevally fishing area is given in Table 1.

Table 1: TRE 1 & 7 area sampled fishing years (denoted by the later calendar year e.g. 2012–13 = 2013).

Stock	Area	Area code	Fishing years sampled
TRE 1	Bay of Plenty	BPLE	2008, 2009, 2013
TRE 1	East Northland	ENLD	2007, 2008, 2009, 2013
TRE 1	Hauraki Gulf	HAGU	Not sampled
TRE 7	Ninety Mile Beach	NMB	2007, 2008, 2010, 2013
TRE 7	Kaipara to North Taranaki	KMNT	2007, 2008, 2010, 2013
TRE 7	South Taranaki Bight	STB	2007, 2008, 2010, 2013
TRE 7	Kaipara to Manukau	KM	2013
TRE 7	North Taranaki Bight	NTB	2013

Catch at age analyses for the areas and years given in Table 1 are published in various Ministry for Primary Industries Fishery Assessment Reports (see Walsh et al. 2009, 2010, 2012a, 2014a). The area specific proportion at-age estimates from these reports were used in the analyses that follow.

2.2.2 Estimating Year Class Strength (YCS)

The published YCS data comprises a proportion and an associated coefficient of variation (CV). For the purposes of combining proportions from different years, published CV's were converted to effective sample sizes, i.e. using multinomial error (Crone & Sampson 1998). Otolith reader precision falls off markedly after age 20 (Walsh et al. 2014d), meaning that year class strength estimates for older ages are likely to be less precise than for earlier ages, so for this reason fish older than 19 years have been excluded from the stock area year-class strength comparisons.

Year class strengths for a given sampling year were expressed as log deviates from a linear regression line fitted to the log proportions (i.e. catch curve following Ricker 1975). Curve fits did not include a plus group age class. The age of 100% selection by the trawl method (amax) was thought to be 4 years; sensitivity to this assumption was tested using amax 3 and amax 5.

The data from each area provides a maximum number of observations of the same year class equivalent to the number of sampling years (Table 2). Increasing or reducing amax by one, likewise increases or decreases the number of year classes available in the comparisons by one, i.e. fewer year class comparisons with amax 5, whereas the greatest number occur under amax 3.

Table 2: Number of catch-at-age year class observations by TRE 1 & 7 sub-areas corresponding to amax 4.

Year Class	BPLE	ENLD	NMB	KMNT	STB	KM	NTB
1988	-	1	1	1	1	-	-
1989	1	2	2	2	2	-	-
1990	2	3	2	2	2	-	-
1991	2	3	3	3	3	-	-
1992	2	3	3	3	3	-	-
1993	2	3	3	3	3	-	-
1994	3	4	4	4	4	1	1
1995	3	4	4	4	4	1	1
1996	3	4	4	4	4	1	1
1997	3	4	4	4	4	1	1
1998	3	4	4	4	4	1	1
1999	3	4	4	4	4	1	1
2000	3	4	4	4	4	1	1
2001	3	4	4	4	4	1	1
2002	3	4	4	4	4	1	1
2003	3	4	4	4	4	1	1
2004	3	3	3	3	3	1	1
2005	2	2	2	2	2	1	1
2006	1	1	2	2	2	1	1
2007	1	1	1	1	1	1	1
2008	1	1	1	1	1	1	1
2009	1	1	1	1	1	1	1

The expected YCS value for a given year-class was the mean of the YCS log deviates for each sampling year, weighted by sample multinomial error.

Two approaches were used to compare YCS signals between areas:

1. Paired area Pearson correlation analysis
2. Paired area likelihood ratio tests

2.2.3 Paired area Pearson correlation analysis

Strong Pearson correlations are expected when the general pattern in mean YCS between areas are similar. Strong positive correlations are denoted by Pearson values close to 1, whereas strong negative correlations (i.e. equal and opposite) are denoted by values close to -1. Positive Pearson correlations in YCS between areas greater than 0.5 would be "moderate" evidence that recruitment patterns are similar Pearson values larger than 0.7 could be considered evidence of "strong" recruitment similarity. However, the 'similarity' conclusion is more conclusively established when the 95% confidence interval on the Pearson correlation value does not include 0 (i.e. no relationship), i.e. i.e. P[Pearson = 0] < 0.05. The Pearson correlation analysis involved running a series of paired comparisons of the expected value YCS indices from each area.

2.2.4 Paired area likelihood ratio tests

Although Pearson correlation is good at testing for similar patterns in expected YCS it can be insensitive to differences in magnitude. For example, year classes being predominately below average (weak) in one series and above average (strong) in another could still result in a strong Pearson correlation.

A likelihood ratio approach suggested by Ian Doonan may better account for differences in YCS magnitude as well as pattern. This approach involves fitting a set of individual YCS parameters to the YCS log-linear deviates using sum of squares. An analogous likelihood ratio test is performed to see if doubling the parameter space to account for area provides a significantly better fit to the combined area set of derived YCS log deviates when area is ignored (Equation 1). The derived SS ratio is assumed to come from a chi-square distribution with equivalent degrees of freedom equal to the number of independent year class strengths compared (Equation 1).

$$-nObs\ Log\left(\frac{SS_{area}}{SS_{all}}\right) \sim \chi^2{}_{df=nYCS}$$

Where:

$nObs$	total number of YCS log deviate observations
$nYCS$	Number of independent year class strengths compared
SS_{area}	Total sum of squares with two area parameters (i.e. 2 × *nYCS* parameters)
SS_{all}	Total sum of squares one combined area parameter (i.e. *nYCS* parameters)

Equation 1

2.2.5 Area mean weight at-age comparisons (growth)

Also available for the catch sampling data series are estimates of mean weight-at-age. Area differences in mean weight-at-age (i.e. growth) were assessed using Tukey paired comparison tests (Tukey 1949).

2.3 Results

2.3.1 YCS comparisons

Plots of the weighted mean YCS deviates (relative to amax 4) show little similarity between the Bay of Plenty and the other TRE 1 & 7 areas (Figure 3). East Northland and Ninety Mile Beach show similar YCS patterns (ups and downs) despite some obvious differences in relative magnitude (Figure 3). KMNT and STB YCS patterns appear dissimilar to those of the other areas (Figure 3).

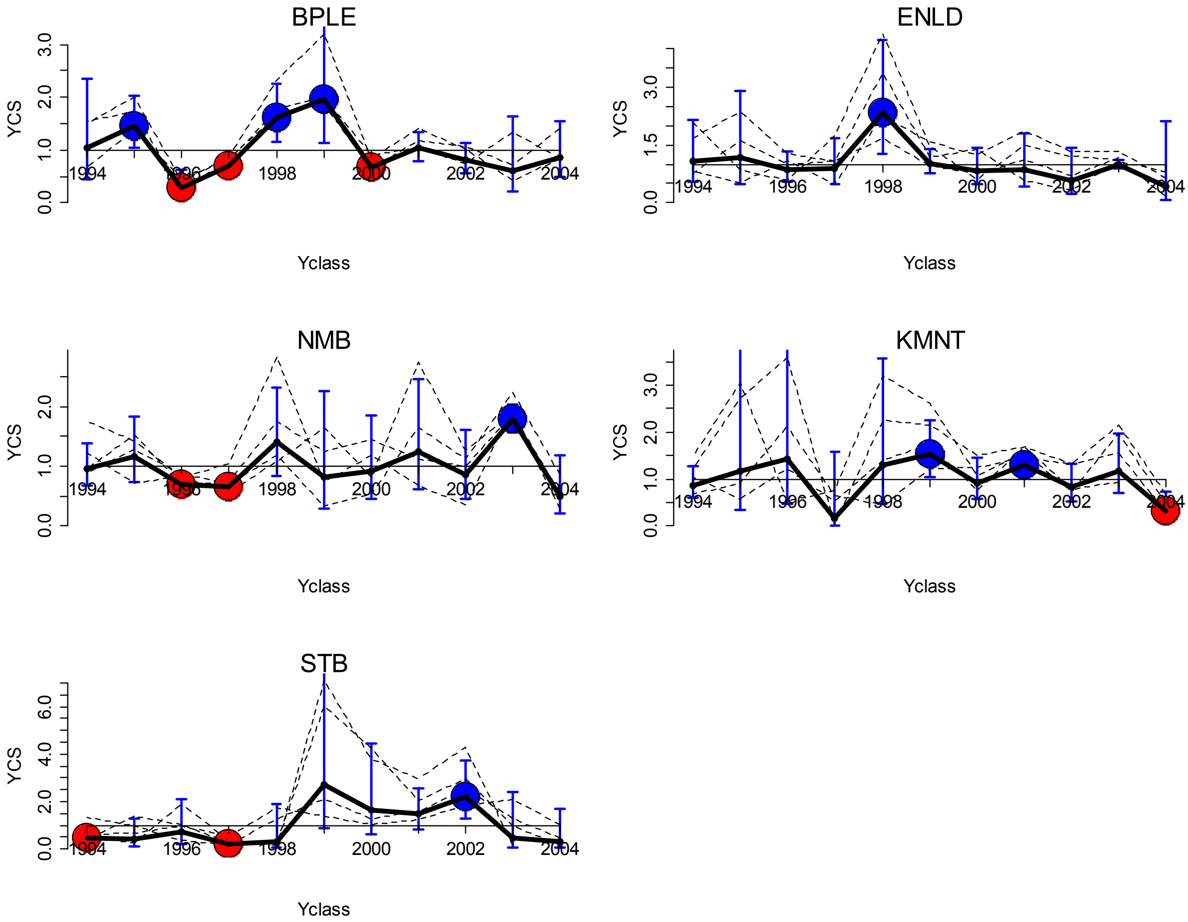


Figure 3: Relative difference in Year Class Strength (YCS) derived from multiple years of single trawl catch-at-age sampling corresponding to amax 4 where there are at least three independent YCS observations. Year class indices are expressed as log deviates from the predicted log-linear catch-at-age decay rate (catch curve) in each sampling year. Dotted lines are the individual year deviates; large dots denote where the 95% CI on the median YCS does not include 1 (i.e. we are 95% confident of the YC being either strong (blue) or weak (red)).

2.3.2 Area Pearson correlation results

Including the Bay of Plenty in the area comparison table required dropping the minimum year class observation limit to 3 as only three years of sampling data were available for this area (Table 2). Correlations based on an amax of 4 failed to produce any significant level of positive YCS correlation between the Bay of Plenty and the other four areas (Table 3).

The correlation matrix suggests that there is a clinal trend in YCS from northern New Zealand, including ENLD down the west coast (Table 3). ENLD correlated strongly with NMB, but not with the lower regions whereas NMB correlated reasonably well with KMNT, but not with STB (Table 3).

Table 3: Pearson correlation of TRE 1 & 7 area YCS indices (1994–2004) derived from bottom trawl catch-at-age sampling corresponding to amax = 4; minimum number of observations = 3; number of year classes compared = 11. P = probability that 95% confidence interval on the Pearson correlation value does not include 0; p values < 0.05 (deemed to be significant correlation) are bolded.

	ENLD	NMB	KMNT	STB
BPLE	0.41 (P<0.21)	0.24 (P<0.47)	0.17 (P<0.63)	0.11 (P<0.76)
ENLD		**0.65 (P<0.03)**	0.44 (P<0.17)	-0.21 (P<0.53)
NMB			**0.6 (P<0.05)**	0.02 (P<0.96)
KMNT				0.52 (P<0.1)

2.3.3 Sensitivity to age of maximum selection (amax)

An amax of 3 allows the inclusion of the 2005 year class into the area correlations under a 3 observation minimum criteria. Again ENLD and NMB areas were significantly correlated under an amax 3 catch curve regression criteria with the down-coast clinal YCS pattern being more pronounced (Table 4).

Table 4: Pearson correlation of TRE 1 & 7 area YCS indices (1994–2005) derived from bottom trawl catch-at-age sampling corresponding to amax = 3; minimum number of observations = 3; number of year classes compared = 12. P = probability that 95% confidence interval on the Pearson correlation value does not include 0; p values < 0.05 (deemed to be significant correlation) are bolded.

	ENLD	NMB	KMNT	STB
BPLE	0.37 (P<0.24)	0.29 (P<0.37)	0.19 (P<0.56)	0.05(P<0.87)
ENLD		**0.75 (P<0.00)**	**0.62 (P<0.03)**	-0.05 (P<0.89)
NMB			**0.75 (P<0.00)**	0.2 (P<0.54)
KMNT				**0.58 (P<0.05)**

An amax of 5 reduced the number of year classes, with the most recent year being 2003. None of the areas were correlated in the amax 5 selection criteria and there was less evidence of a clinal trend as seen in the other amax options (Table 5).

Table 5: Pearson correlation of TRE 1 & 7 area YCS indices (1994–2003) derived from bottom trawl catch-at-age sampling corresponding to amax = 5; minimum number of observations = 3; number of year classes compared = 10. P = probability that 95% confidence interval on the Pearson correlation value does not include 0; p values < 0.05 (deemed to be significant correlation) are bolded.

	ENLD	NMB	KMNT	STB
BPLE	0.52 (P<0.12)	0.27 (P<0.46)	0.17 (P<0.64)	0.02 (P<0.95)
ENLD		0.35 (P<0.33)	0.22 (P<0.54)	-0.56 (P<0.09)
NMB			0.46 (P<0.18)	-0.01 (P<0.98)
KMNT				0.48 (P<0.16)

Changing the amax criterion relative to a three-observation cut-off rule also altered the number of year classes used in the correlations so it is not clear if differences between Tables 3–5 were due to the choice of amax or the number of year-classes included in the correlations. To gain some insight into which of these factors is more likely to be important, correlations were undertaken using amax of 5 with the same 12-year classes (1994–2005) used in the amax 3 correlations; to do this required relaxing the minimum observation criteria to 1. This analysis produced a correlation matrix (Table 6) similar to that produced with amax 3 (see Table 4), thus supporting the hypothesis that the specific years used in the correlations rather than the choice of amax had greater influence on the correlation outcome.

Table 6: Pearson correlation of TRE 1 & 7 area YCS indices (1994–2005) derived from bottom trawl catch-at-age sampling corresponding to amax = 5; minimum number of observations = 1; number of year classes compared = 12. P = probability that 95% confidence interval on the Pearson correlation value does not include 0; p values < 0.05 (deemed to be significant correlation) are bolded.

	ENLD	NMB	KMNT	STB
BPLE	0.35 (P<0.26)	0.13 (P<0.69)	0.11 (P<0.74)	0 (P<1)
ENLD		**0.64 (P<0.02)**	0.49 (P<0.1)	-0.19 (P<0.56)
NMB			**0.66 (P<0.02)**	0.25 (P<0.44)
KMNT				**0.56 (P<0.06)**

2.3.4 Likelihood ratio test for comparing area YCS indices

To include Bay of Plenty again required changing the observational limit on the individual year classes to 3. There was a significant improvement in the likelihood ratio by doubling the parameter space to include area in all area comparisons with Bay of Plenty (Table 7), a conclusion independent of the choice of amax.

Table 7: Bay of Plenty comparisons to other areas based on minimum observation limit of 3. Chi-square probability that area explains a significant level of YCS variation.

Amax	ENLD	NMB	KMNT	STB
3	0.001	0.000	0.000	0.000
4	0.004	0.000	0.002	0.000
5	0.011	0.000	0.006	0.000

Removing Bay of Plenty from the area cross comparisons allowed the number of YCS observations to be increased to 4. The same clinal pattern in YCS similarity as seen in the Pearson correlation tables was also evident in the likelihood ratio test comparisons (Table 8). Unlike the Pearson correlation the likelihood ratio tests were relatively consistent across all values of amax (Table 8).

Table 8: East Northland and TRE 7 area YCS comparisons based on minimum observation limit of 4. Chi-square probability that area explains a significant level of YCS variation. Bold values indicate that "area" is not a significant determinant of YCS variation, i.e. area YCS patterns are not significantly different.

Amax 3

	NMB	KMNT	STB
ENLD	**0.357**	**0.066**	0.000
NMB		**0.081**	0.000
KMNT			**0.054**

Amax 4

	NMB	KMNT	STB
ENLD	**0.363**	**0.076**	0.000
NMB		**0.156**	0.000
KMNT			0.033

Amax 5

	NMB	KMNT	STB
ENLD	**0.674**	**0.079**	0.000
NMB		**0.206**	0.000
KMNT			**0.054**

2.3.5 Area comparisons of 20+ age class proportions

Another way of comparing age class differences between areas is to look at the relative difference in proportion of fish older than 20 years (20+) in the population (Figure 4). The KMNT and STB area samples had markedly higher accumulation of fish in the 20+ age classes compared to the ENLD and NMB areas (Figure 4).

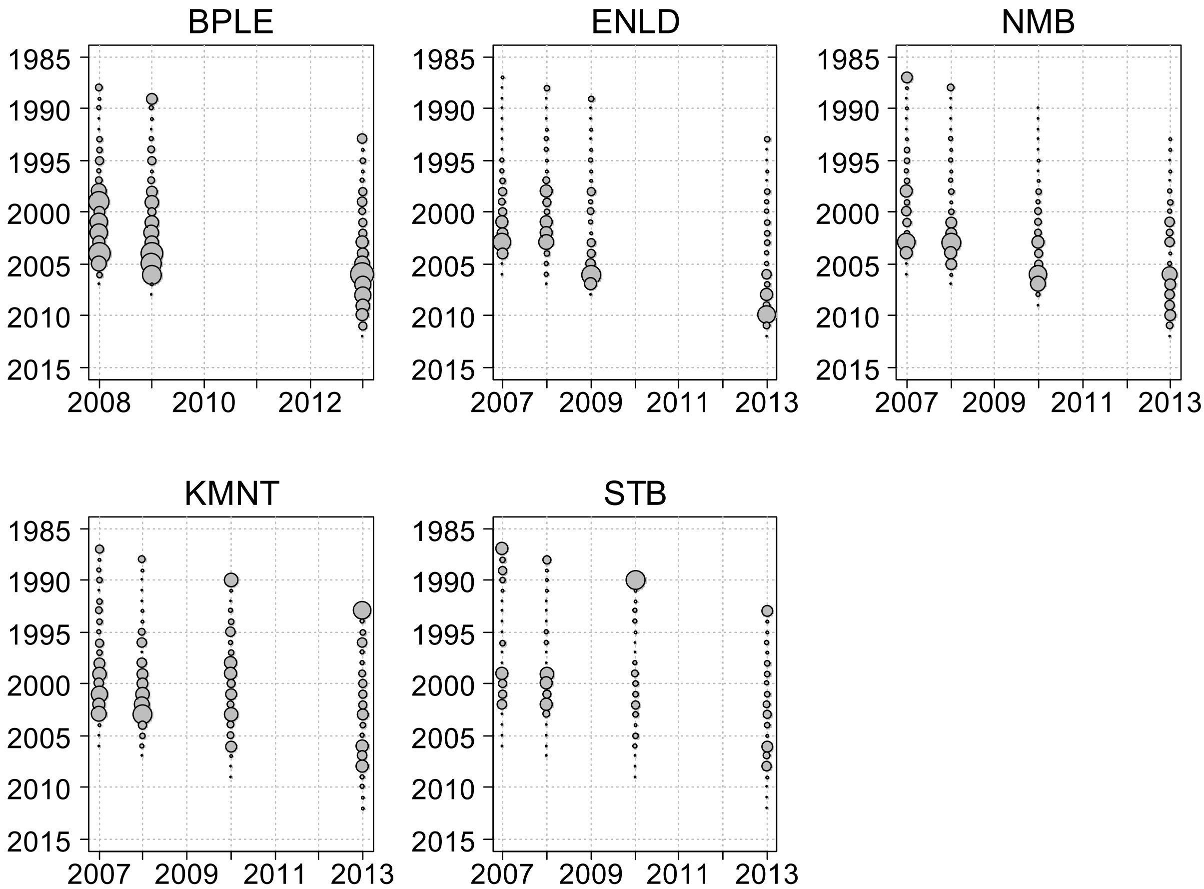


Figure 4: **Time series of proportional age-frequency distributions by year-class (vertical axis) and sample-year (horizontal axis) from the TRE 1 & 7 bottom trawl fishery from 2006–07 to 2012–13. Symbol area is proportional to the proportion at age. The proportion of the oldest year class in each year on the x axis is represented by an aggregate (20+) age group.**

2.3.6 Area patterns in mean weight at-age (growth)

Patterns in mean weight at-age from each area show high variability between sampling years so it is difficult to determine whether growth rates had changed through time (Figure 5). Trevally from the Bay of Plenty area had consistently lower mean weight at-age (growth) than fish from the other regions (Figure 5); however, analysis of variance (ANOVA) was found to be a more informative way to compare area mean weights.

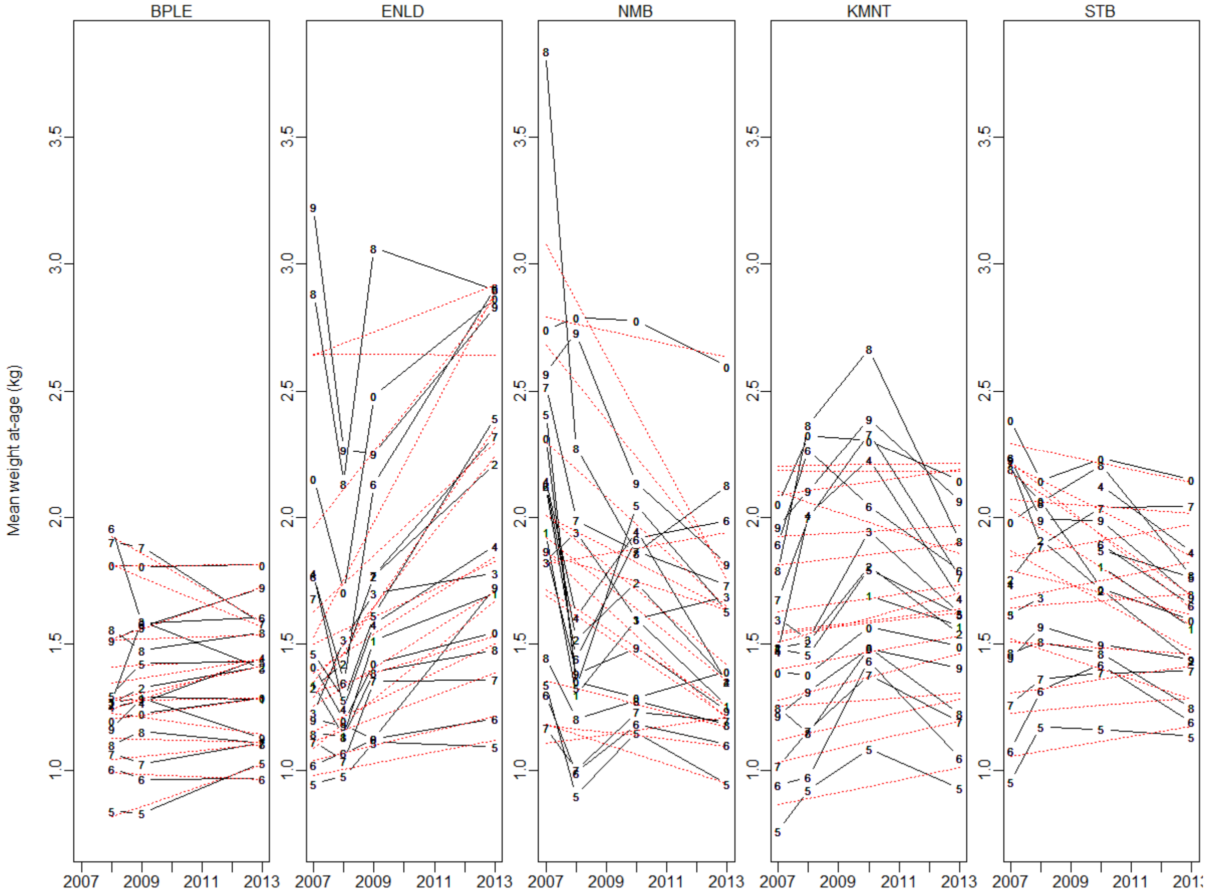


Figure 5: **Mean weight at age (for ages 5 to 20+) by area. The plotting symbols identify the age class (e.g., '1' is used for both 1- and 11-year olds). Trends in these mean lengths are shown by regression lines (red dotted lines).**

An analysis of variance comparing the mean weight data from each area produced significant differences on all Bay of Plenty area comparisons; none of the other area comparisons were significant (Table 9).

Table 9: **Tukey paired comparison tests from an ANOVA of the area mean weight data. Shaded cells denote significant difference in the area-pair means.**

Area comparisons	Difference in means	Lower 95	Upper 95	Significance
ENLD-BPLE	0.33	0.08	0.57	0.000
KMNT-BPLE	0.27	0.03	0.52	0.020
NMB-BPLE	0.38	0.13	0.63	0.000
STB-BPLE	0.35	0.1	0.6	0.000
KMNT-ENLD	-0.05	-0.28	0.18	0.970
NMB-ENLD	0.05	-0.17	0.28	0.970
STB-ENLD	0.03	-0.21	0.26	1.000
NMB-KMNT	0.11	-0.12	0.34	0.690
STB-KMNT	0.08	-0.16	0.31	0.890
STB-NMB	-0.03	-0.26	0.2	1.000

Analysis of variance was also used to look for evidence of temporal shifts in mean weight within areas. Very few of the paired year comparisons were significant, with the overall conclusion being that there was little evidence of temporal shifts in growth within areas (Table 10).

Table 10: Tukey paired comparison tests from an ANOVA of the area and year mean weight data. Shaded cells denote significant difference in the year-pair means within areas.

Area	Sample years	Significance	Area	Sample years	Significance
BPLE	2009–2008	0.989	KMNT	2008–2007	0.698
BPLE	2013–2008	0.97	KMNT	2010–2007	0.054
BPLE	2013–2009	0.995	KMNT	2010–2008	0.455
ENLD	2008–2007	0.673	KMNT	2013–2007	0.917
ENLD	2009–2007	0.949	KMNT	2013–2008	0.969
ENLD	2009–2008	0.354	KMNT	2013–2010	0.212
ENLD	2013–2007	0.182	STB	2008–2007	0.999
ENLD	2013–2008	0.014	STB	2010–2007	0.997
ENLD	2013–2009	0.438	STB	2013–2007	0.663
NMB	2008–2007	0.056	STB	2010–2008	0.987
NMB	2010–2007	0.147	STB	2013–2008	0.804
NMB	2010–2008	0.971	STB	2013–2010	0.554
NMB	2013–2007	0.021			
NMB	2013–2008	0.981			
NMB	2013–2010	0.843			

2.4 Discussion and Conclusions

Patterns in YCS and regional differences in mean weight at-age provide compelling evidence for a separate Bay of Plenty stock within TRE 1. Alternatively, similarities in YCS and the proportion of fish older than 20+ suggest that ENLD and NMB may be part of the same stock. Overall, the YCS data is suggestive of a clinal shift in age composition from north to south down TRE 7. Differences in age structure between NMB and STB suggest that these two TRE 7 areas are parts of separate stocks. The degree of separation of the KMNT area is unclear; this area could be part of either the NMB or STB stocks. Evidence that the KMNT area fits better with STB is seen in the similar accumulation of fish older than 20 years in both areas. NMB has markedly fewer fish aged 20 or more than the KMNT and STB areas although this may in part be due to migration of older fish south. However migration does not account for the observed differences in year class strength between NMB and STB.

The post 2006 catch sampling data suggests that the TRE 1 & 7 area is made up of at least three separate stocks:

1. Bay of Plenty (TRE 1)
2. East Northland – Ninety Mile Beach (TRE 1 & 7)
3. Kaipara Manukau and North Taranaki – South Taranaki Bight (TRE 7).

The remainder of this report specifically deals with TRE 1 and so precludes any further consideration or inclusion of the Ninety Mile Beach area with the East Northland component of TRE 1. Highly significant differences in trevally YCS and or growth between East Northland and Bay of Plenty areas are a strong basis to conclude that the two areas constitute separate stocks as these differences would be unlikely to be sustained through time if there was a reasonable degree of inter-area mixing (homogeneity).

As will be seen in Section 3.2.1, very little trevally is taken commercially from the inner Hauraki Gulf (Figure 2). Catch at-age observations from the Hauraki Gulf trawl fishery are lacking, so it is not possible to determine into which trevally stock area (ENLD or BPLE) the Hauraki Gulf more appropriately belongs. The assumption made for the remaining analyses in this report is that TRE 1 is comprised of two biological stocks:

- the East Northland – Hauraki Gulf stock (ENHG);
- the Bay of Plenty stock (BPLE).

3 TRE 1 RELATIVE ABUNDANCE: COMMERCIAL BOTTOM TRAWL CPUE

3.1 Introduction

Deriving an acceptable index of abundance for trevally has historically been challenging. Bottom Trawl surveys were conducted in TRE 1 sub-areas during the 1980s and 1990s, but relative biomass estimates from research trawl are not believed to be directly proportional to stock abundance due to the mixed demersal–pelagic nature of trevally behaviour (Kendrick & Bentley 2010, Ministry for Primary Industries 2015). Until recently commercial catch and effort data were considered to be inappropriate for deriving TRE 1 abundance indices because trevally is taken largely as by-catch to other target fisheries. However, in light of recent improvements in grooming and Catch per Unit Effort (CPUE) standardisation methods, the utility of commercial CPUE data warrants further consideration. Here we present a characterisation of the TRE 1 fishery as well as the first CPUE analysis for the TRE 1 fishery management area.

3.2 Methods

3.2.1 TRE 1 characterisation, data sources and initial setup

A characterisation of patterns in TRE 1 catch by fishing year, fishing method, month, statistical area, target-species, was undertaken for the period October 1989 to September 2013 (hereafter referred to as the 1990–2013 fishing years) using data extracted from the Ministry for Primary Industries (MPI) commercial catch reporting system (Appendix 1). The dataset extract included all effort details and associated catch weights (all species including trevally) from all trips landing TRE 1 catch. This dataset was initially groomed so that on water estimates of catch were linked to the effort variables associated with each event (e.g. fishing location, fishing method, target species, tow speed). In turn, this information was then linked to landed catch weights for the relevant fishing trip. This allowed us to then prorate the actual trip landed weight totals across the effort information (i.e. individual sets, tows or days) on the basis of the estimated catch ratios. The link between the two data tables was the common trip number field (trip_key).

Trawl catch-effort information for the period October 1989 to September 2013 was collected pursuant to three types of MPI reporting forms. Catch Effort Landing Return forms (CEL) were predominantly utilised over the earliest part of the TRE 1 catch-effort series (1990–1995). CEL forms only allow fishers to record information at an amalgamated daily catch level. The adoption of Trawl Catch Effort Processing Return (TCP) forms by some vessels in 1996 meant that fishers could provide catch and effort data at the tow level. TCP and CEL forms were replaced in 2007 with the Trawl Catch Effort Return (TCE) form. The main difference between the TCP and the other forms is that the TCE form allows fishers to provide catch estimates for the top 8 species caught per event, whereas the CEL and TCE forms only allowed fishers to report the top 5 species caught at the day or tow-event level.

To ensure data consistency across the form type series we simplified all data so only the top five species were listed. This meant that if our species of interest, trevally, was listed on the TCE form as either the 6^{th}, 7^{th} or 8^{th} highest in catch weight for a fishing event it was given a catch of ‘0’. The weight of trevally from that fishing event would still be present in the landed weight for the trip, however. That weight would be assigned to individual fishing events within that trip based on the ratio of estimated weights from events that caught trevally and listed it in the top 5 species by catch weight. For trips where trevally was landed, but no trevally was recorded in the top five species from any of the individual tows, then the trip landed weight of trevally was assigned evenly across all of the tows in that trip, i.e. landed catch was prorated by effort.

3.2.2 Data grooming and preparation for CPUE analysis

3.2.2.1 Incorporating ‘0 catch trips’

For CPUE analyses we started with the data described above, but constrained the fishing methods incorporated to just bottom trawl (BT), as only this method was deemed capable of providing an index of abundance within TRE 1. To prepare our data for CPUE analyses we also needed to incorporate fishing events where trevally could have been caught, but were not (i.e. legitimate zero catches; whole trips where trevally were not caught were not included in our dataset at this stage). We used the target species and depth of each fishing event to identify BT events where trevally were likely to be caught. We then extracted a second dataset from the MPI database, where trevally was not landed from an entire trip (where the fishing method was BT), but met the target species and depth criteria we specified. This legitimate zero information was then appended to the previous dataset for CPUE analysis.

3.2.2.2 Detailed grooming of catch and effort variables for TCP/TCE and CEL datasets

The first component of data grooming was to assess the trevally catch variable itself for outliers. We initially plotted the frequency distribution of all trevally catches from all events (with 0 catch events removed and log transformed), deciding on a cut off for what was an outlier as over 3.5 standard deviations (sd) from the median. This rule was then recursively applied to trevally catch data for each vessel (i.e. using vessel specific medians), with any outliers being deleted from the dataset. A similar process was followed for each of the effort variables associated with fishing events. Here we would initially plot the frequency distribution for that variable and decide on upper and lower cut off values. If any values were outside this range, they were replaced with the median value for that vessel. If there were still values outside our specified range (this occurred for vessels that had recorded few events and had a vessel median that was outside the specified range) that entry was assigned as ‘NA’.

The change in temporal resolution in the TRE 1 trawl CPUE with the introduction of the TCP form in 1996 (i.e. move from daily to tow level reporting) required us to create two different reporting level series: a tow-level TCP/TCE series (1996–2013); and a day-level CEL/TCP/TCE series (1990–2013). The creation of the longer day-level series required reducing the temporal resolution of TCP/TCE data by amalgamating the data to the daily level.

3.2.2.3 Spatial variable grooming

For the TCP/TCE dataset, a latitude and longitude is provided for the start position of each fishing event. For some fishing events, however, this position might fall on land, or far out to sea. Furthermore, our purpose was to conduct a CPUE analysis that describes trends in trevally abundance, which would be best estimated from where the majority of trevally catches occur. Therefore, we plotted trevally catches by event and defined a polygon that constrained qualifying events to where the core of TRE 1 catches occurred. As part of the CPUE analysis (see below) one of the explanatory variables used in this process is a categorical description of the location of each fishing event. Usually this is defined by the statistical area that fishers are required to report. For the TCP/TCE data, however, precise latitudes and longitudes were available, so it was possible to define our own spatial categories based on catch rate patterns in the TRE 1 fishery. As such, we chose to use our own spatial categories for the TCP/TCE data (called ‘new_polygons’), whereas for the CEL time series we used the statistical areas as reported by the fishers.

3.2.2.4 Data 'rollup' to trip level and redefinition of effort variables

As previously mentioned, fishing can be reported at different levels of temporal resolution, whether that be an individual fishing event, a day's fishing which could encompass multiple events, or an entire fishing trip which could encompass multiple days. For some CPUE analyses it was necessary to further reduce the temporal resolution of the data, 'rolling up' to a longer time period such as the whole trip. For the response variable, catch, this simply required adding up the catches from individual events. A similar process was followed for some of the explanatory variables including effort_num and duration. For other explanatory variables we needed to choose a value that represented that variable for the whole trip (i.e. potentially across multiple events where more than one value for each variable was recorded). We decided that this process would be best conducted if variables were categorical. Two variables, new_poly and target species, were already categorical. For the remaining continuous variables (effort_width, effort_height, effort_depth and effort_speed), we first plotted the frequency distribution of each variable, decided on three to four categories that represented the spread for that variable and then assigned each event to one of these categories. Now that all variables were in categorical form we were able to choose a dominant value from all of the events within a trip to represent that variable for the entire trip. We did this by choosing the value that was most frequently listed for that trip. Where a trip had listed an equal number of events with different values it was given a value of 'multi'. For the variable new_polygon, however, there were fewer categories. Therefore, where a trip listed two or more values for new_polygon those values were combined to create a new category to represent that trip.

3.2.2.5 Dataset definition and core vessel selection

Before a CPUE analysis can be conducted a fleet of core vessels must be selected. This is conducted so that only vessels which have fished in TRE 1 with consistency, and are therefore more likely to be representative of trevally abundance, are included. As this is the last process before CPUE analysis, however, data must first be subdivided into appropriate blocks for which an index of abundance is desired. One major consideration was the stock within the TRE 1 fishery management area. On the basis of the spatial analysis presented in Section 2, our analysis recognised two sub-stocks: East Northland-Hauraki Gulf (ENHG: Statistical Areas 002, 003, 005, 006; Figure 2) and Bay of Plenty (BPLE: Statistical Areas 008, 009, 010; Figure 2).

Another major consideration was form type, which determined the time range of the dataset (either the CEL dataset, 1990–2013, which has daily resolution, or the TCP/TCE dataset, 1996–2013, which has event level resolution). Some consideration was also needed for some of the other issues discussed above, including whether data were 'rolled up'. Only once these considerations had been addressed would a dataset be defined allowing a vessel selection to be conducted. Selecting a fleet of core vessels involves inspecting plots of the relationship between the number of vessels that could be selected, the number of trips per year those vessels conducted, the number of years within the fishery for those vessels and the overall percentage of catch that those vessels accounted for. Minimum values were then selected for the number of years and trips per year. The resulting dataset was then inspected in terms of data coverage (ensuring that each year of the time series was represented by multiple vessels) and to ensure that the percentage of catch that those vessels accounted for was above 60% for most years. If these conditions were not met or there were still too many vessels in the core fleet (about 40 or more), then the number of years and trips per year criteria were adjusted (see Appendix 2 and Appendix 3 for graphics used in the process of selecting the core vessels used in calculating the final standardised CPUE index for the ENHG and BPLE sub-stocks).

3.2.3 CPUE analysis methods

Annual catch indices (assumed to represent trevally availability) were derived using Generalised Linear Modelling (GLM) procedures (Vignaux (1994), Francis (1999)). The GLMs were conducted using the statistical software package R. The response variable in the GLM was log catch for lognormal analysis, or presence/absence for binomial analysis. Fishing year was entered as a categorical covariate (explanatory) term on the right-hand side of the model. Standardised CPUE abundance indices (canonical) were derived from the exponential of the fishing year covariate terms as described in Francis (1999).

To accommodate a non-linear relationship with the response variable (log catch) all continuous variables (including effort terms) were "offered" to the GLMs as third order polynomials (unless they had been converted to categorical variables as described in the rollup procedure above). A forward fitting, stepwise, multiple-regression algorithm was used to fit GLMs to the groomed catch and effort data. The stepwise algorithm generates a final regression model iteratively and uses a simple model with a single predictor variable, fishing year, as the initial or base model. The reduction in residual deviance relative to the null deviance is calculated for each additional term added to the base model. The term that results in the greatest reduction in residual deviance is added to the base model if this results in an improvement in residual deviance of more than 1%. The algorithm repeats this process, updating the model, until no new terms can be added.

The approach taken with all the GLMs was to enter fishing 'effort' as a covariate (i.e., "right-hand" model term), with catch as the regressor variable. This is algebraically analogous to subtracting effort from catch in log-space. The GLM standardisation of the zero and positive catch ratios was structured in a similar fashion to that described above, but used a binomial link function. The response variable in the binomial model was either "1" for a positive catch or "0" for a null catch. Indices of abundance derived from the lognormal and binomial models were also combined into a unified index using the method described by Vignaux (1994).

Explanatory variables offered to GLM models were:

- Fishing year (forced as the first term, 1990–2013 for CEL and 1996–2013 for TCP/TCE)
- Vessel (individual vessel key, the number of vessels depends on the specific dataset in use)
- Month (12 categories)
- New_polygon (see Section 3.2.3.2) or statistical area (variable used depends on whether applied to CEL or TCP/TCE dataset, length is either three or four categories)
- Target species (selected from the six main targets of TRE catch: TRE, SNA, TAR, JDO, GUR, BAR)
- Season (summer (DecemberFebruary), autumn (MarchMay), winter (JuneAugust), spring (SeptemberNovember))
- Duration (length of trawl event in hours, offered as a third order polynomial unless part of a rolled up analysis where it becomes a categorical variable)
- Effort_height (distance (m) between headline and bottom rope, offered as a third order polynomial unless part of a rolled up analysis where it becomes a categorical variable)
- Effort_width (distance (m) between wings of the trawl net, offered as a third order polynomial unless part of a rolled up analysis where it becomes a categorical variable)
- Effort_depth (depth of a fishing event (m), offered as a third order polynomial unless part of a rolled up analysis where it becomes a categorical variable)
- Effort_speed (speed the trawl net is towed at (knots), offered as a third order polynomial unless part of a rolled up analysis where it becomes a categorical variable)
- SOI (Southern Oscillation Index, the monthly barometric pressure difference between Darwin and Tahiti, offered as a third order polynomial)
- SST (Sea Surface Temperature, monthly average recorded at Leigh, offered as a third order polynomial)

Variables that were considered, but not offered to GLM models because of a high collinearity with other explanatory variables were: Effort_num (the number of fishing events within a data record), Vessel dimensions (length × draught × beam in metres), Vessel engine size (kilowatts), Swept distance (duration × speed), and Swept area (distance × effort_width).

3.2.3.1 Detailed grooming of catch and effort variables

The variable ranges used to remove or replace outliers within the TRE 1 bottom trawl time series can be found in Table 11. For the CEL catch data 11 outliers were removed, whereas for the TCP/TCE catch data no outliers were found. For all of the explanatory variables considered a small amount of data replacement was conducted, except for the effort_width and effort_height variables in the TCP/TCE dataset, where a higher percentage of data was replaced. The vast majority of the data replacements conducted for these variables were due to no entry being made in the original raw data extract we received.

Table 11: Details of the data grooming process showing the outlier cut off values and the number of values replaced or removed by form type and variable. Catch = the weight of trevally (kg) caught in a fishing event; Effort_num = the number of fishing events within a data record, this is always 1 for TCP/TCE form types; Duration = the length of a fishing event (hours); Effort_width = the distance (m) between the wings of the trawl net; Effort_height = the distance (m) between the headline and bottom rope of a trawl net; Effort_speed = the speed (knots) at which the trawl net is towed for an event.

Form type	Variable	Outlier cut off values	No. values replaced or removed
CEL (1990–1995)	Catch	>3.5 sd from median	11/35702
	Effort_num	>15 tows	309/35691
	Duration	>24 hours	423/35691
	Effort_width	>150 m	294/35691
	Effort_height	>30 m	493/35691
TCP/TCE (1996–2013)	Catch	>3.5 sd from median	0/128570
	Effort_num	NA, all values = 1	NA
	Duration	>15 hours	399/128570
	Effort_width	>150 m	22037/128570
	Effort_height	>30 m	3044/128570
	Effort_speed	>5 knots	432/128570

3.2.3.2 Spatial variable grooming

Our next data grooming step was to constrain the data considered to the core spatial areas where trevally catches are made within TRE 1. This was only possible for the TCP/TCE dataset (post 1996), which contains a latitude and longitude of where trawl events began. After plotting the spatial position of the TCP/TCE data we defined a polygon that represented the core area of trevally catches (green line in Figure 6). As a result this excluded 5602 fishing records (from a total of 128 570) that were outside of this polygon.

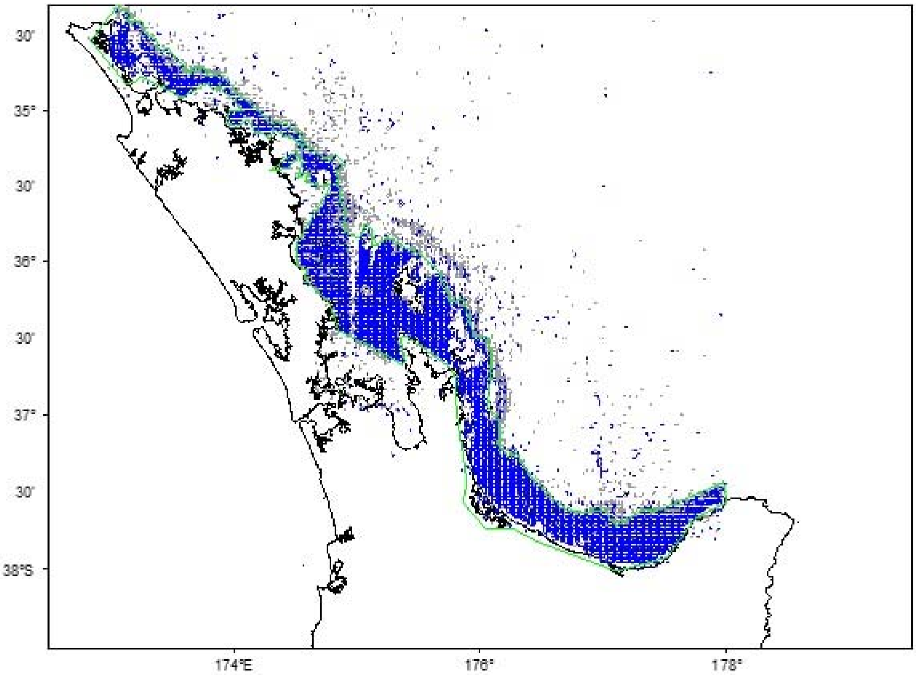


Figure 6: Distribution of trevally catches (1996–2013), with 0 catch events in grey, and positive catch events in blue. The green polygon defines the core area of TRE 1 catches, all fishing events outside of this polygon were removed (see methods for a detailed description).

The latitude and longitude associated with the TCP/TCE data also allowed us to reconsider the categorical representation of fishing location (usually statistical area). The spatial distribution of unstandardized trevally catch rates demonstrated a pattern of three reasonably discrete areas within each of the ENHG and BPLE sub-stocks (Figure 7), which were consistent between different fishing years within the time series. As such we defined three new_polygons within each sub-stock (Figure 7), with all fishing events assigned to one of these.

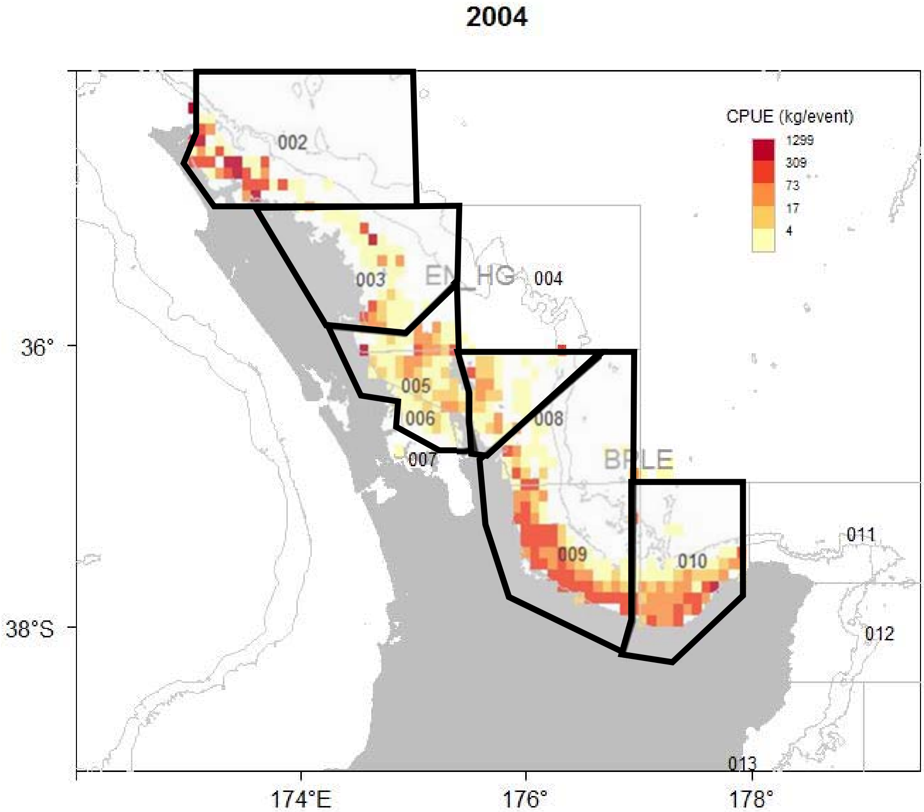


Figure 7: The distribution of TRE 1 CPUE (example shown for the 2004 fishing year). Statistical area boundaries and labels in grey, and the boundaries of the new spatial category 'new_polygon' in bold. From north to south the new_polygon labels are: 002_new, 003_new, 005_006_new, 008_new, 009_new, 010_new. Catch grid size = 0.08 ° longitude.

3.3 Results

3.3.1 TRE 1 characterisation

Trevally catch within TRE 1 has rarely reached the TACC limit of 1500 t (Figure 8). Catches are dominated by the BPLE sub-stock, with catches from ENHG decreasing over time.

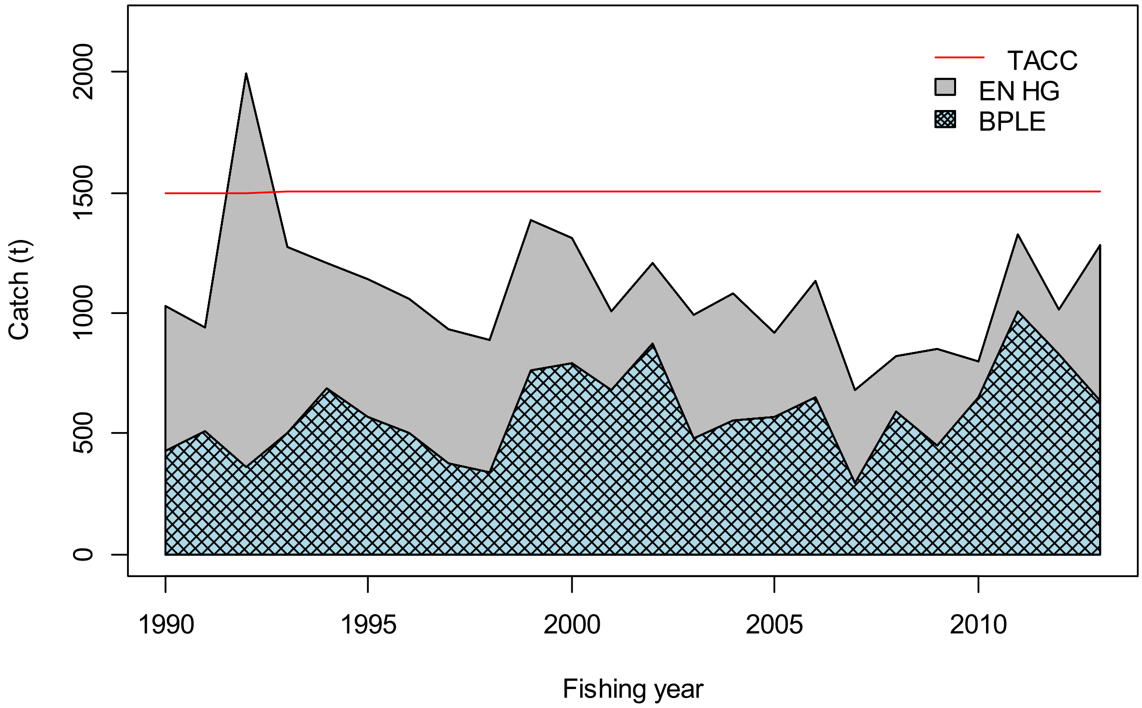


Figure 8: Catch (t) of trevally within TRE 1 by sub-stock from 1990–2013. Total Allowable Commercial Catch indicated by the red line.

In the ENHG sub-stock catches are dominated by Statistical Areas 002 and 003, although catches in area 003 have decreased over time (Figure 9). In the BPLE sub-stock Statistical Areas 008, 009 and 010 all make similar contributions, with catches from areas 008 and 010 increasing over time (Figure 9).

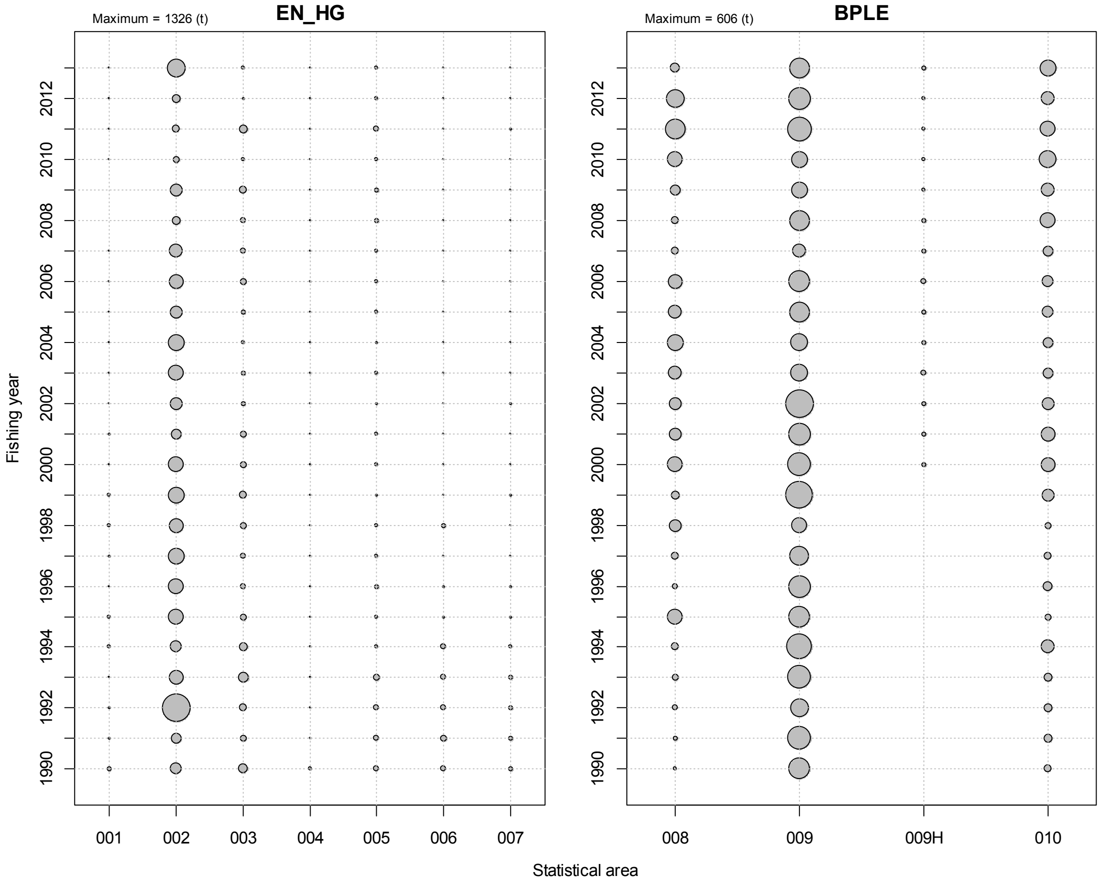


Figure 9: Trevally catch (t) by statistical area (see Figure 2) and year for the two sub-stocks within TRE 1. Bubble area proportional to catch tonnage. Statistical Area 009H is Tauranga Harbour.

Catches in both sub-stocks are dominated by purse seine and bottom trawl, with bottom trawl becoming increasingly important in the BPLE sub-stock since 1999 (Figure 10). Other important methods include beach seine and set net, although the catch of these methods has steadily declined in both sub-stocks. Danish seine is responsible for small catches in the BPLE sub-stock and bottom pair trawl is responsible for small catches in the ENHG sub-stock.

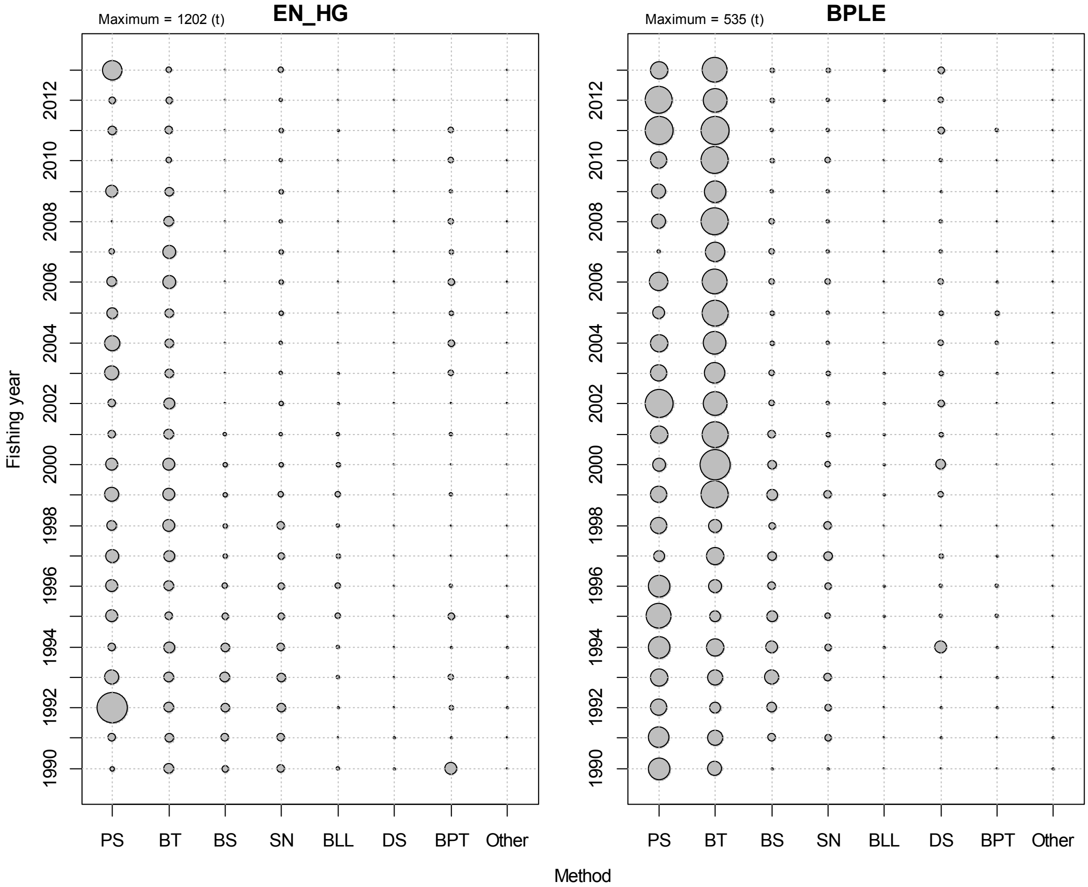


Figure 10: **Trevally catch (t) by fishing method and year for the two sub-stocks within TRE 1. Bubble area proportional to catch tonnage. PS = purse seine, BT = bottom trawl, BS = beach seine, SN = set net, BLL = bottom longline, DS = Danish seine, BPT = bottom pair trawl.**

The fine scale spatial distribution of bottom trawl catches (Figure 11) illustrates the importance of the BPLE sub-stock, with the majority of catch taken throughout the western and eastern Bay of Plenty (Statistical Areas 009 and 010). Significant bottom trawl catches are also taken from the northern most part of the ENHG sub-stock (Great Exhibition Bay, Statistical Area 002).

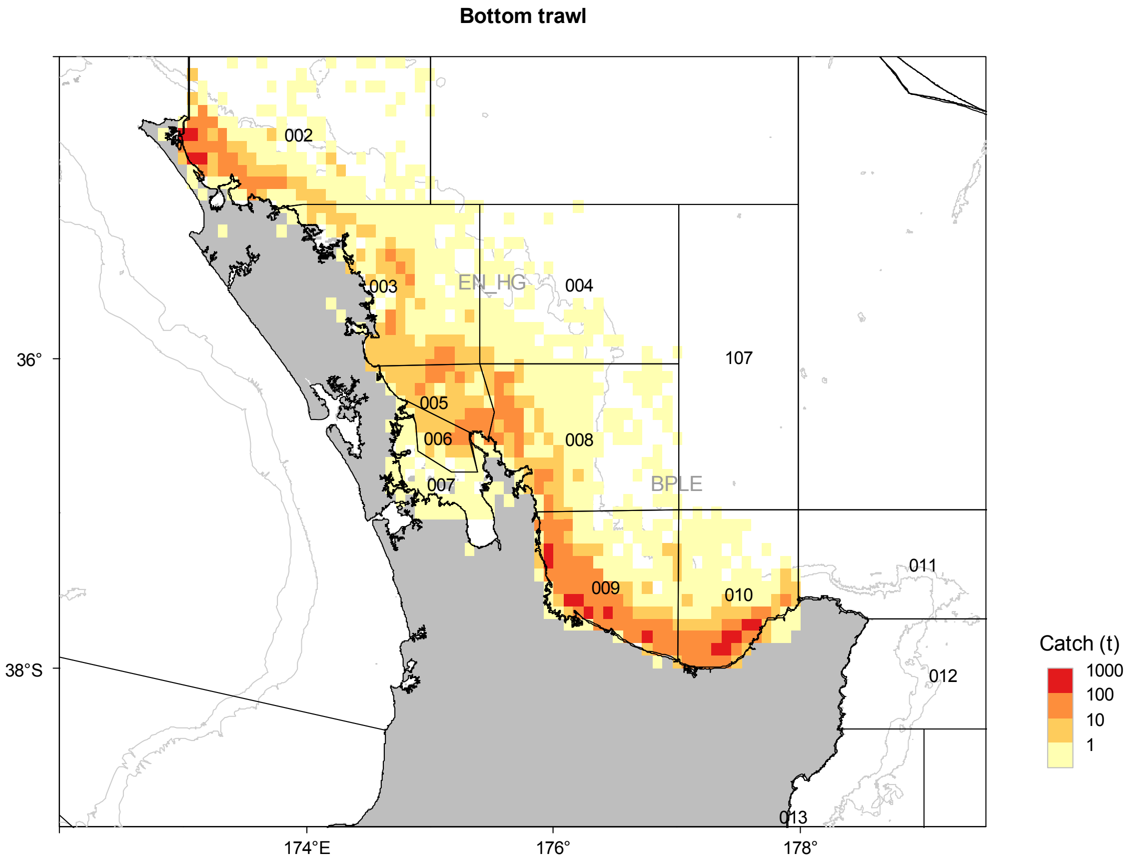


Figure 11: Distribution of total trevally caught by bottom trawl in TRE 1 between the 1990 and 2013 fishing years. Catch grid size = 0.08 ° longitude.

Bottom trawl catches of trevally demonstrate a seasonal pattern (Figure 12), with highest catches being taken between December and May in most years.

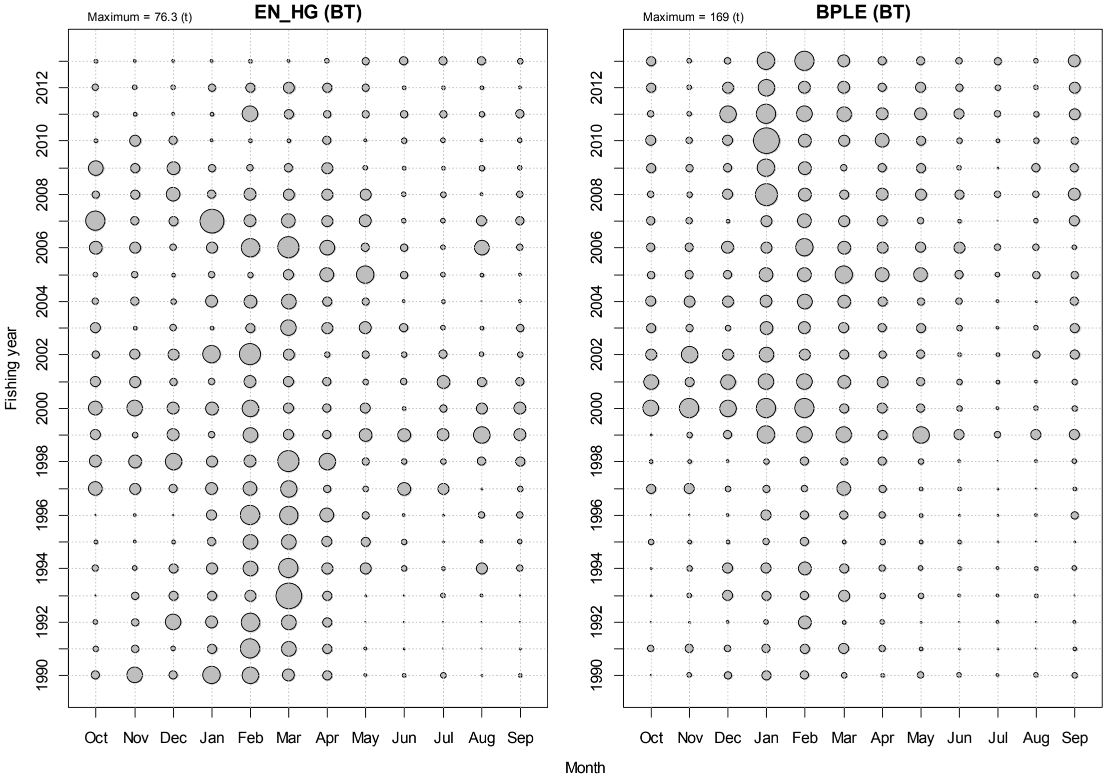


Figure 12: Bottom trawl trevally catch (t) by month and year for the two sub-stocks within TRE 1. Bubble area proportional to catch tonnage.

The main target species listed when trevally was caught by bottom trawl in both the ENHG and BPLE sub-stocks were snapper and trevally (Figure 13). John dory and tarakihi were the next most important target species in the ENHG sub-stock – john dory has become more important in recent years, while tarakihi has become less important. In the BPLE sub-stock, target species other than snapper and trevally are listed less frequently.

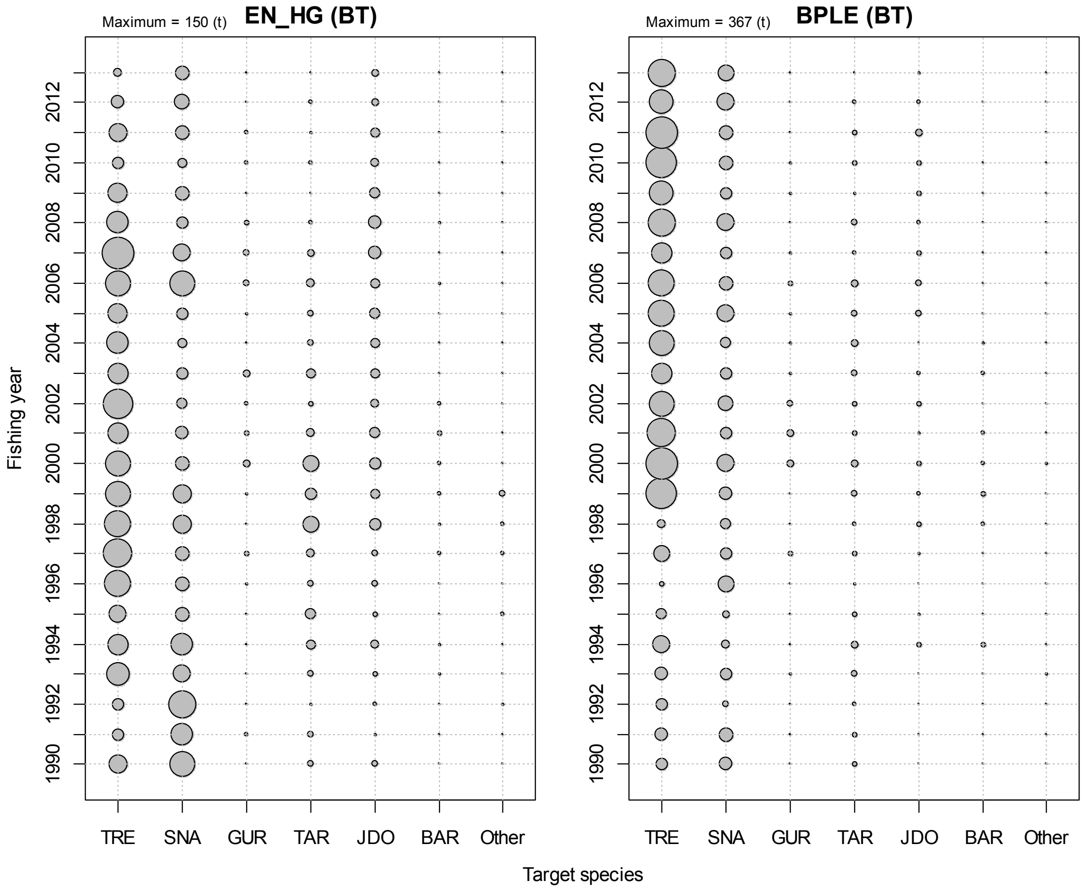


Figure 13: Bottom trawl trevally catch (t) by target species and year for the two sub-stocks within TRE 1. Bubble area proportional to catch tonnage.

3.3.2 Data grooming

3.3.3 Standardised CPUE analysis

3.3.3.1 East Northland event level analysis

Initial CPUE analysis for the ENHG TCP/TCE dataset produced a lognormal index that declined through time, while the binomial index contained a positive trend (Figure 14). The Northern Inshore Working Group (NINSWG) was concerned by the contradictory interpretation of binomial and log-normal indices and asked for more exploration of the underlying data to be undertaken. Various factors were investigated including: (1) constraining CPUE analyses to different combinations of target species and area fished, (2) not offering the variable 'target species' to the CPUE GLM so as to allow other explanatory variables to be incorporated into the model, and (3) plotting different combinations of effort variables to assess interactions (e.g. effort_speed or tow duration through time and by target species). These investigations either still produced CPUE analyses with opposing lognormal and binomial trends, or did not provide any clear insight as to what was driving this pattern.

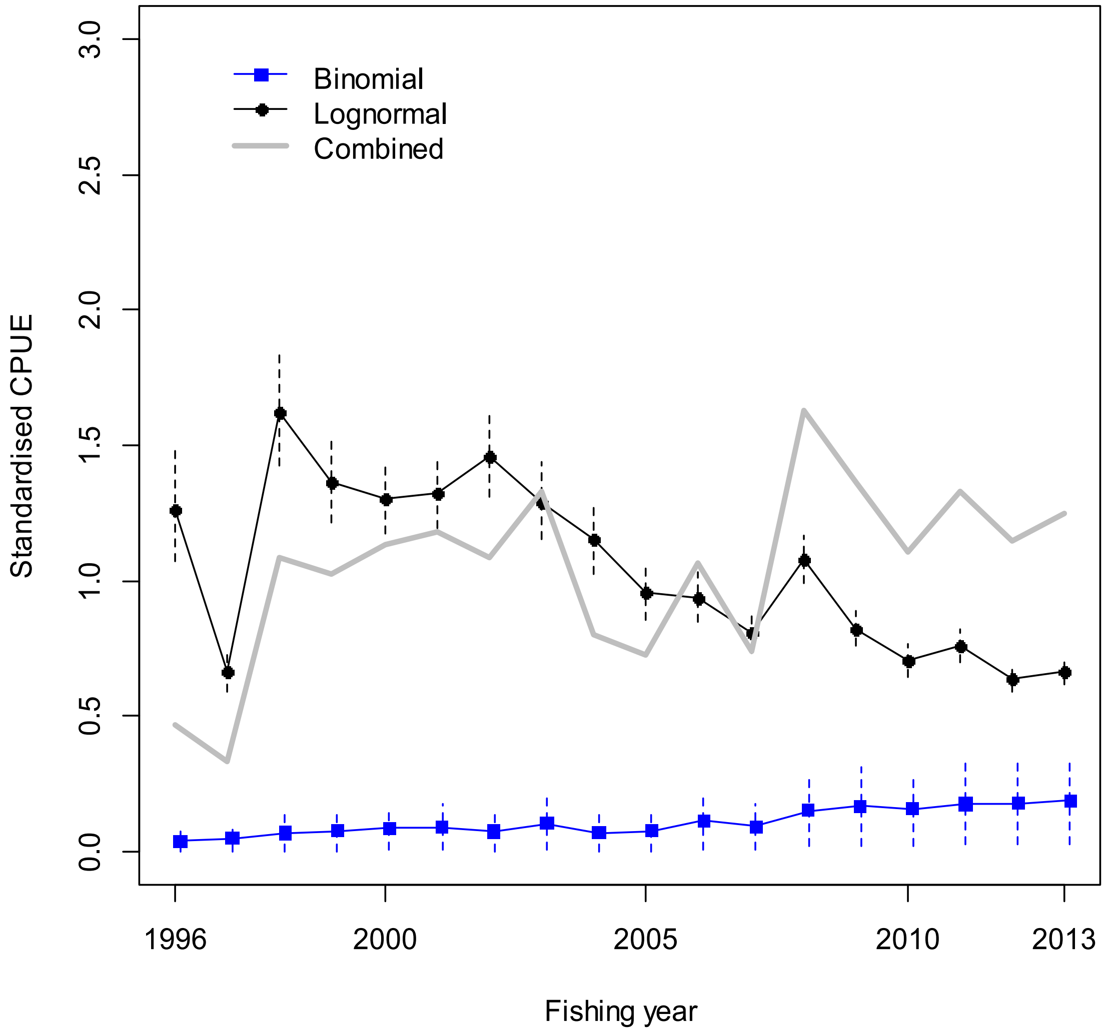


Figure 14: Standardised CPUE index for the ENHG sub-stock generated from TCP/TCE data analysed at the level of the individual fishing event. Note the opposing slopes of the lognormal and binomial indices which necessitated further investigation and analysis.

3.3.3.2 Data 'rollup' to trip level

An alternative investigation, similar to that of Langley et al. (2015), assessed how the total of fisher at-sea estimated catches had changed through time compared to the "true" landed catch totals (both in kilograms) (Figure 15).

This analysis demonstrated that for the at-sea estimated catches the proportion of 0 catches had decreased, the proportion of smaller catches (under 50 kg) had increased, and the proportion of larger catches (over 50 kg) had increased through time (Figure 15). Alternatively, the landed catch totals for the same trips did not demonstrate much trend through time for these same categories (Figure 15). This suggested that a change in reporting behaviour had occurred, where fishermen were more likely to report smaller catches in their at-sea data in recent years. Using data 'rolled up' to the trip level reduced the potential to incorporate this reporting bias, because landing weights associated with each trip are verified by a Licenced Fish Receiver. When data is aggregated at the trip level many of the effort variables that would usually be incorporated in a standardised CPUE analysis have multiple values for each trip. To allow us to incorporate these variables in our rolled up CPUE analyses we followed the methods outlined in Section 3.2.3.1, in which we treated all explanatory variables as categorical and chose a dominant value to represent that variable for each trip. The remaining CPUE analyses and diagnostics presented are for data that has been rolled up to the trip level.

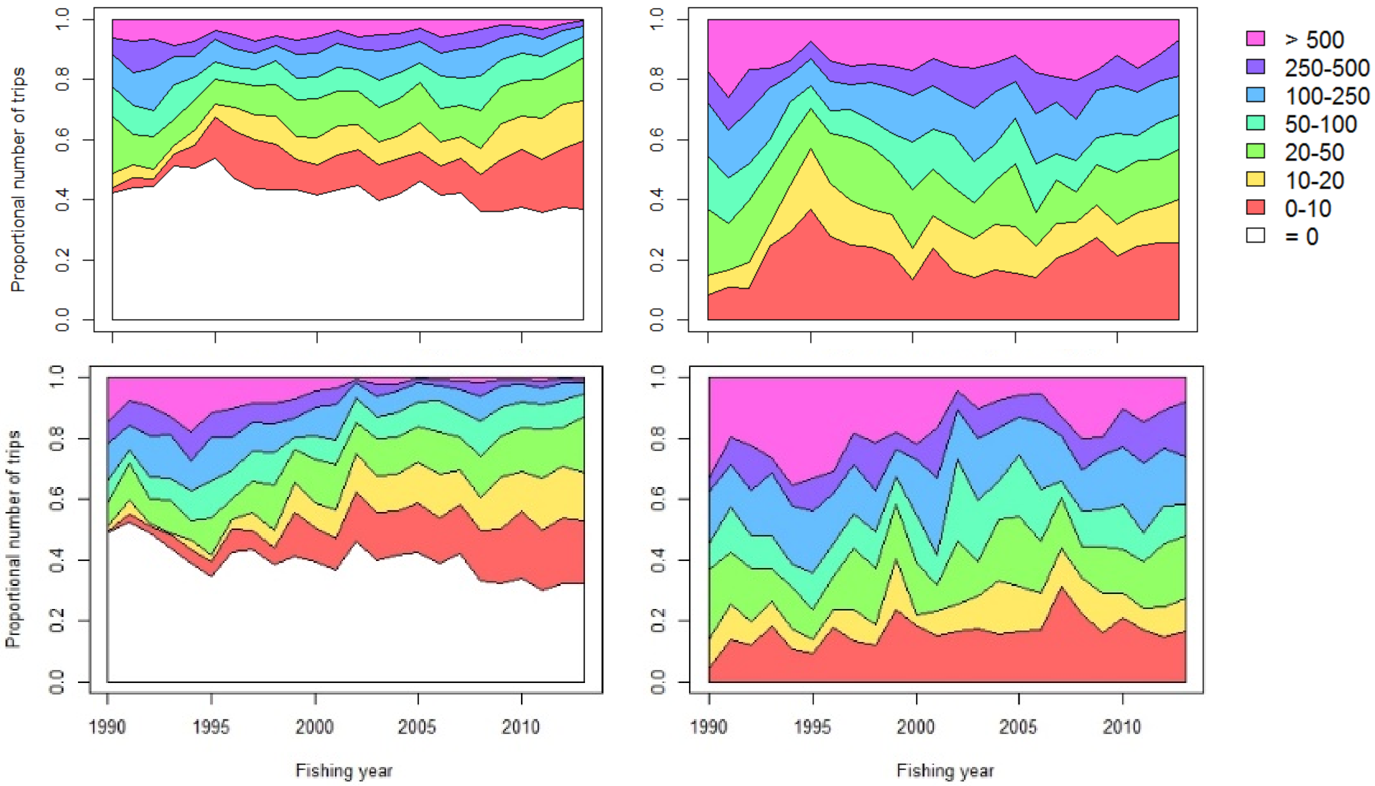


Figure 15: **Proportion of trips within different catch size strata (kg). Left side is for estimated trevally catch and right side is for corresponding landings, top row is the ENHG sub-stock and the bottom row is the BPLE sub-stock (both from the CEL dataset). Only trips where trevally from TRE 1 was landed have been included. Note: an adjustment was made in the latter TCE data component of this series to limit reporting to only the top 5 species.**

3.3.3.3 ENHG trip-level standardised CPUE abundance index

Standardised CPUE analysis of the ENHG sub-stock (TCP/TCE dataset) between 1996 and 2013 produced a lognormal index which had little trend and variation of about 50% of the overall average value (Figure 16). The fit of the lognormal model appeared to be good, with residuals approaching a normal distribution and a lack of high leverage outliers (Figure 17). There was a lack of uniformity in the pattern of residuals plotted against predicted values (Figure 17); the likely impact of this is not on the index per se, but on index confidence intervals. We also produced a binomial index based on the ratio of "eligible" trips (Section 3.2.2.1) where trevally was or was not landed, i.e. the proportion of zero catch trips (Appendix 5). This standardised binomial catch data CPUE analysis produced an index with a slight positive trend, and as a result the combined index was very similar to the original lognormal index (Figure 16). We also conducted standardised CPUE analyses for the longer CEL dataset, however, there was poor agreement between the lognormal and combined indices so this analysis was not continued. The combined model based on standardised CPUE analysis of the TCP/TCE dataset was chosen as an index of relative abundance for the ENHG sub-stock by the working group (Appendix 4). For the TCP/TCE dataset the overall lognormal model explained about 45 % of variation within the dataset, while the binomial model explained about 23 % (Table 12). The factor 'vessel' explained a high percentage of variation within the lognormal model (over 25%) and had the most effect of any variable during the CPUE standardising process (Figure 18). Vessel (with about 3.5 %) was the second most important variable in the binomial model behind tow duration (about 10 %) (Table 12; see Appendix 6 for plots illustrating the influence of selected variables on the lognormal CPUE index).

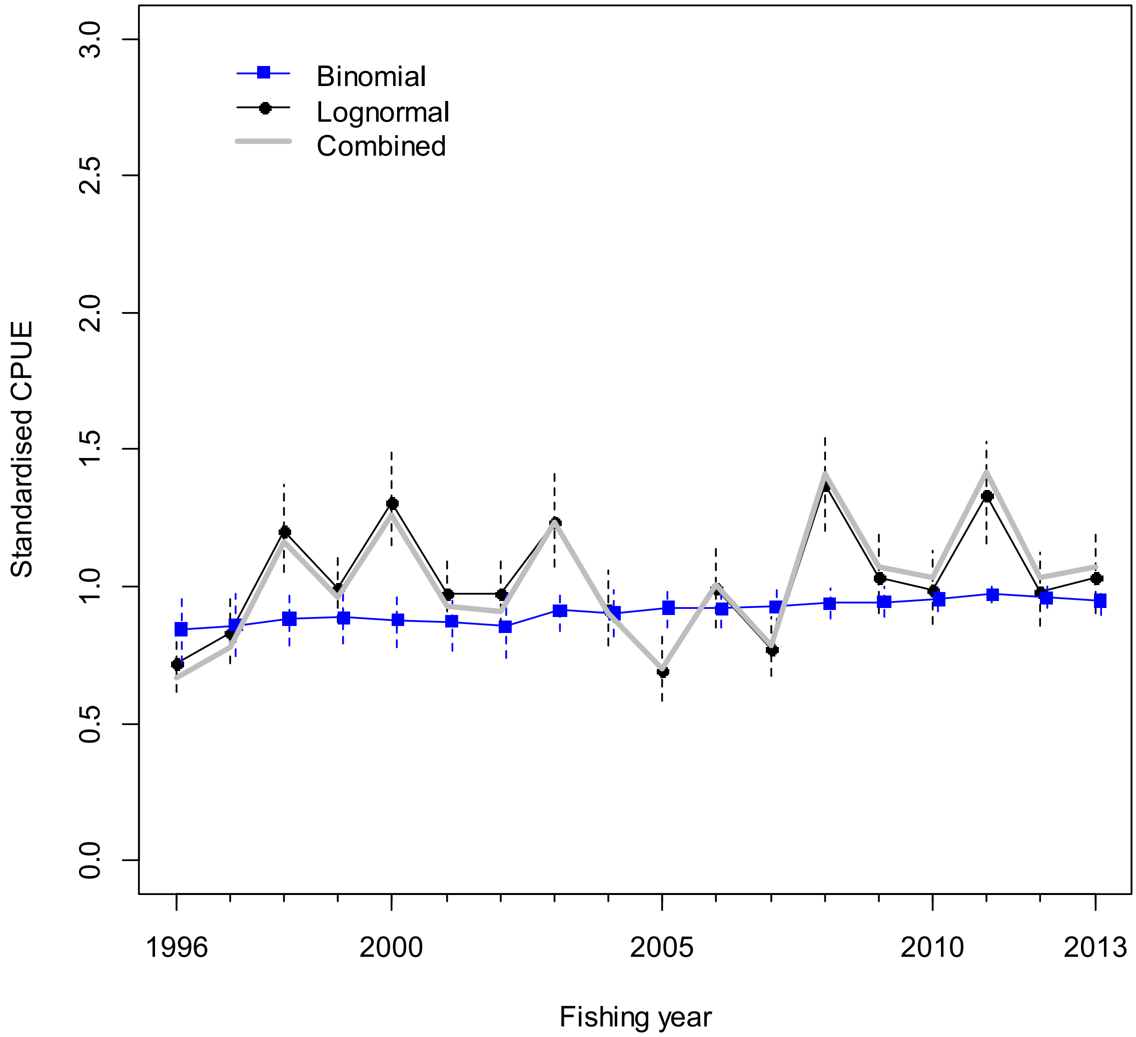


Figure 16: Standardised CPUE index for the ENHG sub-stock. The TCP/TCE dataset was used for this analysis where fishing events were rolled up to the trip level. For a list of terms picked by this analysis and their associated R^2 values see Table 12

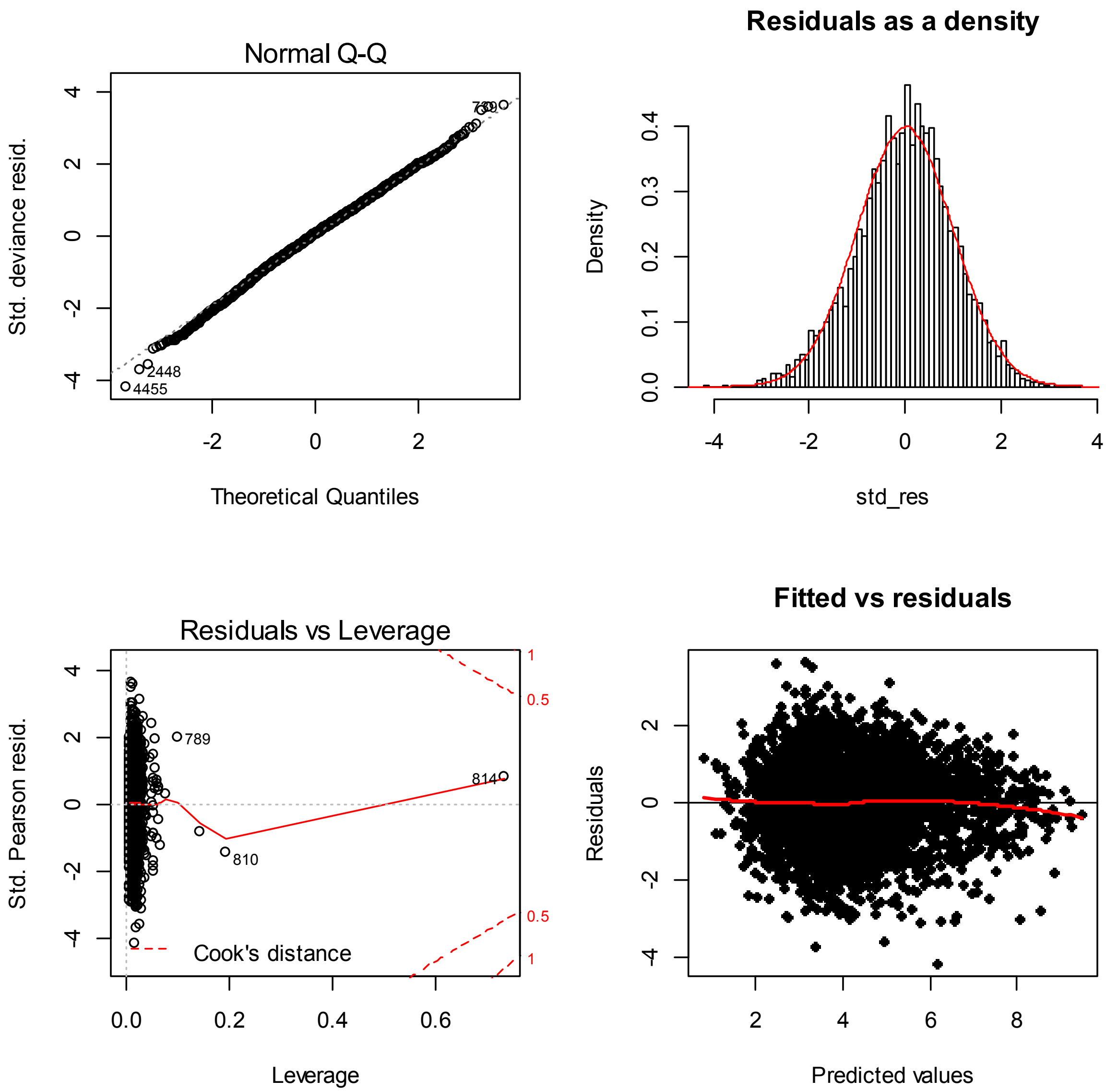


Figure 17: **Analysis of the fit of the lognormal regression model for ENHG trevally catches from the TCP/TCE dataset rolled up to the trip level. Top left panel is a QQ plot comparing the quantiles of a theoretical normal distribution to that of the residuals from the regression analysis. Top right panel is a histogram of the residuals from the regression analysis. Bottom left panel is a Cook's distance plot investigating the leverage of individual data points. Bottom right panel is a plot of model residuals against the fitted values of the model itself.**

Table 12: Variables selected and variation explained by the lognormal and binomial CPUE analyses of the ENHG sub-stock TCP/TCE dataset rolled up to the trip level (plot of index presented in Figure 16).

Lognormal		Binomial	
Variable	**R^2**	**Variable**	**R^2**
Fishing year	0.02	Fishing year	0.03
Vessel	0.28	Duration	0.14
Target species	0.35	Vessel	0.17
Duration	0.39	Month	0.20
New_polygon	0.42	New_polygon	0.22
Month	0.45	Effort_depth	0.23

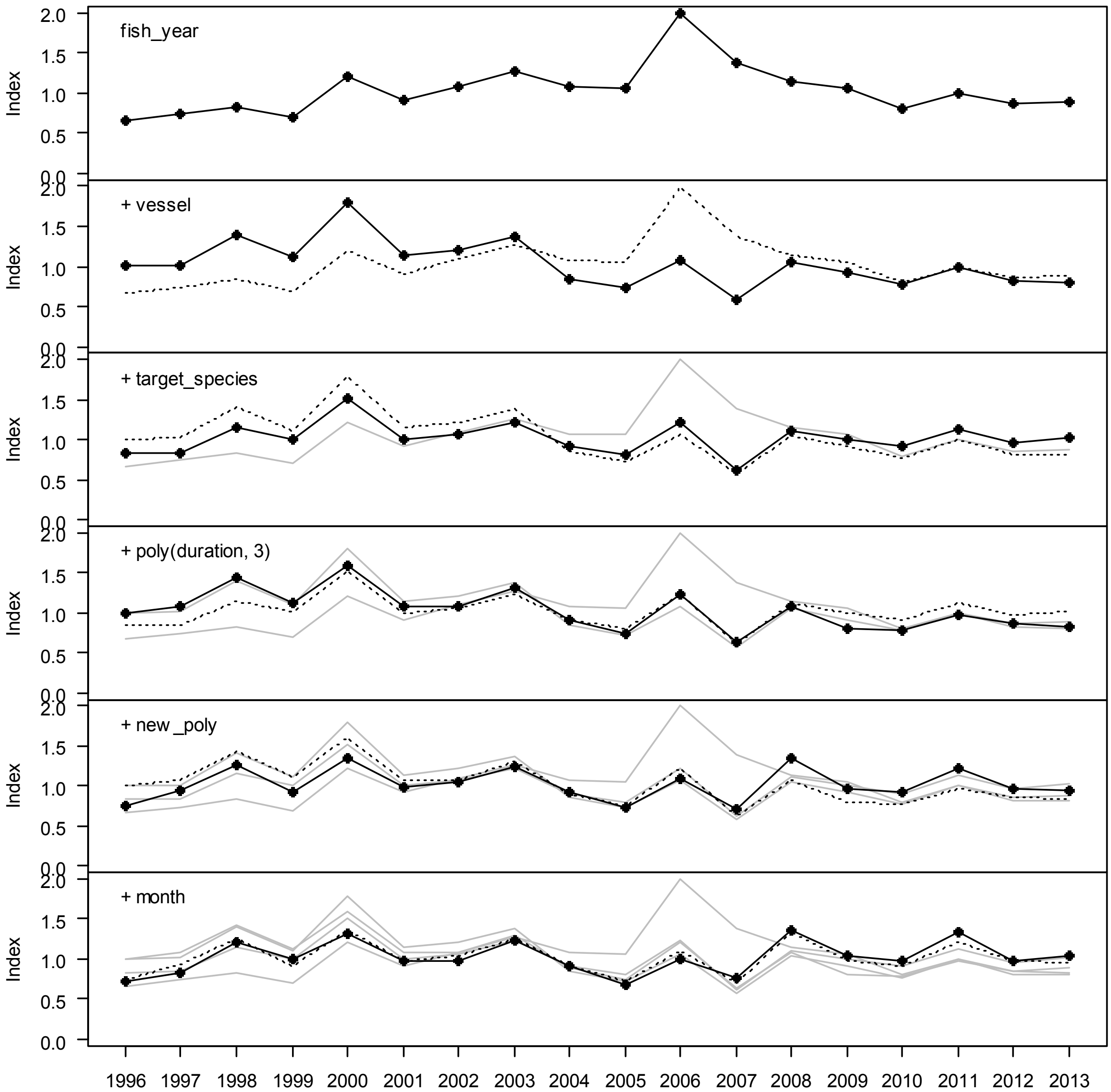


Figure 18: Step plot of the lognormal model for ENHG trevally catch from the TCP/TCE dataset rolled up to the trip level. The plot starts with just fishing year and sequentially adds additional variables that the lognormal CPUE analysis model had selected.

3.3.3.4 BPLE trip level standardised CPUE abundance index

Standardised CPUE analysis of the BPLE sub-stock (TCP/TCE dataset rolled up to the trip level) between 1996 and 2013 produced a lognormal index which had little trend, but oscillations of over 50% of the overall average value (Figure 19). A binomial index of probability of capture was based on the ratio of "eligible" (Section 3.2.2.1) trips where no trevally was landed, i.e. zero trips (Appendix 5). The standardised CPUE analysis using binomial catch data produced an index without trend, and as a result the combined index was very similar to the original lognormal index (Figure 19). We also conducted standardised CPUE analyses for the longer CEL dataset (also rolled up to the trip level and with target constrained to the categories that accounted for the majority of trevally catch: 'SNA' or 'TRE'; Figure 20). This longer time series also had good agreement between the lognormal and combined indices, and furthermore was very similar to the TCP/TCE index described above (Pearson's correlation coefficient = 0.80; Figure 21). As such, the CEL trip level rollup analysis with constrained target was chosen as an index of relative abundance of trevally in the BPLE sub-stock by the working group (Appendix 7) and all further diagnostics for the BPLE sub-stock relate to this analysis. For this longer time series (1990–2013) both the lognormal and the binomial indices had a positive trend, although again the lognormal index contained oscillations of over 50% of the overall average value (Figure 20). The fit of the lognormal model appeared to be good, with residuals approaching a normal distribution and a lack of high leverage outliers (Figure 22). The lognormal model explained about 54 % of variation within the dataset, while the binomial model explained about 29 % (Table 13). Both models selected the same five terms, but in different order, with the factor 'duration' explaining the most variation and having the biggest effect on both models (about 17 % for the lognormal and about 9 % for the binomial; Table 13 and Figure 23; see Appendix 8 for plots illustrating the influence of selected variables on the lognormal CPUE index).

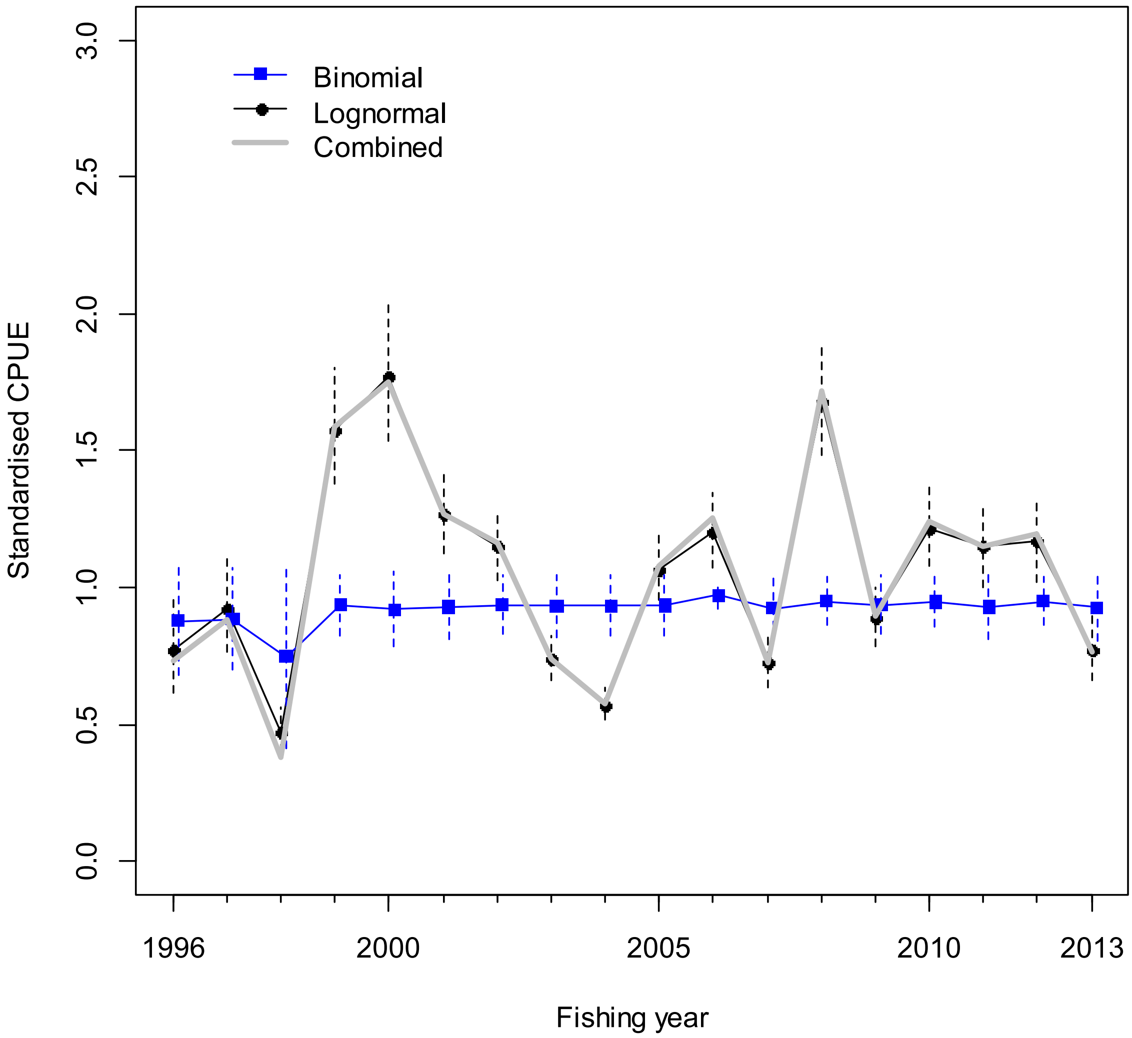


Figure 19: Standardised CPUE index for the BPLE sub-stock TCP/TCE dataset rolled up to the trip level.

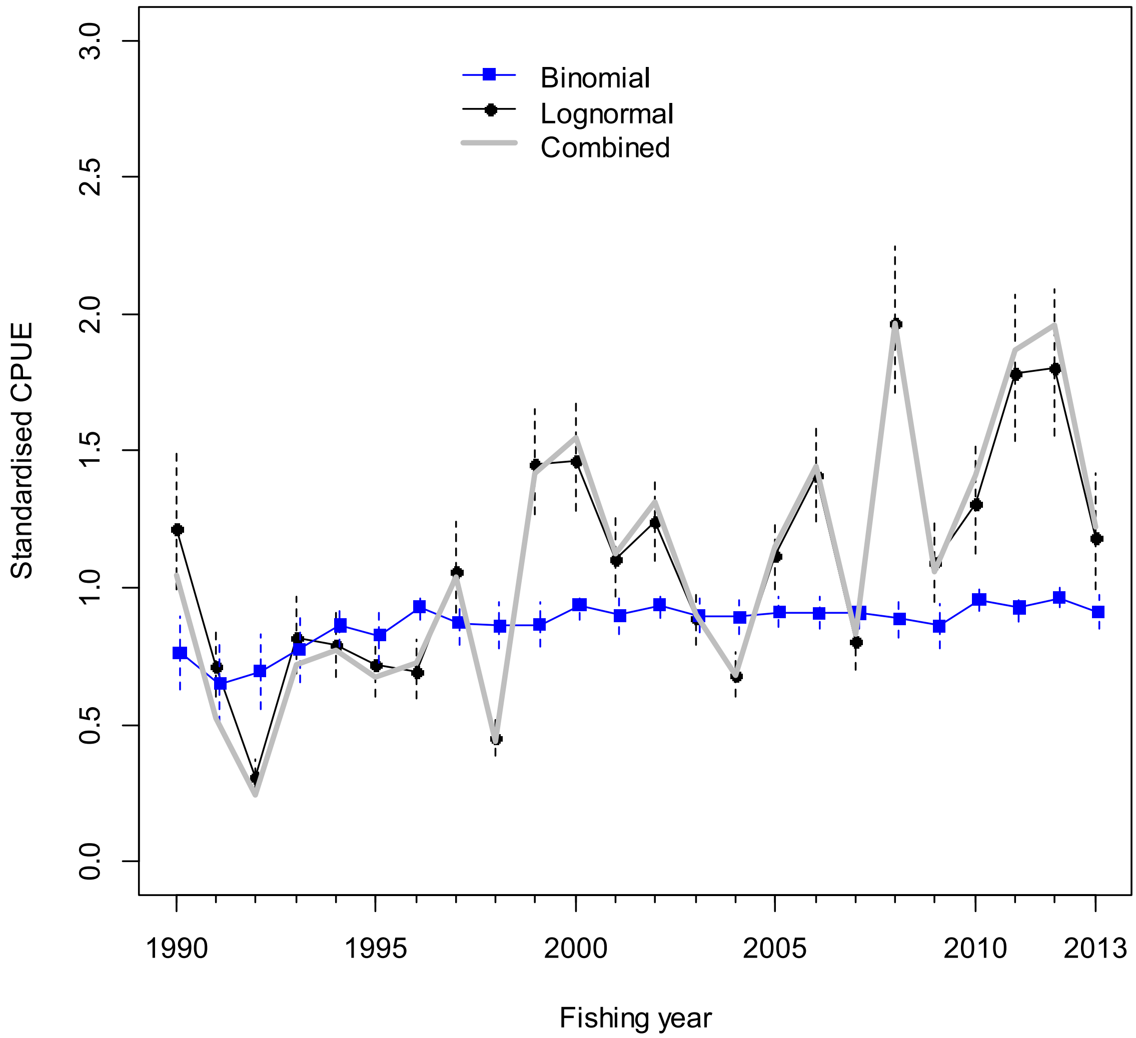


Figure 20: Standardised CPUE index for the BPLE sub-stock CEL dataset rolled up to the trip level with constrained target. For a list of terms picked by this analysis and their associated R^2 values see Table 13.

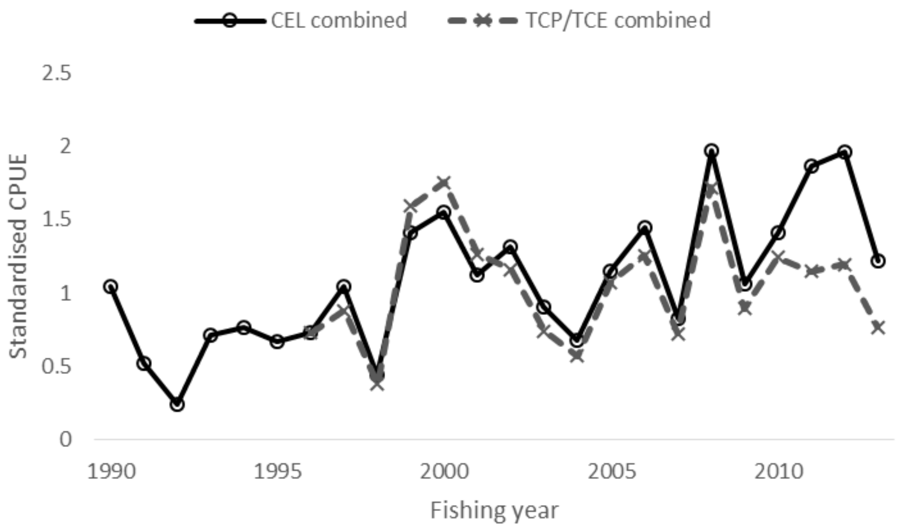


Figure 21: Comparison of the BPLE sub-stock combined (lognormal and binomial) standardised CPUE indices for the CEL and TCP/TCE trip level rollups. For the years where these indices overlap (1996–2013) they have a Pearson's correlation of 0.80.

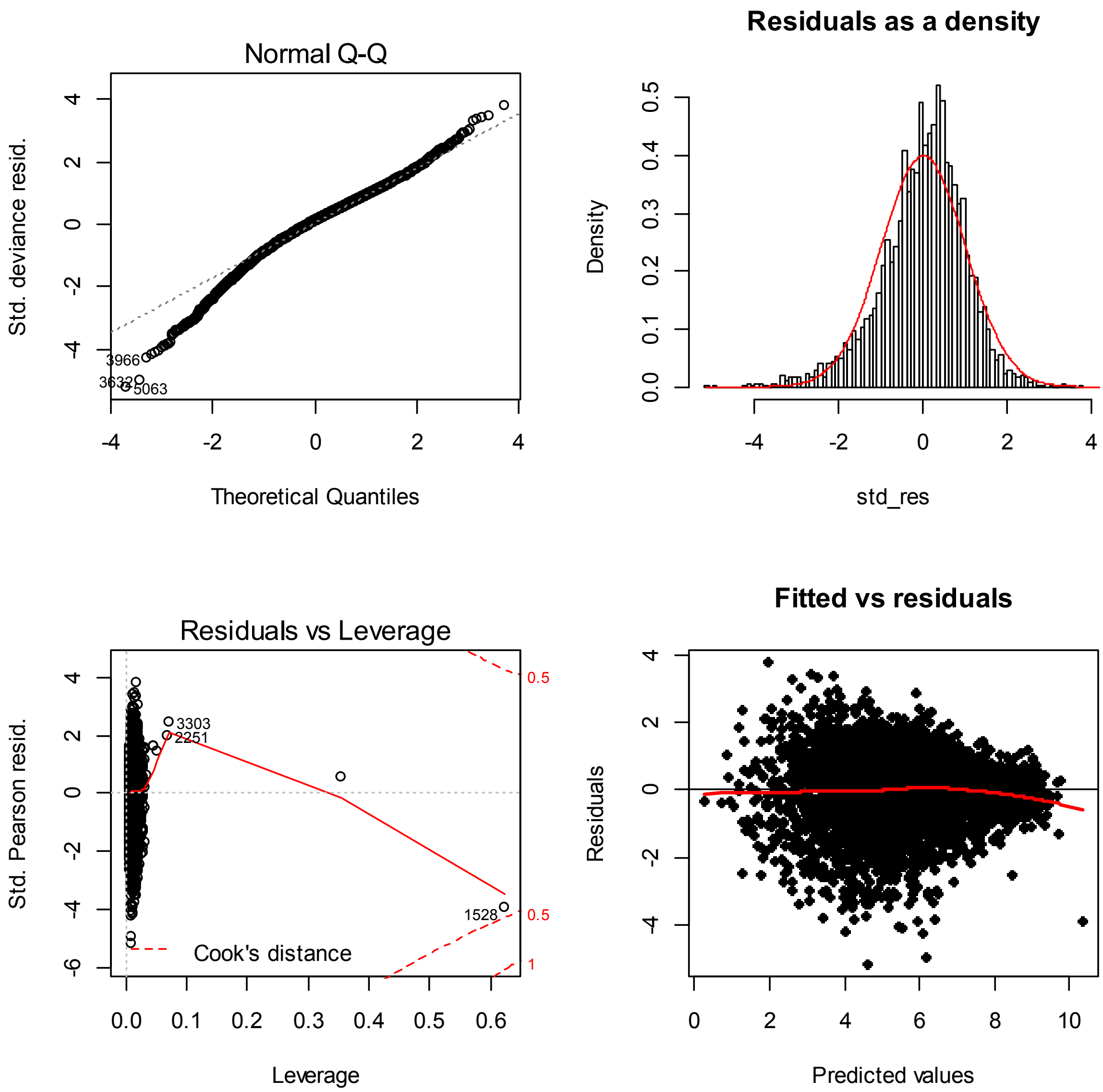


Figure 22: **Analysis of the fit of the lognormal regression model for BPLE trevally catches from the CEL trip level rollup with constrained target dataset. Top left panel is a QQ plot comparing the quantiles of a theoretical normal distribution to that of the residuals from the regression analysis. Top right panel is a histogram of the residuals from the regression analysis. Bottom left panel is a Cook's distance plot investigating the leverage of individual data points. Bottom right panel is a plot of model residuals against the fitted values of the model itself.**

Table 13: **Variables selected and variation explained by the lognormal and binomial CPUE analyses of the BPLE sub-stock CEL dataset rolled up to the trip level with constrained target (plot of index presented in Figure 20**

Lognormal		Binomial	
Variable	**R^2**	**Variable**	**R^2**
Fish year	0.09	Fish year	0.06
Duration	0.27	Duration	0.16
Target species	0.41	Vessel	0.22
Month	0.50	Target Species	0.27
Vessel	0.55	Month	0.29

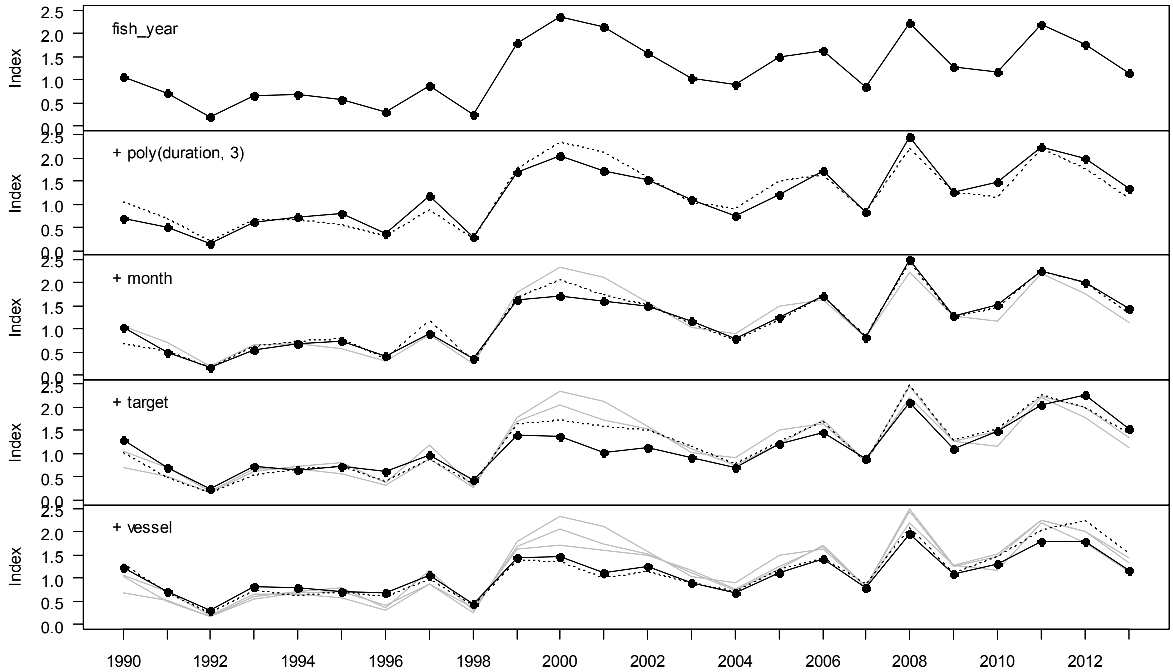


Figure 23: Step plot of the lognormal model for BPLE trevally catch from the CEL trip level rollup with constrained target dataset. The plot starts with just fishing year and sequentially adds additional variables that the lognormal CPUE analysis model had selected.

3.4 DISCUSSION

Establishing an acceptable index of abundance for trevally from commercial bottom trawl data was problematic, especially in the ENHG area. The key issue was establishing agreement between the lognormal and binomial CPUE indices. When the catch data was analysed at the event level this did not occur because of a trend in the on water reporting of small catches, which was not present in the verified landed weights from the same fishing trips. This effect was also observed within the JDO 1 fishery (MPI 2015). Such a pattern is not necessarily surprising as trevally is a bycatch species (the majority of our data set contained events with 0 catches of trevally), so other factors may have high leverage to determine CPUE. For example, fishing effort is likely to be directed towards more important species, or influenced by changes in market value or the availability of quota within the mix of species being caught (rather than being randomly distributed with respect to the species of interest) (Dunn et al. 2000). Here we rolled data up to the trip level to eliminate these on-water reporting issues, and furthermore constrained the fishery to a core area and also to core target species. This resulted in better agreement between the lognormal and binomial indices. The potential downside to such a constraint, however, is that CPUE analysis of a more constrained fishery can potentially mask hyperstability if it is occurring (Rose & Kulka 1999).

The final CPUE indices produced were reasonably flat (although the BPLE index had a slight upward trend). Given that the largest commercial extractions of trevally occurred prior to the beginning of the CPUE indices produced here (see Section 5 below), such a result appears reasonable. Verifying this pattern against other potentially contrasting sources of information (e.g. Section 4 aerial sightings, Section 7 population age structure) will be conducted within the assessment (Section 8).

4 TRE 1 RELATIVE ABUNDANCE: PURSE SEINE AERIAL SIGHTINGS INDEX

A potential index of abundance in TRE 1 is the aerial Sightings Per Unit Effort (SPUE) index (Figure 24). This index was based on records of trevally school sightings and associated tonnage estimates provided by a single pilot (Red Barker), who has been locating schools of pelagic fish for purse seiners working in the south western Bay of Plenty since 1975. Generalised Additive Modelling (GAM) was used to generate two sightings indices, a log-normal model of positive sightings data, and a binomial model of the proportion of trevally sightings in each grid square, which were then combined to provide a single abundance index (Taylor 2014a and b).

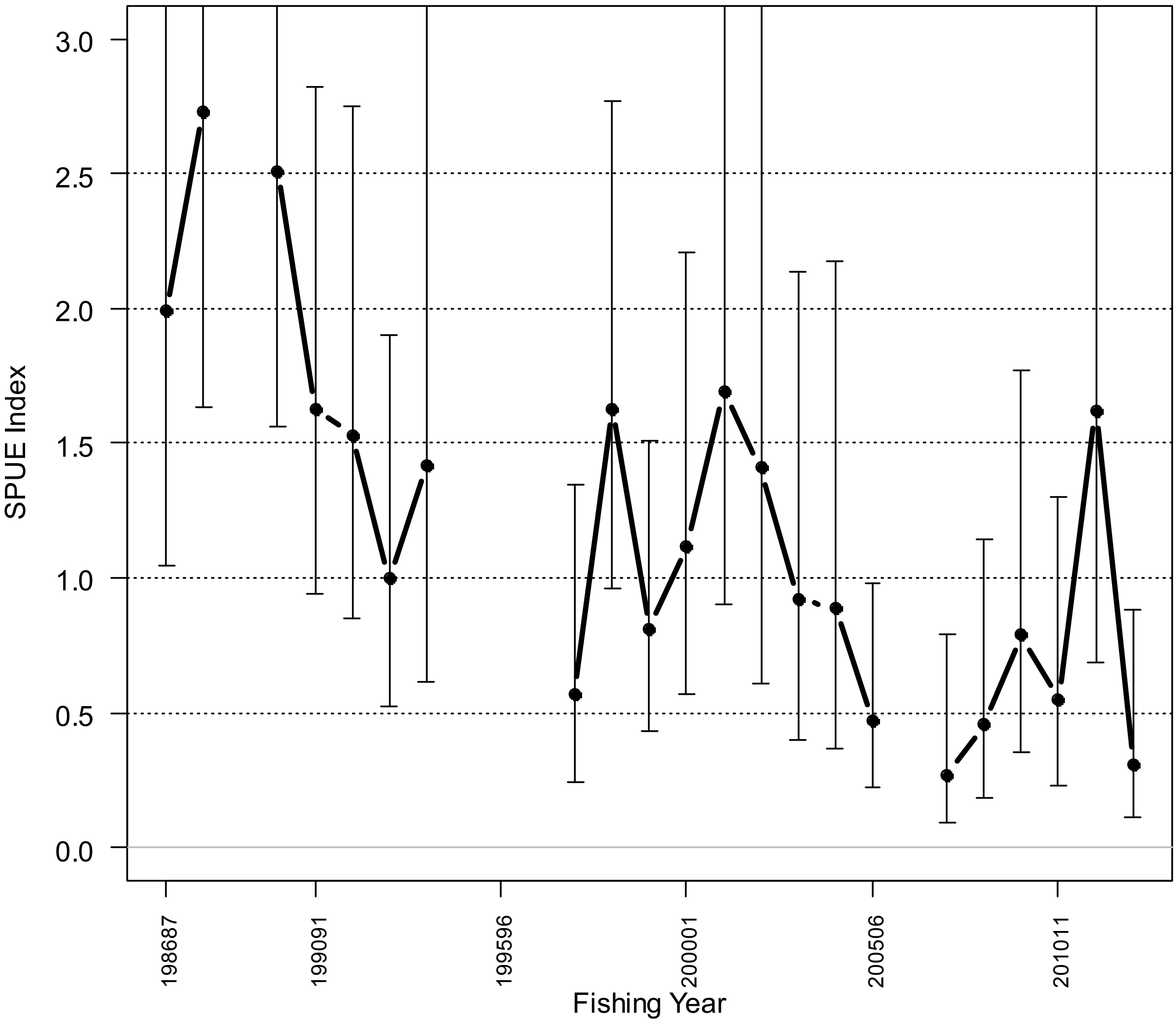


Figure 24: **Final normalised combined indices of relative abundance (SPUE) for trevally generated as the combination of the binomial and lognormal regressions; vertical bars are the 95% confidence intervals (Reproduced from Taylor 2014b).**

5 COMMERCIAL CATCH HISTORY

5.1 Data sources and issues:

The TRE 1 commercial catch histories for the various method area fisheries after 1989–90 were derived from the Ministry for Primary Industries (MPI) catch effort reporting database (*warehou*); catches for method and area between 1981–82 and 1989–90 were constructed on the basis of data contained in archived MPI databases.

Commercial catch histories for the period 1931 through to 1982 were derived from two sources as follows (Francis & Paul 2013):

1. 1931–73: Annual Reports on Fisheries, compiled by the Marine Department to 1971 and the Ministry of Agriculture and Fisheries to 1973 as a component of their Annual Reports to Parliament

published as Appendices to the Journal of the House of Representatives (AJHR). From 1931 to 1943 inclusive, data were tabulated by April–March years; these were equated with the main calendar year (e.g. 1931–32 landings are treated as being from 1931). From 1944 onwards, data were tabulated by calendar year.

2. 1974–82: Ministry of Agriculture and Fisheries, Fisheries Statistics Unit (FSU) calendar year records published by King (1985). The available data grouped catches for all species comprising less than 1% of the port totals as "Minor species". An FSU hardcopy printout dated 23 March 1984 held by NIWA was used to provide species-specific catches in these cases.

Confidence in the reported catch totals, spatial and method catch allocations varies across the time series as follows:

1931–1973 Annual port of landing catches are reported, so it is possible to "estimate" QMA totals, but more difficult to infer sub-area totals as there is no method information.

1974–1982 FSU period and first use of "area" reporting, which enables the split of catches to TRE 1 sub-areas, although methods reported for these data are considered unreliable.

1983–1988 FSU reporting system later series use of current statistical area boundaries allowing inference of area and method splits, but compliance declined after 1985 and ceased in 1988.

1988–1989 No data records can be located for this year.

1989–1990 to present Current MPI reporting system

5.2 1989 – 2013 Recent catch data

5.2.1 Main commercial methods

In Section 3.3.1 it was shown that the TRE 1 commercial catch after 1989 is taken by four principal methods: Bottom trawl (BT); Purse seine (PS); Setnet (SN); Bottom pair trawl (BPT); all other methods account for less than 4% of the annual landed catch (Figure 25).

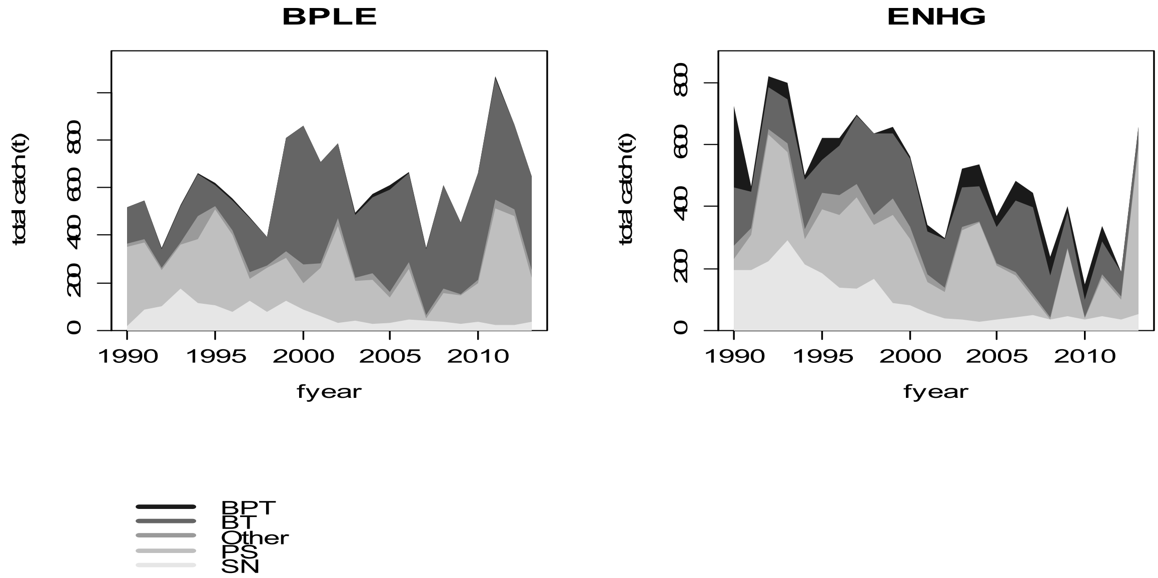


Figure 25: **Bay of Plenty (BPLE) and East Northland-Hauraki Gulf (ENHG) commercial annual trevally catches from 1989–90 through to 2012–13 by fishing method.**

Catch-at-age data on which gear selectivity could be estimated was only available for purse seine and bottom trawl methods. This limitation necessitated combining catches from set net, ring net and beach seine with purse seine, for stock assessment modelling proposes (Figure 26). Similarly, bottom pair trawl and all other method catches were combined with bottom trawl (Figure 26). The model-derived selectivity estimates from purse seine and bottom trawl were also assumed to apply to these other methods.

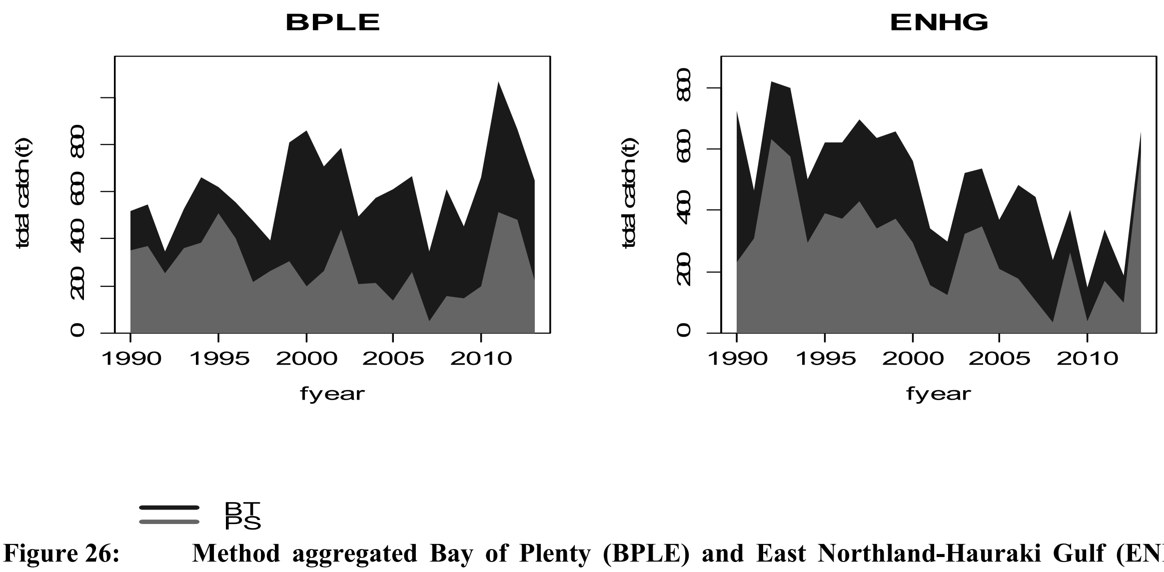


Figure 26: **Method aggregated Bay of Plenty (BPLE) and East Northland-Hauraki Gulf (ENHG) commercial annual trevally catches from 1989-90 through 2012-13.**

5.3 FSU Catch 1983 -1988

Data collected under the Fisheries Statistical Unit (FSU) reporting system covers the period 1982–1988. Reporting by current MPI statistical reporting areas was first introduced in 1983 under the FSU, enabling the east coast Northland trevally fishery to be more accurately apportioned into BPLE and ENHG stock areas after this date. Fisher reporting compliance under the FSU declined after 1985 and ceased in 1988. Virtually no spatial reporting data were collected between October 1988 and the start of the current MPI system in October 1989. FSU data integrity issues can be seen in the comparison between 'official' (Ministry for Primary Industries 2015 reported landings and FSU database annual catch totals (Table 14).

Table 14: Comparison between FSU TRE 1 reported data totals and reported landed catch (tonnes) or the MPI 'official' catches aggregated by both calendar and fishing year.

Calendar year	Fishing year	MPI official Cal. year total	MPI official fyear total	FSU Cal. year total	FSU fyear total	FSU BPT/2 Cal. year total
1983	82–83	1 534	0	1 783	0	1 457
1984	83–84	1 798	0	2 155	0	1 703
1985	84–85	1 887	0	2 314	0	1 759
1986	85–86	1 431	0	1 504	0	1 203
1987	86–87	0	982	0	765	0
1988	87–88	0	1 111	0	885	0

The FSU database and MPI (2015 calendar-year totals do not match; the FSU totals being consistently higher for the 1983–1986 calendar years (Table 14). It appears that the discrepancy can in part be explained by double counting of the bottom pair trawl catch in the FSU database (i.e. due to both vessels reporting the same catch). Halving this component in the FSU data (FSU BPT/2 in Table 14) brought the total more in line with the MPI annual catch totals (Table 14). Official landed catch totals are reported by fishing year after 1986; the decline in FSU compliance is demonstrated by the lower FSU compared to official totals over this latter period (Table 14).

Catch by method for the later FSU years were derived by summing the FSU data and prorating these totals to match the published TRE 1 totals. The 1982–83 fishing year was assigned the 1983 calendar year totals. The "missing" 1988–99 fishing year was assigned the same catch and area ratios as the 1987–88 fishing year, with the total prorated to match the MPI (2015) total for that year. There were only four TRE 1 methods listed in the FSU data series, i.e. no "other" category (Figure 27).

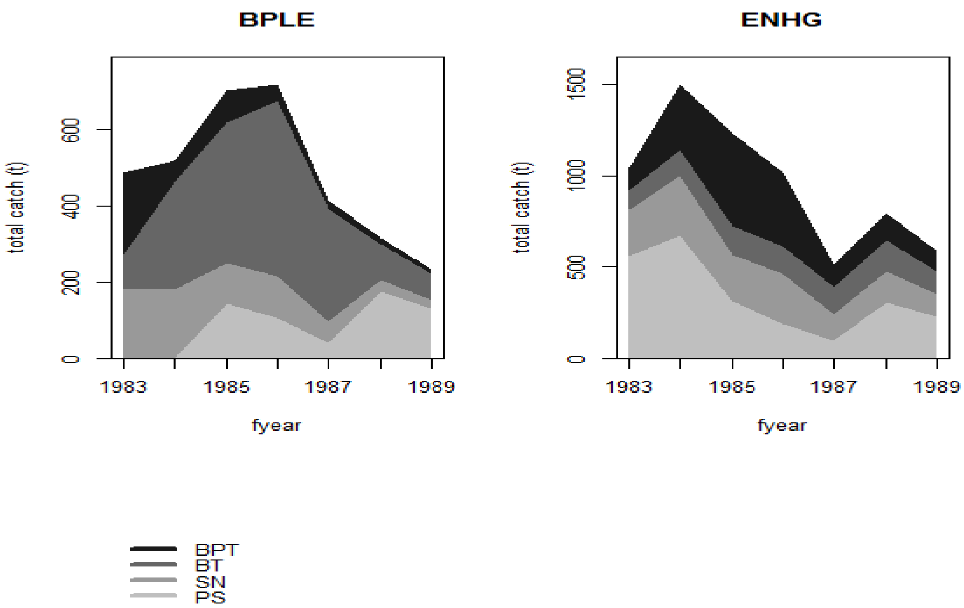


Figure 27: **Bay of Plenty (BPLE) and East Northland-Hauraki Gulf (ENHG) commercial annual trevally catches from 1982–83 through 1988–89 by fishing method as derived from the FSU data series.**

Again, for stock assessment modelling purposes the FSU data were aggregated into two method types as described in Section 5.2 (Figure 28).

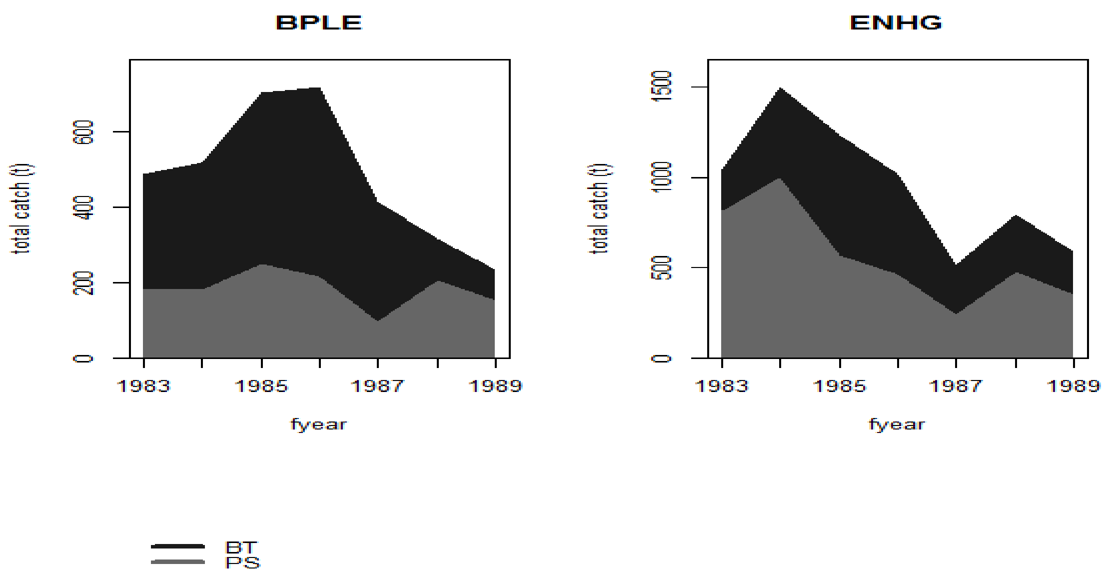


Figure 28: **Method aggregated Bay of Plenty (BPLE) and East Northland-Hauraki Gulf (ENHG) commercial annual trevally catches from 1982–83 through to 1988–89 by fishing method as derived from the FSU data series.**

5.4 Historical catch 1931 – 1982

Catch totals are reported only as calendar years prior to 1982. For the purpose of stock assessment modelling fishing-year totals were assumed to be the same as the calendar year totals; the calendar year referencing the second year of the fishing year pair, e.g. the 1982 annual catch represents the 1981–82 fishing year. There was limited method information associated with the historical TRE 1 data series prior to 1982, meaning that the method composition of the catch pre-1982 is highly uncertain (Figure 29).

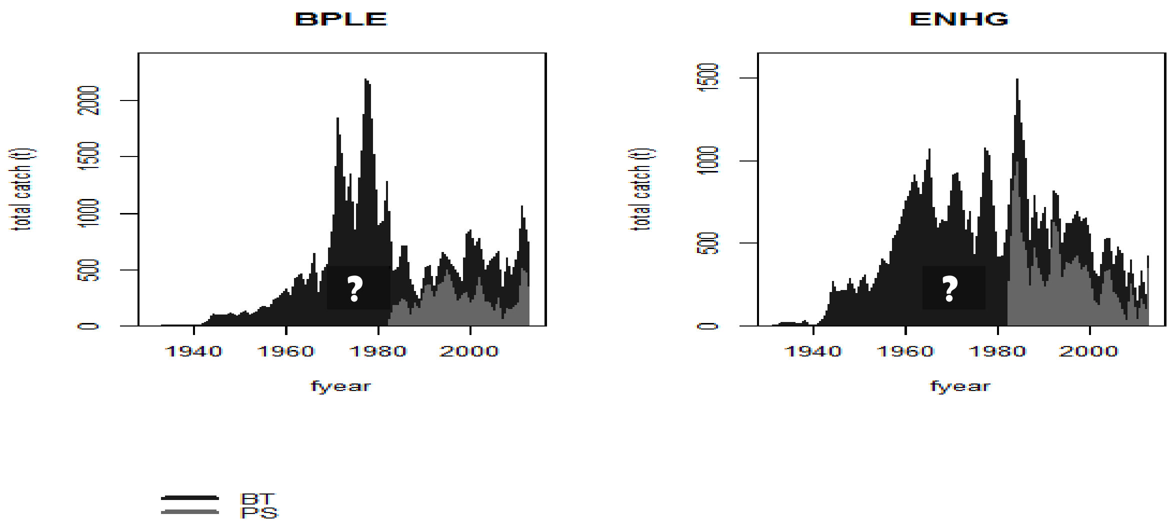


Figure 29: Method aggregated Bay of Plenty (BPLE) and East Northland-Hauraki Gulf (ENHG) commercial annual trevally catches from 1931–32 through to 2012–13 by fishing method. Method splits highly uncertain pre 1982–83.

5.5 "Unseen catch" adjustments

There is strong anecdotal and direct evidence that the reported TRE 1 catch totals given in Figure 29 under-represent the actual commercial removals. The "unseen" catch can be divided into three components: unreported, discarded and foreign harvest.

5.5.1 Unreported catch adjustment

For most New Zealand stocks, including TRE 1, historical illegal and or unreported catch tonnages are unknown. In the absence of better information the standard approach is to assume that under-reporting was 20% prior to the 1986–87 fishing year and 10% thereafter (Francis & McKenzie 2015). The effect of scaling the TRE 1 catch history series by these ratios is seen in Figure 30.

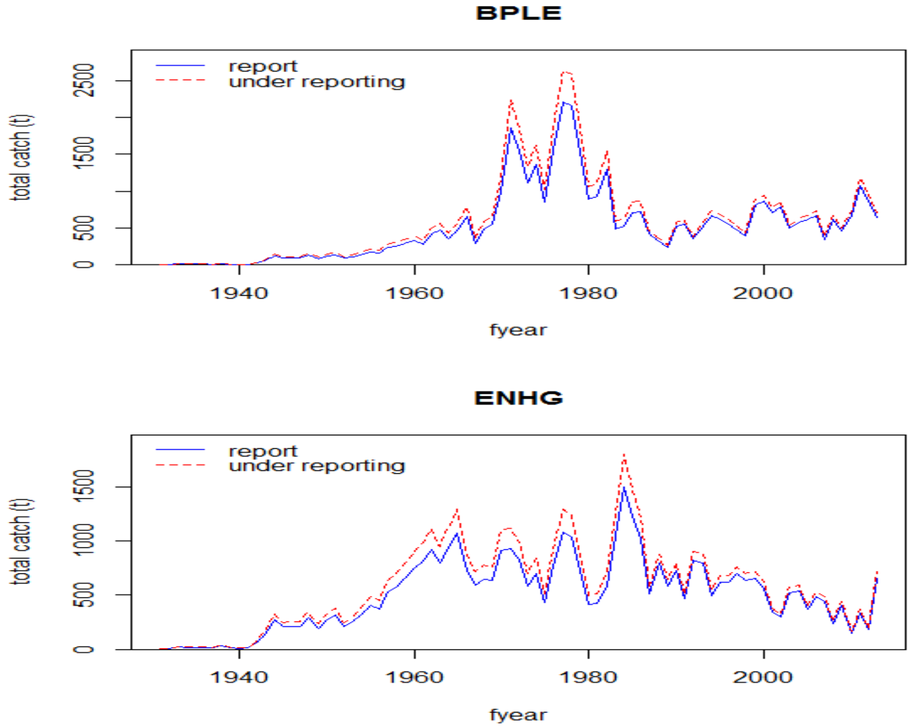


Figure 30: **Effect of adjusting the Bay of Plenty (BPLE) and East Northland-Hauraki Gulf (ENHG) commercial trevally catch totals for 20% under-reporting prior to 1986-87 10% after.**

5.5.2 Discarded catch

James (1984) provides estimates of the quantities of trevally discarded at sea; these being obtained through experienced trawl fishermen interviews. According to James (1984) it is likely that more than 50% of trevally caught by bottom trawl prior to 1955 were dumped. However, by 1960 this had decreased to about 30%. By the mid-1960s, as markets improved, less than 3% were being discarded, and by the late 1960s all trevally caught by bottom trawl were being landed. The predicted amount of discarded trevally catch resulting from applying these ratios to the TRE 1 catch history totals (after under-reporting adjustment; Figure 30) is given in Figure 31.

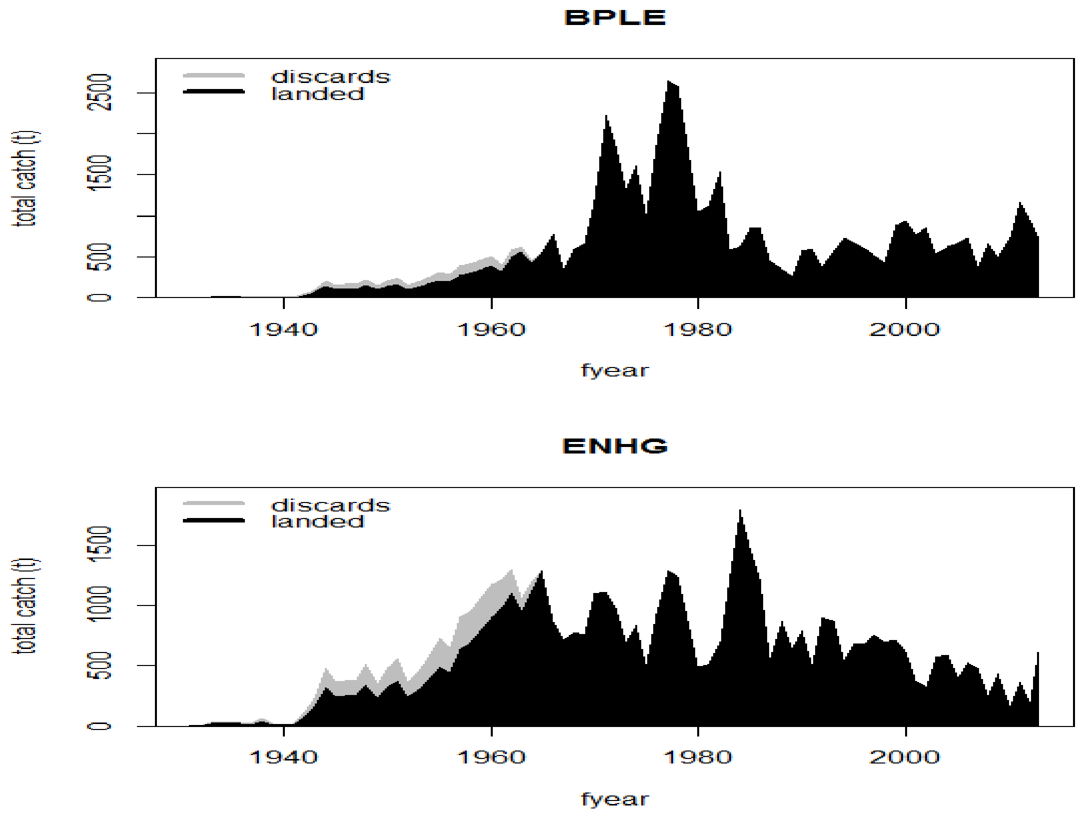


Figure 31: Effect of adjusting the Bay of Plenty (BPLE) and East Northland-Hauraki Gulf (ENHG) commercial trevally catch totals for discarding in accordance with discard percentages given in James (1984).

5.5.3 Unreported foreign catches

Prior to the introduction of the 200 n. mile Exclusive Economic Zone (EEZ) in 1977 foreign vessels could fish to within 12 n. mile from the New Zealand coastline. Japanese and Russian vessels were known to fish coastal New Zealand waters during the 1960s and early 1970s and it is likely that these vessels caught significant quantities of trevally during this period (Francis & Paul 2013). However, as no data exists on which to estimate the quantity of TRE 1 taken by foreign vessels, no allowance for foreign catch has been made to the TRE 1 annual catch estimates in this report.

5.6 Final commercial catch history used for the BPLE stock assessment

In addition to the adjustments of catch quantity described above, James (1984) also provides information on the proportion of trevally catch taken by trawling, purse seine, and non-power nets between 1960 and 1982. This information was used to create the fishing method split of the "adjusted" Bay of Plenty annual catch totals (Figure 31) between these years. In addition, the James (1984) gear ratio for 1959–60 fishing year was applied back to 1930–31. The final catch history series used in the Bay of Plenty stock assessment (Figure 32) is given in Appendix 11 (copy of CASAL model input file).

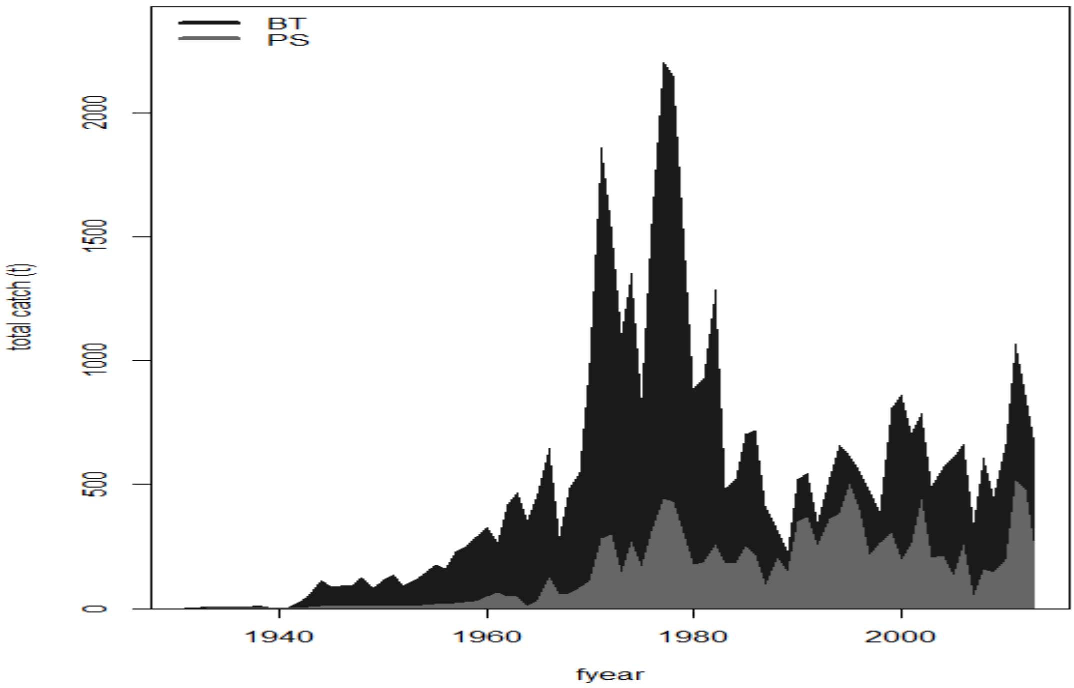


Figure 32: Method aggregated Bay of Plenty (BPLE) commercial annual trevally catches from 1931–32 through to 2012–13 by fishing method. Pre 1982 method splits given by James (1984).

Note: As no assessment was done for the East Northland-Hauraki Gulf stock no model catch history data were prepared (refer Section 8.1)

6 RECREATIONAL CATCH HISTORY

Direct estimates of annual recreational harvest of trevally from the three areas of TRE 1 (East Northland, Hauraki Gulf and Bay of Plenty) are available from aerial-access surveys conducted in 2004–05 and 2011–12 (Hartill et al. 2007, 2013; Table 15). Reliable recreational catch estimates for all other years are unavailable (Bruce Hartill pers. comm.).

Table 15: Recreational catch of trevally (tonnes) from aerial surveys in the 2004–05 and 2011–12 fishing years (Hartill et al. 2007, 2013)

Stock	2004–05	2011–12
East Northland Hauraki Gulf	58	80
Bay of Plenty	47	49

An approach similar to that adopted for the recent SNA 1 assessment was used to construct a recreational catch history for the two TRE 1 stock areas (Francis & McKenzie 2015). Specifically, the approach was to apply the average of the 2005 and 2012 survey estimates across all fishing years between 1969–70 and 2012–13 inclusive, then ramp down the average-catch to 10% of that value in 1930–31 (Figure 33). As the customary harvest is not known, no additional allowance was made to the ‘assumed’ recreational harvest totals given in Figure 33.

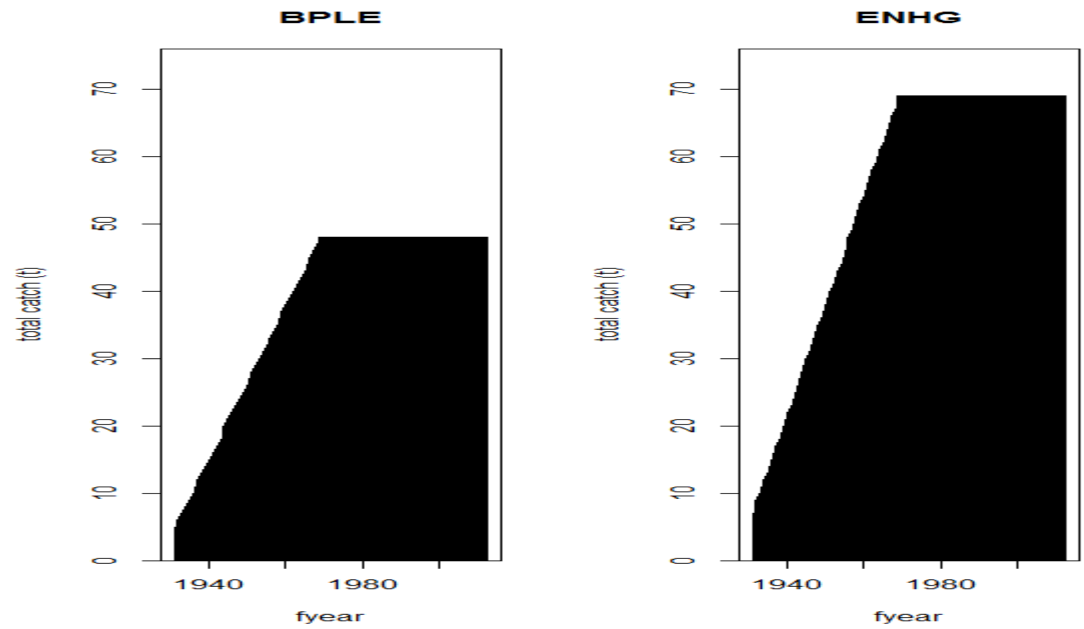


Figure 33: Derived Bay of Plenty (BPLE) and East Northland-Hauraki Gulf (ENHG) recreational annual trevally catches from 1930–31 through to 2012–13.

7 TRE 1 CATCH AT AGE OBSERVATIONS (ALL DATA)

7.1 Available age data

As discussed in Section 2, catch sampling data with which to estimate year class strength within TRE 1 is available (intermittently) back to the 1997–98 fishing year. Age estimates based on otoliths are available for all sampled fish and ages extend out to 40 years. In past trevally stock assessments, the age cohort data entered into the stock assessment models has been truncated at 20 years; the 20 year cohort thus being an amalgamation of all older age classes (Langley & Maunder 2009). Truncating at 20 years has the advantage of ensuring model year class strength estimates are based on age-observations where reader precision is high (see also Section 2.2.2); however, having fewer age-cohorts in the model limits both the number of recruitment deviates that can be estimated and possibly also the model power to estimate gear selectivity and/or natural mortality. For the assessments presented in this report the available catch at-age series were extended out to 29 years with a 30th year being a plus group.

The utility of ENHG and BPLE catch at-age data series to estimate year class strength is potentially compromised in three ways:

1. Pre 2007–08 TRE 1 catch sampling programmes did not formally recognise East Northland and Bay of Plenty stratifications (Walsh et al. 2010), therefore not all areas and methods are represented in all years TRE 1 sampling took place.
2. Inconsistences and uncertainties in age readings are likely to be present in the pre-2006–07 TRE 1 age data (Walsh et al. 2014a).
3. Inclusion of potentially “less precisely” aged 20 – 30 year old classes in the estimation series.

In combination these factors are likely to reduce model precision on recruitment variation (i.e. less precisely estimated recruitment deviates).

Catch-at-age data from the ENHG component of TRE 1 are intermittently available from the 2006–07 fishing year onwards for bottom trawl, and from the 2000–01 fishing year for purse seine (Figure 34; Figure 35). Catch at-age data from the BPLE component of the TRE 1 stock are intermittently available from the 1997–98 fishing year onwards for both fishing methods (Figure 36; Figure 37).

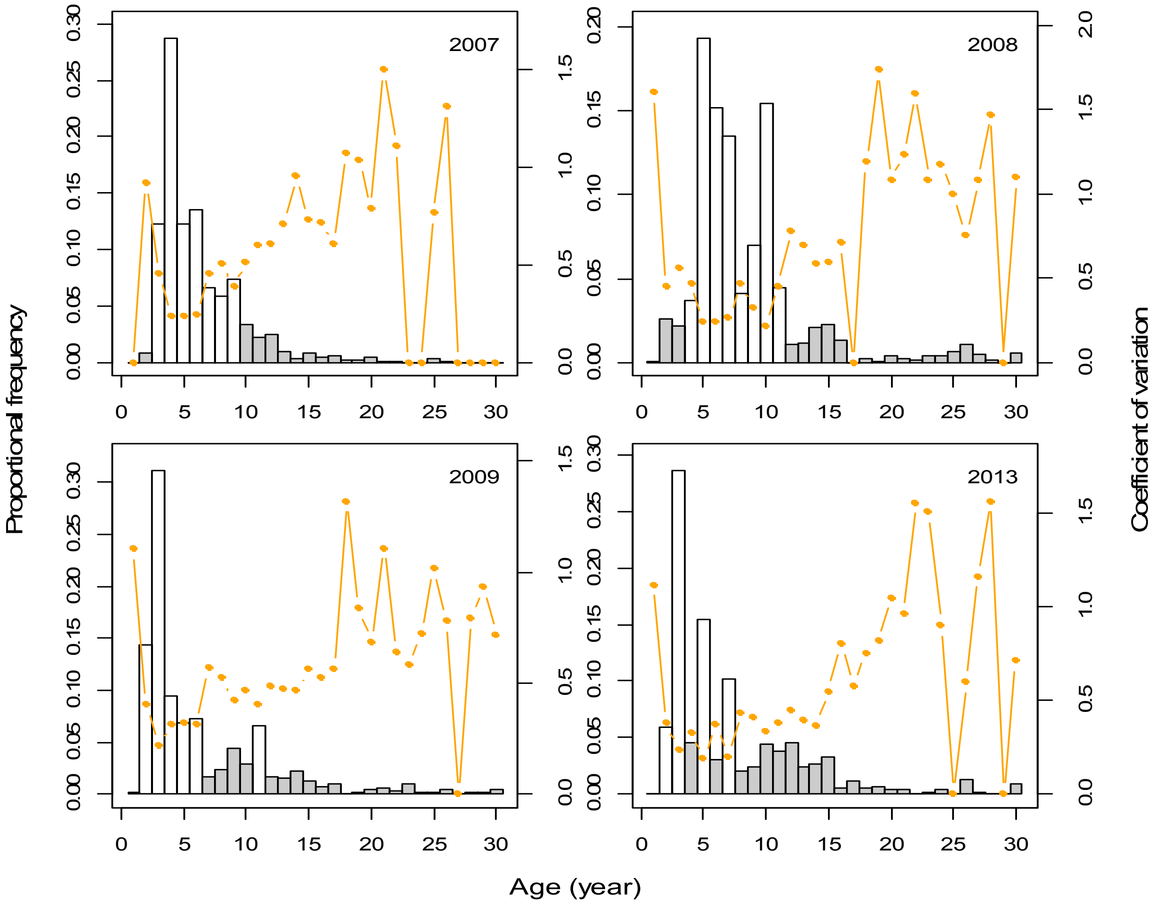


Figure 34: Proportional catch at-age estimates from the East Northland/Hauraki Gulf (ENHG) bottom trawl fishery.

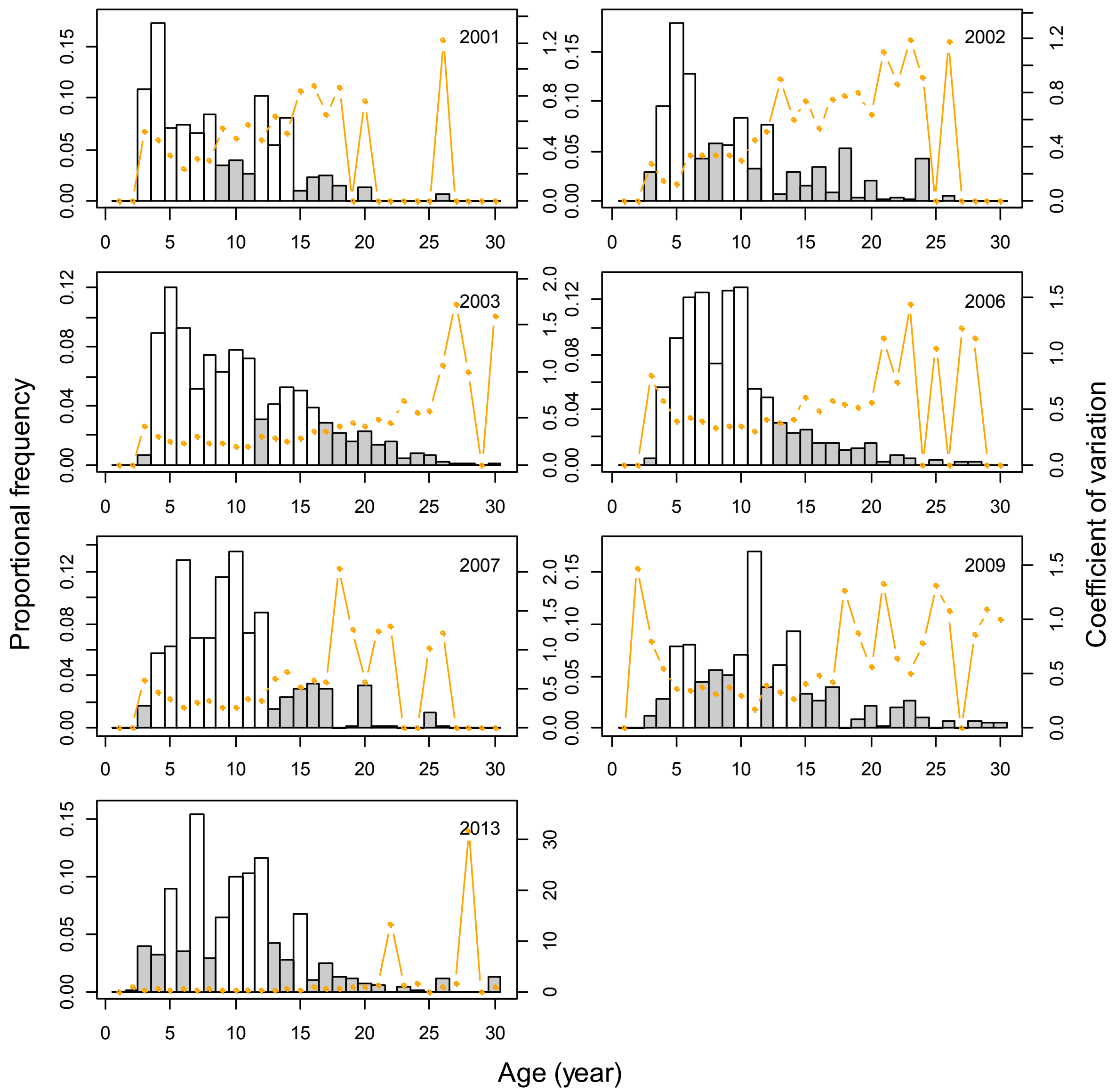


Figure 35: Proportional catch at-age estimates from the East Northland/Hauraki Gulf (ENHG) purse seine fishery.

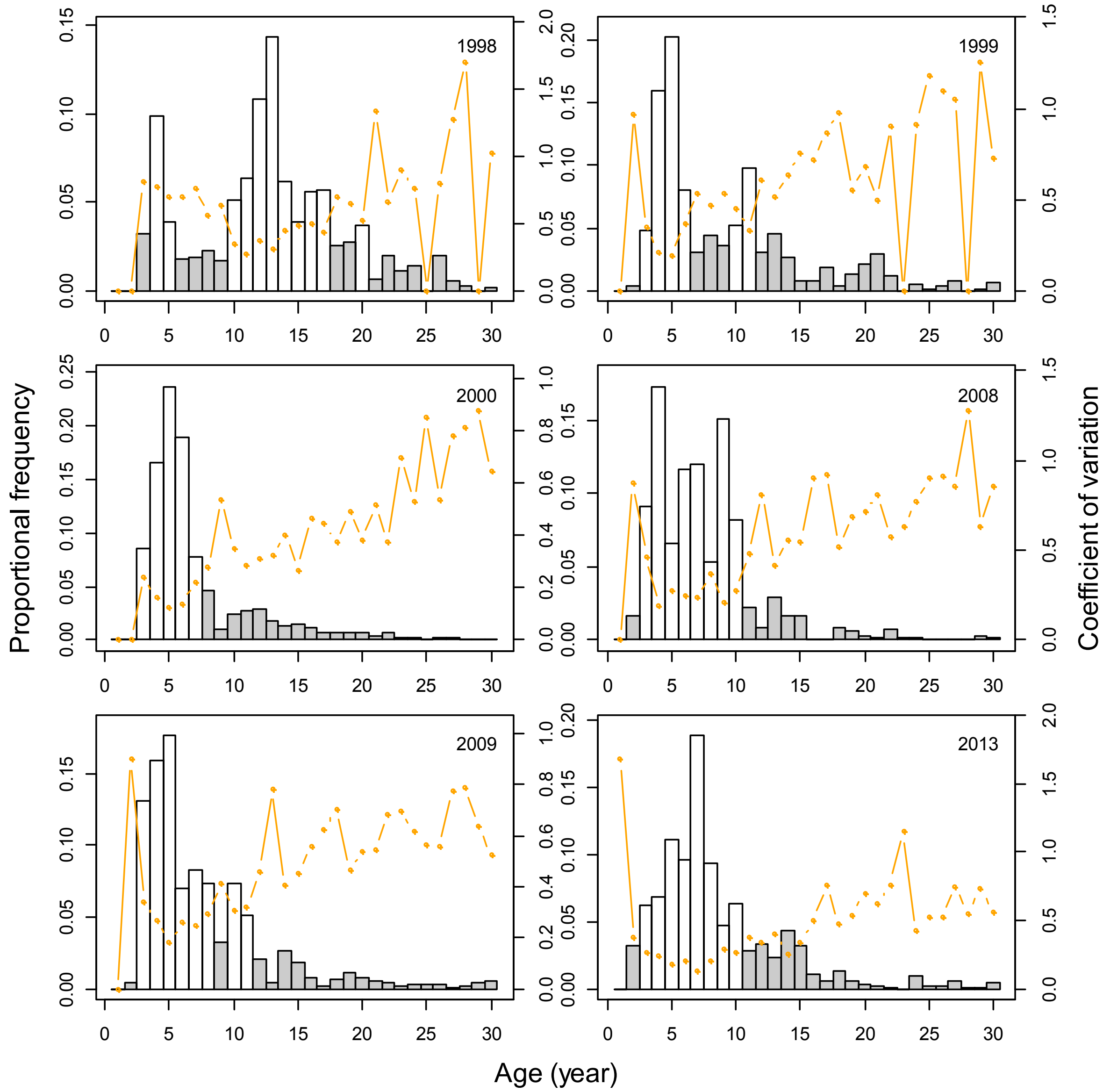


Figure 36: **Proportional catch-at-age estimates from the Bay of Plenty (BPLE) bottom trawl fishery.**

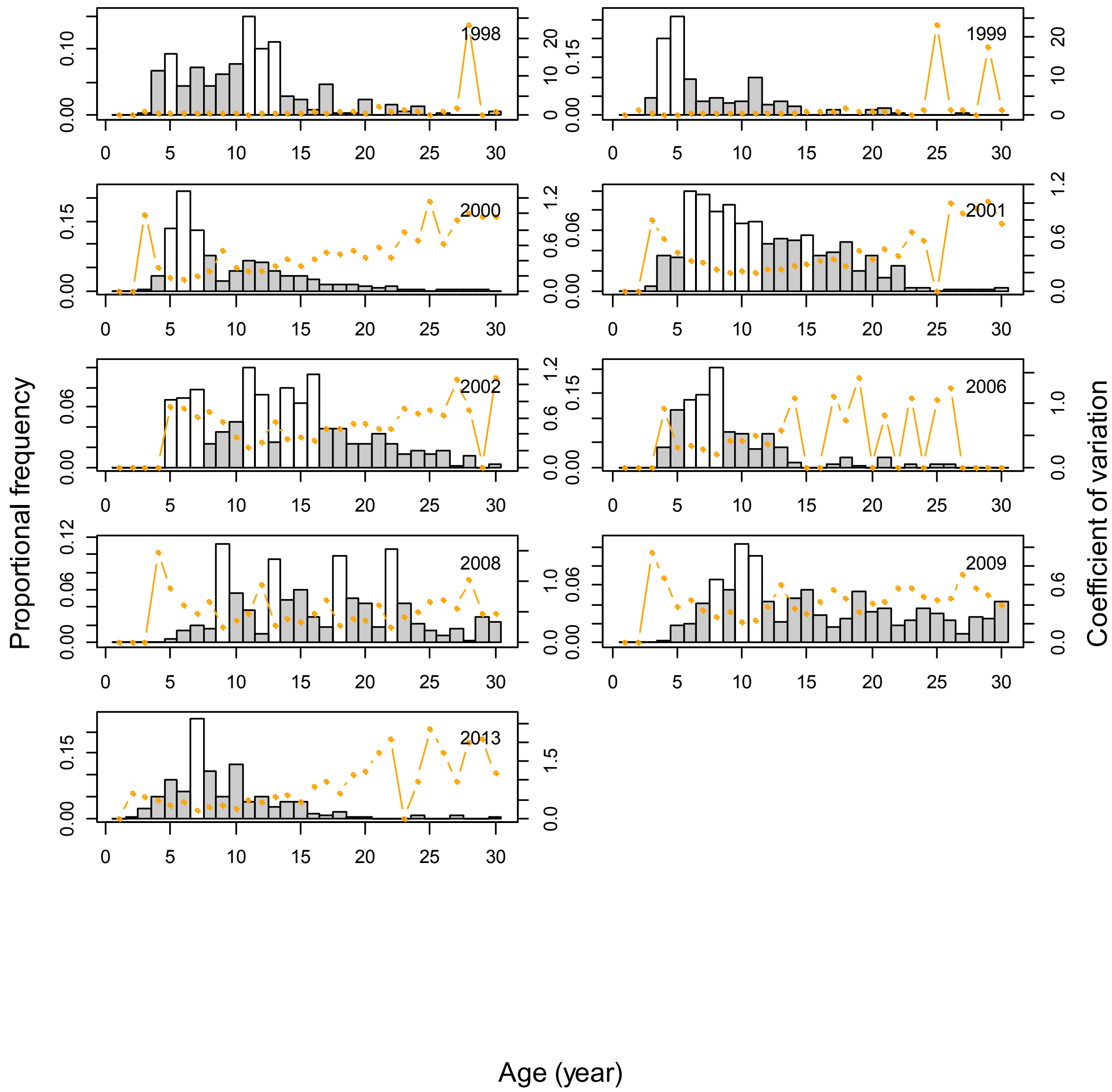


Figure 37: Proportional catch at-age estimates from the Bay of Plenty (BPLE) purse seine fishery.

7.2 1970s Bay of Plenty purse seine catch at-age estimates as published in James (1984)

Catch-at-age estimates for the 1970s Bay of Plenty purse seine fishery are published in James (1984) (Figure 38). The level of sampling undertaken, the degree of fishery representativeness, and the estimation of CV's are, however, unknown. The robustness of the Bay of Plenty stock assessment to the inclusion of these data was investigated as a model sensitivity run.

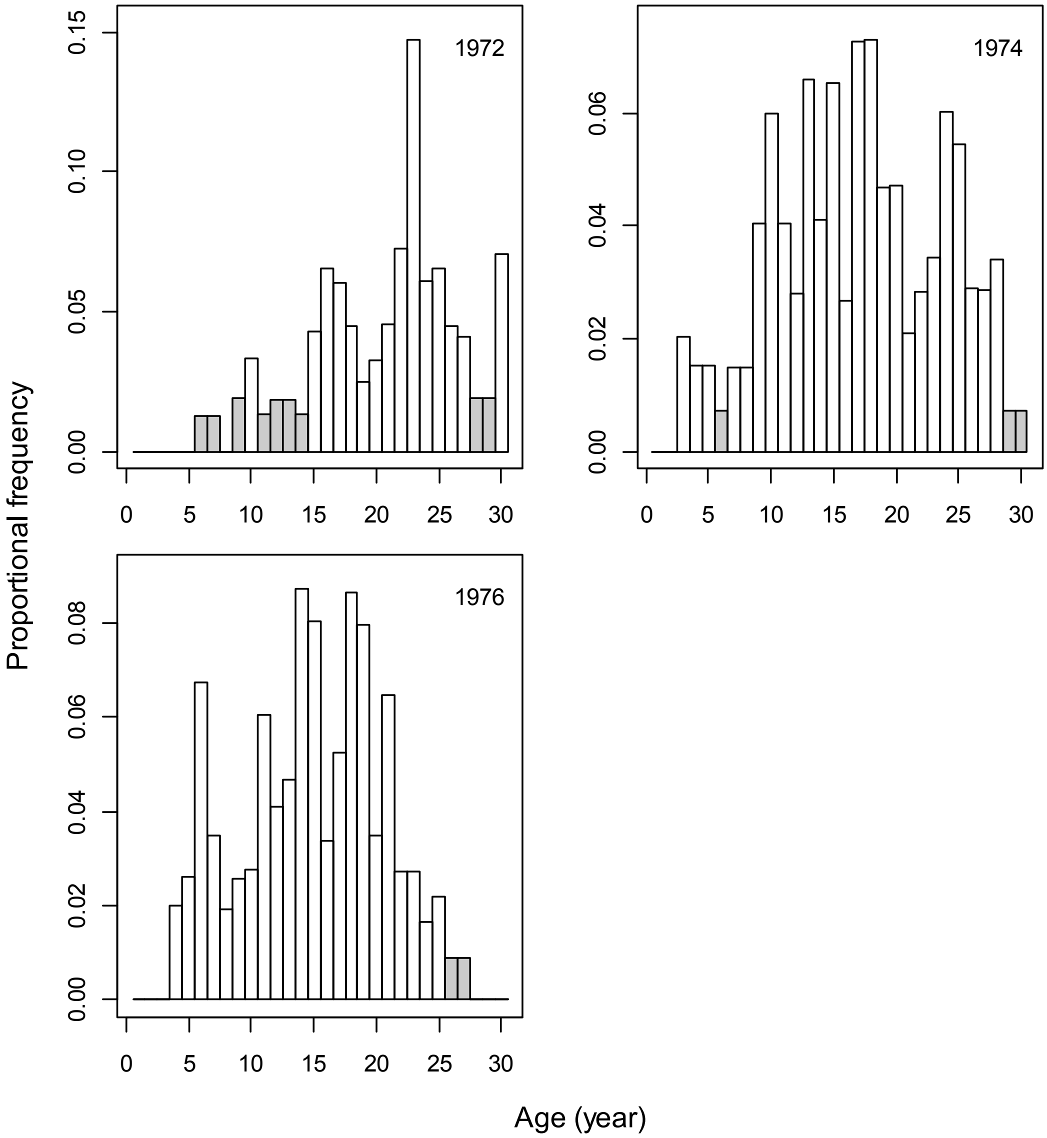


Figure 38: Proportional catch at-age estimates from the Bay of Plenty (BPLE) purse seine fishery as published in James (1984).

7.3 Year class strength observations

On the recommendation of the Northern Inshore Working Group, year class strength estimation in TRE 1 assessment modelling was restricted to survey age observations between 3 and 29 years inclusive. In addition, stock assessment modelling only incorporated year classes where at least two independent survey observations (looks) were available.

7.3.1 Bay of Plenty catch at-age data power to estimate YCS

The BPLE purse seine and bottom trawl catch at-age series provide two or more observations of year class strength for 37 consecutive annual spawning events between 1970 and 2006 inclusive (Appendix 9). Year class strength predictions as derived through catch curve analysis of the bottom trawl and purse seine series are seen in Figure 39 and given in Appendix 9 (see Section 2.2.2 for methods). Patterns in mean year class strength for bottom trawl and purse seine (Figure 39) are moderately correlated (Pearson correlation coefficient of 0.7).

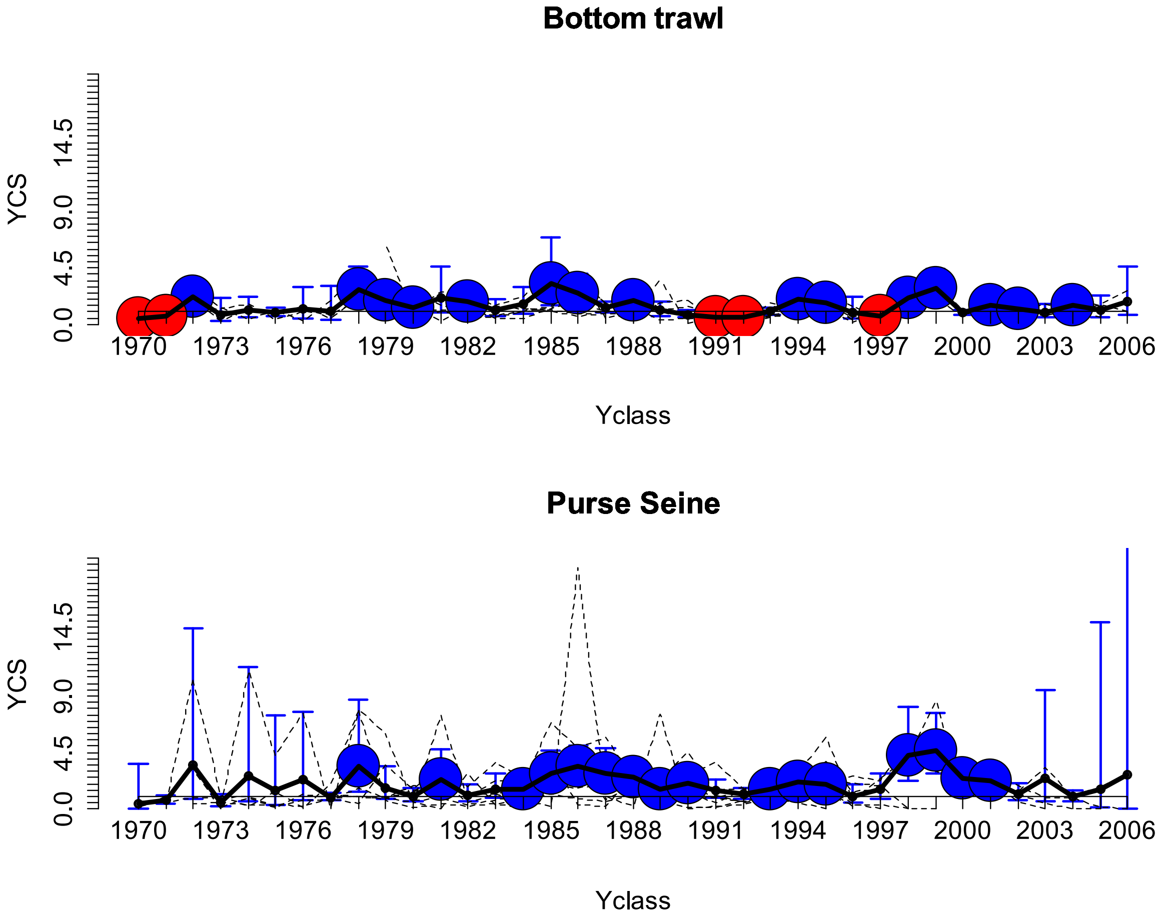


Figure 39: Bay of Plenty (BPLE) year class relative strength (1970 to 2006) as derived through catch-curve regression analysis of bottom trawl and purse seine age data. Solid lines trace weighted mean YCS as derived from two or more survey years; bars denote 95% CI; dotted lines are the predicted YCS indices as derived from each independent sampling year; coloured circles denote strong (blue) and weak (red) year classes (i.e. 95% CIs do not include 1.0).

Although the trends in mean year class strength are broadly similar in the two method fisheries (Pearson correlation coefficient of 0.7), year class strength estimates as derived from purse seine are generally less precise (i.e. as denoted by higher between survey variability) than those from bottom trawl (Figure 39).

7.3.2 East Northland catch at-age data power to estimate YCS

The ENHG catch at-age series provide two or more observations of year class strength for 28 consecutive annual spawning events between 1978 and 2006 inclusive for bottom trawl (Appendix 10) and 34 consecutive annual spawning events between 1973 and 2006 inclusive for purse seine (Appendix 10). Year class strength predictions as derived through catch curve analysis of the bottom trawl and purse seine series are given in Figure 40. Patterns in mean year class strength for bottom trawl and purse seine (Figure 40) were marginally correlated (Pearson correlation coefficient of 0.58).

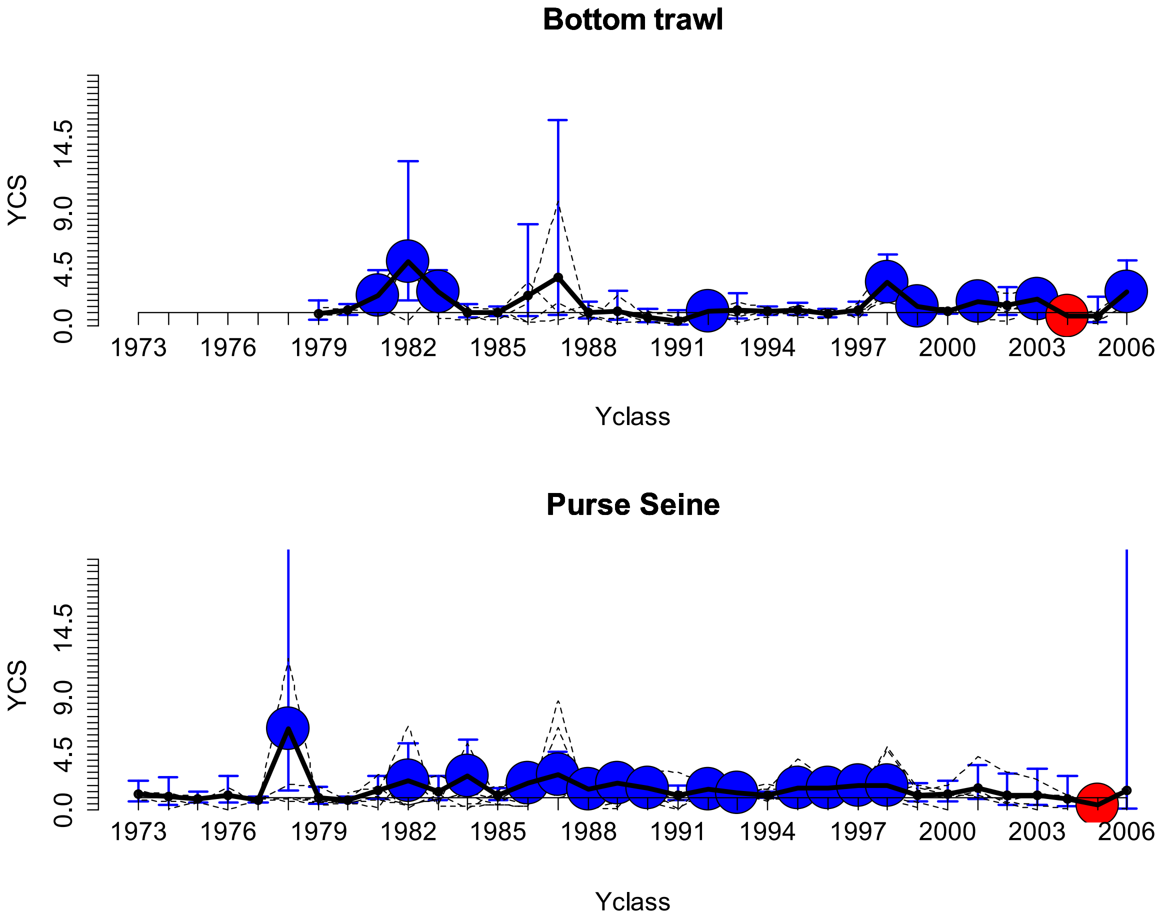


Figure 40: East Northland/Hauraki Gulf (ENHG) year class relative strength (1970–2006) as derived through catch-curve regression analysis of bottom trawl and purse seine age data. Solid lines trace weighted mean YCS as derived from two or more survey years; bars denote 95 % CI; dotted lines are the predicted YCS indices as derived from each independent sampling year; coloured circles denote strong (blue) and weak (red) year classes (i.e. 95% CIs do not include 1.0).

7.3.3 Likely causes of variability in the TRE 1 catch at-age series and implications for stock assessment

The level of inter-annual variability in age-range evident in the TRE 1 purse seine and bottom trawl catch sampling data series (Figure 34 – Figure 38) is largely implausible in terms of stock dynamics and therefore is more likely to reflect changes in trevally availability by length to the two fishing methods.

Despite being largely a target fishery (Walsh et al. 2014a), purse seine has higher inter-annual variability than bottom trawl in terms of the proportion of trevally older than 20 years (Figure 35, Figure 37 and Figure 38). The variability is largely explained by the size-specific schooling behaviour of trevally and the targeting dynamics of the purse seine fishery. The fishery targets large surface schools of trevally; typically fishers have some prior knowledge of the average length of trevally in a school and thus can exercise choice on the basis of mean fish-length. However, low sample size is also likely to be a major cause of inter-annual age variability. The TRE 1 annual purse seine catch typically comprises less than 10 landings, with each landing typically made up of less than three targeted schools (Walsh et al. 2014a). As a result the low number of surface schools "sampled" from the fishery in any given year may not have been representative of all available year classes in that year, i.e. annual sampling may have often been disproportionate relative to age.

The catch at-age time series from the TRE 1 bottom trawl fishery shows markedly less inter-annual variability than the purse seine series especially in the portion of age classes older than 20 years (Figure 34 and Figure 36). The lack of year-class variability relative to purse seine is likely to be in part due to the method being more consistently representative of the available stock in given years. Unlike the purse seine fishery, the TRE 1 bottom trawl fishery operates throughout the year, covers a broad spatial area and annual catches are made up of many individual fishing events or "tows" (see Section 3.3.1). Although inter-annual variability in year class in the bottom trawl catch at-age series is less than in the purse seine series, in comparison to the SNA 8 catch at-age time series (Walsh et al. 2014c) the TRE 1 bottom trawl series is markedly more variable and annual progression of strong and weak age classes less discernible. The main difference between the SNA 8 and TRE 1 trawl fisheries is that SNA 8 is largely a target fishery (Walsh et al. 2014c), whereas TRE 1 is largely a by-catch fishery (see Section 3.3.1). It is highly likely that the same fishery dependant issues influencing annual TRE 1 bottom trawl catchability (see Section 3.3.3.2) may also have affected the annual selection of trevally by length and age.

The presence of high levels of inter-annual variability in the TRE 1 purse seine and single trawl catch-at-age is likely to make it difficult for stock assessment models to estimate individual year class strength parameters (i.e. recruitment deviates) with precision. High inter-annual variability in the proportion of fish older than 20 years in the purse seine series is also likely to limit a model's power to estimate selectivity of older age-classes for this method.

8 BAY OF PLENTY STOCK ASSESSMENT

8.1 The base model

The Northern Inshore Working Group agreed for an assessment of only the BPLE component of the TRE 1 fishery to be conducted, due to the initial difficulties experienced with obtaining an index of relative abundance for the ENHG area. The model presented here therefore provides an assessment of the BPLE component of the TRE 1 quota management area, the boundaries of which corresponds to Statistical Areas 008, 009 and 010 given in Figure 2. The assumption of the model is that the Bay of Plenty stock is closed; such that immigration and emigration is low relative to recruitment, and that fishing pressure outside the Bay of Plenty has negligible effect on trevally productivity within it.

The model structure is completely defined by the associated CASAL input file, population.csl, (given in Appendix 11) together with the CASAL User Manual (Bull et al. 2012). The model partitions the modelled population by age (ages 1–30, where the last age was a plus group) and stock. As with previous trevally models (e.g., Langley & Maunder 2009, McKenzie 2007), this model did not distinguish fish by sex. The model covered the time period from 1931 to 2013 (when discussing the model structure and inputs, '2013' means the fishing year 2012–13), there is only one time-step in each year; the stock is assumed to be in a virgin state in 1930–31. The total catch history is divided into three fisheries: bottom trawl (BT); purse seine (PS); recreational (REC).

A single growth path is assumed, parameterised as a von Bertalanffy growth curve. Model estimates of biomass are derived deterministically from numbers at age via the growth curve, and length-weight relationship. Spawning stock biomass is determined by an ogive defining the proportion mature in each age class. Natural mortality is applied as a constant rate over all age classes (one parameter). The carrying capacity of the stock is determined by mean recruitment (R_0) being the average number of 1-year old fish recruiting to the stock each year. Mean recruitment (R_0) is adjusted by the Beverton and Holt stock recruitment function which has the effect of reducing the number of recruits added each year relative to current spawning-stock biomass.

The processes occurring within each time-step and the order they occur were:

1. Ageing (in an age-based model).
2. Recruitment.
3. Maturation
4. Natural and fishing mortality (where fishing mortality was applied after half the natural mortality).

8.2 Model parameters

A total of 46 parameters were estimated in the base model (Table 16). Selectivities were assumed to be age-based and double normal (3 parameters), and to depend on fishing method. Selectivity was estimated for the commercial bottom trawl and purse seine fishing methods (total of 6 parameters). The recreational fishery was assigned the same selectivity ogive as that estimated for bottom trawl in the model. Year-class strength deviates were estimated for 37 year-classes deemed estimable from the catch at-age data series (i.e. 1970 – 2006; Section 7.3.1). Although free parameters, year class strength deviates were scaled in the model to have a mean of 1.0 (Haist parameterisation; Bull et al. 2012). All priors on estimated parameters were uninformative, except for the usual lognormal prior on year-class strengths (with a CV of 0.6 and a mean of 1.0). Catchability coefficients were estimated for the two abundance series as "nuisance" q's (Bull et al. 2012).

Some parameters were fixed because they were not estimable with the available data (Table 17); notably natural mortality and stock-recruit steepness were fixed at values used in past assessments (see Langley & Maunder 2009).

Table 16: Details of parameters that were estimated in the base model.

Type	Description	No. of parameters	Prior
R_0	Mean unfished recruitment for each stock	1	uniform-log
YCS	Year-class strengths by year and stock	37	lognormal
Selectivity	Proportion selected by age by a survey or fishing method	6	uniform
Nuisance q	Relative abundance series catchability coefficients	2	uniform-log
		46	

Table 17: Details of parameters that were fixed in the base model.

Natural mortality	m	0.1 y^{-1}
Stock-recruit steepness (Beverton & Holt)	h	0.85
Proportion mature		0 for ages 1–3, 0.5 for age 4, 1 for ages > 4
Length-weight [mean weight (kg) = a (length (cm))^b]		$a = 1.6 \times 10^{-5}$, $b = 3.064$
von Bertalanffy (vB) growth parameters		
	L_∞	47.55
	k	0.29 y^{-1}
	t_0	-0.13
Coefficient of variation on vB length at age	CV	0.085

8.3 Observational data

Two types of observations were used in the base stock assessment (Table 18).

Table 18: Details of observations used in the base stock assessment model.

Type	Likelihood	Source	Range of years	No. of years
Abundance (CPUE)	Lognormal	Aerial sightings	1987–2013	22
		Bottom trawl	1990–2013	24
Compositional (age)	Multinomial	Purse seine	1998–2013	9
		Bottom trawl	1998–2013	6

8.3.1 Degree of similarity (correlation) between the Bay of Plenty abundance indices

Very little similarity is evident in a plot of the aerial sightings and bottom trawl indices (Figure 41); these indices being not significantly correlated ($P<0.29$; Pearson coefficient = -0.25). Despite the lack of congruence, both indices were fitted in the base model because the Working Group reasoned that neither could be rejected on first principles and that differences between the two indices may be accounted for by the different estimated selectivities. The model's sensitivity to this assumption was tested by fitting each abundance index in the model separately.

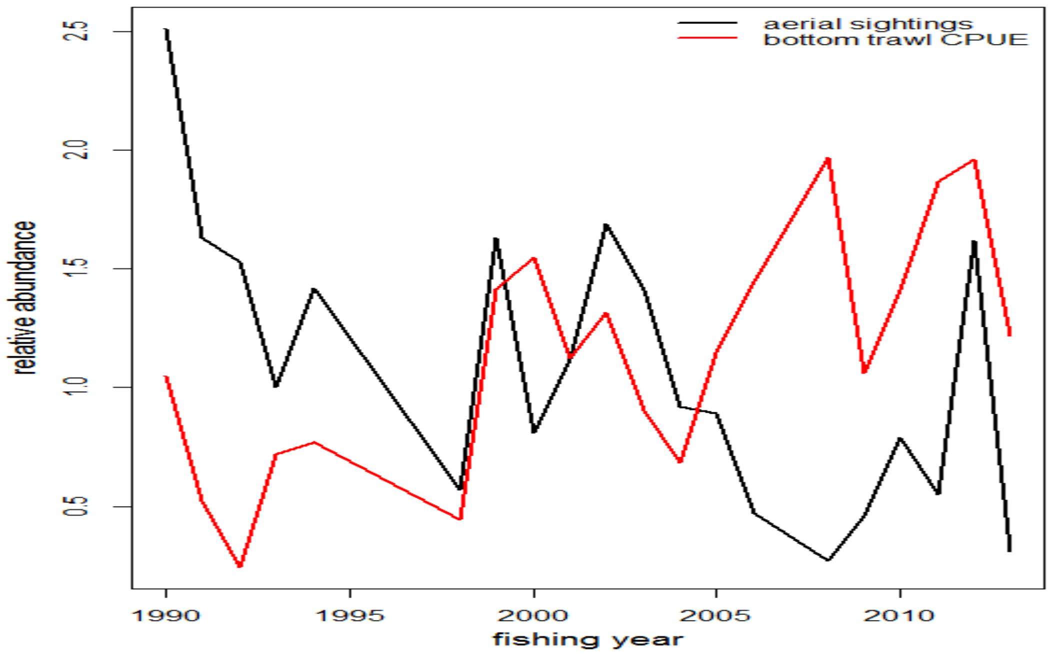


Figure 41: **Comparison of aerial sightings and bottom trawl CPUE indices for the years in common; these indices are not significantly correlated (P<0.29).**

8.4 Base model data weighting

The approach proposed by Francis (2011) was used to weight the different data sets. The first step was to fit a series of Lowess splines of increasing smoothness through the bottom trawl CPUE and aerial sightings indices, calculate the CV of the residuals from each fit, and then for the Working Group to select a CV that corresponded to the desired goodness of fit. After examining the fits in Figure 42, the Working Group opted for an initial CV of 0.3 on the abundance series data.

The next step was to estimate observation-error multinomial sample sizes for each age-composition data set. The raw data were bootstrapped to estimate an observation-error CV for each proportion at age or length, these CVs were plotted against the proportions (in log-log space), and a non-linear regression was used to find the multinomial sample size, *N*, which predicted CVs that best matched the bootstrap CVs (see figure 3 of Crone & Sampson 1998 for an illustration of this regression procedure).

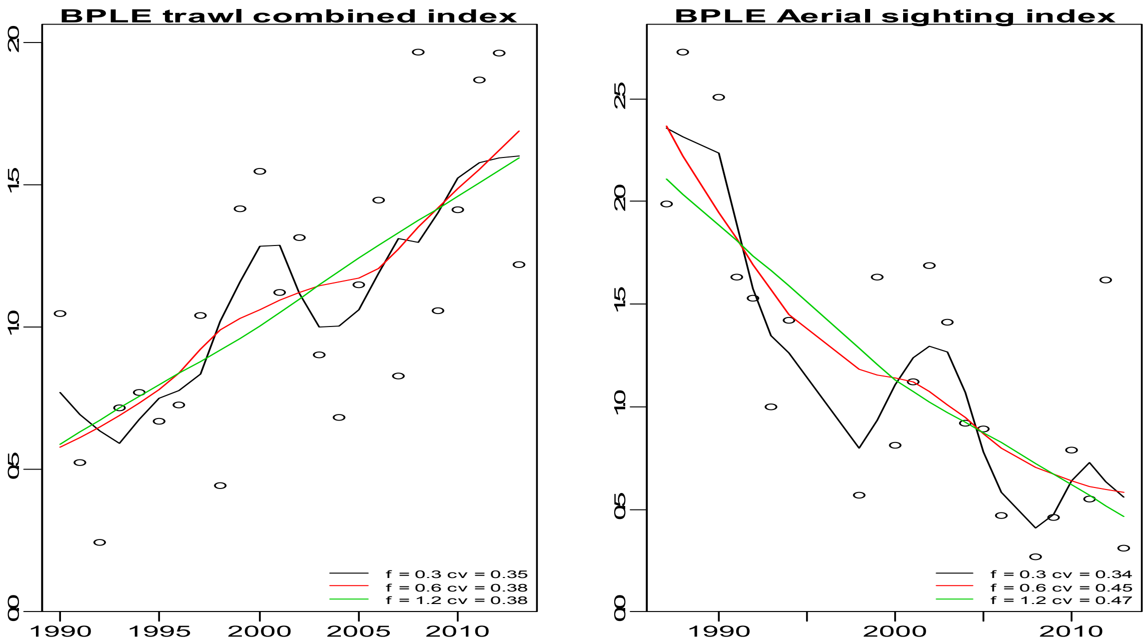


Figure 42: Plot used to decide the weighting assigned to the CPUE observations. Each panel shows lowess smoother lines with varying degrees of smoothness fitted to one of the two CPUE time series used in the base model. The legend in each panel shows, for each fitted line, the lowess smoothness parameter, *f*, and the CV of the residuals.

A two-stage weighting procedure was used to down-weight the composition data to allow for process error. That is, the model was run using the observation-error sample sizes for the composition data; the residuals from the fits to the composition data were used to calculate a weighting parameter, *w*, for each composition data set (using method TA1.8 of Francis 2011); and the original sample sizes were multiplied by the weighting parameters to down-weight these data (Table 19).

Table 19: Weighting parameters, *w*, used to down-weight the multinomial sample sizes in the two-stage weighting procedure relative to CV's 0.2 and 0.3 on the abundance data series

	Data set	
	BT.age	**PS.age**
No. of years' data	6	9
w under abundance CV 0.3	0.037	0.021
w under abundance CV 0.2	0.019	0.021

Down-weighting the compositional data significantly improved the fit to aerial sightings index but only achieved a marginal improvement in the bottom trawl index fit (Figure 43).

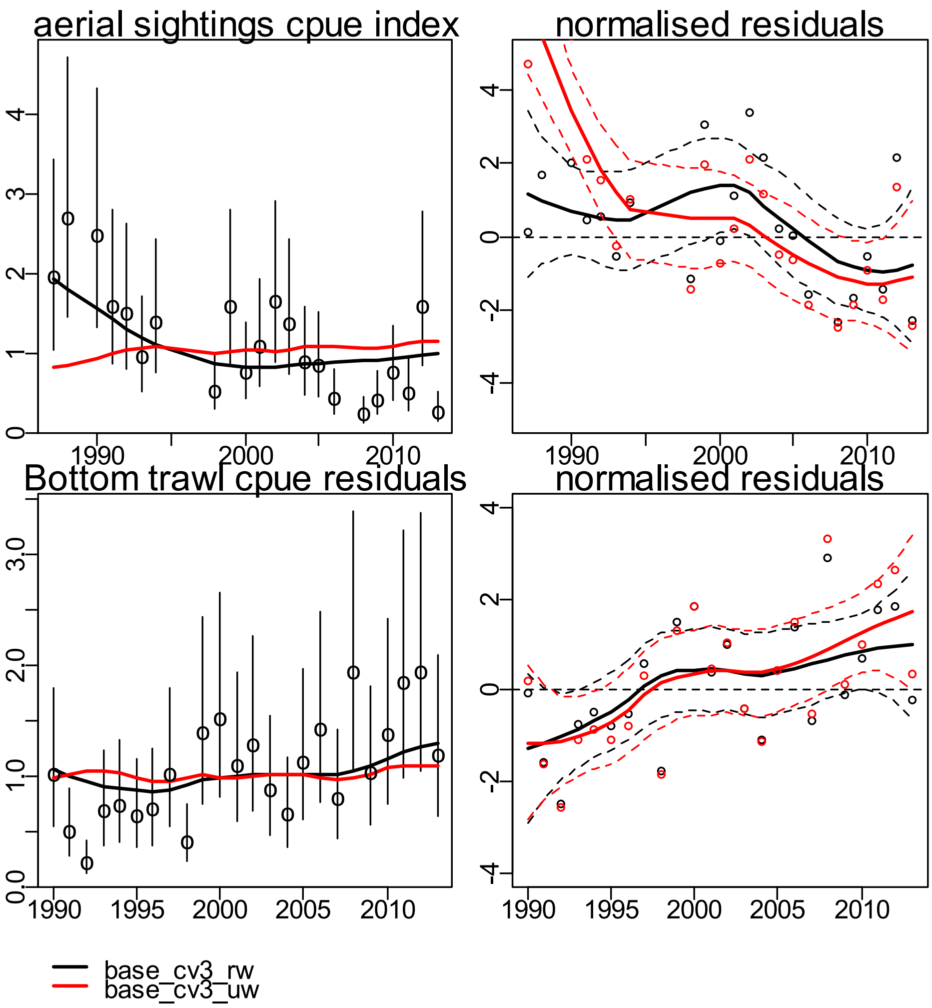


Figure 43: Effect of reweighting the compositional data on the model fits to the aerial sightings and bottom trawl abundance indices. Lines show the unweighted (uw) and re-weighted (rw) model fits; observed indices are shown as 'o', with 95% confidence intervals as vertical lines. The y-axis on the normalised residual plots are standard deviations, dotted lines show the 95% CI range of the residuals for index each year.

After reweighting, the model abundance data fits were found to be "inconsistent" with the minimum level of fit previously agreed to by the NIWG as given in (Figure 42). In an attempt to achieve a "better" fit to the abundance data, the CV on each of these data series was decreased to 0.2 and the compositional data re-weighted (Table 19). This resulted in a much improved fit to the bottom trawl CPUE index and a slight improvement to the aerial sightings fit (Figure 44), this model run thus became the new "base case" assessment model for the BPLE stock.

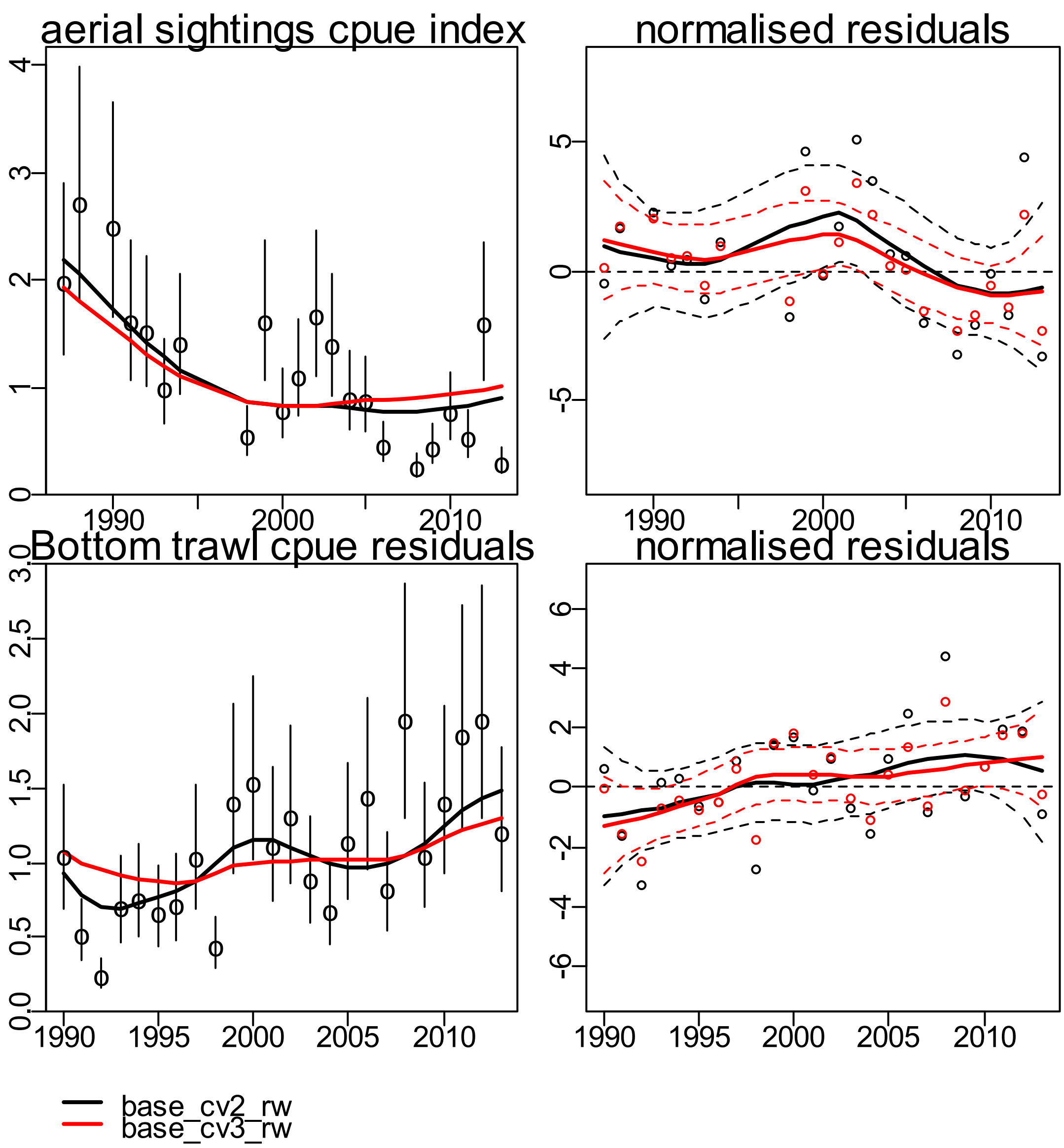


Figure 44: Effect of altering model precision on the aerial sightings and bottom trawl abundance indices. Lines show the model abundance series data fits corresponding to CV 0.2 (CV2) and CV 0.3 (CV3); observed indices are shown as 'o', with 95% confidence intervals as vertical lines. The y-axis on the normalised residual plots are standard deviations, dotted lines show the 95% CI range of the residuals for index each year.

8.5 Base model performance

Patterns in the standardised catch at-age residuals from the model show some clear incompatibilities in model year-class strength predictions and the age compositional data (Figure 45). The model does a reasonable job at estimating the relative proportion of all age classes seen in the purse seine data with the exception of over-estimating the 30+ composite age-class (Figure 45). In contrast to purse seine, the model consistently over-estimates most bottom trawl age classes less than 10 years and consistently under-estimates the older age-classes; i.e. a generally poor fit to the bottom trawl data (Figure 45).

The model does a relatively poor job at matching (predicting) patterns in purse seine and bottom trawl individual year class strengths, notable discrepancies being an extreme (over 3 standard deviations) over-estimate of the 1976 year class evident in the purse seine data and systematic under and over-estimation of recent patterns in year-class strength as seen in the bottom trawl data (Figure 45).

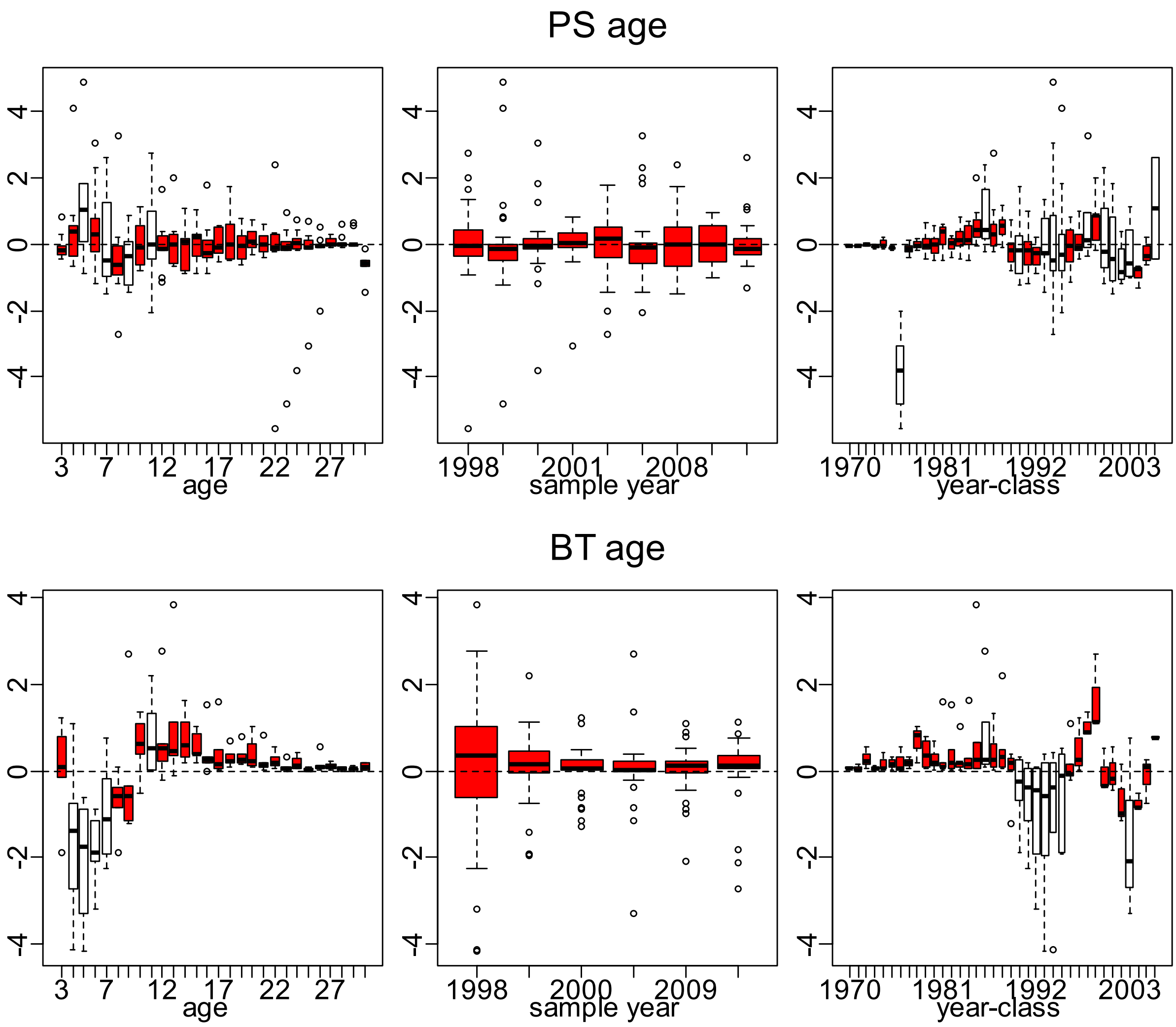


Figure 45: Standardised residual plots of the base model fit to the purse seine (PS) and bottom trawl (BT) catch at-age observations. Boxes show the upper and lower quartile range; points outside dotted lines are extreme values; horizontal lines are medians. First graph shows fits to age aggregated data. Second graph shows fit to age aggregated by sample year. Third graph shows fits to the individual year classes (i.e. recruitment deviates). Negative values represent model over-estimation positive values under-estimation in standard deviation units.

The model prediction of a single 14 fold strong 1975–76 year-class is "implausible" and is likely to be a model artefact caused by conflict or inconsistencies between the various observational data sets (Figure 46).

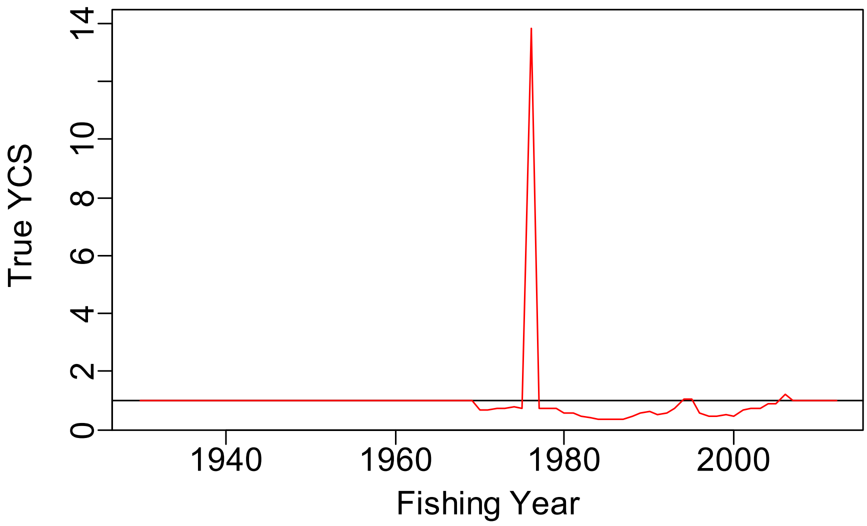


Figure 46: Base model prediction of true (steepness adjusted) year-class strength for fishing years 1970 – 2006.

Constraining the CV on the abundance data so as to achieve a satisfactory fit to these data results in relatively poor fits to the compositional data. This conflict may in part due to requiring the model to fit two conflicting abundance indices (Figure 41), it appears the model achieves a fit to these independent indices by selecting different selectivity parameters for purse seine and bottom trawl (Figure 47). However, it would appear that these selectivities are unrealistic based on year-class-strength patterns in the compositional data (Figure 45).

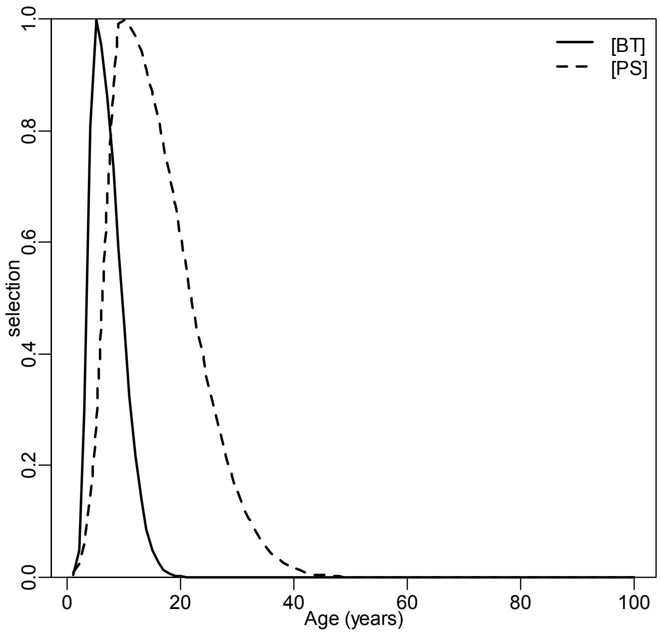


Figure 47: Base model predictions of selectivity at-age for purse seine (dotted lines) and bottom trawl (solid line).

Further evidence of poor model performance is seen in the B0 likelihood profile (Figure 48). There is very little contrast in the B0 total likelihood or in the individual component likelihood terms (Figure 48) and as a result the model had difficulty in distinguishing between total stock productivity values from under one hundred thousand tonnes to over 2 million tonnes.

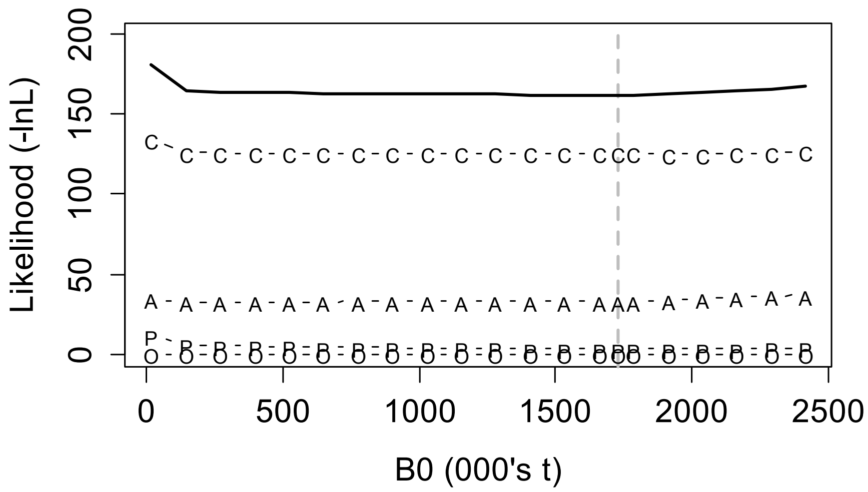


Figure 48: Base model B0 likelihood profile. Solid line is total likelihood; component likelihoods shown as: C (compositional); A (abundance); P (prior penalties); O (other penalties). Dotted vertical line is the MPD. Note: B0 profile was derived from R0 parameter values.

The base model abundance and compositional likelihoods "favour" widely disparate B0 values (%-adjusted minimum given in in Figure 49) being the two extremes on the model's "plausible" range for B0. The final conclusion is that the "base" model is incapable of providing an unambiguous estimate of total productivity and thereby the current status of the Bay of Plenty trevally stock.

The Northern Inshore Working Group requested a model run where the bottom trawl selectivity was fitted as a logistic; this model run resulted in a worse fit to both the compositional abundance data and equally ambiguous productivity estimates as the base model.

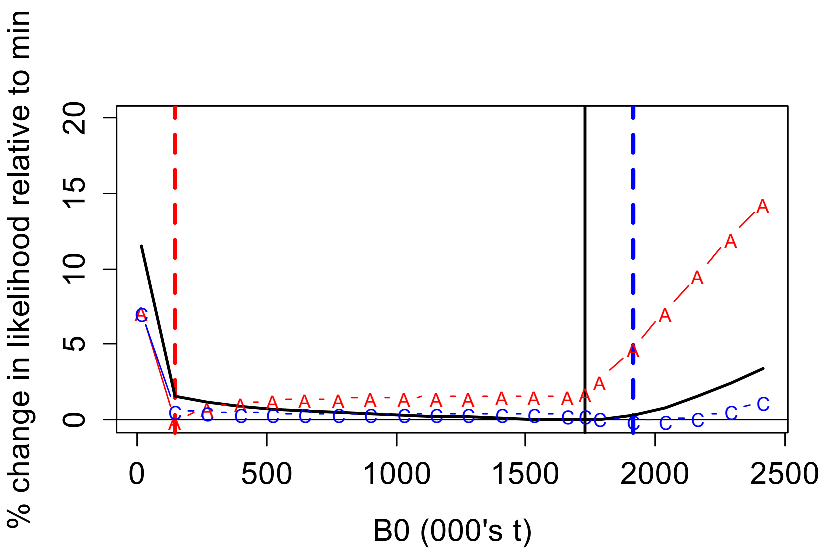


Figure 49: Base model B0 likelihood % change. Plot shows % increase in likelihood for total (solid line), abundance (red A) and compositional (blue C) likelihoods relative to their component minimum (vertical coloured lines). Note: B0 profile was derived from R0 parameter values.

8.6 Inclusion of James 1970s purse seine age data

In an attempt to better inform the model as to the state of the BPLE trevally stock in the early 1970s, the James 1970s purse seine catch at-age data (Figure 38) was added to the compositional data series. In recognition of the high degree of uncertainty as to the validity and precision of these data they were assigned a relatively high level of multinomial error compared to the other compositional data in the model. The James data model produced identical fits to the abundance data, identical selectivity estimates and similarly “poor” fits to the compositional data (compare Figure 45 with Figure 50).

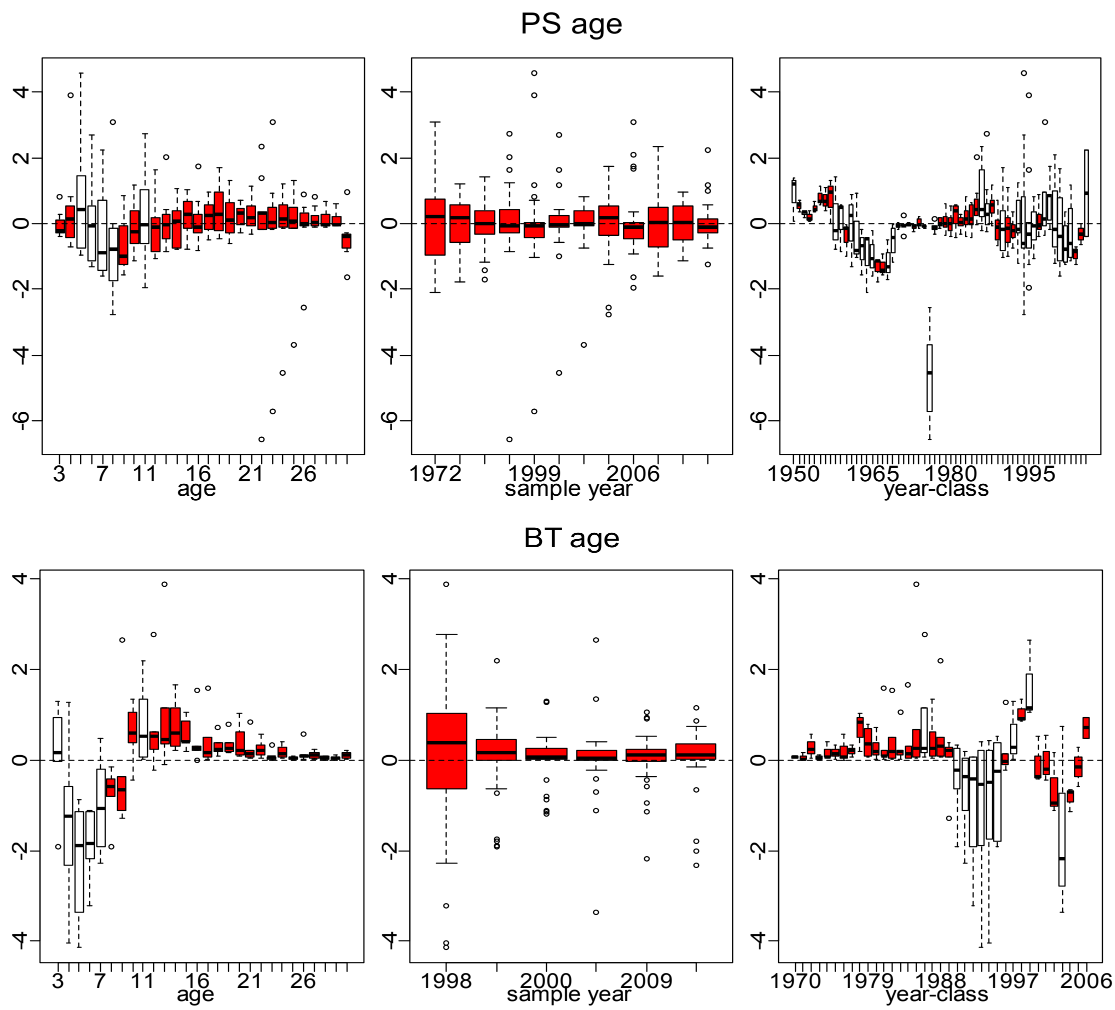


Figure 50: Standardised residual plots of the James 1984 base model fit to the purse seine (PS) and bottom trawl (BT) catch at-age observations. Boxes show the upper and lower quartile range; points outside dotted lines are extreme values; horizontal lines are medians. First graph shows fits to age aggregated data. Second graph shows fit to age aggregated by sample year. Third graph show fits to the individual year classes (i.e. recruitment deviates). Negative values represent model over-estimation positive values under-estimation in standard deviation units.

8.7 Separate abundance series model fits

The overall conclusion from the base model analyses is that it was not possible to fit all the recent abundance and compositional data from the BPLE trevally stock and get a “meaningful” assessment. In an attempt to understand how the incompatibility between the two abundance series might be driving the lack of model fit, separate model runs were undertaken for each abundance series.

8.7.1 Aerial sighting index only model fit

Fitting only to the aerial sightings abundance index resulted in an “acceptable” fit to this series pursuant to a CV of 0.3 (Figure 51).

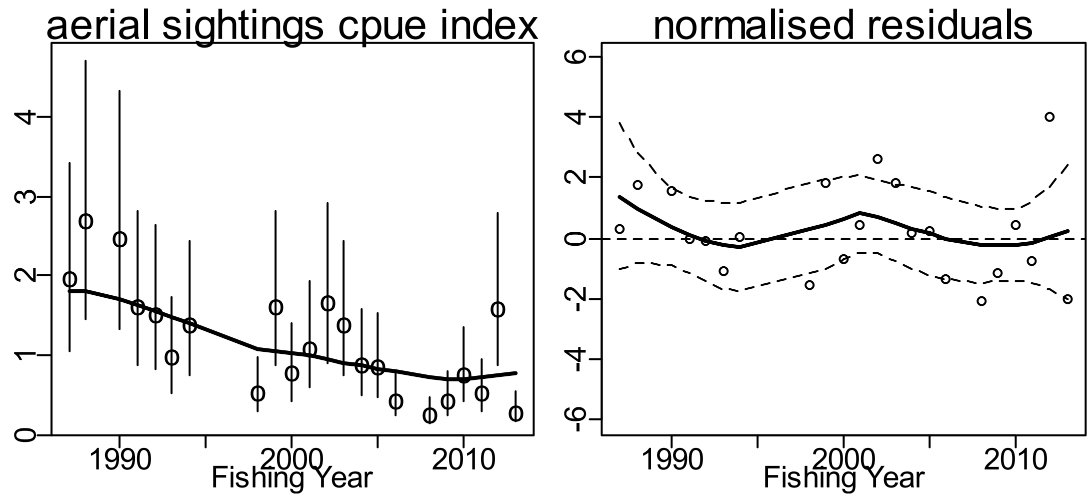


Figure 51: Fit to aerial sighting index under a CV of 0.3 (line). Observed indices are shown as ‘o’, with 95% confidence intervals as vertical lines. The y-axis on the normalised residual plots are standard deviations, dotted lines show the 95% CI range of the residuals for index each year.

Without the constraint of having to fit to a conflicting bottom trawl index, model estimates of purse seine and bottom trawl selectivity were similar (Figure 52).

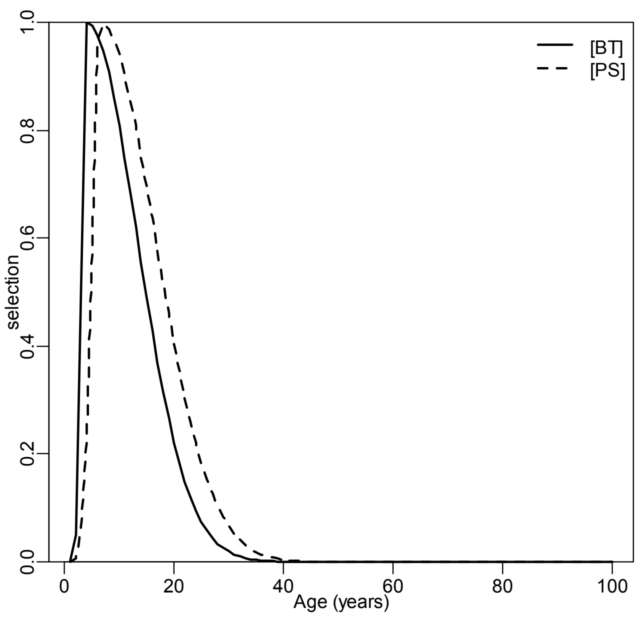


Figure 52: Aerial sighting only model predictions of selectivity at-age for purse seine (dotted lines) and bottom trawl (solid line).

Although the overall fit to compositional data was better than the base model (compare Figure 53 with Figure 45), the model again predicted an abnormally high 1970s year-class (1977–78 year class). This again was highly inconsistent with the observational data (Figure 53 and Figure 54).

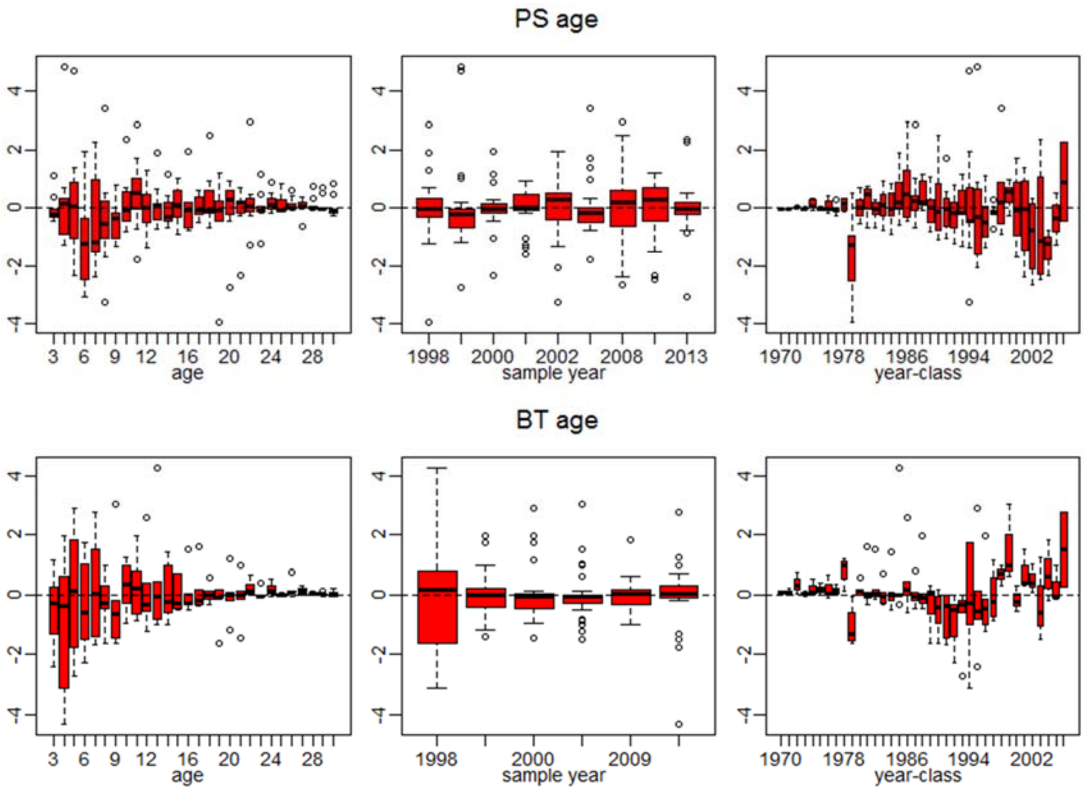


Figure 53: Standardised residual plots of "aerial index only" model fit to the purse seine (PS) and bottom trawl (BT) catch at-age observations. Boxes show the upper and lower quartile range; points outside dotted lines are extreme values; horizontal lines are medians. First graph shows fits to age aggregated data. Second graph shows fit to age aggregated by sample year. Third graph show fits to the individual year classes (i.e. recruitment deviates). Negative values represent model over-estimation positive values under-estimation in standard deviation units.

There was again very little contrast in the B0 total likelihood or in the individual component likelihood terms (Figure 55). The model had difficulty in distinguishing between total stock productivity values over a wide range. Again the abundance and compositional likelihoods "favour" widely disparate B0 values (% adjusted minimum given in Figure 56), selecting the two extremes from the model's "plausible" range for B0.

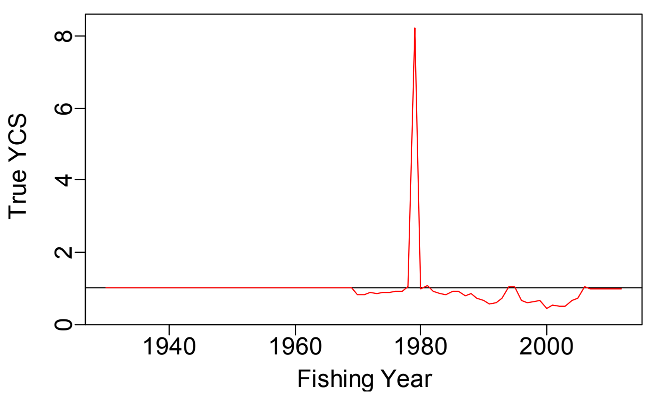


Figure 54: Aerial index only model prediction of true (steepness adjusted) year-class strength for fishing years 1970 – 2006.

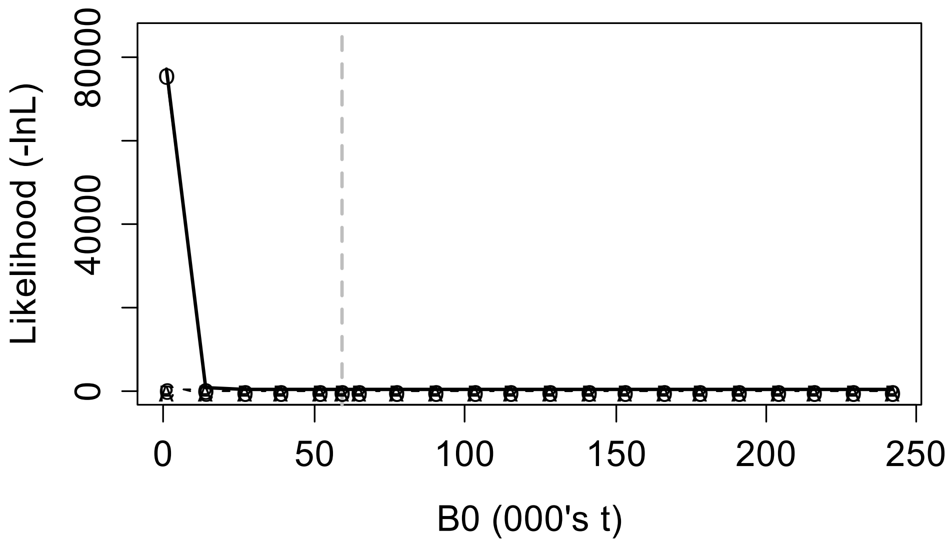


Figure 55: **Aerial index only model B0 likelihood profile. Solid line is total likelihood; component likelihoods shown as: C (compositional); A (abundance); P (prior penalties); O (other penalties). Dotted vertical line is the MPD. Note: B0 profile was derived from R0 parameter values.**

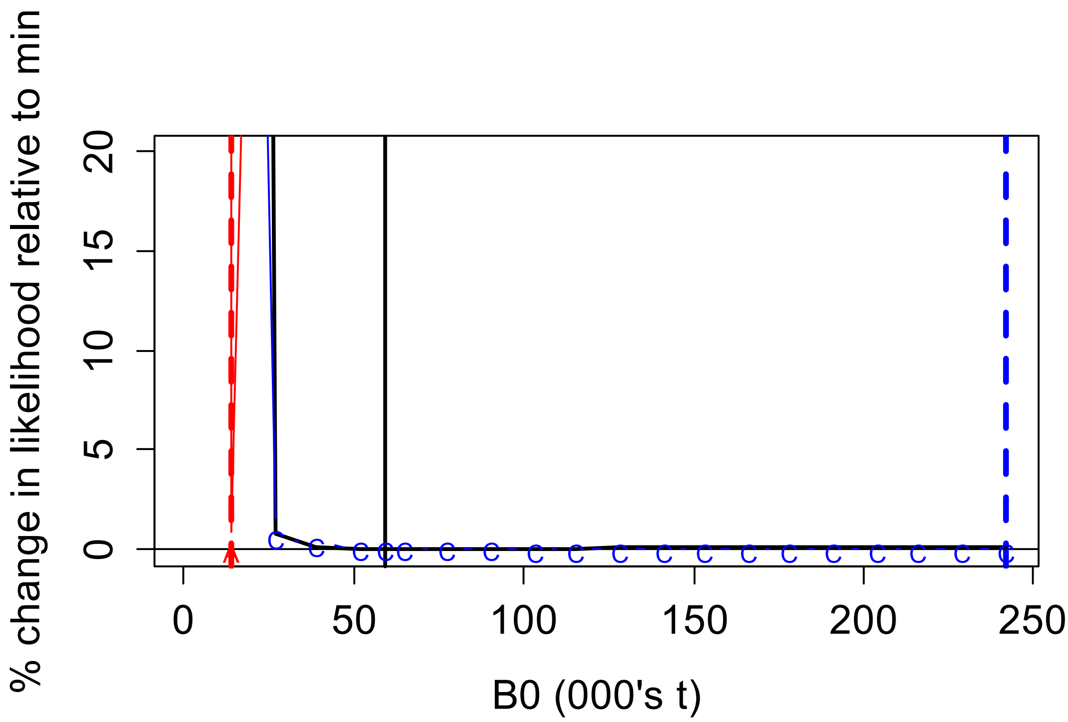


Figure 56: **Aerial index only model B0 likelihood % change. Plot shows % increase in likelihood for total (solid line), abundance (red A) and compositional (blue C) likelihoods relative to their component minimum (vertical coloured lines). Note: B0 profile was derived from R0 parameter values.**

The "Aerial only index" model was unable to accommodate the trend in the aerial sightings index to obtain "acceptable" fits to the compositional data and therefore was not able to deliver a "plausible" assessment for the BPLE trevally stock, i.e. the conflict between aerial abundance and the observed patterns in year-class was unresolvable.

8.7.2 Bottom trawl index only model fit

Fitting only to the bottom trawl abundance index resulted in an “acceptable” fit using a CV of 0.3 (Figure 57).

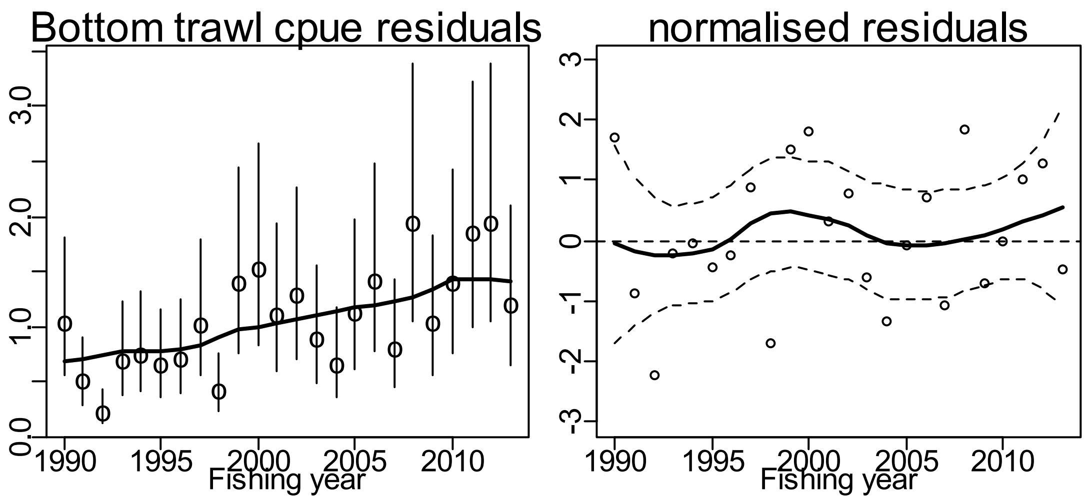


Figure 57: Fit to bottom trawl index using a CV of 0.3 (line). Observed indices are shown as ‘o’, with 95% confidence intervals as vertical lines. The y-axis on the normalised residual plots are standard deviations, dotted lines show the 95% CI range of the residuals for index each year.

The model predicted a broad range of adult age classes selected by bottom trawl and purse seine methods, with purse seine being uniformly selective for all ages older than 8 years (Figure 58).

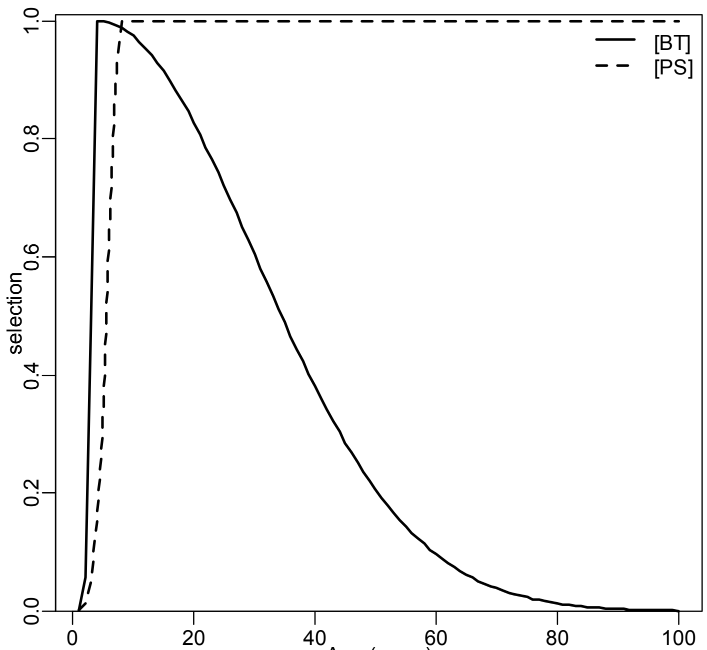


Figure 58: Bottom trawl index only model predictions of selectivity at-age for purse seine (dotted lines) and bottom trawl (solid line).

The model was able to adequately represent the relative proportions of most of the age classes seen in the bottom trawl and purse seine age compositional data series including the 30+ composite age-class (Figure 59). Although residuals in the compositional fits to year-class strength suggest that some of the strong predicted year-classes after 1994 may be over-estimated (Figure 59 and Figure 60), there were no extreme residual deviations in the year-class compositional fits as seen in the previous models (Figure 50 and Figure 53). Overall the model achieved a “reasonable” fit to both compositional data series, model predictions of year class strength were likewise “plausible” (Figure 60).

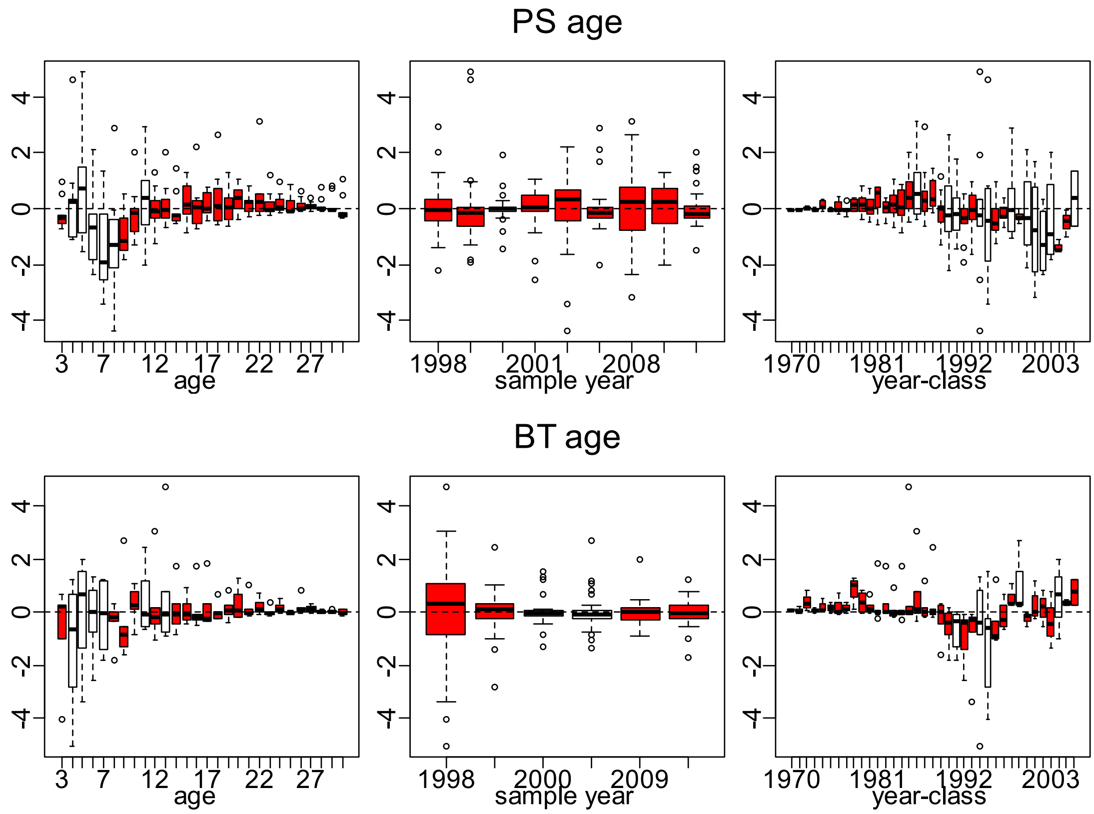


Figure 59: **Standardised residual plots of bottom trawl index only model fit to the purse seine (PS) and bottom trawl (BT) catch at-age observations. Boxes show the upper and lower quartile range; points outside dotted lines are extreme values; horizontal lines are medians. First graph shows fits to age aggregated data. Second graph shows fit to age aggregated by sample year. Third graph show fits to the individual year classes (i.e. recruitment deviates). Negative values represent model over-estimation positive values under-estimation in standard deviation units.**

As with the previous models there was very little contrast in the B0 total likelihood or in the individual component likelihood terms (Figure 61). However, unlike the previous models, both the compositional and abundance likelihood profiles, favoured similar B0 estimates, i.e. the “inferred” stock status from the two data series was broadly consistent (Figure 62).

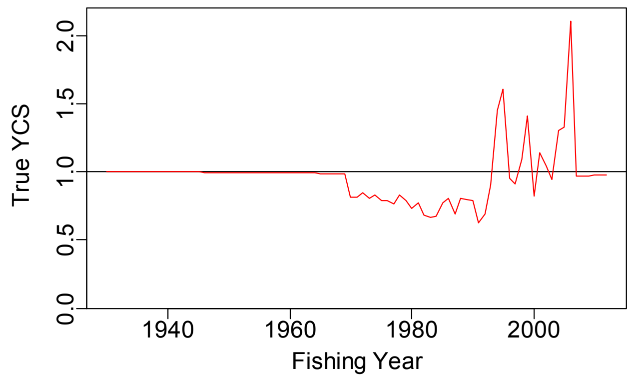


Figure 60: **Bottom trawl index only model prediction of true (steepness adjusted) year-class strength for fishing years 1970 – 2006.**

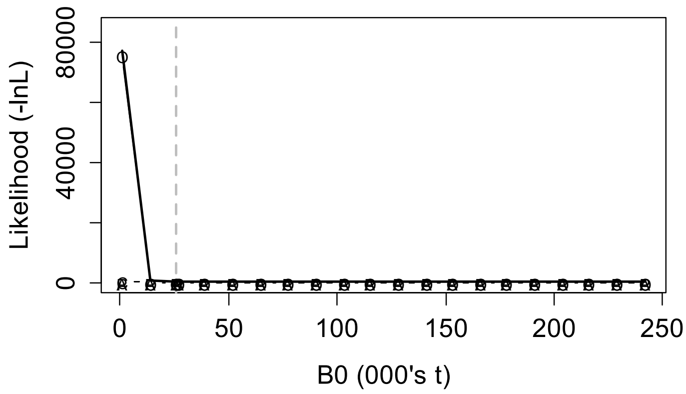


Figure 61: **Bottom trawl only model B0 likelihood profile. Solid line is total likelihood; component likelihoods shown as: C (compositional); A (abundance); P (prior penalties); O (other penalties). Dotted vertical line is the MPD. Note: B0 profile was derived from R0 parameter values.**

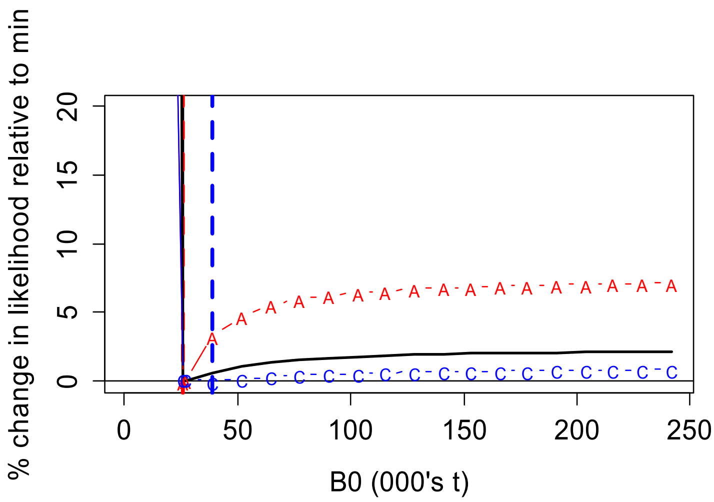
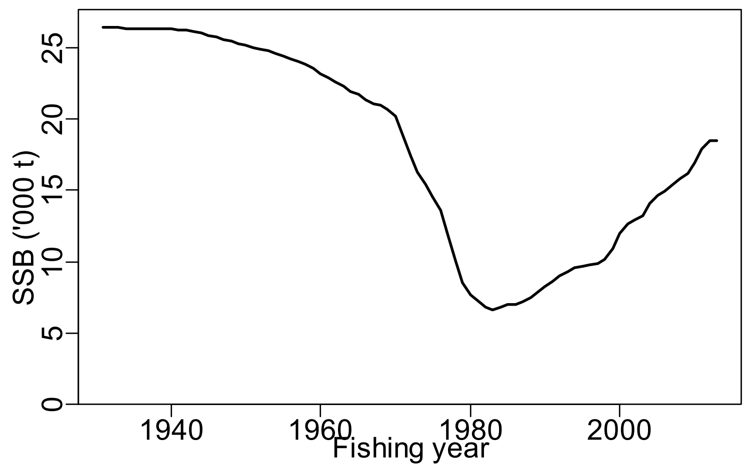


Figure 62: **Bottom trawl index only model B0 likelihood % change. Plot shows % increase in likelihood for total (solid line), abundance (red A) and compositional (blue C) likelihoods relative to their component minimum (vertical coloured lines). Note: B0 profile was derived from R0 parameter values.**

The bottom trawl index only model was able to accommodate the trend in the bottom trawl index while achieving “acceptable” fits to the compositional data. There is no strong basis to reject this model on the grounds of data conflict and poor compositional data fits, hence it is a “credible” model. However, the question as to whether this model also provides “credible” BPLE trevally stock assessment advice requires further investigation.

The spawning stock biomass (SSB) trajectory from the bottom trawl index only model shows that the period of maximum stock reduction occurred during the 1970s (Figure 63), i.e. the time corresponding to high purse seine removals (Figure 32). Consequently, the lowest stock biomass of 30% B0 was predicted to occur in the early 1980s. As a likely consequence of relatively lower annual catches after 1980 the model predicts that the stock steadily rebuilt after 1980, attaining 70% B0 in the final, or “current” (2012–13), fishing year (Figure 63). The steep biomass decline during the 1970s was likely to have been driven by the catch history (Figure 32) as the model has no independent relative abundance information from this period to verify or “describe” the predicted decline. The model’s prediction of increasing biomass after this time was consistent with the bottom trawl abundance index which also encompassed this period (1990–2013) (Figure 57).



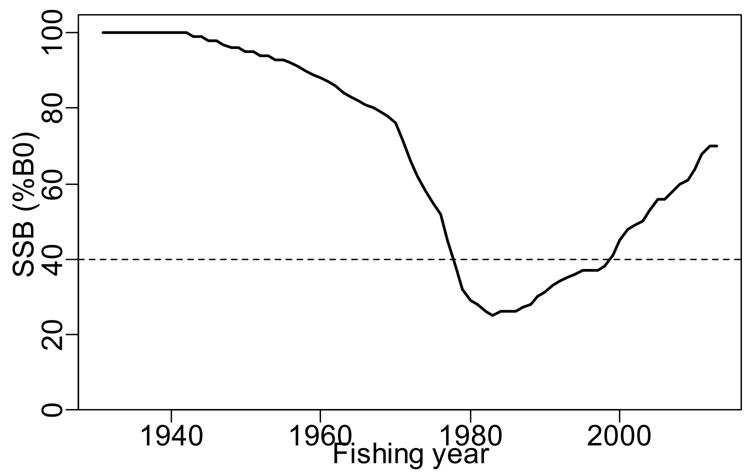


Figure 63: Bottom trawl index only model estimate of spawning biomass (SSB), this is presented in tonnes (upper panel) and as % to the corresponding unfished biomass (B0) (lower panel). Dotted line shows current MPI target biomass (default) for the Bay of Plenty trevally stock (40% B0).

8.8 Conclusions and recommendations

Currently there are four sets of observations that can be used in a model to assess the BPLE trevally stock: bottom trawl abundance index; aerial sightings abundance index; age compositional data from bottom trawl and purse seine; total catch history estimate.

The bottom trawl index, age compositional data series, and catch history were able to be combined in an assessment model to provide a "plausible" assessment, suggesting that these data are broadly consistent. However assessment models incorporating the aerial sightings abundance index in the current report could only achieve good fits to this series at the expense of obtaining good fits to the compositional data.

The aerial sighting index predicts that a significant drop in biomass occurred after the late 1980s (Figure 41), this decline appears to be inconsistent with the catch history and post 1980 age structures seen in the age compositional data. The model fitting only to the bottom trawl index achieved "reasonable" fits to the abundance and compositional data series, with the B0 likelihood profiles for these two data types favouring comparable estimates.

All four BPLE data series were independently derived and there are inherent uncertainties associated with each. The Aerial Sightings Index was tentatively accepted as an index of abundance for Bay of Plenty trevally by the NINSWG in 2012, under the proviso that the final evaluation of this index would be made according to the degree it contrasted with other data inputs in a stock assessment model. Based on the assessment results presented in the FAR, the NINWG rejected the Aerial Sightings index as an index of abundance on 8 April 2016. The WG concluded that the next TRE 1 assessment for the Bay of Plenty should be undertaken using only indices of abundance based on bottom trawl standardised CPUE.

Bottom trawl index:
If used in the assessment, the WG should provide strong guidance as to how tightly the model biomass trajectory should be expected to reflect this pattern.

Catch at-age observational series:
Some concerns with the catch at-age data (Section 7.1) were the presence of inter-annual variability and ambiguities in the progression of strong and weak year-classes particularly in the purse seine series. How these uncertainties may influence model stock-status estimates needs further exploration; future model catch at-age sensitivity runs should include: dropping the purse seine series in the model; limiting the number of year class strengths estimated by the model (e.g. only fitting to year-classes for which independent catch-curve analysis suggests are precisely estimable i.e. with low CV). The Working Group also needs to provide guidance as to what gear selectivity assumptions are "plausible".

Catch history:
The catch history of BPLE trevally is highly uncertain pre-1980 and the model appears to be strongly driven by the "assumed" high catch removals through the 1970s. We feel that it is essential that the sensitivity of the bottom trawl index model stock status predictions to alternative catch history assumptions are explored. This will require further review of the Bay of Plenty catch history information. In light of the review the Working Group will need to agree on a "plausible" range of catch histories to explore in the model. We also recommend looking at sensitivity runs where the model is commenced in 1970 or 1980, in an assumed non-virgin state.

9 DISCUSSION

Catch at-age sampling shows clear differences in both age composition and growth rates (mean length-at-age) between the Bay of Plenty and East Northland regions of TRE 1 suggesting that this quota management area (QMA) is likely to be comprised of two biological stocks. Age structure similarities between the East Northland area of TRE 1 and the northern Ninety Mile Beach area of TRE 7 also suggest that these regions are likely to be part of the same biological stock and we recommend that consideration is given to combining these two areas in future stock assessments. The pattern in age structure progressively changes north to south within TRE 7 so that the areas below Cape Egmont are likely to constitute a separate stock to northern TRE 7 areas. On the basis of the catch-at-age patterns, Ninety Mile Beach and the areas south of Cape Egmont were excluded from the 2015 assessment of TRE 7 (Kaipara – North Taranaki Bight region only; Langley et al. 2015). As no catch sampling has taken place in TRE 2, it is not known how similar the Bay of Plenty trevally sub-stock is to the East Cape region of TRE 2. We recommend that catch sampling is undertaken in TRE 2 in the future to determine the degree of stock separation between the TRE 1 and 2 quota management areas (QMAs).

Strong evidence was found for a systematic change in the reporting of small trevally catches in the Bay of Plenty and East Northland bottom trawl fisheries over the last 20 years. The Working Group believed that the potential for biased CPUE indices from this change was mitigated by aggregating the catch and effort data to the trip level. Although TRE 1 bottom trawl CPUE indices were accepted by the Working Group as reflective of stock abundance, we advise caution in this interpretation as there are a number of aspects in the way the TRE 1 trawl fishery has operated, and catch and effort data recorded, that could mean that these indices are hyper-stable (non-proportional; Dunn et al. 2000, Ye & Dennis 2009) measures of relative abundance. These aspects include the by-catch nature of the fisheries, significant numbers of low or zero catches in the reported data in combination with a change in reporting of these, unrecorded vessel skipper changes, and changing market demands and fisher economic incentives. Because of the requirement to aggregate the TRE 1 trawl-tow catch and effort data to the trip-level it is possible that an “adequate” standardisation of tow-level factors such as position, depth, tow-speed and duration, was not achieved. Because of these issues and problems, we believe CPUE is a “less-than-ideal” monitoring option for the TRE 1 stocks, given their socio-economic importance, and recommend that the future use of fishery independent survey methods be considered (e.g. spotter plane aerial surveys, trawl surveys).

An age-based total catch-history assessment model for the Bay of Plenty trevally stock was unable to achieve “plausible” assessment results when both the aerial sightings and bottom trawl CPUE abundance indices were fitted or when the model was fitted to the aerial sightings index on its own. The main issue with the aerial sightings index was that it predicts a significant drop in Bay of Plenty trevally abundance during the 1980s. Because this is a period of relatively low catches compared to the 1970s, the model has difficultly explaining this decline. In the absence of an aerial index the model predicts the Bay of Plenty stock to have steadily rebuilt through the 1980s and beyond to the present day (2013). The catch-at-age and bottom trawl abundance observations are broadly consistent with increasing biomass after 1980, with their respective model likelihoods predicting similar stock carrying capacity (B0) levels. The Working Group accepted the bottom-trawl-index-only model run as being the most “plausible” but did not accept this model’s stock-status predictions because there had been insufficient time for a thorough exploration of model performance, instead recommending that this be done in a future assessment. The Working Group also recommended that an age-based assessment of the East Northland trevally stock is also undertaken the next time TRE 1 is assessed, in light of there now being an “acceptable” bottom trawl CPUE index for this sub-stock. The WG recommended that new assessments for the TRE 1 east Northland and Bay of Plenty sub-stocks be undertaken once the next catch-at-age project for TRE 1 had been completed.

10 ACKNOWLEDGEMENTS

This work was contracted and funded by the Ministry for Primary Industries under Objectives 1 and 2 of the research project TRE201301. The authors would like to thank Bruce Hartill for developing the recreational catch history used in the model. Generation of the revised commercial catch history derivation used in the final base model and sensitivity analyses was largely undertaken by Malcolm Francis. Acknowledgement is also due to the Northern Inshore Working Group; the review and recommendations this group provided were critical to the final assessment outcome. Marc Griffiths, the

Working Group convenor and chair, is due special recognition for keeping the assessment process on track. Finally, the authors would like to thank Andy McKenzie, Richard O'Driscoll and Marc Griffiths for manuscript review and Marianne Vignaux for the final editorial comments.

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12 APPENDICES

Appendix 1: Format of data provided by MPI for TRE 1 fishery characterisation and CPUE analysis

All trips landing TRE 1 quota between 1/10/1989 and 30/9/2013 as three data tables:

Landing table

event_key
dcf_key
lfr_no
lfr_name
landing_date (as dd/mm/yyyy format, no other extraneous details)
landing_name
species_code
species_name
fishstock_code
state_code
destination_type
unit_type
unit_num
unit_weight
conv_factor
green_weight
green_weight_type
processed_weight
processed_weight_type
form_type
trip
trip_start_date (as dd/mm/yyyy format, no other extraneous details)
trip_end_date (as dd/mm/yyyy format, no other extraneous details)
vessel_key
vessel_name
vessel_id

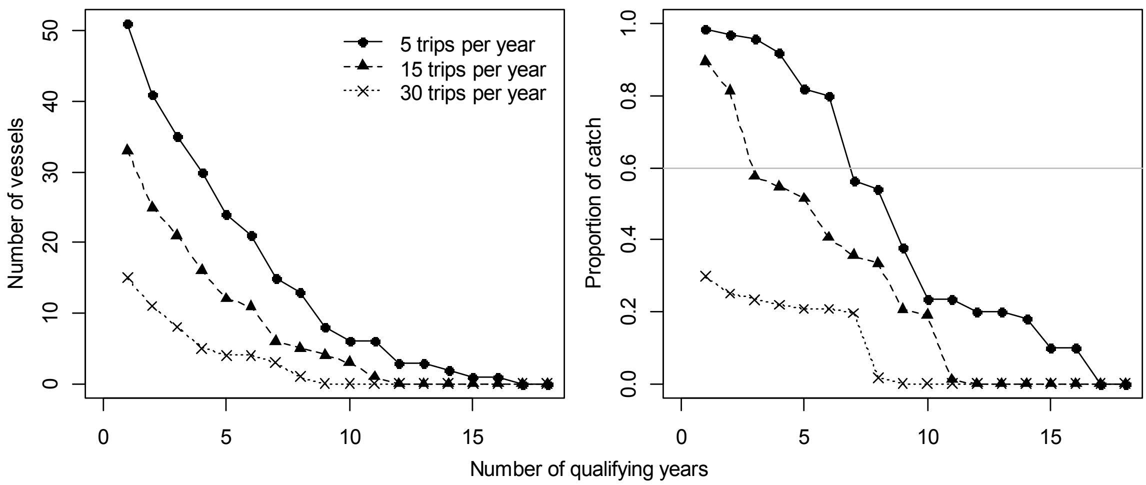
Catch-effort table

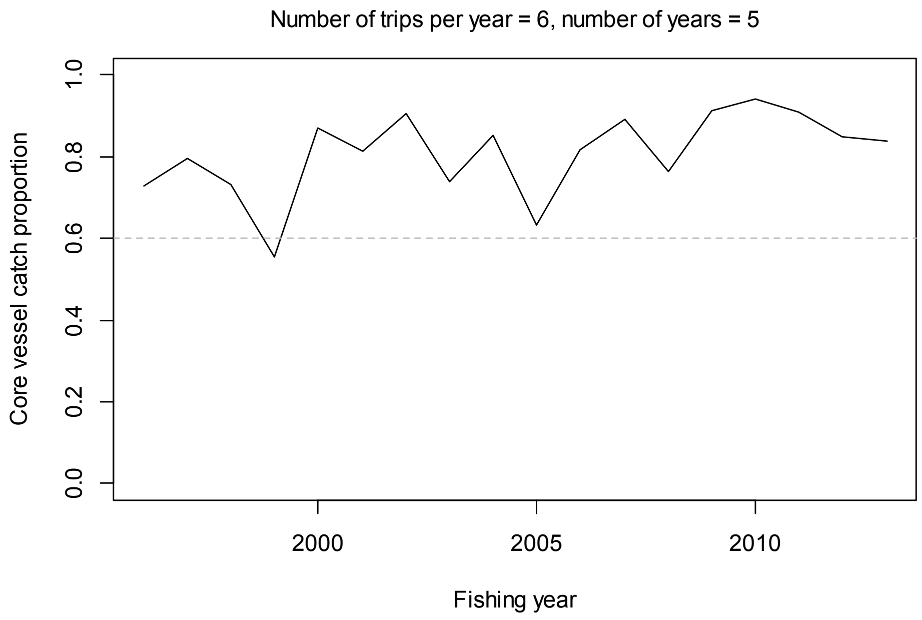
event_key
dcf_key
start_date (as dd/mm/yyyy format, no other extraneous details)
end_date (as dd/mm/yyyy format, no other extraneous details)
primary_method
target_species
fishing_duration
catch_weight
effort_depth
effort_height
effort_num
effort_num_2
effort_seqno
effort_total_num
effort_width
effort_speed
total_net_length
total_hook_num
set_end_datetime
haul_start_datetime
start_lat (fine scale required for spatial analysis)
start_long (fine scale required for spatial analysis)
end_lat (fine scale required for spatial analysis)
end_long (fine scale required for spatial analysis)
pair_trawl_yn
bottom_depth
display_fishyear
start_stats_area_code
vessel_key
vessel_name
vessel_id
form_type
trip

Estimated catch table

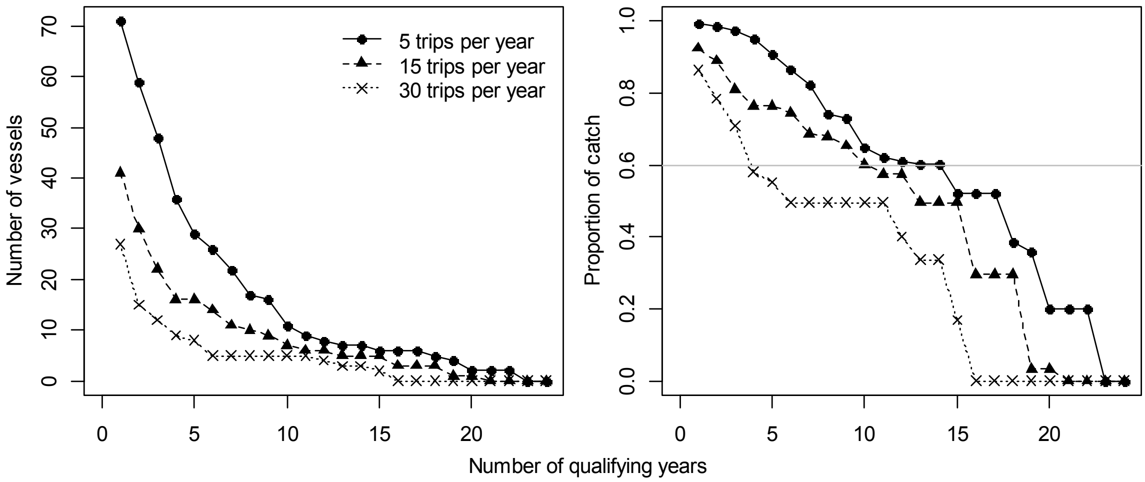
event_key
dcf_key
species_code
catch_weight

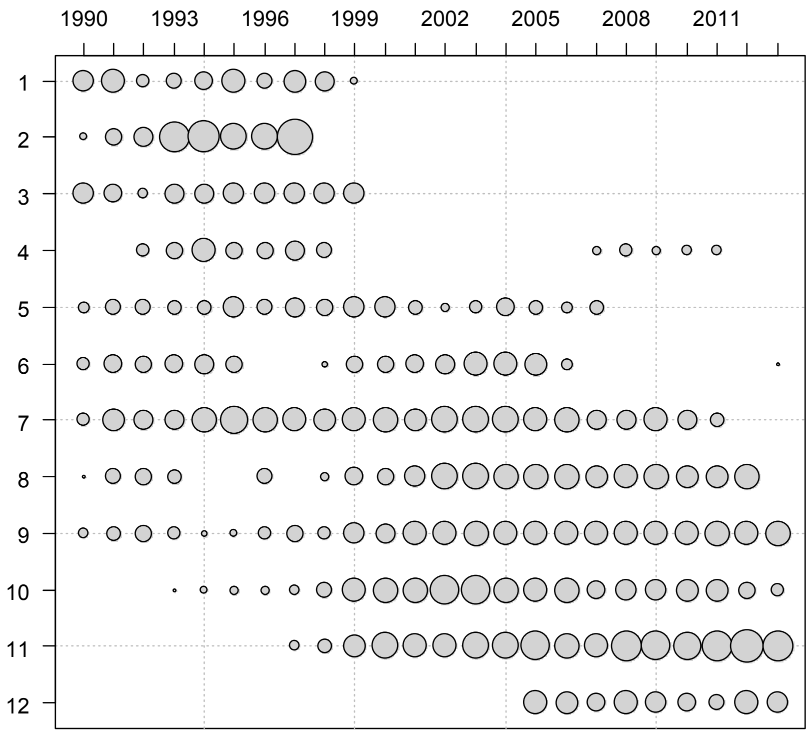
Appendix 2: **Graphics used to aid the vessel selection process and describe the coverage of data for vessels selected from the ENHG sub-stock from the TCP/TCE dataset that had been rolled up to the trip level. Here 18 vessels were selected that had conducted a minimum of 6 trips per year for a minimum of 5 years. The first graphic assesses the number of vessels and the proportion of catch they account for against the number of years those vessels contributed to the fishery in that sub-stock. The second graphic illustrates the coverage of core vessels selected. Circle diameters are proportional to the sum of catch for each vessel in that year. The third graphic illustrates the proportion of all trevally catch within that sub-stock that the core vessels accounted for in each year of the data series.**

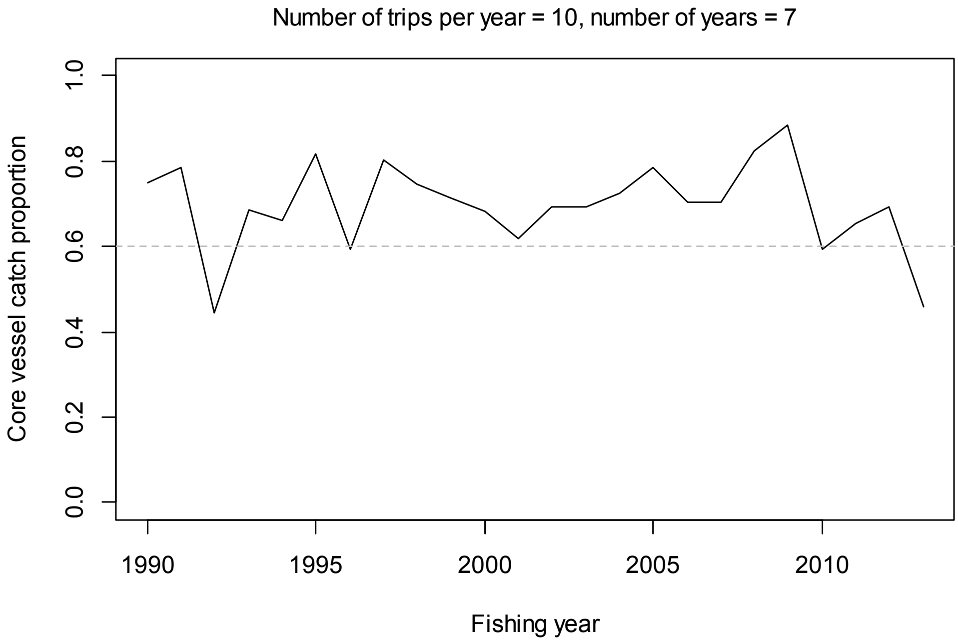



Number of trips per year = 6, number of years = 5
Core vessel catch proportion
0.0
0.2
0.4
0.6
0.8
1.0
2000
2005
2010
Fishing year

Appendix 3: **Graphics used to aid the vessel selection process and describe the coverage of data for vessels selected from the BPLE sub-stock from the CEL dataset that had been rolled up to the trip level. Here 12 vessels were selected that had conducted a minimum of 10 trips per year for a minimum of 7 years. The first graphic assesses the number of vessels and the proportion of catch they account for against the number of years those vessels contributed to the fishery in that sub-stock. The second graphic illustrates the coverage of core vessels selected. Circle diameters are proportional to the sum of catch for each vessel in that year. The third graphic illustrates the proportion of all trevally catch within that sub-stock that the core vessels accounted for in each year of the data series.**






Number of trips per year = 10, number of years = 7
Core vessel catch proportion
0.0
0.2
0.4
0.6
0.8
1.0
1990
1995
2000
2005
2010
Fishing year

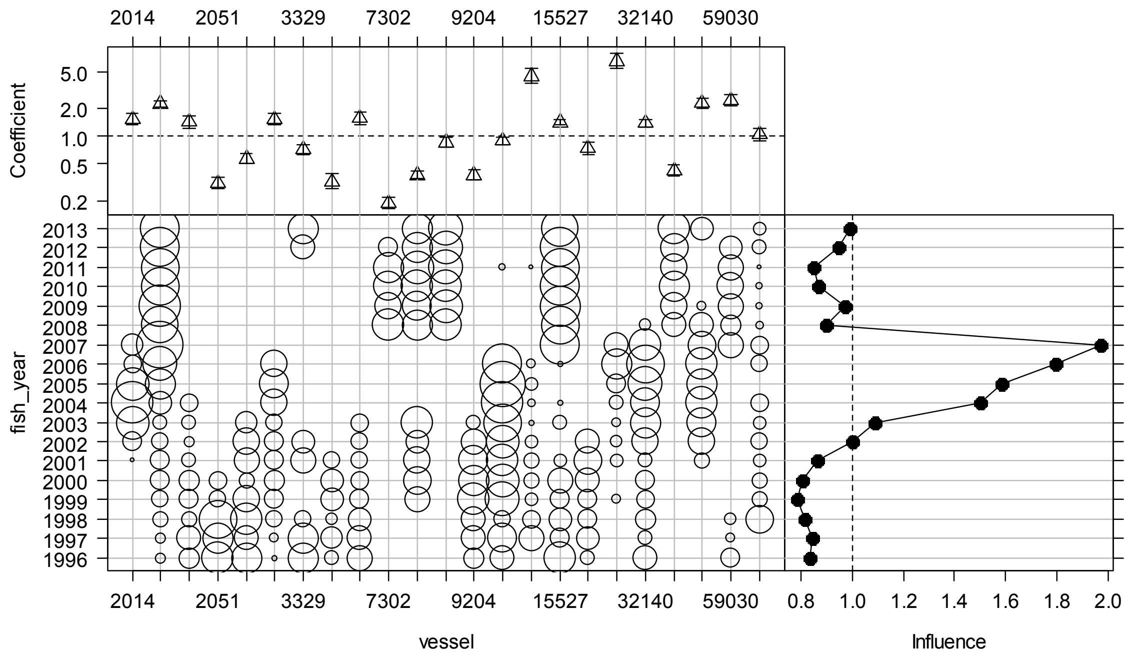
Appendix 4: **Relative abundance index for the ENHG sub-stock. The index accepted by the working group was produced from a combination of the lognormal and binomial standardised CPUE analyses of the TCP/TCE data series rolled up to the trip level.**

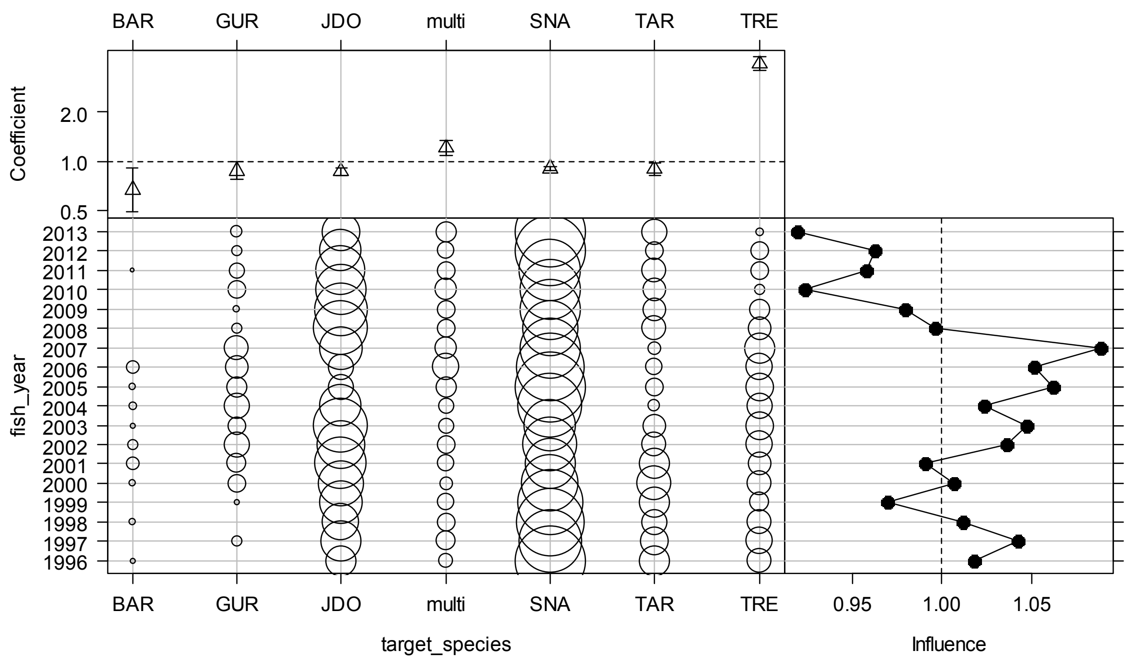
Fishing year	Relative abundance
1996	0.6389964
1997	0.7551327
1998	1.1499481
1999	0.9478061
2000	1.2407448
2001	0.908086
2002	0.8909361
2003	1.2367437
2004	0.9047216
2005	0.6987863
2006	1.011336
2007	0.7954759
2008	1.4326544
2009	1.0882227
2010	1.0517352
2011	1.4545699
2012	1.047894
2013	1.0901953

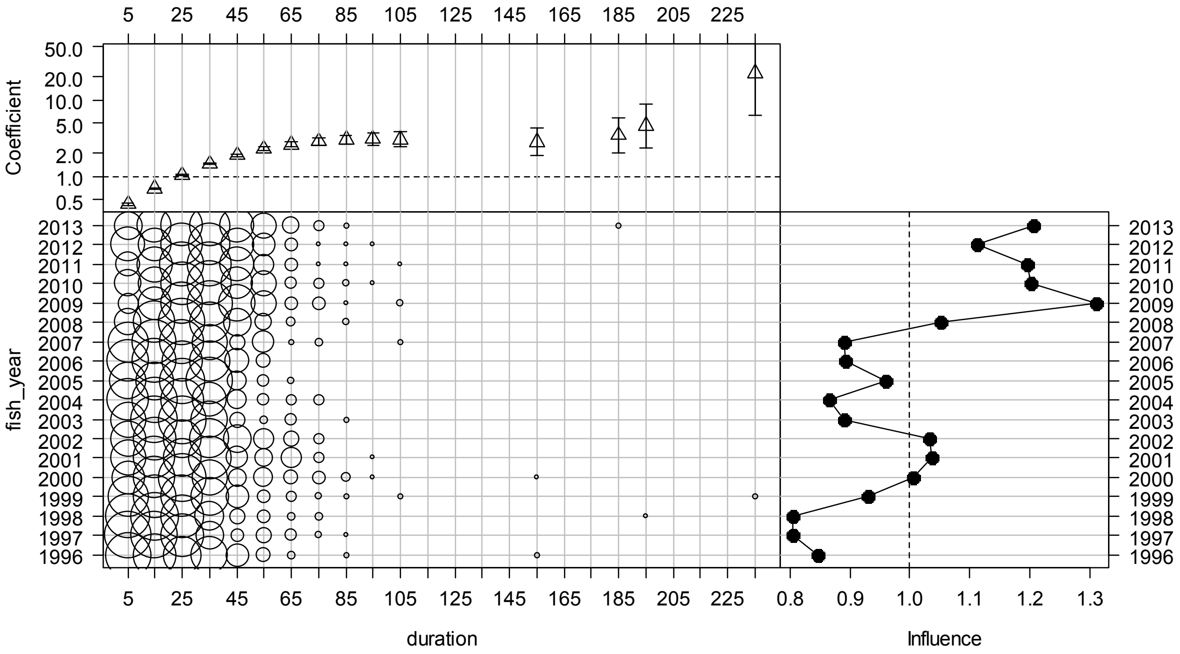
Appendix 5: Proportion of "eligible" trevally trips by the core-vessels where no trevally was landed (zero trips).

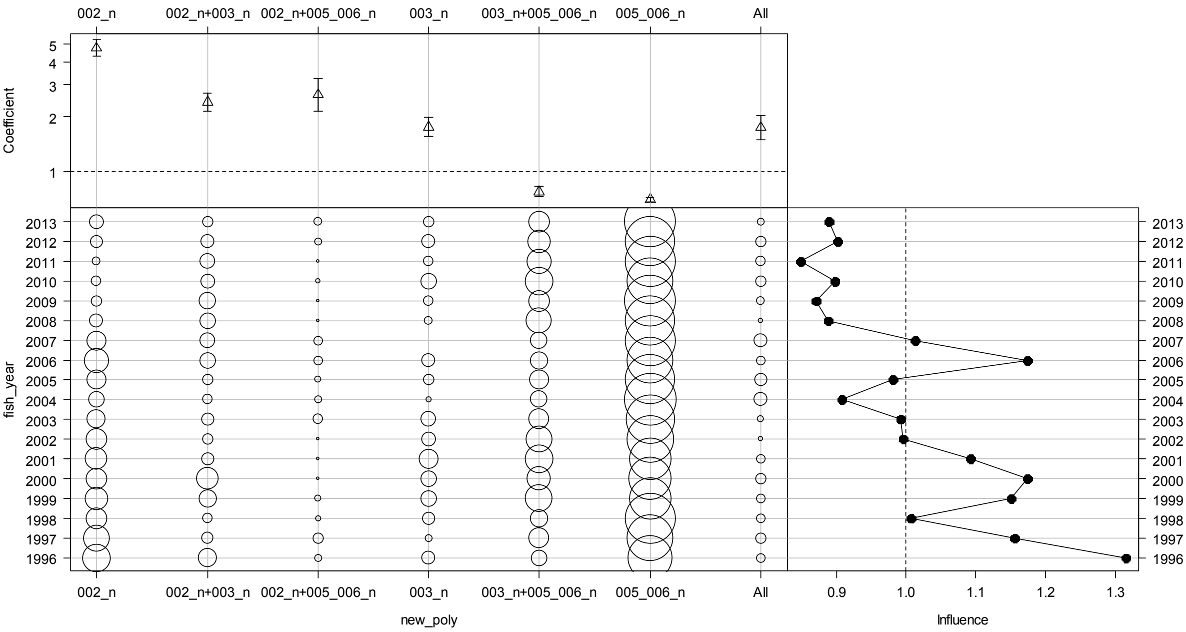
	East Northland & Hauraki Gulf (TCP/TCE reported landings)		Bay of Plenty (CEL/TCP/TCE reported landings)	
Fishing year	Number of trips	Proportion of zero catch trips	Number of trips	Proportion of zero catch trips
1990			128	0.22
1991			208	0.28
1992			174	0.28
1993			177	0.20
1994			228	0.13
1995			169	0.15
1996	285	0.35	191	0.10
1997	351	0.28	210	0.14
1998	389	0.29	178	0.15
1999	337	0.27	252	0.10
2000	327	0.21	249	0.04
2001	372	0.26	257	0.05
2002	343	0.27	303	0.04
2003	262	0.19	336	0.08
2004	263	0.23	319	0.08
2005	180	0.14	343	0.07
2006	200	0.14	295	0.07
2007	260	0.18	231	0.09
2008	338	0.16	246	0.07
2009	299	0.14	240	0.10
2010	304	0.13	194	0.05
2011	279	0.09	193	0.06
2012	287	0.12	200	0.03
2013	271	0.13	144	0.10

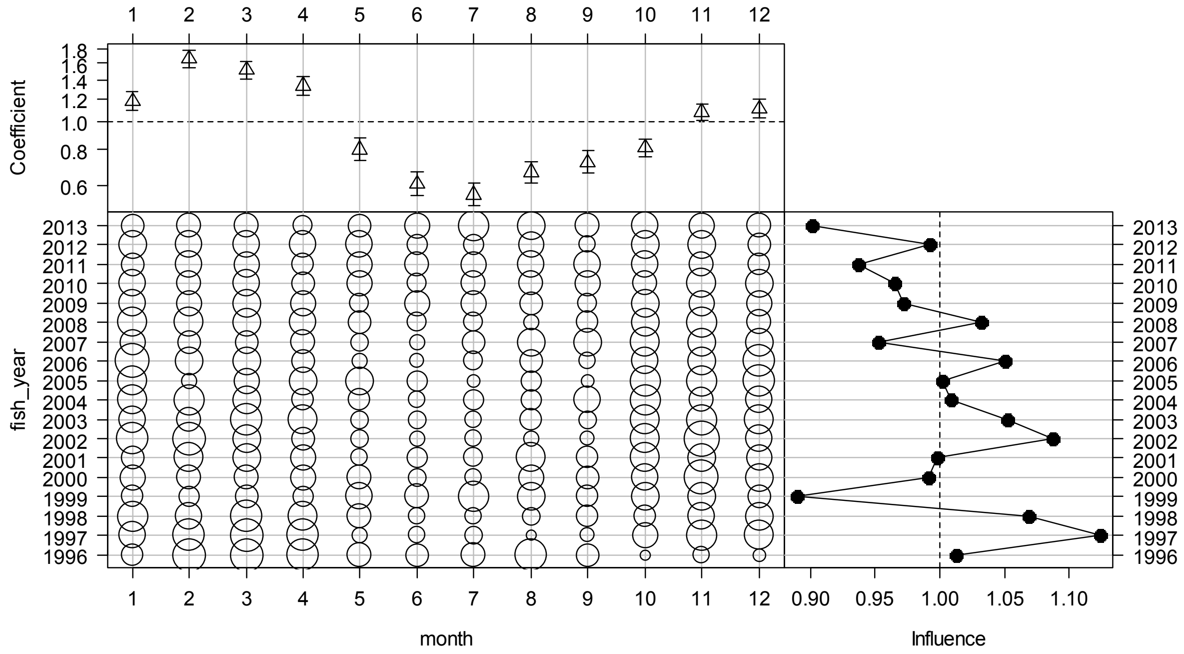
Appendix 6: **Plots illustrating the influence of all significant variables from lognormal regression of trevally catch from the ENHG sub-stock and TCP/TCE dataset. The top panel of each plot represents the relationship between the variable of interest and catch. The bottom left panel represents the distribution of the number of events for the variable of interest in each year of the time series. The bottom right panel represents the proportional influence (with no influence represented at 1) a variable had on the CPUE index for each year of the time series. Continuous variables are plotted on a log scale.**






Coefficient
fish_year
duration
Influence


002_n
002_n+003_n
002_n+005_006_n
003_n
003_n+005_006_n
005_006_n
All
Coefficient
fish_year
new_poly
Influence

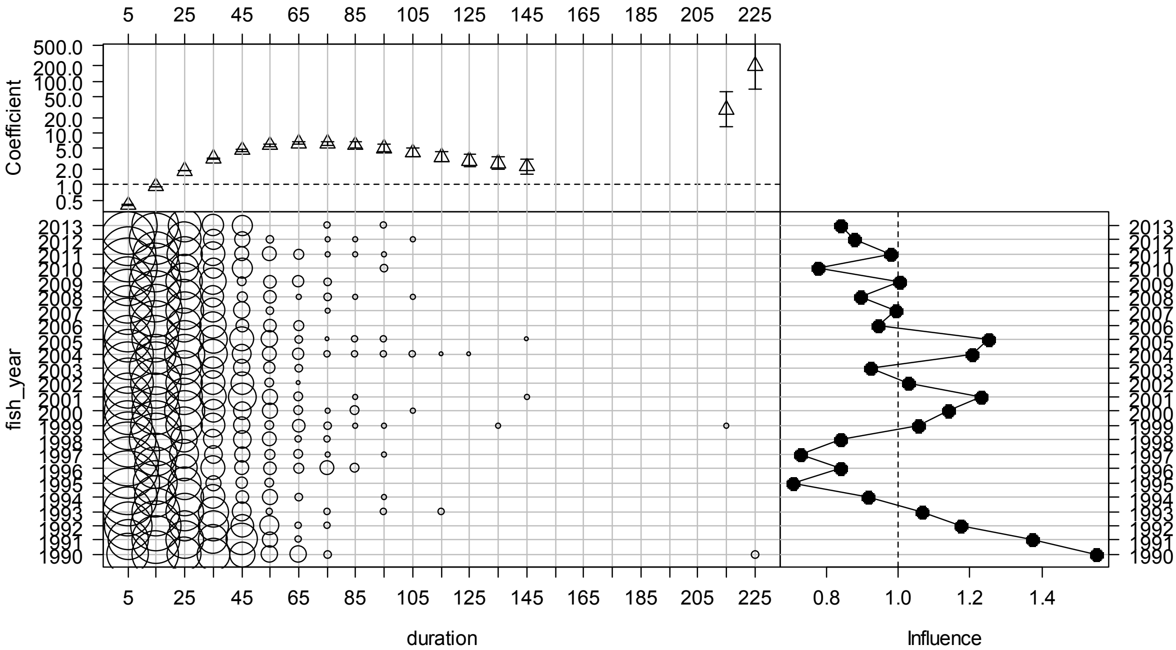


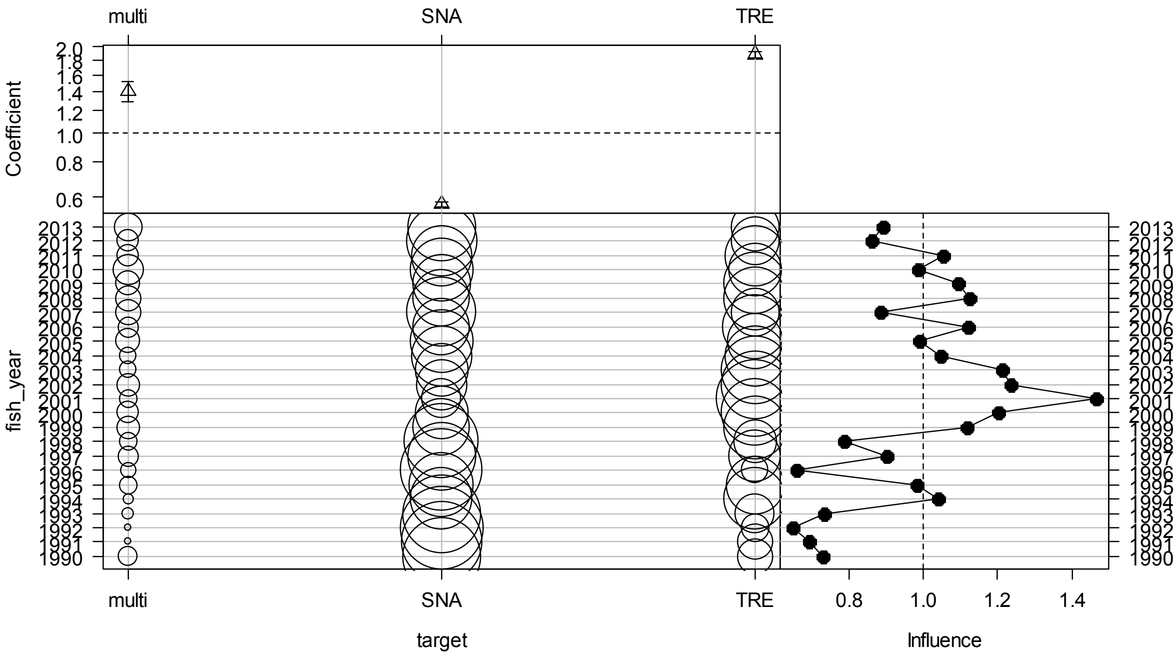
Coefficient
fish_year
month
Influence

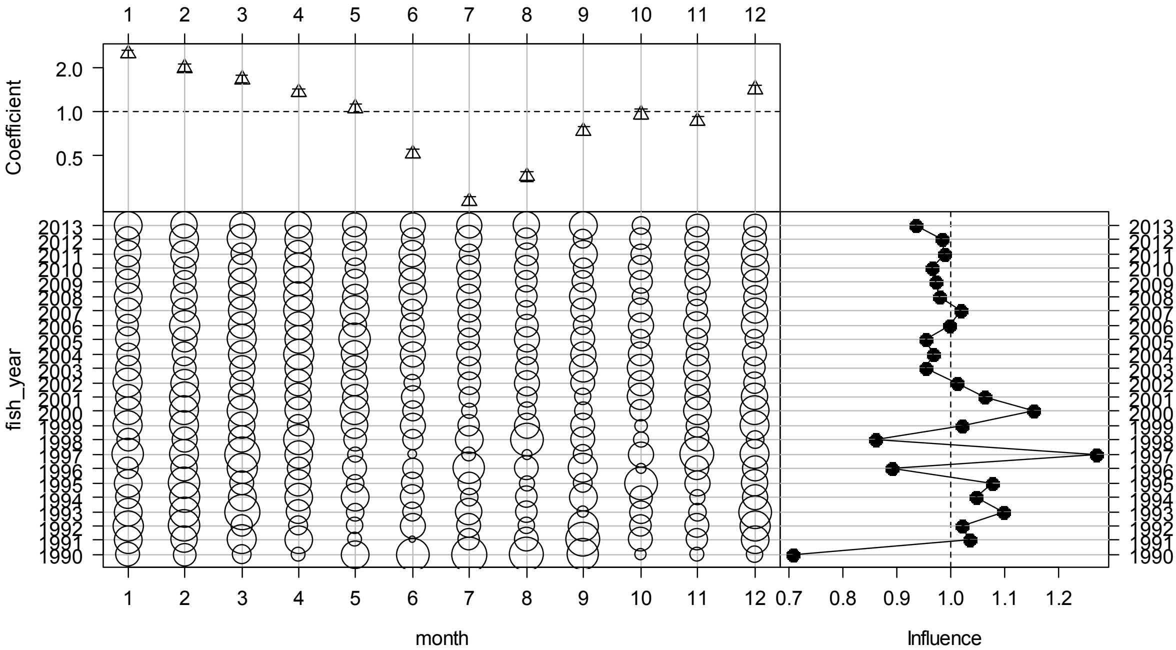
Appendix 7: Relative abundance index for the BPLE sub-stock. The index accepted by the working group was produced from a combination of the lognormal and binomial standardised CPUE analyses of the CEL data series rolled up to the trip level.

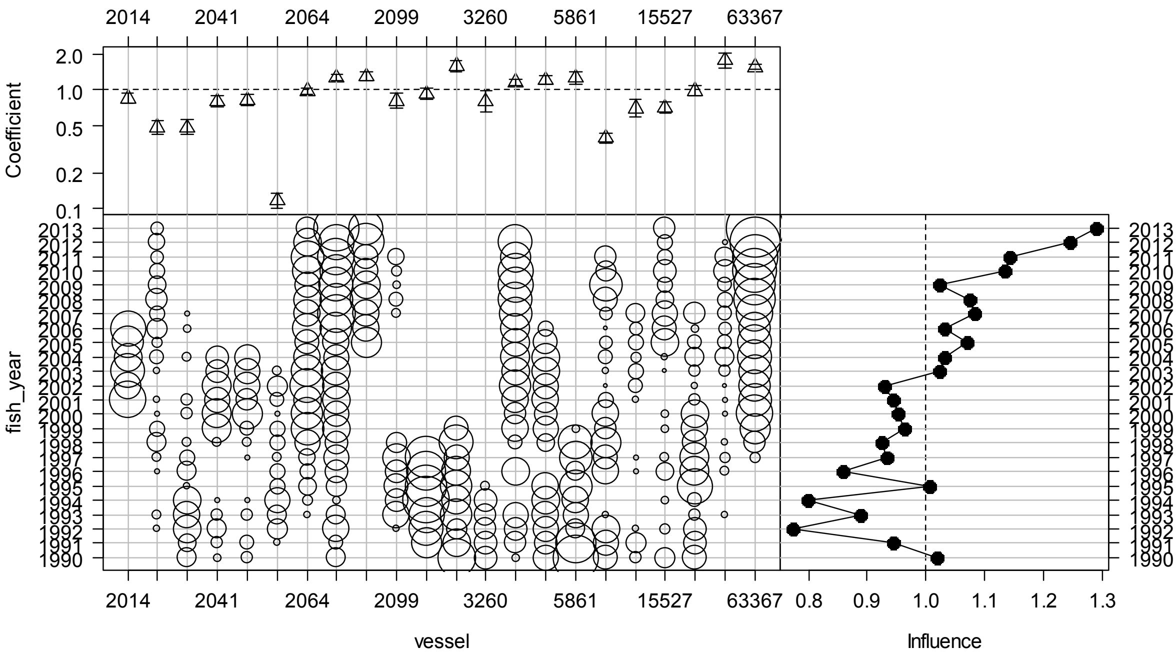
Fishing year	Relative abundance
1990	1.04841
1991	0.522834
1992	0.244385
1993	0.716663
1994	0.770124
1995	0.670743
1996	0.727367
1997	1.042374
1998	0.441629
1999	1.414617
2000	1.5465
2001	1.123085
2002	1.314116
2003	0.902406
2004	0.68299
2005	1.148025
2006	1.444495
2007	0.827147
2008	1.967015
2009	1.059185
2010	1.41079
2011	1.866976
2012	1.962348
2013	1.219304

Appendix 8: **Plots illustrating the influence of all significant variables from lognormal regression of trevally catch from the BPLE sub-stock CEL dataset rolled up to the trip level. The top panel of each plot represents the relationship between the variable of interest and catch. The bottom left panel represents the distribution of the number of events for the variable of interest in each year of the time series. The bottom right panel represents the proportional influence (with no influence represented at 1) a variable had on the CPUE index for each year of the time series. Continuous variables are plotted on a log scale.**






Coefficient
fish_year
month
Influence


Coefficient
fish_year
vessel
Influence

Appendix 9: Bay of Plenty year class strength estimates as derived from catch curve analysis.

Bottom trawl

	Catch sample year									
Year class	**1998**	**1999**	**2000**	**2008**	**2009**	**2013**	**meanYCS**	**L95**	**U95**	**CV**
1970	0.38	0.66	.	.	.	.	0.45	0.26	0.77	0.5
1971	0.60	0.56	0.98	.	.	.	0.62	0.47	0.82	0.5
1972	2.00	2.98	1.37	.	.	.	2.20	1.56	3.11	0.4
1973	0.30	1.29	1.22	.	.	.	0.75	0.27	2.09	3.1
1974	1.20	0.38	1.57	.	.	.	1.14	0.59	2.18	4.4
1975	0.89	1.16	0.39	.	.	.	0.93	0.65	1.34	4.4
1976	1.41	0.25	1.01	.	.	.	1.24	0.51	3.01	3.6
1977	0.46	1.92	0.72	.	.	.	1.08	0.38	3.05	12.1
1978	2.19	4.14	1.90	.	.	.	2.81	1.71	4.62	0.4
1979	1.50	2.58	0.86	6.53	.	.	1.91	1.12	3.25	0.8
1980	1.26	1.34	1.27	0.38	2.68	.	1.36	1.07	1.73	0.9
1981	2.61	0.31	1.17	1.00	1.54	.	2.10	0.95	4.62	1.2
1982	2.34	1.35	0.94	0.54	0.74	.	1.86	1.20	2.90	0.8
1983	1.49	0.49	0.73	0.60	1.46	.	1.16	0.68	1.97	3.9
1984	2.18	0.42	1.02	1.08	1.19	1.21	1.62	0.88	3.00	1.5
1985	4.64	1.20	1.14	1.43	1.06	1.26	3.26	1.54	6.93	0.8
1986	3.22	1.77	0.84	4.11	0.61	3.71	2.49	1.54	4.01	0.6
1987	1.74	1.03	0.92	0.51	0.83	1.59	1.33	0.97	1.81	1.4
1988	1.28	2.78	1.22	0.93	0.93	1.01	1.87	1.21	2.88	0.8
1989	0.40	1.28	0.90	1.69	1.18	3.55	1.10	0.66	1.84	6.5
1990	0.49	0.76	0.67	1.87	1.43	0.04	0.77	0.52	1.15	1.9
1991	0.37	0.77	0.24	0.10	0.73	0.39	0.54	0.34	0.87	1.0
1992	0.33	0.47	0.88	0.11	0.22	0.51	0.57	0.36	0.89	1.0
1993	0.64	1.03	1.19	1.71	0.61	0.63	1.01	0.77	1.33	41.6
1994	1.47	2.22	2.38	1.28	1.16	0.78	2.00	1.58	2.54	0.4
1995	0.44	1.50	2.45	1.82	1.38	1.62	1.76	1.14	2.72	0.9
1996	.	0.38	1.41	0.40	0.18	0.54	0.97	0.43	2.17	25.6
1997	.	.	0.60	0.87	0.75	0.92	0.68	0.55	0.85	0.6
1998	.	.	.	2.49	1.59	2.07	2.09	1.57	2.79	0.3
1999	.	.	.	3.63	1.91	2.37	2.84	1.84	4.39	0.4
2000	.	.	.	1.01	0.71	1.07	0.92	0.72	1.18	2.7
2001	.	.	.	1.79	1.36	1.24	1.55	1.23	1.96	0.5
2002	.	.	.	1.37	1.30	0.87	1.27	1.02	1.57	0.8
2003	.	.	.	0.61	0.92	1.60	0.96	0.56	1.67	12.4
2004	.	.	.	1.26	1.96	0.99	1.48	1.01	2.18	0.8
2005	.	.	.	0.52	1.49	1.59	1.15	0.58	2.28	4.3
2006	.	.	.	.	1.04	2.65	1.81	0.71	4.64	1.1

Purse seine

Year class	1998	1999	2000	2001	2002	2006	2008	2009	2013	meanYCS	L95	U95	CV
	Catch sample year												
1970	0.08	0.65	.	.	.	.	.	.	.	0.46	0.06	3.62	1.9
1971	1.04	0.51	0.54	.	.	.	.	.	.	0.66	0.41	1.06	1.0
1972	3.22	10.47	0.92	0.43	.	.	.	.	.	3.46	0.83	14.36	1.1
1973	0.04	1.13	0.86	0.47	0.11	.	.	.	.	0.48	0.19	1.21	1.4
1974	11.08	0.24	1.01	0.36	0.92	.	.	.	.	2.68	0.63	11.35	1.6
1975	4.25	1.40	0.18	0.31	0.10	.	.	.	.	1.44	0.28	7.45	5.0
1976	7.67	0.15	0.70	0.23	1.22	.	.	.	.	2.32	0.70	7.71	1.6
1977	0.02	1.94	0.70	0.76	0.88	1.18	.	.	.	0.93	0.66	1.30	5.7
1978	7.81	7.97	1.66	0.45	1.04	1.01	.	.	.	3.43	1.36	8.68	0.9
1979	0.88	6.02	0.91	3.51	0.84	0.87	0.71	.	.	1.62	0.77	3.42	2.0
1980	0.55	0.46	1.41	1.57	1.45	1.89	0.09	0.74	.	1.03	0.62	1.69	27.1
1981	7.43	0.04	1.64	3.64	1.94	2.25	0.44	0.80	.	2.34	1.14	4.79	1.2
1982	0.88	2.83	1.19	1.78	1.24	0.54	0.26	0.31	.	1.08	0.61	1.93	10.1
1983	2.25	0.28	1.16	3.74	1.25	1.19	0.44	0.73	.	1.56	0.87	2.80	1.9
1984	2.19	0.17	1.59	2.55	1.92	0.40	0.72	1.00	0.63	1.55	1.08	2.22	1.2
1985	6.91	2.06	1.83	2.04	1.83	3.99	1.56	1.15	0.19	2.81	1.70	4.63	0.7
1986	4.88	2.57	1.62	2.74	4.31	0.29	3.92	0.77	19.26	3.41	2.31	5.04	0.5
1987	5.76	1.48	1.98	2.09	2.88	0.25	0.70	0.63	0.97	2.83	1.66	4.85	0.8
1988	2.37	4.12	2.31	1.87	3.36	2.59	1.83	1.21	0.19	2.54	1.96	3.30	0.4
1989	1.45	1.22	2.11	1.48	0.99	0.74	2.21	1.15	7.53	1.59	1.22	2.06	0.8
1990	0.81	0.85	1.28	1.83	2.79	0.16	4.53	1.92	0.05	2.03	1.30	3.16	0.9
1991	1.05	0.88	0.54	1.52	3.70	0.13	0.88	0.90	0.21	1.47	0.91	2.37	1.9
1992	0.50	0.59	1.60	1.68	1.59	0.72	1.50	0.61	0.29	1.16	0.81	1.66	3.7
1993	0.85	1.13	2.46	1.34	1.18	2.43	3.28	1.11	1.18	1.57	1.12	2.20	1.1
1994	0.48	2.50	3.44	1.39	0.76	3.44	2.79	2.10	1.03	2.18	1.43	3.32	0.8
1995	0.01	1.53	1.86	1.23	2.39	1.67	5.77	1.85	3.78	1.98	1.33	2.95	0.9
1996	.	0.25	0.40	0.36	2.04	2.59	0.71	0.88	1.35	0.95	0.47	1.94	20.1
1997	.	.	0.02	0.33	1.89	2.28	2.48	1.75	1.54	1.55	0.84	2.86	1.8
1998	.	.	.	0.04	0.04	5.58	4.04	3.79	3.89	4.32	2.29	8.15	0.5
1999	.	.	.	.	0.03	3.47	8.57	4.37	3.04	4.62	2.78	7.69	0.4
2000	.	.	.	.	.	2.79	1.35	2.37	1.66	2.40	1.78	3.22	0.3
2001	.	.	.	.	.	1.99	1.71	2.91	2.30	2.25	1.81	2.78	0.3
2002	.	.	.	.	.	0.58	1.23	1.86	1.37	1.17	0.67	2.04	3.5
2003	.	.	.	.	.	0.02	0.38	0.89	3.29	2.46	0.63	9.52	1.5
2004	.	.	.	.	.	.	0.04	0.88	1.01	0.95	0.61	1.47	7.6
2005	.	.	.	.	.	.	0.04	0.13	1.73	1.60	0.17	14.87	4.1
2006	.	.	.	.	.	.	.	0.06	2.75	2.68	0.06	11.80	2.7

Appendix 10: East Northland/Hauraki Gulf year class strength estimates as derived from catch curve analysis

Bottom trawl

Year class	Catch sample year 2007	2008	2009	2013	meanYCS	L95	U95	CV
1979	1.53	0.72	.	.	0.95	0.44	2.04	10.8
1980	1.19	0.95	1.56	.	1.25	0.89	1.76	1.3
1981	1.32	3.11	1.43	.	2.38	1.27	4.43	0.6
1982	5.05	5.82	0.34	.	5.11	1.99	13.11	0.5
1983	0.56	2.75	3.00	.	2.69	1.62	4.46	0.4
1984	0.43	1.38	0.99	0.52	1.08	0.68	1.72	5.9
1985	0.83	1.34	1.00	0.46	1.09	0.78	1.51	4.0
1986	0.26	0.31	3.45	1.83	2.39	0.71	8.08	1.4
1987	1.81	0.42	1.04	9.94	3.82	0.89	16.40	1.1
1988	0.66	0.76	1.57	0.23	1.05	0.58	1.91	11.3
1989	0.53	0.13	1.04	2.35	1.09	0.43	2.76	10.2
1990	1.10	0.32	0.25	0.79	0.65	0.31	1.38	1.7
1991	0.65	0.09	0.08	0.23	0.37	0.11	1.21	1.2
1992	1.05	1.26	1.24	1.02	1.18	1.06	1.30	0.6
1993	0.26	1.81	0.79	0.82	1.20	0.56	2.56	4.1
1994	0.66	1.41	1.06	1.20	1.11	0.81	1.53	3.0
1995	1.40	0.68	1.59	0.74	1.23	0.82	1.85	2.0
1996	0.93	0.52	0.91	1.46	0.91	0.63	1.32	4.1
1997	1.11	1.79	0.84	0.60	1.25	0.81	1.92	1.9
1998	1.92	5.25	2.78	2.70	3.43	2.08	5.66	0.4
1999	1.17	2.01	1.04	1.82	1.50	1.07	2.09	0.8
2000	1.04	0.99	1.30	1.35	1.14	0.98	1.32	1.1
2001	1.65	2.74	0.57	1.99	1.90	1.14	3.18	0.8
2002	1.16	2.60	0.35	1.35	1.59	0.82	3.11	1.4
2003	2.11	2.79	1.25	1.30	2.06	1.45	2.93	0.5
2004	0.70	0.45	0.97	0.59	0.71	0.53	0.97	0.9
2005	.	0.22	1.13	0.39	0.77	0.26	2.28	3.6
2006	.	.	3.08	1.58	2.65	1.36	5.16	0.5

Purse seine

	Catch sample year										
Year class	**2001**	**2002**	**2003**	**2006**	**2007**	**2009**	**2013**	**meanYCS**	**L95**	**U95**	**CV**
1973	1.44	0.82	.	.	.	.	.	1.31	0.74	2.30	1.5
1974	1.26	0.69	0.10	.	.	.	.	1.08	0.45	2.62	10.0
1975	1.10	0.58	0.64	.	.	.	.	0.93	0.58	1.48	5.5
1976	0.97	1.87	0.07	.	.	.	.	1.23	0.56	2.69	3.3
1977	0.85	0.41	0.77	1.03	.	.	.	0.80	0.58	1.08	1.4
1978	0.74	12.12	2.04	0.88	0.98	.	.	6.52	1.57	26.99	0.8
1979	0.65	0.29	1.84	0.74	0.80	.	.	0.99	0.52	1.87	4.9
1980	0.57	0.60	0.82	0.63	0.66	1.38	.	0.77	0.56	1.07	1.5
1981	1.06	0.27	2.79	0.84	1.38	1.87	.	1.60	0.93	2.73	1.4
1982	0.44	2.89	1.98	0.45	6.72	0.18	.	2.33	1.01	5.36	1.2
1983	0.92	0.37	2.78	0.89	0.36	1.28	.	1.45	0.78	2.69	2.0
1984	1.29	5.33	1.61	1.18	0.29	0.14	0.49	2.72	1.33	5.58	1.0
1985	1.03	0.70	1.87	0.40	0.42	1.48	0.39	1.19	0.81	1.75	2.9
1986	0.40	2.44	2.02	2.13	0.34	3.60	0.32	2.11	1.27	3.49	0.9
1987	2.85	0.96	2.32	1.28	6.59	2.26	8.75	2.86	1.76	4.65	0.6
1988	1.67	1.45	2.54	1.00	0.23	0.22	0.20	1.71	1.16	2.55	1.0
1989	2.77	0.26	2.26	1.22	0.11	2.02	0.65	2.15	1.36	3.41	0.8
1990	0.62	2.70	1.45	1.03	3.25	0.71	1.53	1.77	1.08	2.90	1.1
1991	0.83	0.96	0.94	1.47	3.00	0.06	0.10	1.23	0.78	1.95	2.9
1992	0.64	2.07	1.81	1.14	2.18	2.48	1.38	1.70	1.21	2.39	0.8
1993	1.35	1.18	1.65	1.26	1.38	1.48	1.64	1.40	1.26	1.55	0.4
1994	0.94	1.03	1.12	1.71	0.73	1.63	2.03	1.19	0.95	1.49	1.7
1995	0.91	0.63	1.10	1.66	3.51	4.06	1.70	1.81	1.03	3.17	1.3
1996	0.78	1.58	0.63	3.27	2.37	2.31	2.83	1.79	1.13	2.85	1.1
1997	1.64	1.86	0.97	2.72	3.59	1.31	0.84	1.95	1.38	2.76	0.7
1998	0.91	0.84	1.05	1.35	2.49	5.09	4.85	1.94	1.06	3.55	1.2
1999	.	0.21	0.65	1.94	1.21	1.86	1.58	1.19	0.66	2.12	4.1
2000	.	.	0.04	1.58	0.99	1.19	1.99	1.29	0.70	2.36	2.7
2001	.	.	.	1.02	1.52	1.15	4.29	1.81	0.92	3.58	1.1
2002	.	.	.	0.52	0.60	0.80	3.07	1.16	0.46	2.94	6.2
2003	.	.	.	0.04	0.45	1.28	2.40	1.22	0.45	3.30	5.0
2004	.	.	.	.	0.11	1.11	1.23	0.91	0.30	2.72	9.8
2005	.	.	.	.	.	0.36	0.44	0.39	0.32	0.48	0.2
2006	.	.	.	.	.	0.13	1.90	1.57	0.11	22.18	4.2

Appendix 11: Base model population.csl file

This appendix contains the CASAL population.csl file which, together with the CASAL User Manual (Bull et al. 2012) specifies the structure of the base model.

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@max_age 30

@plus_group True

@sex_partition False

@mature_partition False

@n_areas 1

@initial 1931

@current 2013

@final 2018

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aging_time 1
spawning_time 1
spawning_part_mort 0.5
spawning_p 1
growth_props 0
M_props 1
baranov False
fishery_names BPLE_BT BPLE_PS BPLE_REC
fishery_times 1 1 1

@y_enter 1

@standardise_YCS True

@recruitment
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1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981
1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998
1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012
YCS 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
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SR BH
steepness 0.85
first_free 1970
last_free 2006
sigma_r 0.6

@randomisation_method lognormal

@first_random_year 2007

@size_at_age_type von_Bert

@size_at_age_dist normal
```

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t0 -0.13
CV 0.085

@size_weight
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b 3.064

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@natural_mortality
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1947 1948 1949 1950 1951 1952 1953 1954 1955 1956 1957 1958 1959 1960 1961 1962 1963
1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980
1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997
1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013
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286 255 352 373 413 438 305 526 571 443 512 629 280 512 558 1056 1896 1495 1153 1302
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124 170 286 140 557 729 490 382 316 397 520 448 322 497 337 512 609 421 468
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future_catches 468 468 468 468 468
selectivity SEL_BPLE_BT
U_max 0.67

@fishery BPLE_PS
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1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997
1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013
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future_catches 243 243 243 243 243
selectivity SEL_BPLE_PS
U_max 0.67

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1947 1948 1949 1950 1951 1952 1953 1954 1955 1956 1957 1958 1959 1960 1961 1962 1963
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1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997
1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013
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35 37 38 39 40 41 42 43 45 46 47 48 48 48 48 48 48 48 48 48 48 48 48 48 48 48 48 48
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future_years 2014 2015 2016 2017 2018
future_catches 48 48 48 48 48
selectivity SEL_BPLE_BT
U_max 0.67

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