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Assessment of the SNA 1 stocks in 2022 and 2023

New Zealand Fisheries Assessment Report 2024/47

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Plain language summary:

This report documents stock assessment modelling carried out for the northeastern New Zealand snapper stock (SNA 1) during 2022 and 2023.

The 2022 SNA 1 assessment conclusions were sensitive to what catches were assumed to have been taken before 1968. This uncertainty was reduced in the 2023 SNA 1 assessment by starting the models in 1968.

The 2023 east Northland assessment predicted the sub-stock to be at 38% of virgin (unfished) biomass in the 2021–22 fishing-year. Model five-year projections predicted the sub-stock would slowly decline.

The 2023 Hauraki Gulf/Bay of Plenty assessment showed that over-fishing was unlikely to have been occurring. Five-year projections predicted that there was 0.00% probability of over-fishing occurring between 2023 and 2027.

EXECUTIVE SUMMARY

McKenzie, J.R.[1]; Marsh, C. [1]; Doonan, I. [1]; Grüss, A. [1]; Hartill, B. [1]; Langley, A.D.[2]; Starr, P.J.[3] (2024) Assessment of the SNA 1 stocks in 2022 and 2023 *New Zealand Fisheries Assessment Report 2024/47*. 264 p.

Snapper (*Chrysophrys auratus*) is one of New Zealand's most valuable commercial and recreational marine species. This report documents the stock assessment modelling carried out for the northeastern New Zealand snapper stock (SNA 1) during 2022 and 2023, updating the previous 2013 assessment.

The 2022 base model was an updated version of the home-fidelity assessment model used for the 2013 SNA 1 assessment. The 2022 base model commenced in 1900 and described 15 fisheries acting on three fish stocks, with annual migrations between three areas (east Northland, Hauraki Gulf, and Bay of Plenty). Despite similarities to the 2013 assessment model, the 2022 SNA 1 base model struggled to rationalise the observed increase in Hauraki Gulf stock abundance and the possible increase in productivity (mean recruitment) occurring after 2013. The 2022 SNA 1 assessment model predicted outcomes that were highly sensitive to model data weighting and model structural assumptions. The 2022 Plenary felt that more work was needed to better understand and resolve the data lack-of-fit and likelihood conflicts in this model.

After the 2022 assessment, a review of SNA 1 stock structural evidence was undertaken which included VAST analyses of event-level longline CPUE data. The analyses showed that the southern region of Statistical Area 003 was more likely to be part of the Hauraki Gulf sub-stock; as a result, all the Hauraki Gulf and east Northland catch history and observational data series were reanalysed in accordance with this new boundary definition. A review of SNA 1 assessment modelling options was also undertaken. Two assessment models were developed for the 2023 assessment: an independent east Northland model that assumed no movement to or from the other sub-stocks and a home-fidelity movement model for the Hauraki Gulf and Bay of Plenty sub-stocks. Movement in the Hauraki Gulf/Bay of Plenty model was not estimated but fixed at values derived from independent Petersen tag models.

Both models were commenced in 1968 in assumed exploited states; this was achieved by application of pre-1968 fishing mortality parameters ($F_{initial}$). The reason for starting the models in 1968 was to negate the need for the models to account for highly uncertain pre-1968 catch histories.

The 2023 east Northland assessment predicted the sub-stock to be at 38% B_0 in the 2021–22 fishing-year, with a 29% probability of being above the target and 100% probability of being above the soft limit. The east Northland model predicted that the 2021–22 total fishing exploitation rate (U) was 0.057, higher than the estimated $U_{SSB\ B40\%}$ equilibrium target value of 0.052, with a 74% probability that over-fishing was occurring. Model five-year projections with 2021–22 catches and recent recruitments predicted that the stock would slowly decline having a 0.55% probability of being below the soft limit in 2026–27.

The 2023 Hauraki Gulf/Bay of Plenty model was unable to estimate $F_{initial}$ for the Bay of Plenty sub-stock under fixed-movement scenarios, and movement had to be set to zero in the final base model. Ignoring movement is likely to have meant that the individual sub-stock productivity estimates would have been biased. However, as the final stock status predictions from the model were for the combined Hauraki Gulf and Bay of Plenty modelling results, biases are likely to have been balanced out to some degree. A pronounced upward trend in YCS was evident in Hauraki Gulf model predictions providing evidence for a shift in sub-stock productivity after 2000. The 2023 Plenary concluded that B_0 was likely

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to be inappropriate as a sustainability reference measure for management. The 2023 Plenary was more confident in the spawning stock biomass (SSB) predictions from the combined models, as these were found to be relatively robust under different model assumptions and recommended the use of $U_{SSB\ B40\%}$ sustainable measures for the Hauraki Gulf/Bay of Plenty stock complex. The Hauraki Gulf/Bay of Plenty combined model predicted that the 2021–22 total fishing exploitation rate (U) was 0.041, lower than the derived $U_{SSB\ B40\%}$ equilibrium target value of 0.050, with a 0.02% probability that over-fishing was occurring. Model five-year projections with 2021–22 catches and recent recruitments predicted that there was 0.00% probability of the Hauraki Gulf/Bay of Plenty U being above the $U_{SSB\ B40\%}$ reference value between 2023 and 2027.

1 INTRODUCTION

Snapper (*Chrysophrys auratus*) is New Zealand's most valuable commercial coastal marine species and is also the nation's most important recreational species (Hartill et al. 2007). Most New Zealand snapper stocks have been subject to significant exploitation for over a century; National commercial landings peaked in the 1970s at around 18 000 t per annum (Paul & Sullivan 1988; Fisheries New Zealand 2023). Commercial exploitation of snapper has been constrained by a catch limit since the introduction of the Quota Management System (QMS) in 1986. Non-commercial snapper exploitation is regulated primarily by minimum-legal-size and individual bag limits.

Under the QMS there are four snapper Quota Management Areas (QMAs) of commercial and non-commercial significance. The largest volume of catch, both commercial and non-commercial, comes from the east coast North Island QMA known as SNA 1 (Figure 1).

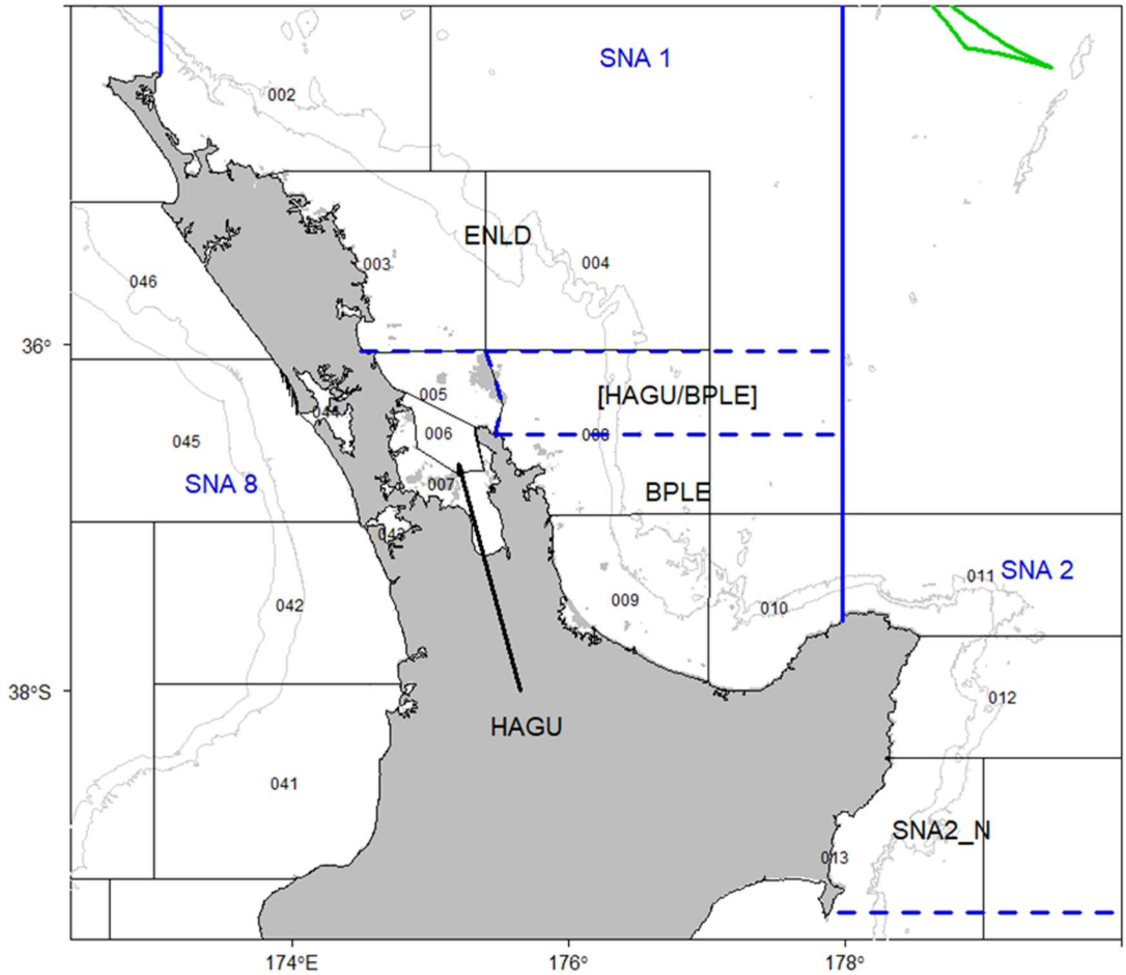


Figure 1: Boundaries for the snapper Quota Management Areas and three subareas within SNA 1: east Northland (ENLD), Hauraki Gulf (HAGU), Bay of Plenty (BPLE), and SNA2_N north. Note: HAGU/BPLE region is included in the Bay of Plenty sub-stock definition for management purposes but is likely to be a mixing zone with the Hauraki Gulf sub-stock.

Monitoring programmes have included commercial catch at-age sampling, recreational harvest surveys, trawl surveys, and tagging programmes for the purposes of biomass and movement estimation. Age-structured population modelling is used to estimate the productivity and status of the SNA 1 stock.

2 PREVIOUS SNA 1 STOCK ASSESSMENTS

Tagging movement, recruitment and growth data suggest that SNA 1 is productively distinct from the other snapper QMAs (Sullivan 1985; Walsh et al. 2022). Fishing pressure across SNA 1 has not been uniform and this is reflected in differences in age composition between SNA 1's three component sub-areas (Figure 1): east Northland (EN); Hauraki Gulf (HG); Bay of Plenty (BP) (Paul 1977; Sullivan 1985). Recent east Northland longline catches show a wider range of age classes and a higher accumulation of biomass older than 20 years than catches from the other areas, suggesting that it has been less intensely fished (Walsh et al. 2022). The smallest proportion of biomass in the older age classes is seen in Bay of Plenty catches (Walsh et al. 2022), which is believed to be a legacy of a relatively high level of trawl fishing during the 1970s. Despite spatial differences in productivity, tagging observations suggest that the level of mixing between the three sub-stocks is significant; especially between Hauraki Gulf and the Bay of Plenty (Sullivan et al. 1988; Gilbert & McKenzie 1999).

The spatial complexity of SNA 1 makes it difficult to assess as a unit stock. One approach has been to assess SNA 1 using amalgamated data from either two sub-stocks or all three (Gilbert et al. 2000). Another approach has been to model each sub-stock independently (Gilbert et al. 1996); the overall SNA 1 yield statistic being the combination of the individual assessments. Both approaches have problems; amalgamation results in an assessment inherently more uncertain because spatial variability is unaccounted for. Assessing the three sub-stocks independently, although accounting for spatial variability, ignores between-area movements and may lead to a biased assessments.

The first spatial SNA 1 stock assessment that allowed for spatial mixing between the three sub-stocks was conducted by Francis and McKenzie in 2012 (Francis & McKenzie 2015a) using a spatially disaggregated movement model developed by McKenzie (2012). The 2013 SNA 1 assessment using this model was accepted by the Plenary. The next formal attempt at a SNA 1 assessment was in 2022, this assessment used a modified version of the 2013 assessment model and was fitted to the 2013 assessment model observational data series with the addition of post 2012 data through to 2020.

2.1 2012 & 2013 SNA 1 Assessments

The 2012 and 2013 assessments of SNA 1 were undertaken using spatially disaggregated movement models (Francis & McKenzie 2015a & b). The main structural differences between these assessments and the previous 1999 assessment (Gilbert et al. 2000) were:

- Separation of the Bay of Plenty and Hauraki Gulf sub-stocks;
- Incorporation of a Beverton & Holt stock recruitment relationship (h = 0.85; note: no stock recruit relationship was assumed in the 1999 SNA 1 assessment).

The deterministic B_{MSY} from the 2012 assessment was 26–27% B_0 for all stocks and areas compared to 20% B_0 in the 1999 assessment; the inclusion of a stock recruit dynamic is largely responsible for the difference in the deterministic B_{MSY}/B_0 ratios between the two assessments (Hilborn & Stokes 2010; McKenzie 2012).

In the 2012 assessment all three SNA 1 stocks were estimated to be below B_{MSY} with east Northland at 15–17% B_0; Hauraki Gulf at 12–14% B_0 and the Bay of Plenty at 5–6% B_0, with no sub-area likely to rebuild in the next five years.

The 2012 assessment model commenced in 1970 with all three stocks in an exploited state; to do this required estimating an offset parameter [$R_{initial}$] on mean recruitment (Francis & McKenzie 2015a; Bull et al. 2012).

Two model performance issues were identified in the 2012 assessment:

1. Poor estimation of initial depletion ($R_{initial}$);
2. Poor MCMC convergence.

There was insufficient time during the 2012 assessment period to fully investigate these and other aspects of model performance. Although the 2012 SNA 1 model made significant progress toward achieving a robust SNA 1 assessment, the Northern Inshore Working Group (henceforth denoted as the "Working Group") felt that further investigations were needed to resolve the performance issues before the results could be considered useful for management.

2.1.1 Observational data

Model Catch Histories

There were two SNA 1 model variants; a 1970 commence model and a 1900 commence model. The assessment modelling, therefore, required compiling commercial and non-commercial catch histories back to 1900. SNA 1 area-method catch histories were derived as described in Appendix 1.

In 2012, the dominant SNA 1 commercial fishing methods were bottom longline (LL), bottom trawl (BT), pair bottom trawl (PBT) and Danish seine (DS). In the 2012 assessment all other methods were lumped into a single method class "other" (OTH); the predominant method under this class being setnet. For the 2013 assessment the OTH method-area catches were prorated across the other primary model methods. As with previous SNA 1 assessments, allowance for unreported catch was done by inflating the reported catch history by 20% pre-1986 and 10% post 1986.

Non-commercial catch histories were ascribed to the dominant non-commercial method (bottom longline). The derivation of recreational harvest catch histories differed between the 2012 and the 2013 assessments (see Francis & McKenzie 2015a & b).

Abundance

Fishery independent abundance observations used in the 2012 and 2013 assessment models were a Bay of Plenty sub-stock absolute recruited biomass estimate in 1983–84 from tagging, and a series of research trawl population estimates (as numbers) for the Hauraki Gulf.

Fishery dependent abundance series used in the models consisted of commercial longline catch per unit effort (CPUE) abundance indices for East Northland, Hauraki Gulf, Bay of Plenty, and a bottom trawl CPUE index for the Bay of Plenty. The longline CPUE indices covered the period 1989–90 to 2010–11, the Bay of Plenty trawl index covered the period 1995–96 to 2010–11.

Tagging

The models were fitted to tag mark-recapture data from East Northland and Hauraki Gulf release events in 1984–85 and from an all SNA 1 release event in 1993–94. In most other respects all the mark-recapture experiments were similar, i.e. thirteen-month recovery period, recaptures being restricted to commercial methods, the collection of length data to convert scanned catch weights to length frequencies. The tag observational datasets provided to the model had been corrected for tag-loss, initial mortality, under-reporting/detection, and trap-avoidance (Francis & McKenzie 2015a).

Compositional data

Catch at-age observations were intermittently available from the 1970s and 1980s. Between 1989–90 and 2009–10 catch-at-age data were collected annually from most SNA 1 sub-stocks. Most of the SNA 1 catch-at-age data were longline; the main justification being that this method is believed to select a broad range of age classes and hence the age composition of the catch is more reflective of the underlying population age structure than the catches of the other methods (bottom trawl; Danish seine). Limited catch-at-age data were available from bottom trawl and Danish seine fisheries prior to 1995 but only for the Hauraki Gulf and Bay of Plenty areas.

In addition to the Hauraki Gulf research trawl series, catch-at-age observations were available from three Bay of Plenty trawl surveys and one east Northland trawl survey.

Length compositional data from recreational boat-ramp surveys conducted in all three areas between 1991 and 2011 were used by the models.

2.1.2 Model structure & parameterisation

The spatially disaggregated SNA 1 assessment model was developed using NIWA's CASAL modelling platform (Bull et al. 2012). The base model recognised SNA 1 as being comprised of three separate biological sub-stocks and used a home fidelity (HF) dynamic to model movement of these sub-stocks between three spatial areas: East Northland, Hauraki Gulf; and Bay of Plenty (Figure 1). Under the HF dynamic, movement is an attribute of the individual fish not the area in which it currently resides; stocks and areas can therefore be decoupled such that during some of the model time steps a given area may contain fish from one or more stocks. The HF decoupling property meant that the model could provide yield estimates (MSY, B_{MYS}, B_0, etc) relative to both sub-stocks and areas. To avoid confusion about areas and sub-stocks in this report we will, henceforth, use two-letter abbreviations (EN, HG, BP) for areas, and longer abbreviations (ENLD, HAGU, BOP) to denote biological stocks.

The model partitioned the modelled population by age (ages 1–20, where the last age was a plus group), stock (three stocks, corresponding to the parts of the population that spawn in each of the three subareas of SNA 1 shown in Figure 1), area (the three subareas), and tag status (grouping fish into six categories – one for untagged fish, and one for each of five tag release episodes). That is, at any point in time, each fish in the modelled population would be associated with one cell in a 20 × 3 × 3 × 6 array, depending on its age, the stock it belonged to, the area it was currently in, and its tag status at that time.

As with previous snapper models (e.g., Gilbert et al. 2000), this model did not distinguish fish by sex. The 2012 assessment model covered the period 1970 to 2011, with two time-steps in each year (Table 1). Note, model years corresponded to commercial fishing years being October 1^{st} through to September 30^{th} of the following year, these denoted in the model (and this report) by second of the two years (e.g., the 1970 model year is the 1969–70 fishing year).

There were two sets of migrations: in time step 1, all fish returned to their home (i.e., spawning) area just before spawning; and in time step 2, some fish moved away from their home area into another area. This second migration may be characterised by a 3 × 3 matrix, in which the ijth element, p_{ij}, is the proportion of fish from the ith area that migrate to the jth area.

Table 1: The time steps in each year of the 2012 base model, and the model processes and observations that occur at each step.

Time step	Model processes (in temporal order)	Observations[2]
1	age incrementation, migration to home area, recruitment, spawning, tag release	
2	migration from home area, natural and fishing mortality[1]	biomass, length and age compositions, tag recapture

[1]Fishing mortality for each of the 20 fisheries (see Section 2) was applied after half the natural mortality
[2]The tagging biomass estimate was assumed to occur immediately before the mortality; all other observations occurred half-way through the mortality.

There were three key assumptions of the 2012 base model (Table 2) that were found necessary to allow for an assessment. There is no evidence for the first two of these, and the third is simply a convenience.

Table 2: Three key assumptions of the 2012 base model.

1	All fish were in their home grounds at the time of tagging
2	The proportions migrating at time step 2, p_{ij}, were the same each year
3	All tag recaptures in any year occurred in time step 2 after the migration away from the home area

Because all observational data, except for tag release observations, represent only timestep two, the model did not allow for any "true" season dynamics in the stocks regarding exploitation, i.e. it was effectively a single season model.

The 1970 start model made use of a R_0 off-set parameter ($R_{initial}$) (one for each sub-stock) to establish each sub-stock at an exploited relative biomass state in 1970. This approach assumes that each stock had the stable age distribution which would arise if in the preceding years its recruitment was constant at some fraction ($R_{initial}$) of the mean unfished recruitment (R_0) (refer Bull et al. 2012).

A marked reduction in snapper growth rates was evident in the longline catch at-age data series between 1990 and 2010 (Francis & McKenzie 1915b). To accommodate changing growth in the 2013 SNA 1 assessment, growth was specified in the model by three mean length at-age matrices (one for each sub-stock) covering the years 1989 to 2011. Growth prior and after this period was assumed to be equivalent to, respectively, the matrices first and last year row values. The sub-stock growth matrix mean length values were derived from longline catch sampling data. The growth matrix approach was necessary to accommodate the progressive reduction in growth observed over the sampling period.

Six migration parameters defined the 3 × 3 HF migration matrix (note: there were only six parameters because the proportions in each row of the matrix must sum to 1).

The model assumed a Beverton and Holt stock recruitment dynamic with steepness (h) fixed at 0.85. Natural mortality (m) was likewise fixed at 0.075 (see Table 4).

Selectivities were assumed to be age-based and double normal, and to depend on fishing method but not on area. Three selectivities were estimated for commercial fishing (for longline, bottom trawl, and Danish seine); one for the (bottom trawl) research surveys; and two for recreational fisheries (for before and after a change in recreational size limit in 1995). These and other parameters estimated in the 2012 base model are given in Table 3.

Table 3: Details of parameters that were estimated in the base 2012 SNA 1 assessment model

Type	Description	No. of parameters	Prior
R_0	Mean unfished recruitment for each stock	3	uniform-log
$R_{initial}$	Pre-1970 recruitment (as proportion of R_0)	3	uniform
YCS	Year-class strengths by year and stock	115[1]	lognormal[2]
Migration	Proportions migrating from home grounds	6	uniform
Selectivity	Proportion selected by age/length by a survey or fishing method (6 method selectivity ogives [3 parameters each])	18	uniform[3]
q	Catchability (for relative biomass observations)	5	uniform-log
		150	

[1]YCSs were estimated for years 1969–2007 (for ENLD and HAGU) and 1971–2001 (for BOP)
[2]With mean 1 and coefficient of variation 0.6
[3]Except for the recreational selectivities, where normal priors were assumed for each parameter with means 4.55, 0.50, 10.24 (pre-1995) and 5.30, 0.50, 10.40 (post-1995) and coefficients of variation 0.20, 0.05, and 0.05 (both pre- and post-1995)

Some parameters were fixed, either because they were not estimable with the available data (notably natural mortality and stock-recruit steepness were fixed at values determined by the Working Group), or because they were estimated outside the model (Table 4).

Table 4: Details of parameters that were fixed in the base 2012 & 2013 SNA 1 assessment model

Natural mortality	0.075 y^{-1}
Stock-recruit steepness	0.85
Tag shedding (instantaneous rate, 1985 tagging)	0.486 y^{-1}
Tag detection (1985 and 1994 tagging)	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]	$a = 4.467 \times 10^{-5}$, $b = 2.793$
Mean lengths at-age	provided for years 1989–2011
Coefficients of variation for length at-age	0.10 at-age 1, 0.20 at-age 20
Pair trawl selectivity	$a_1 = 6$ y, $\sigma_L = 1.5$ y, $\sigma_R = 30$ y
[1]Selectivity for other fishing methods	$a_1 = 7$ y, $\sigma_L = 2$ y, $\sigma_R = 6.5$ y

[1]"Other methods" catch assigned to Bottom trawl in 2013 assessment

2.1.3 Assessment results and conclusions

In the 2012 assessment all three SNA 1 stocks were estimated to be below the soft-limit ($B_{20\%}$) with east Northland at 15–17% B_0; Hauraki Gulf at 12–14% B_0 and the Bay of Plenty at 5–6% B_0, with no sub-area likely to rebuild in the next five years.

However, two model performance issues were identified in the 2012 assessment:

1. Poor estimation of initial depletion ($R_{initial}$);
2. Poor Monte Carlo Markov Chain (MCMC) convergence.

Improved MCMC convergence and resolution of the poor $R_{initial}$ estimation issue were achieved in the 2013 SNA 1 assessment by improved re-weighting of the model tagging data and by adopting a total catch history modelling approach (i.e. 1900 commence model). Other changes to the 2012 model were revised and updated commercial and recreation catch histories and updates of all commercial CPUE indices to include the 2011–12 fishing year. Despite the loss of the three $R_{initial}$ estimated parameters, the 2013 SNA 1 model estimated 26 more parameters than the 2012 model to be able to estimate recruitments further back in time (Table 3 cf. Table 5).

Table 5: Details of parameters that were estimated in the base 2013 SNA 1 assessment

Type	Description	No. of parameters	Prior
R_0	Mean unfished recruitment for each stock	3	uniform-log
YCS	Year-class strengths by year and stock	136[1]	lognormal[2]
Migration	Proportions migrating from home grounds	6	uniform
Selectivity	Proportion selected by age by a survey or fishing method	18	uniform
q	Catchability (for relative biomass observations)	5	uniform-log
		168	

[1]YCSs were estimated for years 1966–2007 for ENLD, 1951–2007 for HAGU, and 1971–2001 for BOP
[2]With mean 1 and coefficient of variation 0.6

In the 2013 SNA 1 assessment, the $\%B_0$ 95% confidence ranges as derived from MCMC model posterior predictions were: east Northland 18–30% B_0; Hauraki Gulf 19–29% B_0 and the Bay of Plenty at 3–9% B_0. The $\%B_0$ 95% confidence range on the combined Hauraki Gulf/Bay of Plenty stock complex was 15–23% B_0.

Five-year projections were carried out under 'status quo' conditions, which were taken to mean constant catches (equal to the 2012 and 2013 catches) for the commercial fisheries and constant exploitation rate (equal to the average of the 2008–2012 rates) for the recreational fisheries. Projection results varied depending on the future recruitment and growth assumptions, with stocks projected to decline if all observed recruitment variants were used and to increase if only the most recent 10 years of recruitment were assumed (Francis & McKenzie 2015b).

2.2 2022 SNA 1 Preliminary Assessment

The 2022 SNA 1 assessment model was also developed using NIWA's CASAL modelling platform (Bull et al. 2012).

2.2.1 SNA 1 model spatial stock structural assumptions

There was some uncertainty in the 2013 assessment as to whether the northern region of Statistical Area 008 should be included as part of the Hauraki Gulf sub-stock (Figure 1). This northern region of 008 was included in the Hauraki Gulf for the LL and BT event-level CPUE analyses but not for the day and trip-level analyses. The northern region of 008 catch was included in the Bay of Plenty model catch history as it was not possible to subdivide 008 catches prior to 2007.

2.2.2 Observational data

Commercial Catch Histories

The pre-1990 commercial catch histories compiled for the 2013 assessment model (Appendix 1) were also used for the 2022 assessment model. However, post 1989–90 SNA 1 catch histories were regenerated and updated through to the end of the 2019–20 fishing year (Figure 2; Appendix 2). Model post-1990 catch histories were based on landed-catch method-area demographics prorated to the "official" Monthly Harvest Return totals (Figure 2). Important changes occurring post the 2013 assessment were a progressive reduction in catch the in Hauraki Gulf sub-stock (Figure 2), and the introduction of the Modular Harvest System (MHS) trawl method in 2015 (Figure 3). MHS catch histories were factored into the 2022 assessment as a specific method in addition to BT, PBT, DS, and LL (Table 6). As with the 2013 assessment, other method-area annual catches were prorated across each of the five explicit model method annual catches. The allowance for unreported catch was again achieved by inflating the reported catch history by 20% pre-1986 and 10% post 1986.

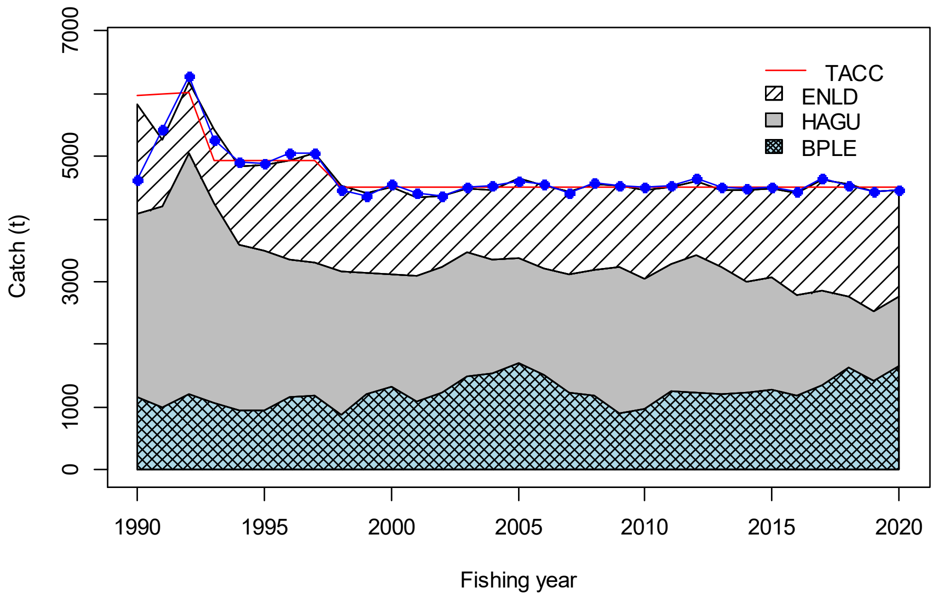


Figure 2: SNA 1 sub-stock commercial catch 1989–90 to 2019–20. Solid lines are Monthly Harvest Return totals, the blue line is the reported landing return totals, the red line is the Total Allowable Commercial Catch.

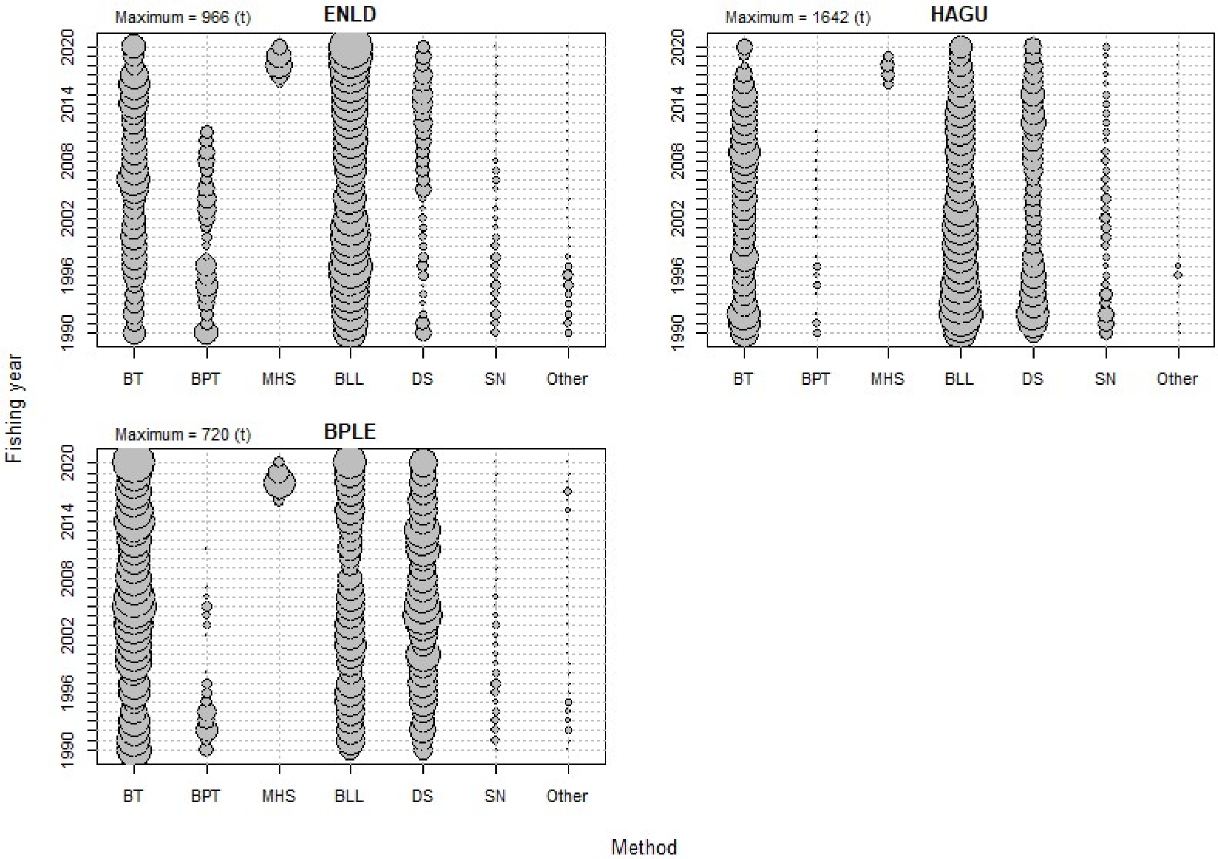


Figure 3: SNA 1 sub-stock area main commercial method catches in weight (in t) 1989–90 to 2019–20; circle areas are relative to the maximum catch listed on each graph.

Recreational catch histories

SNA 1 recreational harvest for fishing years post 2000–01 were derived by combined estimates from aerial-access and National panel surveys with relative catch data indices from boat ramp monitoring surveys (Figure 4; Appendix 3)

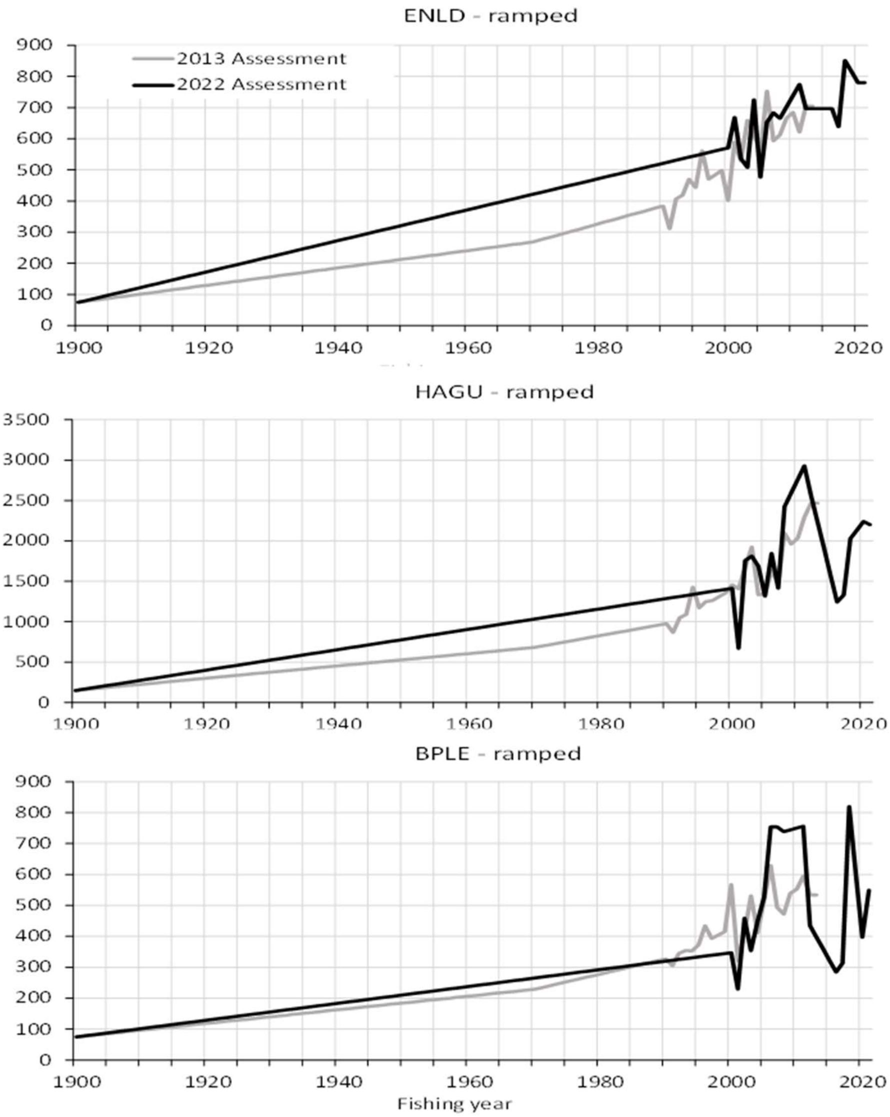


Figure 4: SNA 1 regional annual recreational harvest 1900–01 to 2020–21. Post 2000–01 estimates derived using methods given in Appendix 3. Estimates back to 1900–01 were derived by ramping back from the regional 2000–01 estimated values to assumed 1900–01 catch values of: 75 t for East Northland; 150 t for Hauraki Gulf; 75 t for Bay of Plenty. Grey lines show catch histories assumed in the 2013 SNA 1 assessment.

Fishery independent abundance observations

There have been two additional trawl surveys conducted in the Hauraki Gulf and Bay of Plenty regions since the 2013 assessment, in the 2019–20 and 2021–21 fishing years (Parsons et al. 2021; Parsons & Bian 2022). Before the 2019–20 Hauraki Gulf and Bay of Plenty trawl surveys, Parsons et al. (2021) undertook a review of the stratification boundaries and timing of the previous survey series. As a result of their review, new stratification boundaries were adopted for the upcoming Hauraki Gulf and Bay of Plenty surveys. Parsons et al. (2021) reanalysed the earlier Hauraki Gulf and Bay of Plenty survey data with their revised stratification which resulted in the exclusion of some of the earlier surveys due to lack of consistency with the revised stratification. The additional and revised Hauraki Gulf and Bay of Plenty trawl surveys that were deemed comparable and, therefore, used in the 2022 SNA 1 assessment models were: Hauraki Gulf 1984–85, 1986–87, 1988–89, 1989–90, 1990–91, 1992–93, 1993–94, 1994–95, 2000–01, 2019–20, 2020–21; Bay of Plenty 1989–90, 1991–92, 1995–96, 2019–20, 2020–21 (Table 6).

Table 6: Details of observations used in the 2022 SNA 1 assessment model. Areas are East Northland (EN), Hauraki Gulf (HG), and Bay of Plenty (BP).

Type	Likelihood	Area	Source	Range of years	No. of years
Absolute biomass	Lognormal	BP	1983 tagging	1983	1
Relative biomass[1]	Lognormal	EN	longline	1990–2020	31
		HG	longline	1990–2020	31
		BP	longline	1990–2020	31
		BP	bottom trawl	1996–2020	25
		HG	research survey age-5+	1985–2021	11
		BP	research survey age-5+	1990–2021	5
Relative numbers[2]	Lognormal	HG	research survey age-1	1985–2021	11
		HG	research survey age-2	1985–2021	11
		HG	research survey age-3	1985–2021	11
		HG	research survey age-4	1985–2021	11
		BP	research survey age-1	1990–2021	5
		BP	research survey age-2	1990–2021	5
		BP	research survey age-3	1990–2021	5
		BP	research survey age-4	1990–2021	5
Age composition	Multinomial	EN	longline	1994–2020	20
		HG	longline	1990–2010	19
		BP	longline	1985–2010	18
		EN	MHS	2020	1
		BP	MHS	2020	1
		HG	Danish seine	1970–2020	12
		BP	Danish seine	1995–2020	2
		HG	bottom trawl	1975–2020	7
		BP	bottom trawl	1990–2020	6
		HG	research survey	1985–2021	11
		BP	research survey	1990–2021	5
		EN	research survey	1990	1
		EN	recreational fishing	1994–2018[3]	13
		HG	recreational fishing	1991–2018[3]	14
		BP	recreational fishing	1991–2018[3]	14
		HG	research survey age-5+	1985–2021	11
		BP	research survey age-5+	1990–2021	5

		Area tagged	Year tagged[4]	Areas recaptured	Years recaptured
Tag recapture	Binomials	EN	1984	EN, HG	1984, 1985
		HG	1984	EN, HG	1984, 1985
		EN	1993	EN, HG, BP	1994, 1995
		HG	1993	EN, HG, BP	1994, 1995
		BP	1993	EN, HG, BP	1994, 1995

[1] CPUE (catch per unit effort) or bottom trawl research survey
[2] Bottom trawl research survey
[3]All length composition data sets were split into pre-1995 (2 years) and post-1995 (11 years) post-2015 because recreational selectivity was assumed to change in 1995 and in 2015 due to minimum-legal-size changes
[4]Fish labelled as tagged in 1984 were tagged between 21 October and 8 December in that year; those labelled 1993 were tagged between 27 October 1993 and 15 January 1994

Hauraki Gulf and Bay of Plenty trawl surveys have ostensibly been optimised to estimate snapper pre-recruit abundance. The ability of these surveys to monitor adult (age five and above) snapper has been conjectural. To accommodate the pre and post-recruit utility of the Hauraki Gulf and Bay of Plenty trawl survey series to monitor snapper abundance, separate age-specific snapper abundance indices were derived from the survey series for input to the 2022 assessment; these consisted of four indices for ages one through four (as numbers), and a combined index for ages five and above (as biomass) (Figure 5, Figure 6, Table 6).

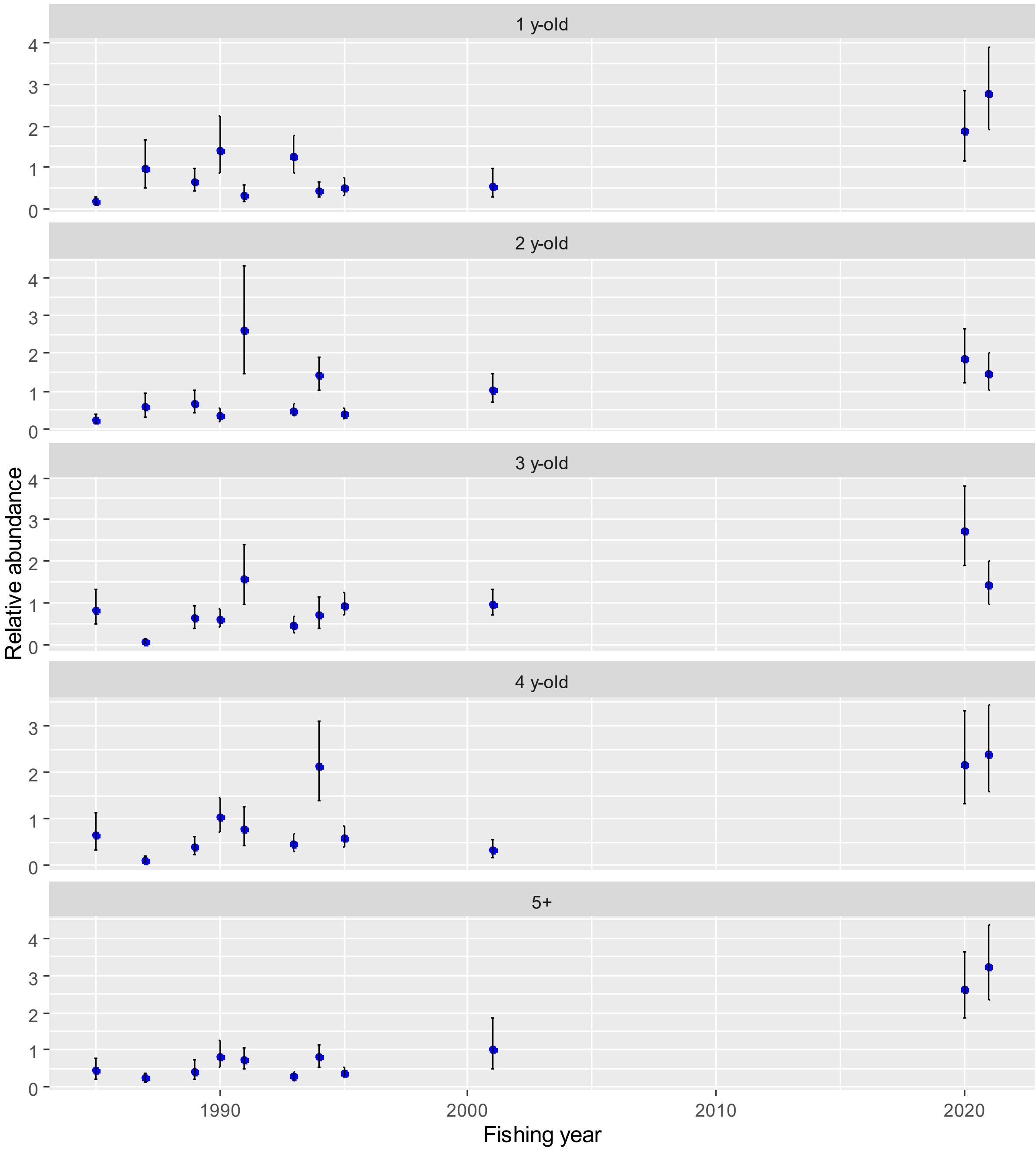


Figure 5: Hauraki Gulf trawl survey relative snapper abundance ages 1–4 (numbers), and 5+ (biomass). Vertical lines are survey log 95% confidence intervals.

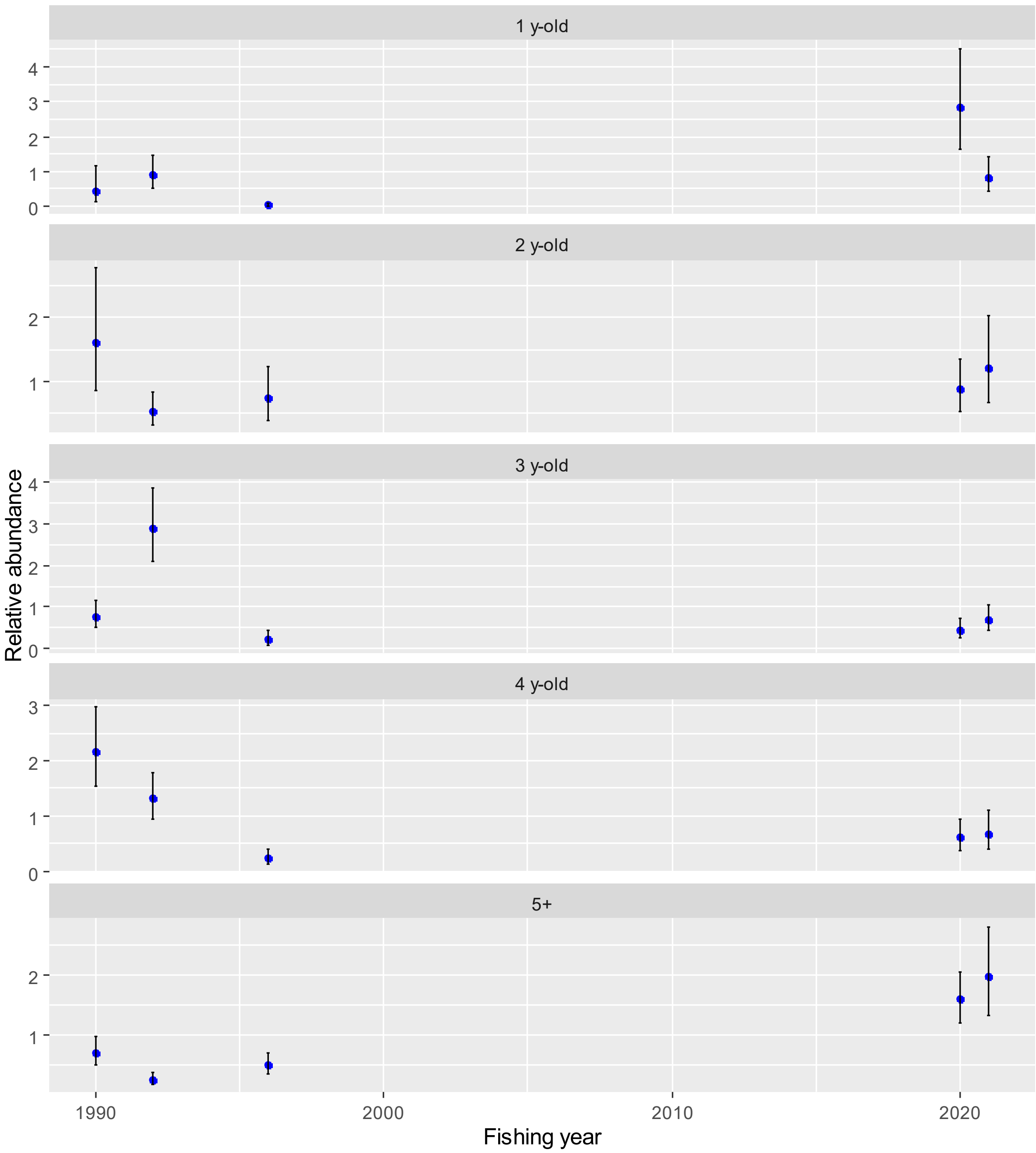


Figure 6: Bay of Plenty trawl survey relative snapper abundance ages 1–4 (numbers), and 5+ (biomass). Vertical lines are log 95% confidence intervals.

As with the 2013 assessment, the Bay of Plenty sub-stock absolute recruited biomass estimate in 1983–84 from tagging was also fitted in the 2022 SNA 1 model.

Fishery dependent abundance observations

The 2022 assessment models were fitted to same area-method CPUE series used in the 2013 assessment but updated through to the end of the 2019–20 fishing year, i.e. the three separate sub-stock longline CPUE indices covered the period 1989–90 to 2019–20, the Bay of Plenty bottom trawl index covered the period 1995–96 to 2019–20 (Table 6). The derivation of these indices and associated diagnostics are given in Appendix 4.

The east Northland standardised longline index, although fluctuating, shows a general increasing trend over the series history (Figure 7). As, expected, the general pattern in 2013 index and the updated index matched reasonably well over the common years (Figure 7).

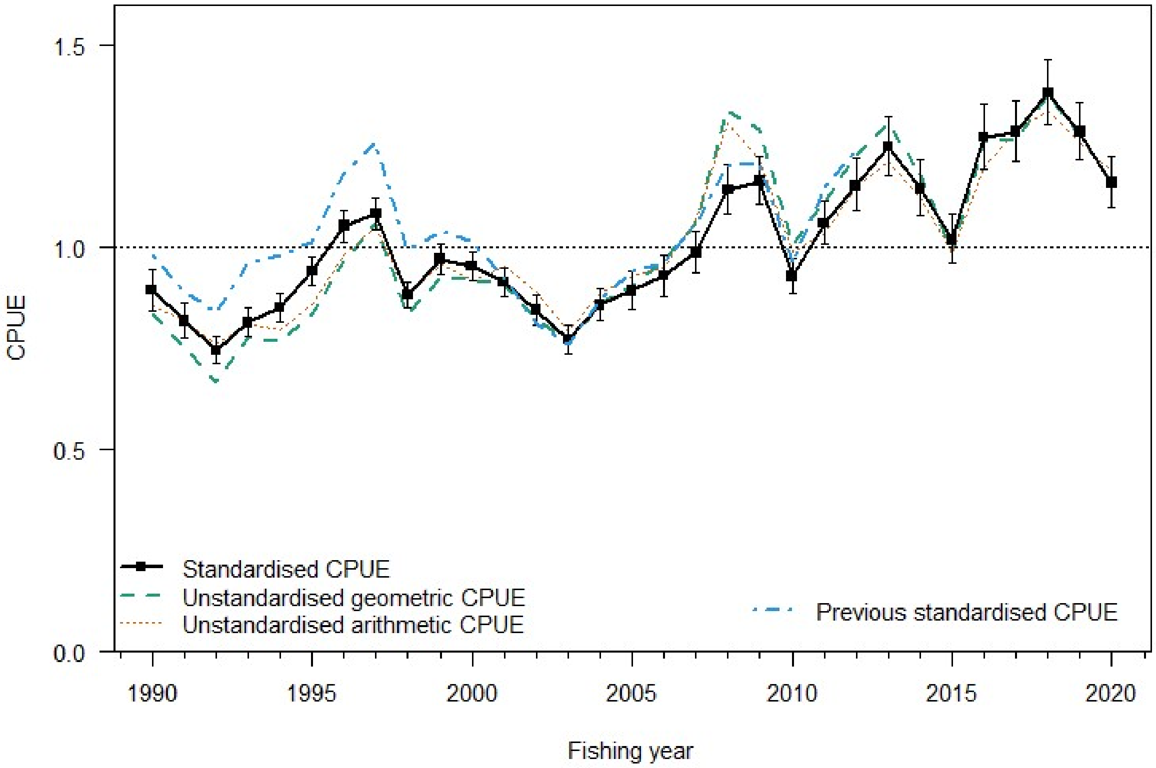


Figure 7: East Northland longline snapper CPUE standardised and unstandardised indices. Index from 2013 assessment shown for comparison.

The Hauraki Gulf standardised longline index, although fluctuating, shows a pronounced increase between 1994–95 and 1998–99, followed by a less extreme increase after 2004–05 (Figure 8). The general pattern in 2013 index and the updated index again matched reasonably well over the common years (Figure 8).

The Bay of Plenty standardised longline index shows a steadily increasing trend throughout the series after an initial drop over the first three years (Figure 9).

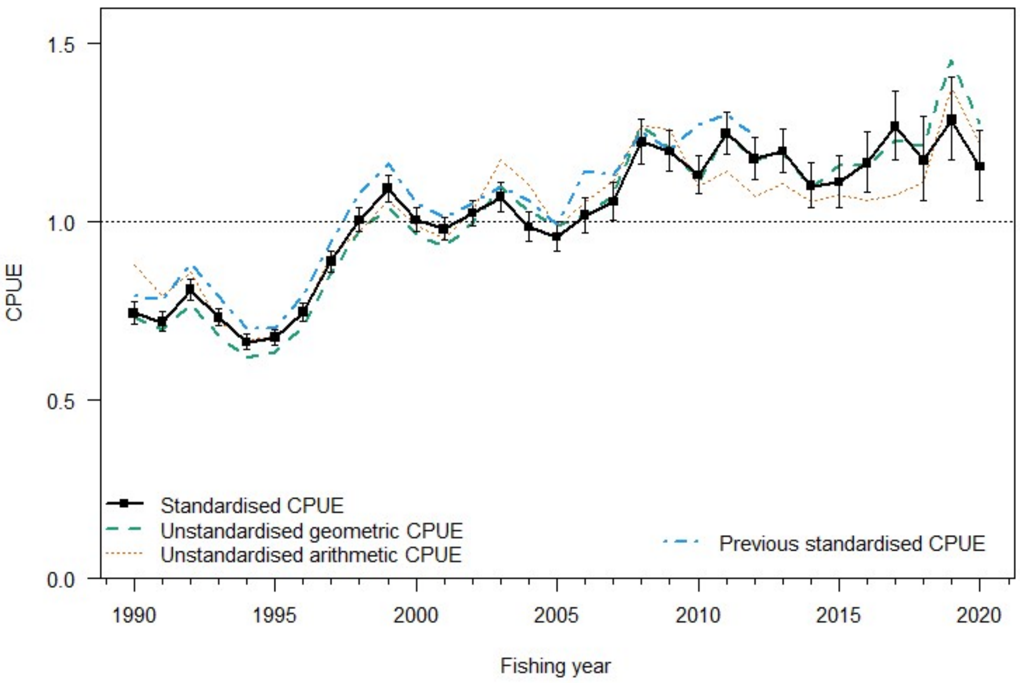


Figure 8: Hauraki Gulf longline snapper CPUE standardised and unstandardised indices. Index from 2013 assessment shown for comparison.

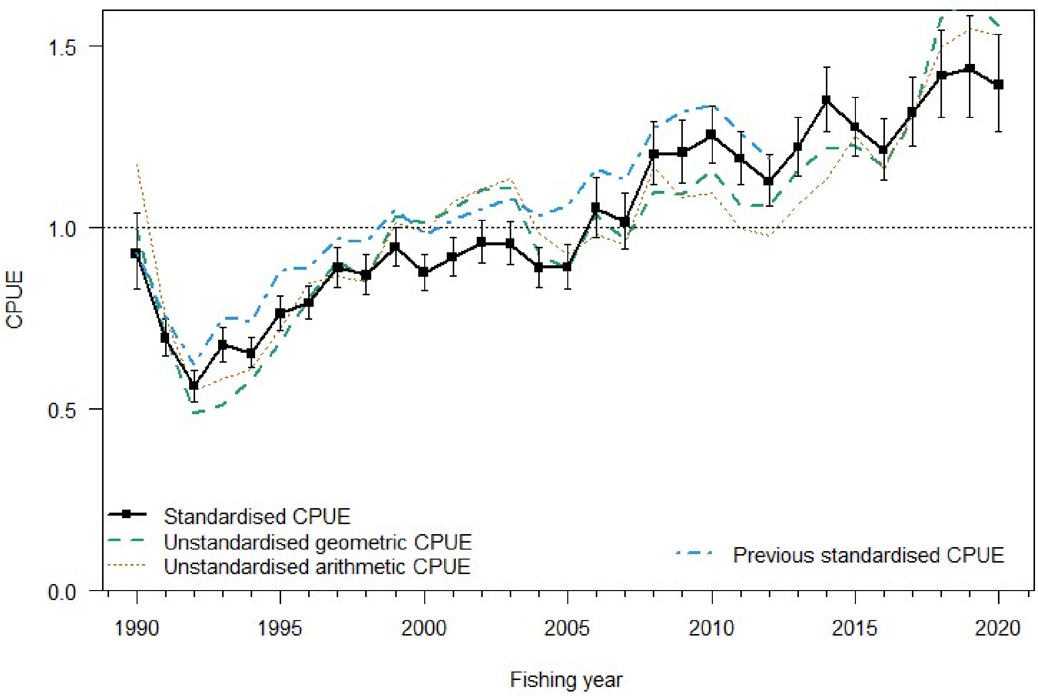


Figure 9: Bay of Plenty longline snapper CPUE standardised and unstandardised indices. Index from 2013 assessment shown for comparison.

The Bay of Plenty bottom trawl combined delta-lognormal index (Appendix 4) shows a pronounced increase after 2015–16, being relatively flat prior to this (Figure 10). The trend in the binomial index was minimal and as a result the combined delta index closely matched the lognormal (positive catch) index (Figure 10). Again, the general pattern in 2013 index and the updated index again matched reasonably well over the common years (Figure 10).

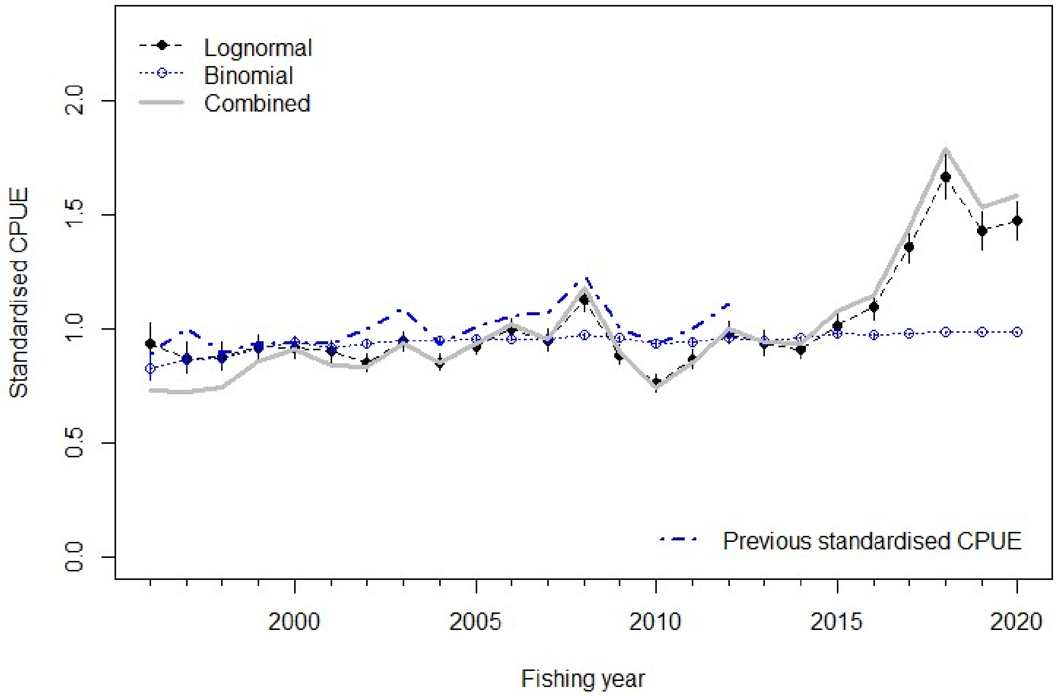


Figure 10: Bay of Plenty bottom trawl lognormal, binomial, and combined delta-lognormal indices. Index from 2013 assessment shown for comparison.

Tagging data

The tagging data input files used by the 2022 SNA 1 assessment model were the same as those used in the 2013 assessment (see Section 2.1.1; Table 6).

Trap shyness adjustment

There was evidence of a trap-shyness effect in the 1993 SNA 1 tagging programme data such that fish tagged by a given release method appear less likely to be caught again by the same method relative to other methods (Gilbert & McKenzie 1999). Trap-shyness acts to positively bias the tag population estimates, i.e. adjusting tag recoveries for trap shyness reduces the final biomass estimates.

The presence/absence of trap-shyness in the SNA 1 tagging data, and its estimated magnitude, has been highly conjectural as the observed method recovery ratio discrepancies can also be explained by mark-rate spatial heterogeneity in the data. The presence of trap-shyness in the SNA 1 tagging data is yet to be conclusively proven or disproven. The 2012, 2013, 2022 base-case SNA 1 assessment models were fitted to tag recovery data **adjusted** for trap-shyness.

Compositional data

SNA 1 age and length compositional data from commercial and recreational fisheries and research surveys date from the early 1970s. The 2022 SNA 1 assessment model included all commercial and survey compositional data used in the 2013 assessment, however most of these data series were reanalysed to expand the age frequency observations out to age 30+ (these data were formerly truncated at age 20+ in the 2013 assessment model (Francis & McKenzie 2015b).

Different to the 2013 assessment, for the 2022 assessment the time series of recreational compositional data were converted from length to age-frequency external to the assessment model to eliminate potential biases caused by incorrect within-model length-age growth transition (Table 6). Conversion of the recreational length data required application of appropriate sub-stock area-year age-length keys. Age-length key data coming from either the recreational fishery itself or from commercial catch sampling in the same year.

Post-2013 compositional data available to the 2022 SNA 1 assessment comprised commercial and recreational sampling data and fishery independent trawl survey data (Table 6).

Mean length at-age (growth)

Progressive declines in SNA 1 regional growth rates have been observed in longline catch age date since the early 1990s (Appendix 5). As with the 2013 assessment, declining SNA 1 regional growth rates were accommodated in the 2022 SNA 1 assessment models using area-year-specific mean-length at-age matrices (Appendix 5). These growth matrices were expanded to cover all ages out to 30+ years and to include additional years of longline and research trawl catch at-age observational data (Appendix 5). The expanded SNA 1 model growth matrices represented the fishing-year range 1989–90 to 2019–20 for the Hauraki Gulf and Bay of Plenty sub-stocks, and fishing years 1993–94 to 2019–20 for the East Northland sub-stock.

Variation about mean length at-age was assumed to be log-normally distributed specified in the model relative to fixed coefficients of variation (CV) of 0.1 at age 1 and 0.2 at age 30+ (note: model CVs on the intermediate ages were derived through interpolation).

As with the 2013 assessment, growth prior to and after these periods were assumed to be equivalent to, respectively, the matrices first and last year-row values.

2.2.3 Model structure

The 2022 SNA 1 assessment model had largely the same structure as the total catch history (commence 1900) 2013 model described in Section 2.1.2, primarily being an update of that assessment. The main structural differences between the base 2013 and base 2022 SNA 1 assessment models were as follows:

- Number of modelled age classes was increased from 1–20+ to 1–30+ in the 2022 model;
- Separate length weight parameters were introduced for each sub-stock;
- All recreational compositional data in the 2022 model were converted from length to age external to the assessment model, using appropriate age length keys from derived from longline age samples;
- MHS was added as a separate method in the 2022 model, this fishing method did not exist in 2013;
- Model selectivities were disaggregated by both method and area in the 2022 model, whereas the 2013 model only estimated method specific selectivities;
- Bay of Plenty trawl survey abundance and compositional data were included in the 2022 model, these data were not used in the 2013 model;
- Only one Hauraki Gulf trawl survey abundance index was fitted in the 2013 model, i.e., the total estimated number of snapper surveyed in each year across all ages, whereas, in the 2022 model, five separate trawl survey age series for ages 1–4 and 5+ were fitted with 5+ abundance fitted as weight not numbers.

Descriptions of 2022 SNA 1 model fixed and estimated parameters are given in Table 7 and Table 8. Some parameters were fixed, either because they were not estimable with the available data (notably natural mortality and stock-recruit steepness were fixed at values determined by the Working Group), or because they were estimated outside the model (Table 7).

The 2022 assessment also revisited the option of commencing the assessment model in 1970 as was done in the 2012 SNA 1 assessment (Francis & McKenzie 2015a). Starting the model in 1970 avoids the need to account for the highly uncertain pre-1970 catch history but introduces the complication of having to derive the 1970 starting biomass for each stock. Commence-1970 SNA 1 model 1970 starting biomasses were derived through three R_0 offset parameters (one for each sub-stock), these being estimated parameters (Table 8; Bull et al. 2012).

Table 7: Details of parameters that were fixed in the base 2022 SNA 1 assessment model

Natural mortality	0.075 y^{-1}
Stock-recruit steepness	0.85
Tag shedding (instantaneous rate, 1985 tagging)	0.486 y^{-1}
Tag detection (1985 and 1994 tagging)	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]	
East Northland	$a = 3.49 \times 10^{-5}$, $b = 2.870$
Hauraki Gulf	$a = 4.94 \times 10^{-5}$, $b = 2.771$
Bay of Plenty	$a = 4.30 \times 10^{-5}$, $b = 2.813$
Mean lengths at-age	provided for years 1989–2021
Coefficients of variation for length at-age	0.10 at-age 1, 0.20 at-age 20
Selectivity	
Pair trawl (PT) (double-normal; all areas)	$a_1 = 6$ y, $\sigma_L = 1.5$ y, $\sigma_R = 30$ y
East Northland MHS (EN_MHS) (double-normal)	$a_1 = 8.12$ y, $\sigma_L = 2.24$ y, $\sigma_R = 145$ y
Bay of Plenty MHS (BP_MHS) (double-normal)	$a_1 = 4.92$ y, $\sigma_L = 0.74$ y, $\sigma_R = 41$ y
East Northland Recreational pre-1995 (REC_ENPre95) (double-normal)	$a_1 = 5.27$ y, $\sigma_L = 0.93$ y, $\sigma_R = 19.7$ y
East Northland Recreational post-2015 (REC_ENPost2015) (double-normal)	$a_1 = 7.65$ y, $\sigma_L = 1.65$ y, $\sigma_R = 145$ y
Hauraki Gulf Recreational pre-1995 (REC_HGPre95) (double-normal)	$a_1 = 6.50$ y, $\sigma_L = 1.64$ y, $\sigma_R = 135$ y
Hauraki Gulf Recreational post-2015 (REC_HGPost2015) (double-normal)	$a_1 = 5.29$ y, $\sigma_L = 0.50$ y, $\sigma_R = 10.39$ y
Bay of Plenty Recreational pre-1995 (REC_BPPre95) (double-normal)	$a_1 = 5.09$ y, $\sigma_L = 0.87$ y, $\sigma_R = 147$ y
Bay of Plenty Recreational post-2015 (REC_BPPost2015) (double-normal)	$a_1 = 10.15$ y, $\sigma_L = 2.64$ y, $\sigma_R = 146$ y
East Northland trawl survey 1+ (EN_RES) (double-normal)	$a_1 = 2.67$ y, $\sigma_L = 0.75$ y, $\sigma_R = 11.66$ y

Table 8: Details of parameters that were estimated in the base 2022 SNA 1 assessment model

Type	Description	No. of parameters	Prior
R_0	Mean unfished recruitment for each stock	3	uniform-log
YCS	Year-class strengths by year and stock	159 (141[3])[1]	lognormal[2]
$R_{initial}$	1970 commence model R_0 offset parameter	3[3]	uniform
Migration	Proportions migrating from home grounds	6	uniform
Selectivity	East Northland long line (EN_LL) (logistic)	2	uniform
	Hauraki Gulf long line (HG_LL) (logistic)	2	uniform
	Bay of Plenty long line (BP_LL) (logistic)	2	uniform
	Hauraki Gulf bottom trawl (HG_ST) (double-normal)	3	uniform
	Bay of Plenty bottom trawl (BP_ST) (double-normal)	3	uniform
	Hauraki Gulf Danish seine (HG_DS) (double-normal)	3	uniform
	Bay of Plenty Danish seine (BP_DS) (double-normal)	3	uniform
	East Northland Recreational post-1995(REC_ENPost95)(double-normal)	3	uniform
	Hauraki Gulf Recreational post-1995(REC_HGPost95)(double-normal)	3	uniform
	Bay of Plenty Recreational post-1995(REC_BPPost95)(double-normal)	3	uniform
	Hauraki Gulf trawl survey age 5+ (HG_RES_5) (double-normal)	3	uniform
	Bay of Plenty trawl survey age 5+ (BP_RES_5) (double-normal)	3	uniform
q	Catchability (for relative biomass observations)	14	uniform-log
		215(200[3])	

[1]YCSs were estimated for years 1975–2015 for ENLD, 1952–2020 (1970–2020[3]) for HAGU, and 1972–2020 for BOP
[2]With mean 1 and coefficient of variation 0.6
[3]1970 commence model only

2.2.4 Model likelihoods, priors, penalties, and weighting

Trawl survey abundance assumed error

A process error CV value of 0.1 on all trawl survey indices was assumed by the model in addition to analytical CVs as derived external to the model (*after* Parsons & Bian 2022).

Commercial CPUE abundance assumed error

All commercial CPUE abundance indices were fitted with an assumed CV of 0.3. This value was agreed by the working group after inspection of model fits over a range of "plausible" error values (Appendix 6).

Tagging likelihood assumed error (dispersion)

For the tag-recapture observations, process error was specified by application of a dispersion parameter (ø) in the likelihood function (Bull et al. 2012). The tag-recapture log-likelihood weightings were modified by multiplying them by 1/ø. A ø value of one means the tagging likelihood is naturally weighted, i.e. weighting equivalent to the number of recovered tags observed. Values of ø greater than one have the effect of inverse-proportionally down-weighting the tagging likelihoods.

Compositional likelihood error

All compositional datasets were first assigned a multinomial error value as calculated from their derived analytical CVs, this being a standard approach in New Zealand stock assessments.

Priors and Penalties

Except for the model year-class parameters, model parameter priors were either uniform or uniform-log (Table 8). Year-class priors were assumed to be log-normally distributed with a mean of one and a CV of 0.6 (Table 8). Strong likelihood penalties were applied in the model if the predicted biomass available to a fishery in any given year was less than the "true" catch history. Strong penalties were also applied when the mean of the predicted year-class strengths (YCSs) did not equal to one.

Model likelihood weighting

The Francis TA1.8 reweighting process was used to down-weight the individual compositional likelihoods relative to assumed error on the abundance likelihoods (Francis 2011).

The method used in the 2013 SNA 1 assessment to downweight the tagging likelihoods (Francis & McKenzie 2015b; Appendix 7) was then applied. After which a Francis compositional reweighting was undertaken a second time to fine-tune the overall model likelihood weightings.

2.2.5 Alternative model comparative fits and predictions

All-likelihoods 1900 model Medium Posterior Density (MPD) fits:

The model achieved "acceptable" fits to Bay of Plenty trawl survey abundance series but was unable to fit the recent Hauraki Gulf age 5+ biomass estimates (Figure 11 and Figure 12). The Bay of Plenty bottom trawl and longline CPUE fits were also acceptable (Figure 13 and Figure 14). However, the model predicted a consistently higher Hauraki Gulf biomass after 2010 than seen in the longline CPUE (Figure 14). The model also predicted an increase in East Northland biomass after 2002 which was not evident on the longline CPUE (Figure 14).

There was a lack-of-fit issue with the Hauraki Gulf 1973 Danish Seine 20+ age cohort, this cohort was predicted as strong by the model but was not observed (Figure 15). The Working Group felt that lack of representative sampling in 1973 was the most likely explanation for the lack of fit because a very strong 20+ cohort was evident in 1972 which the model was able to fit (Figure 15). There were also fitting issues to the early Hauraki Gulf bottom trawl catch at-age 1975 and 1976 4, 5, 6, 7, and 30+ age cohorts (Figure 16), which the Working Group reasoned were due to differences in selectivity pre and post 1985. As these discrepant observational likelihoods were assigned low relative weighting compared to the other trawl and Danish seine compositional likelihoods, they were retained in subsequent models.

There were occasional lack-of-fits to the 5 and 6 age cohorts in the Hauraki Gulf and Bay of Plenty trawl survey age 5+ at-age compositional data series (Figure 17), which the Working Group felt were due to an inappropriate choice of selectivity function (double normal). Other selectivity parametrisations were investigated but none were found to perform any better.

Fits to the post 1985 commercial catch at-age observational series were accepted by the Working Group, as were fits to the recreational at-age compositional series (Appendix 8).

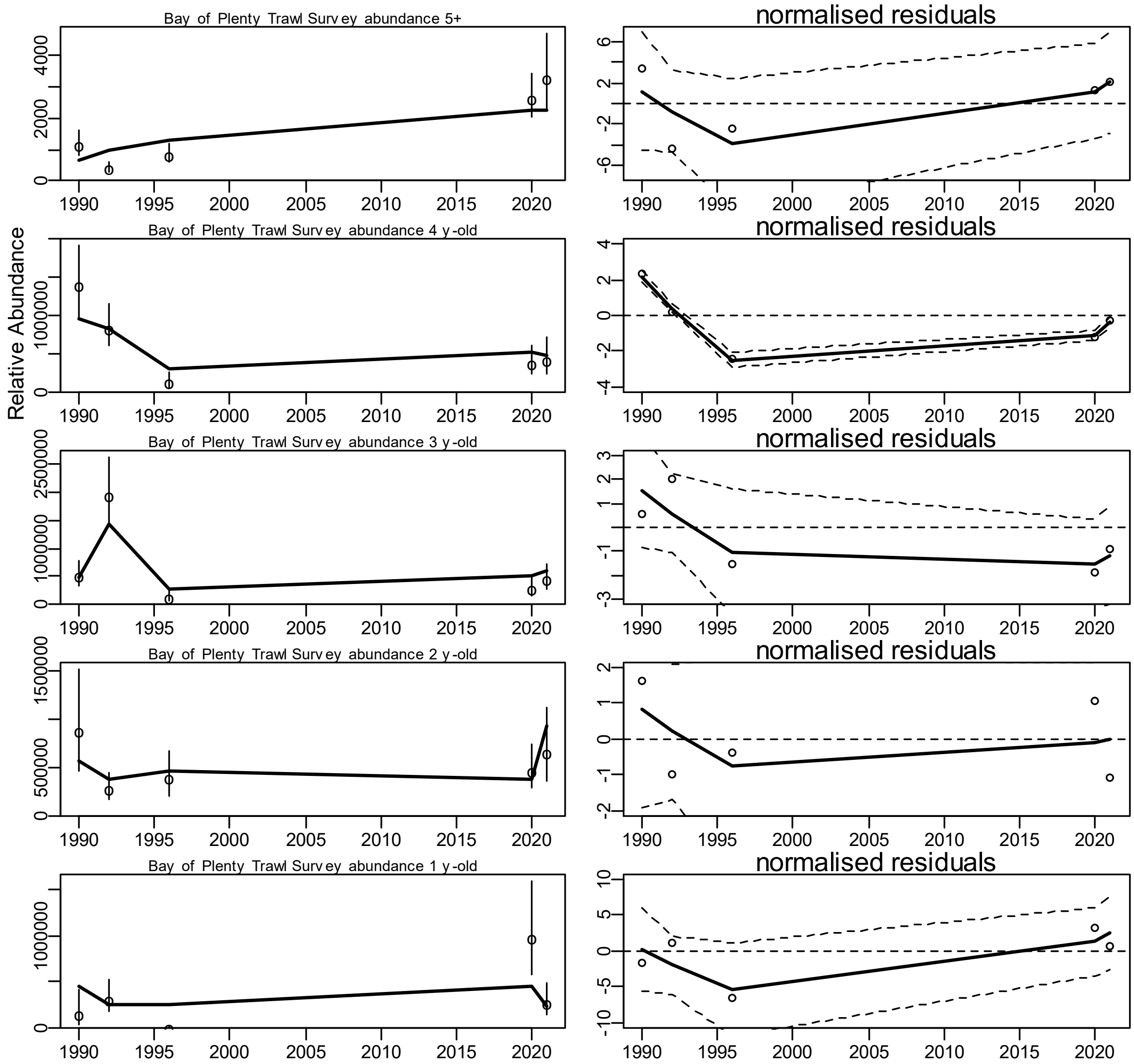


Figure 11: All-likelihoods 1900 model Bay of Plenty trawl survey abundance fits.

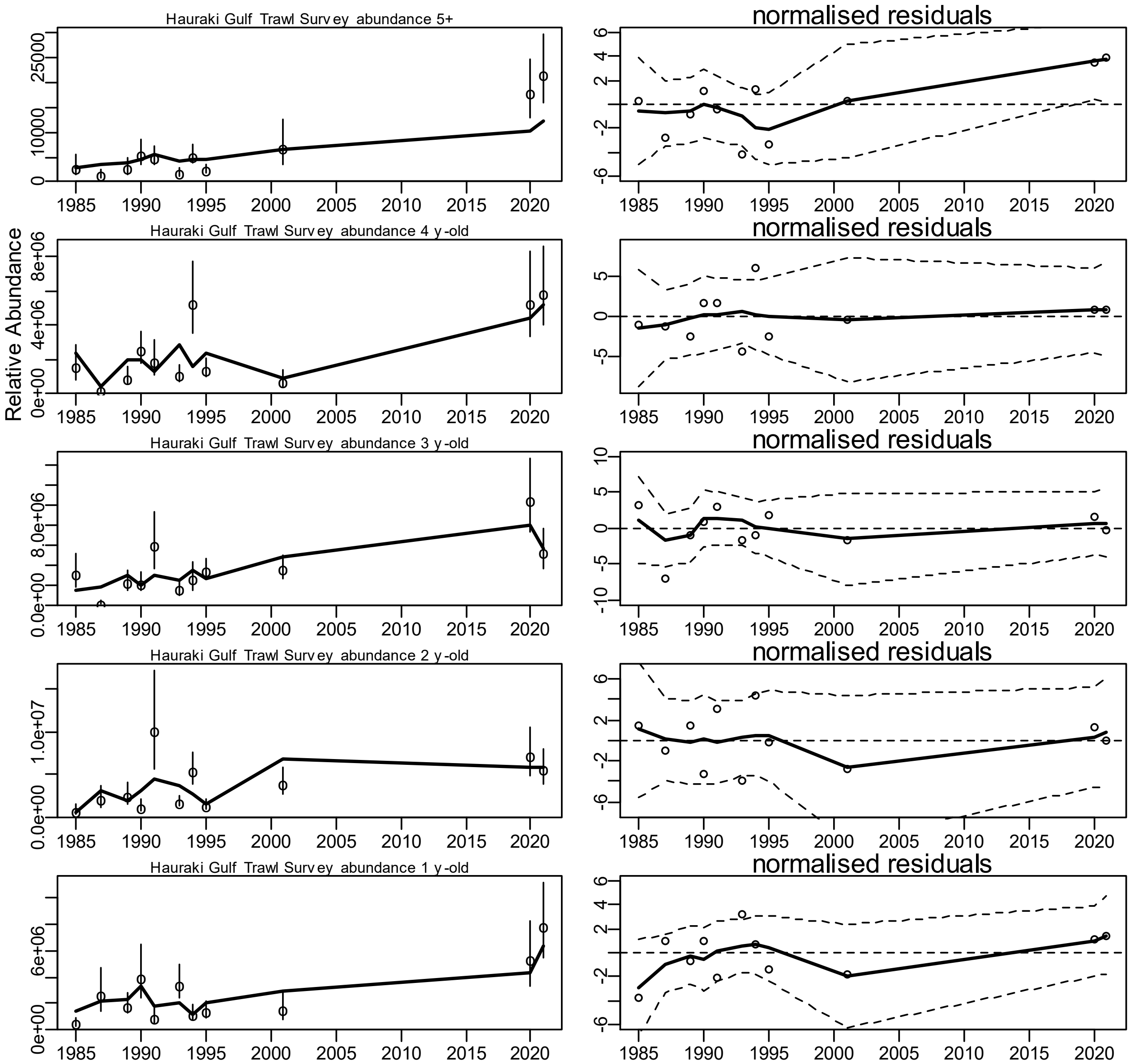


Figure 12: All-likelihoods 1900 model Hauraki Gulf trawl survey abundance fits.

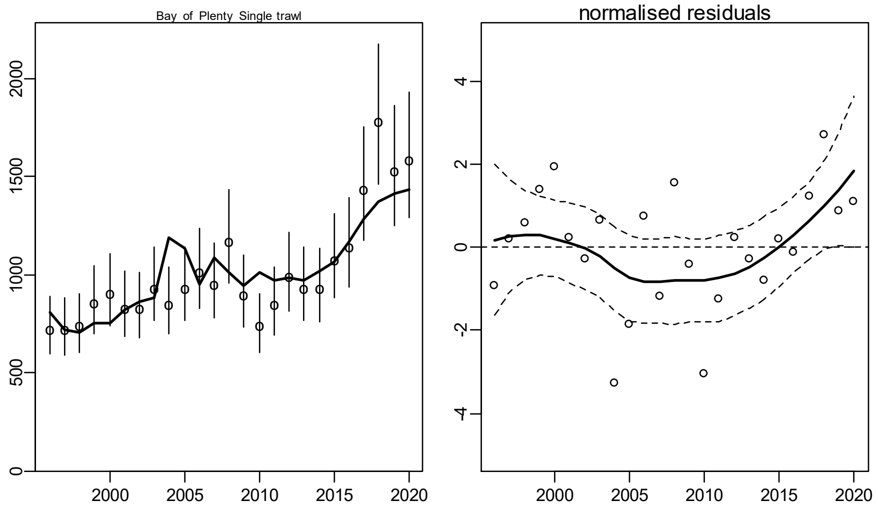


Figure 13: All-likelihoods 1900 model Bay of Plenty bottom trawl CPUE fit.

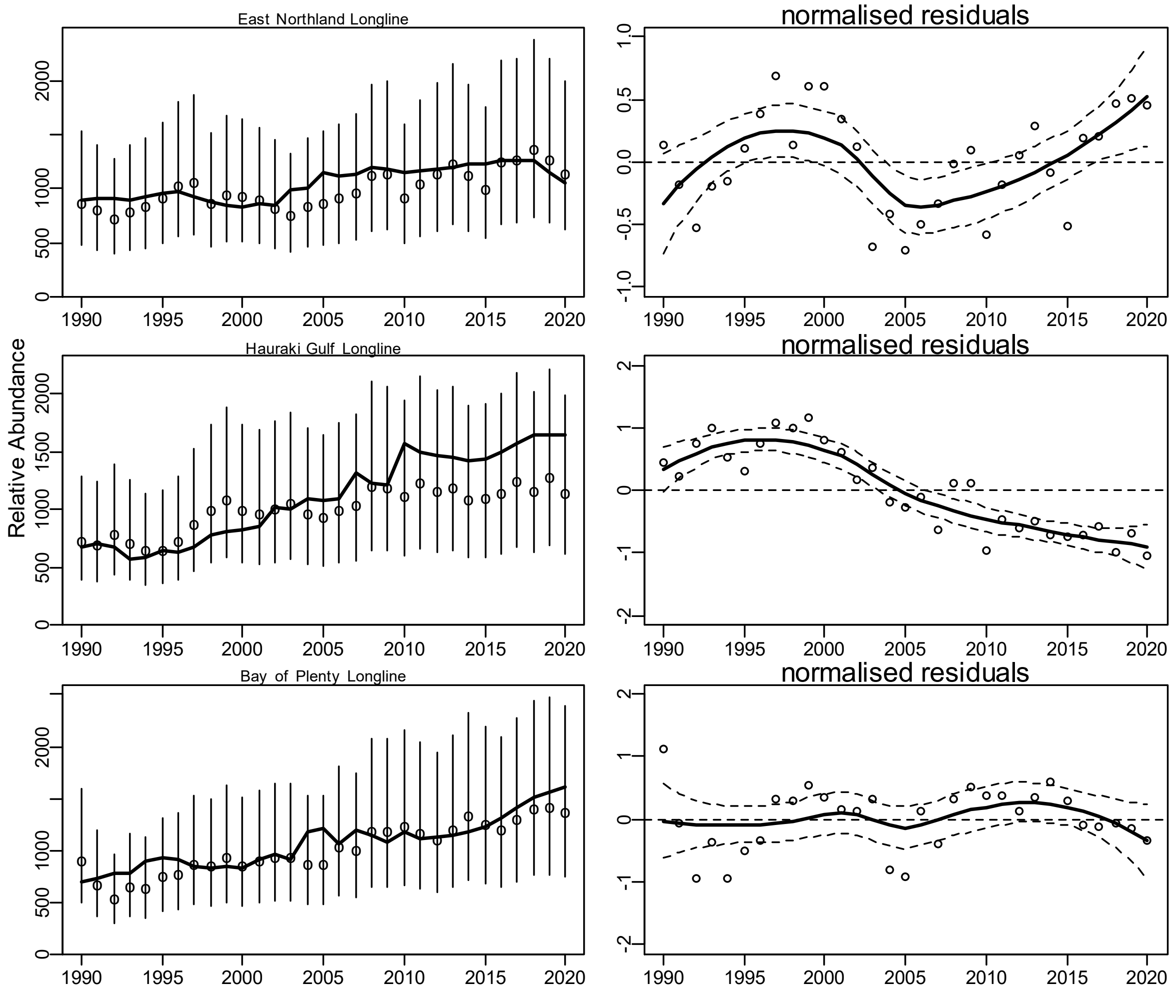


Figure 14: All-likelihoods 1900 model east Northland, Hauraki Gulf, and Bay of Plenty longline CPUE fits.

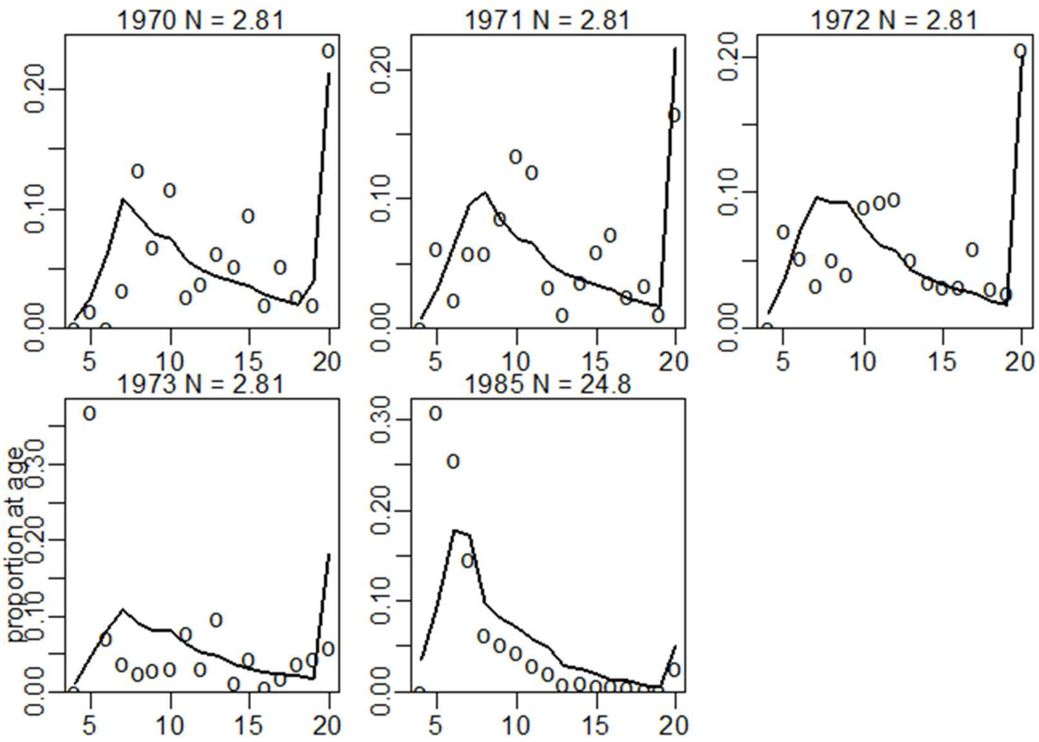
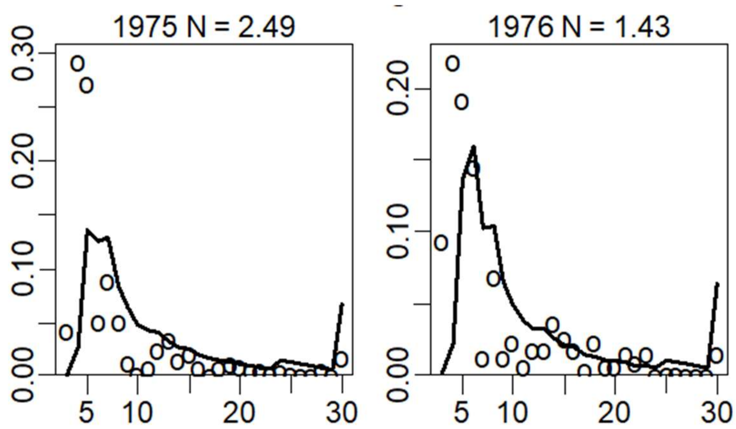


Figure 15: All-likelihoods 1900 model Hauraki Gulf early Danish seine catch at-age fits (plus group 20+). N = effective multinomial error after likelihood reweighting.

a.



b.

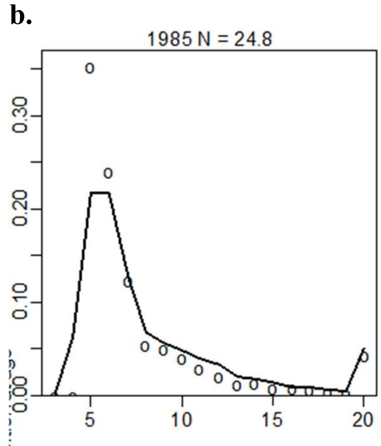
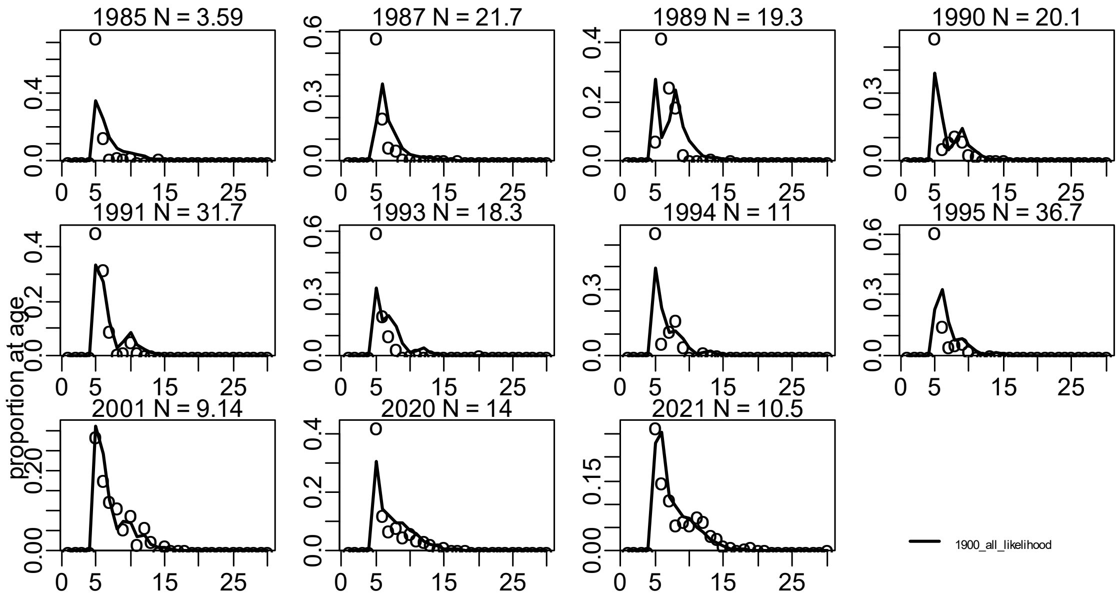


Figure 16: All-likelihoods 1900 model Hauraki Gulf early bottom trawl catch at-age fits; a. plus group 30+, b. plus group 20+. N = effective multinomial error after likelihood reweighting.

a.



b.

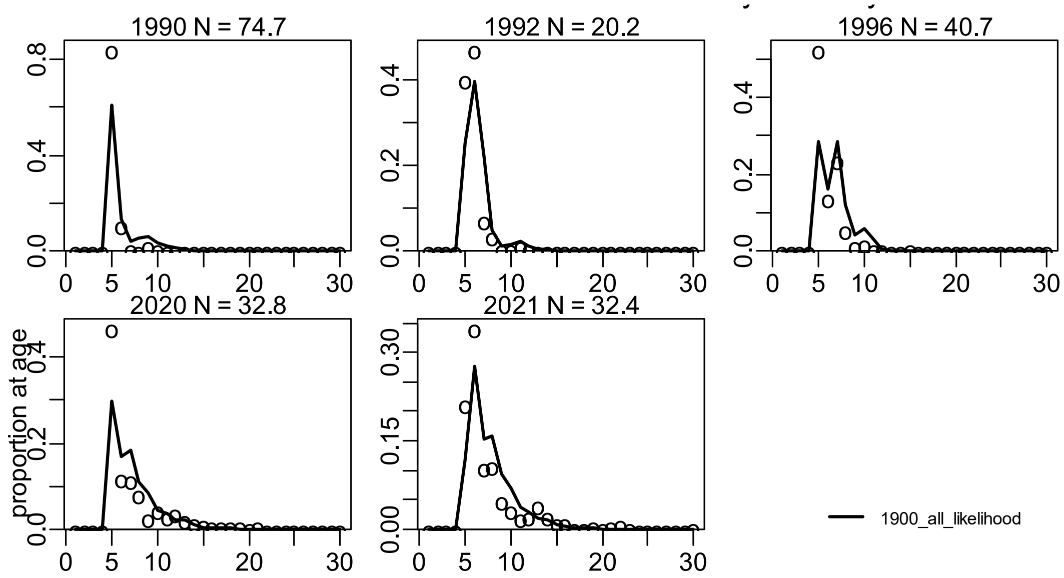


Figure 17: All-likelihoods 1900 model fits to trawl survey 5+ compositional at-age observations, a. Hauraki Gulf survey series, b. Bay of Plenty survey series. N = effective multinomial error after likelihood reweighting.

The lack of fit to the Hauraki Gulf longline CPUE in the all-likelihood model raised concerns from the Working Group that the longline fishery catch rates were hyperstable (Figure 14). Discussions with SNA 1 longline fishers suggest they had been moderating their catch rates. This led the Working Group to recommend the removal of the Hauraki Gulf and Bay of Plenty longline data from the model, as the model was still being informed on relative abundance within these sub-stock areas from the respective 5+ trawl survey biomass indices. Due to a lack of an alternative east Northland survey abundance index, the east Northland longline CPUE series had to be retained. The reduced longline CPUE model is referred to in this report as the "reduced-LL-CPUE 1900" model.

All-likelihood 1900 and reduced-LL-CPUE 1900 model MPD comparative fits and predictions.

The reduced-LL-CPUE model fits to Bay of Plenty trawl survey abundance series were almost identical to the all-likelihood model (Figure 18). The reduced-LL-CPUE model fits to Hauraki Gulf trawl survey abundance series were mostly the same as the all-likelihood model but with a slightly improved fit to the 2020 and 2021 age 5+ biomass points (Figure 19). The reduced-LL-CPUE model also achieved a slightly better fit to the 1983 Bay of Plenty tag biomass estimate (Figure 20).

The reduced-LL-CPUE model and all-likelihood model fits to Bay of Plenty bottom trawl and east Northland longline CPUE indices were similar (Figure 21 and Figure 22). The fit to the tag movement observations were effectively identical between the two models over all release-recovery area survey permutations, except for the 1994 and 1995 Bay of Plenty release recovery permutation to which the reduced-LL-CPUE model achieved marginally poorer fits (Figure 23).

There were no discernible differences between the reduced-LL-CPUE and all-likelihood model fits to any of the compositional data sets (Appendix 8).

The selectivity predictions from the two models show no appreciable differences (Figure 24), a result consistent with the similarity in model compositional fits (Appendix 8). Differences were seen in the post-2000 Hauraki Gulf and Bay of Plenty YCS estimates (Figure 25), where these differences are consistent with model differences in the Hauraki Gulf and Bay of Plenty virgin spawning stock biomass (B_0) estimates (Table 9). The Hauraki Gulf and Bay of Plenty stock prognoses predictions from the two models differed, whereas their east Northland stock-status predictions were not substantively different (Figure 26). The reduced-LL-CPUE model Hauraki Gulf and Bay of Plenty stock-status predictions were respectively, more optimistic, and more pessimistic than the all-likelihood model (Table 10 and Figure 26). The trade-off between Hauraki Gulf and Bay of Plenty respective model B_0 estimates did not appear to be driven by differences in movement, the movement estimates from each model being not appreciably different (Table 11).

Both east Northland model Spawning Stock Biomass (SSB) trajectories were inconsistent with (well above) the Petersen tag biomass estimates[4], as were the model Hauraki Gulf SSB trajectories although less so (Figure 26).

[4] Shown as pseudo-observations as these biomass estimates were not actually fitted in either model.

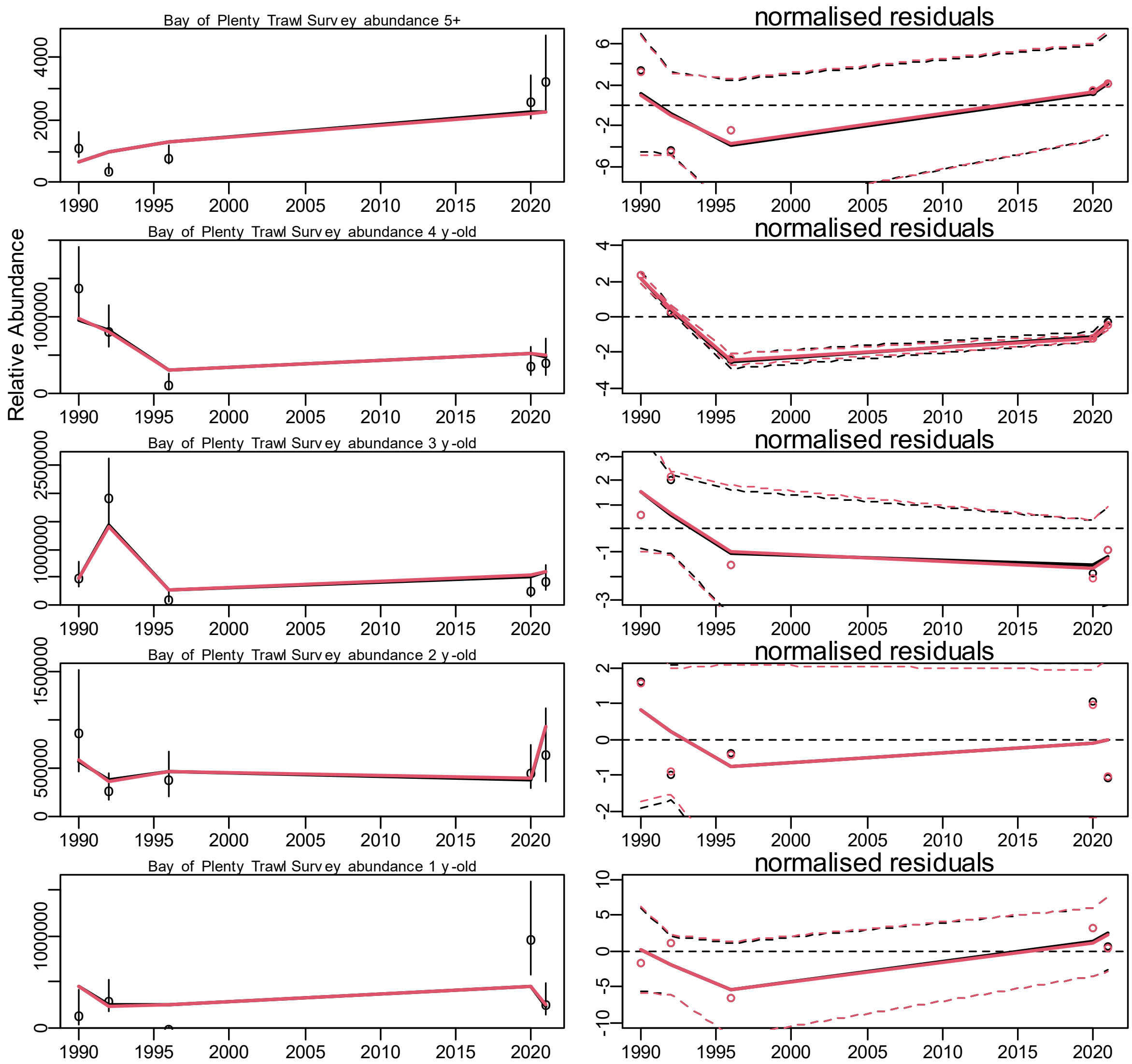


Figure 18: All-likelihood (black) and reduced-LL-CPUE (red) 1900 model Bay of Plenty trawl survey abundance comparative fits.

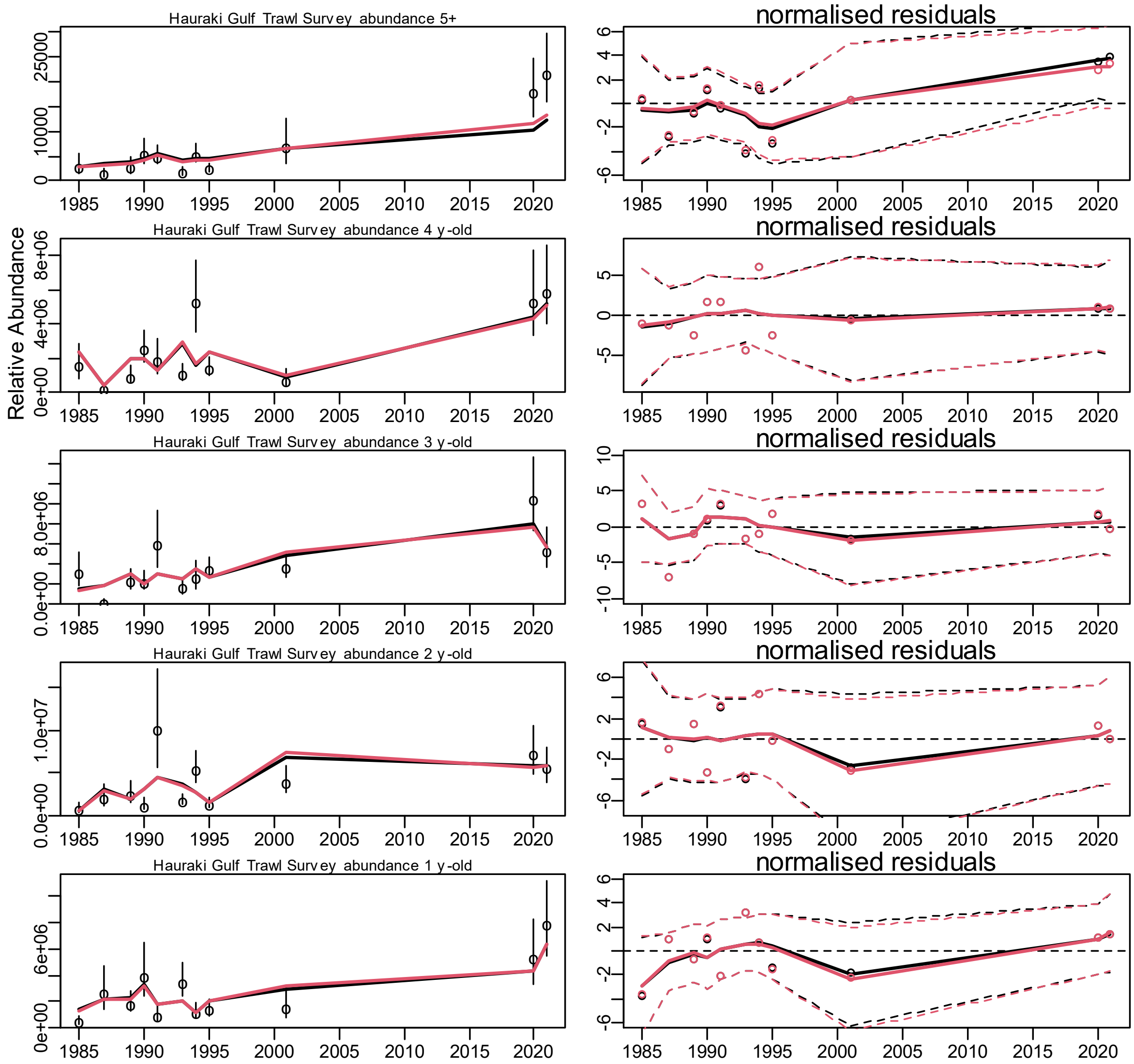


Figure 19: All-likelihood (black) and reduced-LL-CPUE (red) 1900 model Hauraki Gulf trawl survey abundance comparative fits.

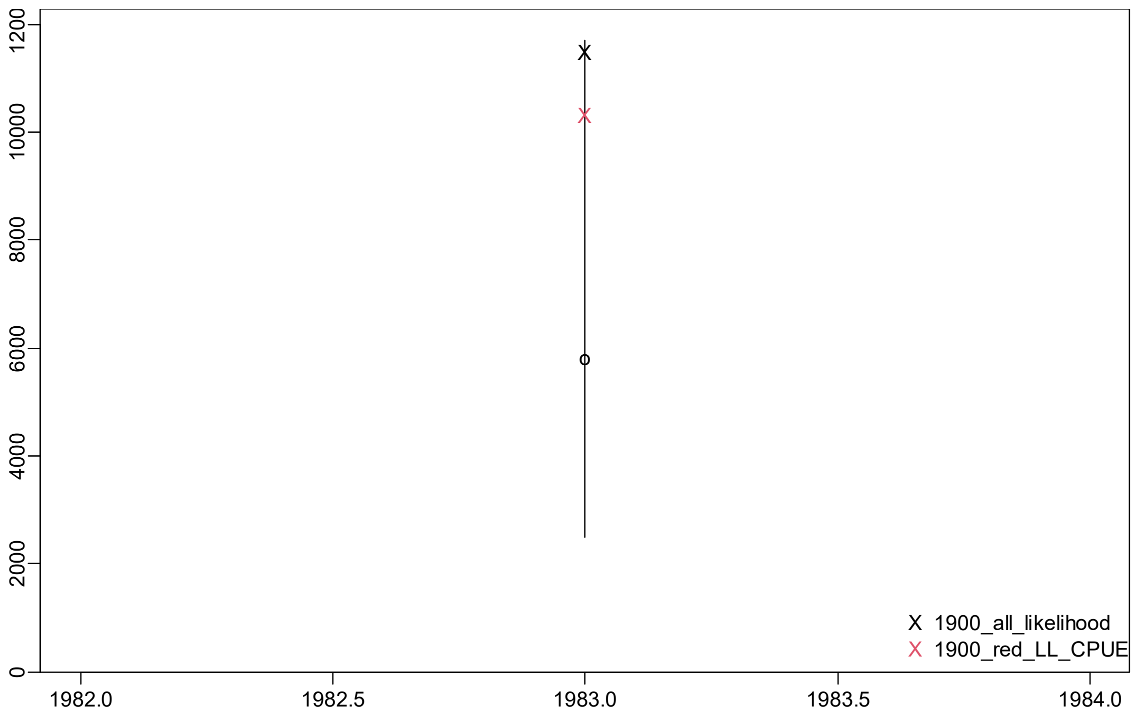


Figure 20: All-likelihood (black) and reduced-LL-CPUE (red) fits to Bay of Plenty 1983 tag recruited biomass estimate.

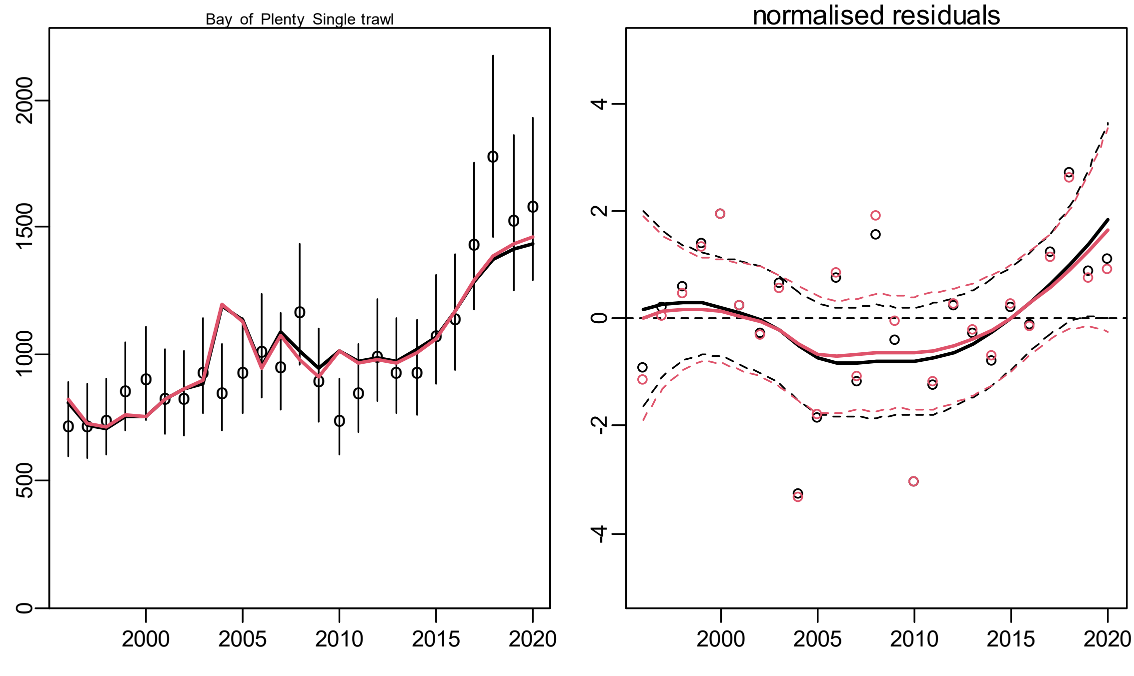


Figure 21: All-likelihood (black) and reduced-LL-CPUE (red) 1900 model Bay of Plenty bottom trawl CPUE fits.

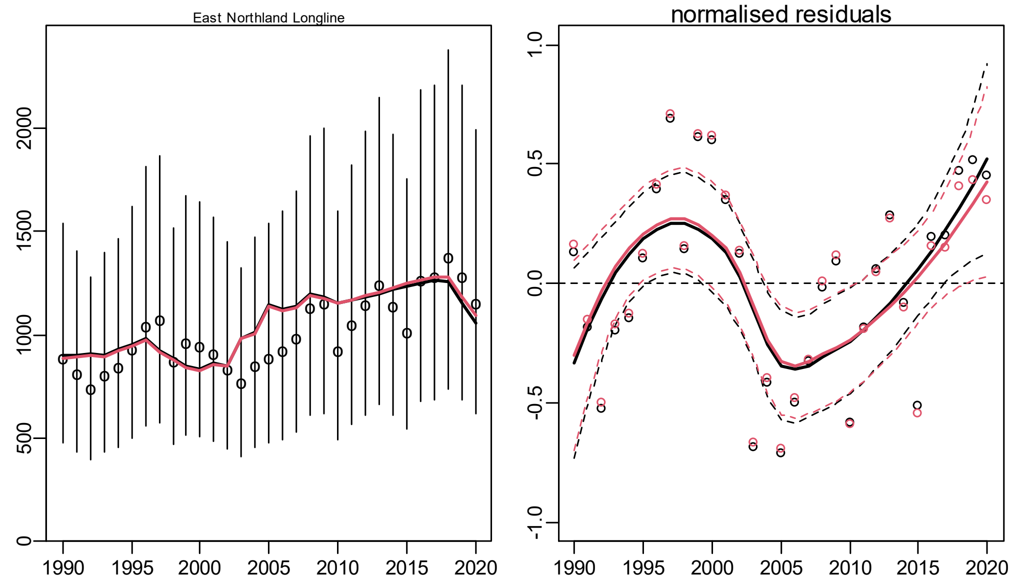


Figure 22: All-likelihood (black) and reduced-LL-CPUE (red) model east Northland CPUE fits.

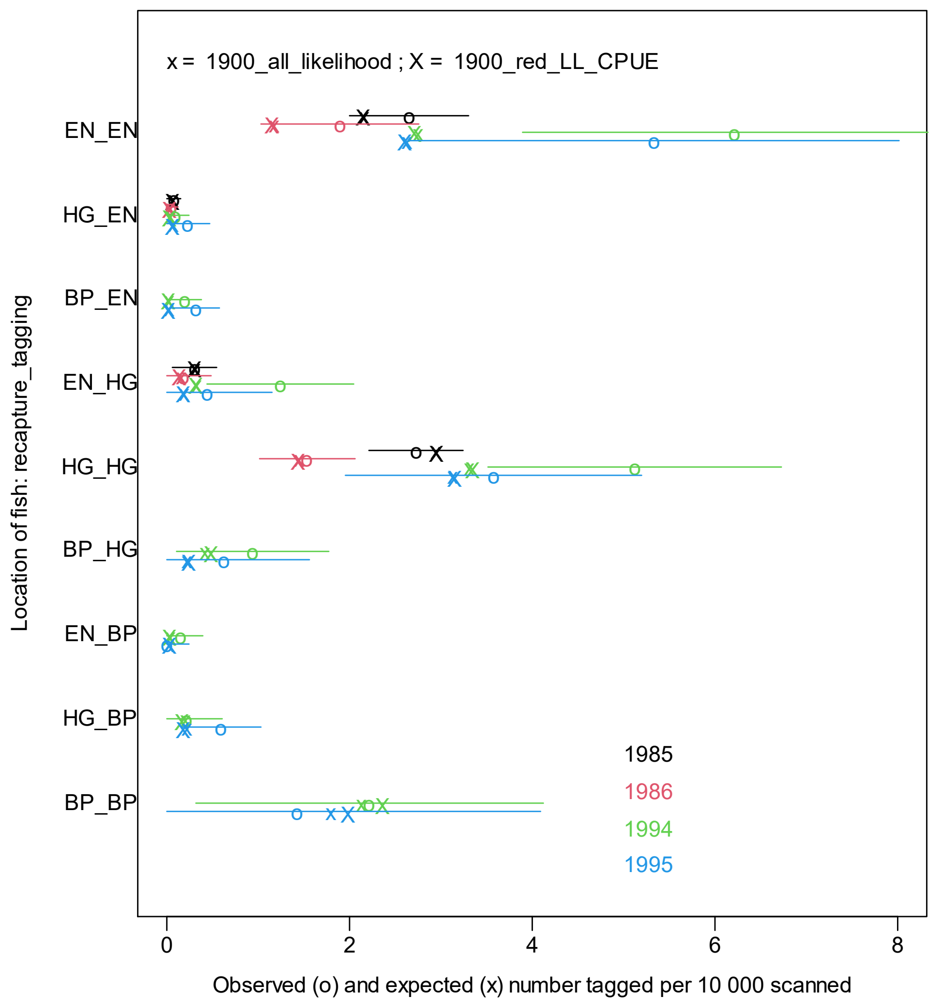


Figure 23: All-likelihood (×) and reduced-LL-CPUE (X) model tag recovery observations.

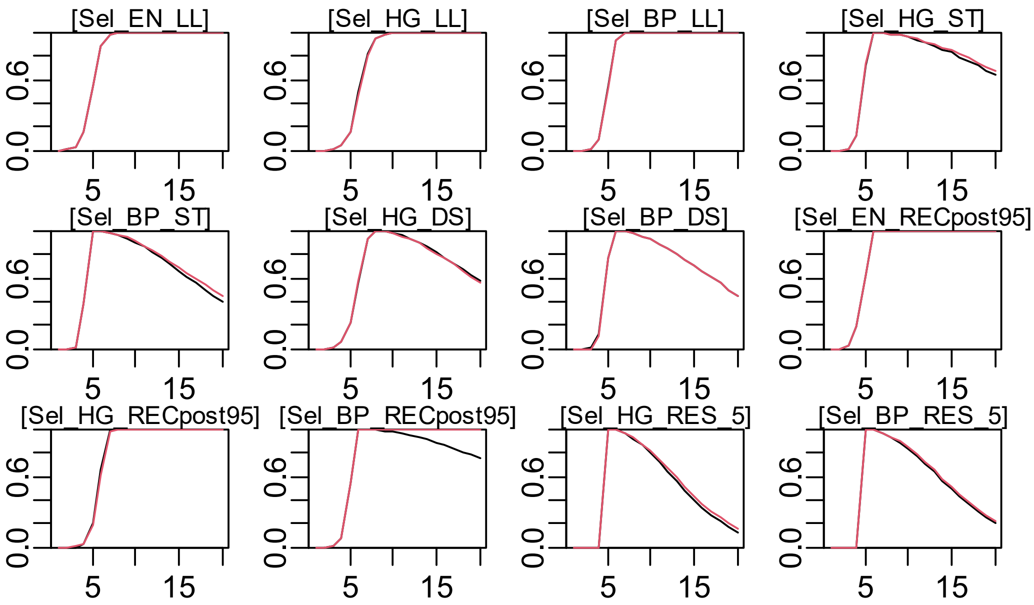


Figure 24: All-likelihood (black) and reduced-LL-CPUE (red) model estimated area-gear selectivities.

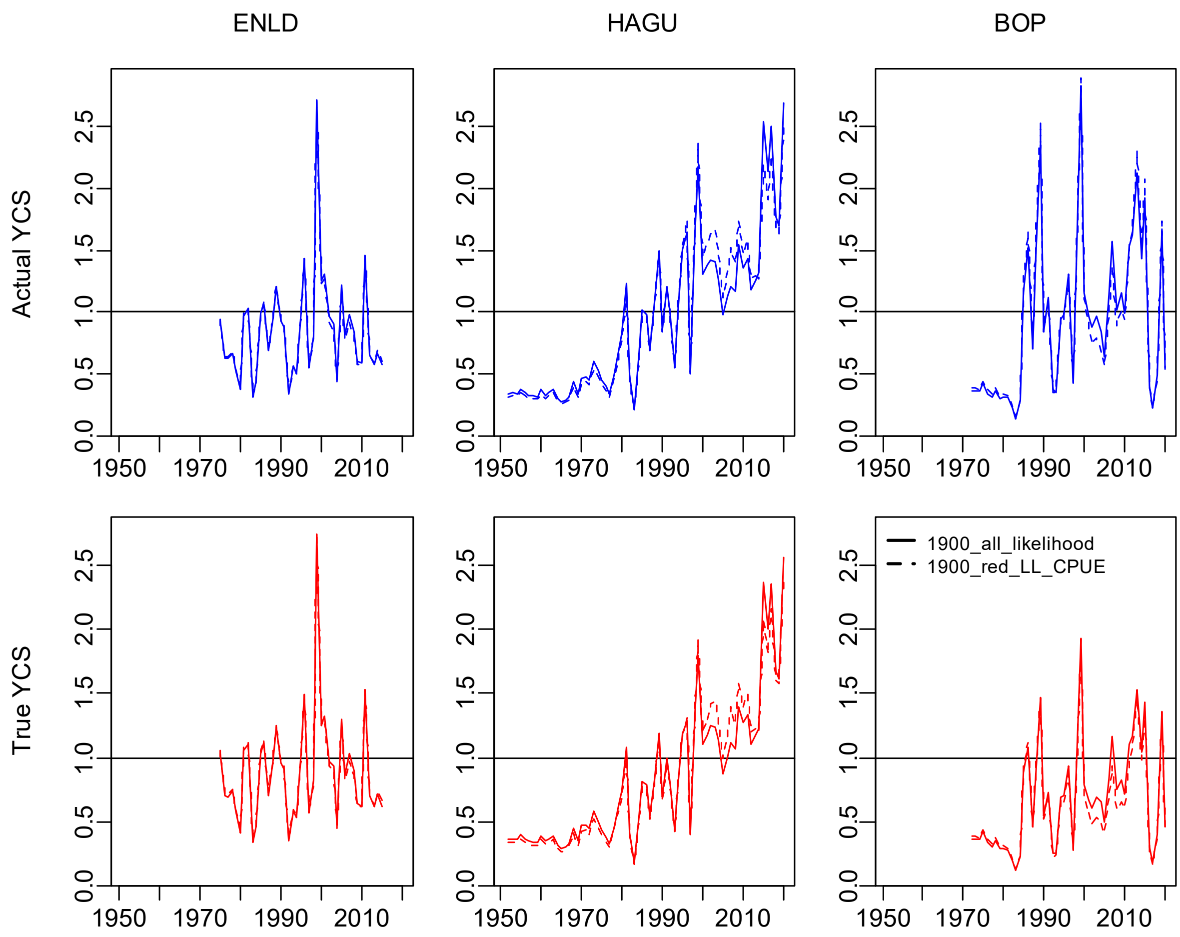


Figure 25: All-likelihood and reduced-LL-CPUE model stock Year Class Strength (YCS) estimates. The actual YCS estimates (top row) are unadjusted for steepness (*h*).

Table 9: SNA 1 stock and area unexploited spawning stock biomass (B_0) model estimates

By stock

	ENLD	HAGU	BOP
1900_all_likelihood	90, 540	287, 020	112, 299
1900_reduced-LL-CPUE	89, 278	310, 109	101, 486

By area

	EN	HG	BP
1900_all_likelihood	112, 52	285, 199	91, 709
1900_reduced-LL-CPUE	113, 690	298, 011	89, 171

Table 10: SNA 1 stock and area current stock-status (B_{2021}/B_0) model estimates

By stock

	ENLD	HAGU	BOP
1900_all_likelihood	26%	31%	12%
1900_reduced-LL-CPUE	27%	34%	10%

By area

	EN	HG	BP
1900_all_likelihood	25%	28%	13%
1900_reduced-LL-CPUE	26%	31%	12%

Table 11: Model stock/area proportional movement estimates

1900_all_likelihood

		To area		
From home stock		EN	HG	BP
	ENLD	0.963	0.032	0.005
	HAGU	0.076	0.884	0.04
	BOP	0.035	0.255	0.71

1900_reduced-LL-CPUE

		To area		
From home stock		EN	HG	BP
	ENLD	0.964	0.031	0.004
	HAGU	0.075	0.88	0.045
	BOP	0.043	0.22	0.737

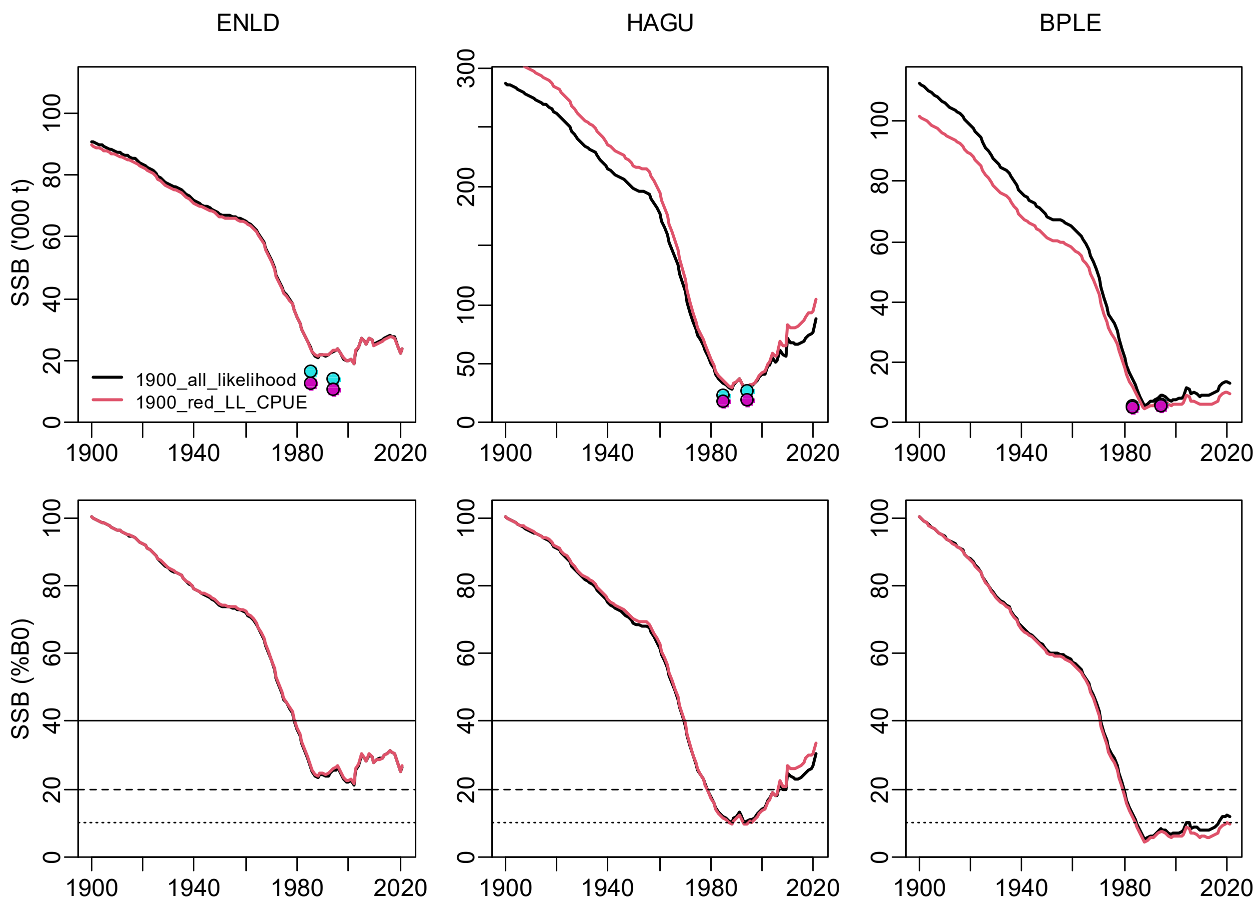


Figure 26: All-likelihood model (black line) and reduced-LL-CPUE model (red line) SSB and stock-status predictions. The dots are Petersen tag biomass estimates (dark blue trap-avoidance; light blue no trap-avoidance). Note: the plotted tag biomass estimates were not directly fitted in the models.

A comparative model run with the survey abundance data removed (no-survey) was undertaken to better understand how influential the Hauraki Gulf and Bay of Plenty trawl survey abundance indices were on the SNA 1 assessment stock status predictions.

No-survey and all-likelihood 1900 model MPD comparative fits and predictions.

There were minimal differences in the all-likelihood and no-survey model fits to the east Northland and Bay of Plenty longline CPUE series (Figure 27). However, the respective model fits to the Hauraki Gulf longline CPUE series diverged markedly after 2010 (Figure 27). This result indicated that the poorer fit of the all-likelihood model to the post 2010 Hauraki Gulf longline series was largely driven by conflict with the Hauraki Gulf survey series abundance signal.

The all-likelihood and no-survey model fits to the Bay of Plenty bottom trawl CPUE index were similar (Figure 28), again suggesting that abundance likelihood conflict in the 2022 SNA 1 assessment was largely between the Hauraki Gulf longline CPUE and the Hauraki Gulf survey abundance series.

The only marked difference in compositional likelihood fits between the no-survey and all-likelihood models were in the Hauraki Gulf longline compositional likelihoods, the no-survey model producing the better fit (the no-survey Hauraki Gulf longline total compositional likelihood being 645 compared to 691 for the all-likelihood model). The improved fit to the Hauraki Gulf longline compositional series by the no-survey is seen most strongly as differences in the predicted YCS residual distributions between the two models (Figure 29). Differences in the selectivity predictions between the no-survey and all-likelihood models were relatively minor for the comparable compositional series (Figure 30).

There was a marked difference in Hauraki Gulf predicted YCSs between the two models (Figure 31). Specifically, the all-likelihood model predicted a continued upward trend in Hauraki Gulf YCS post-2005, whereas the no-survey model post-2005 YCS predicted trend was downward (Figure 31).

There were differences between the two models also in Bay of Plenty stock/area movement predictions, with the no-survey model predicting nearly double the proportional movement to the Hauraki Gulf area than the all-likelihood model (Table 12).

The two models produced markedly different B_0, biomass (SSB), and status (% B_0) predictions for the Hauraki Gulf and Bay of Plenty stocks (Table 13; Figure 32). The no-survey model overall Hauraki Gulf productivity prediction (B_0) was nearly a third lower than the all-likelihood model prediction, and its Bay of Plenty productivity prediction nearly a third higher (Table 13). The combination of lower Hauraki Gulf R_0 and recent YCS resulted in the no-survey model predicting a general decline in SSB as occurring after 2010, the predicted Hauraki Gulf SSB in the final year (2021) being almost half that predicted by the all-likelihood model (Figure 32). Despite differences in stock productivity between the two models, their current stock-status predictions were only markedly different for the Hauraki Gulf stock (Table 14).

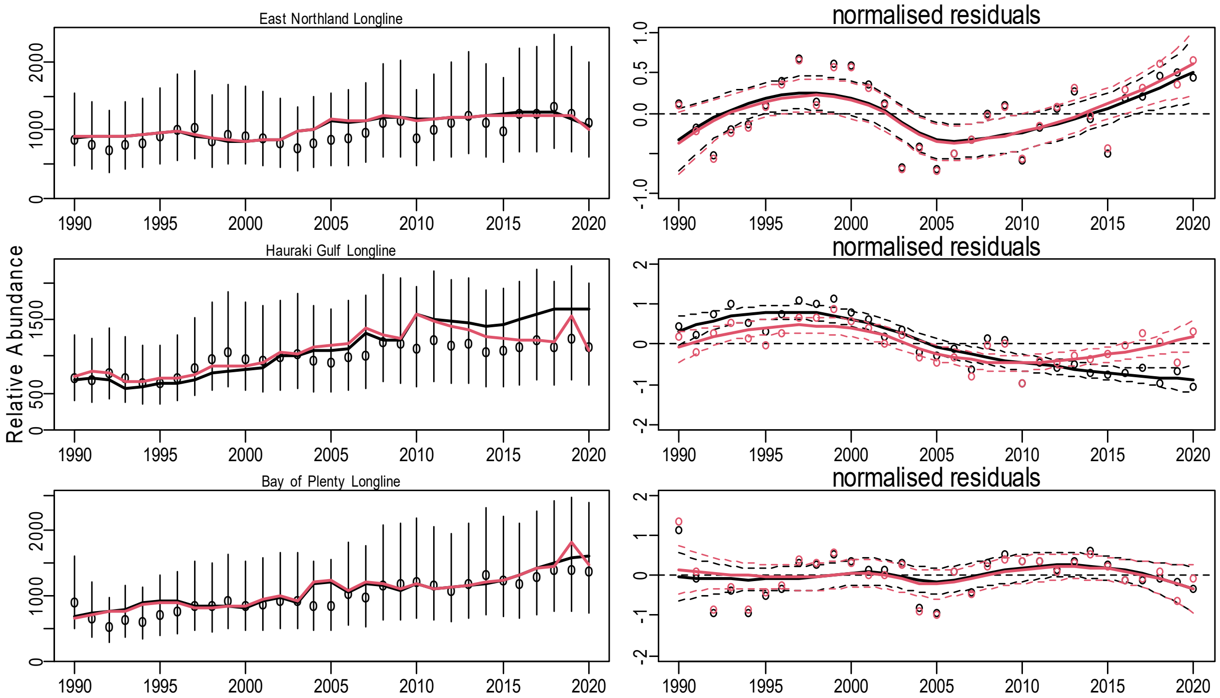


Figure 27: All-likelihood (black line) no-survey (red line) and model fits to east Northland, Hauraki Gulf, and Bay of Plenty longline CPUE.

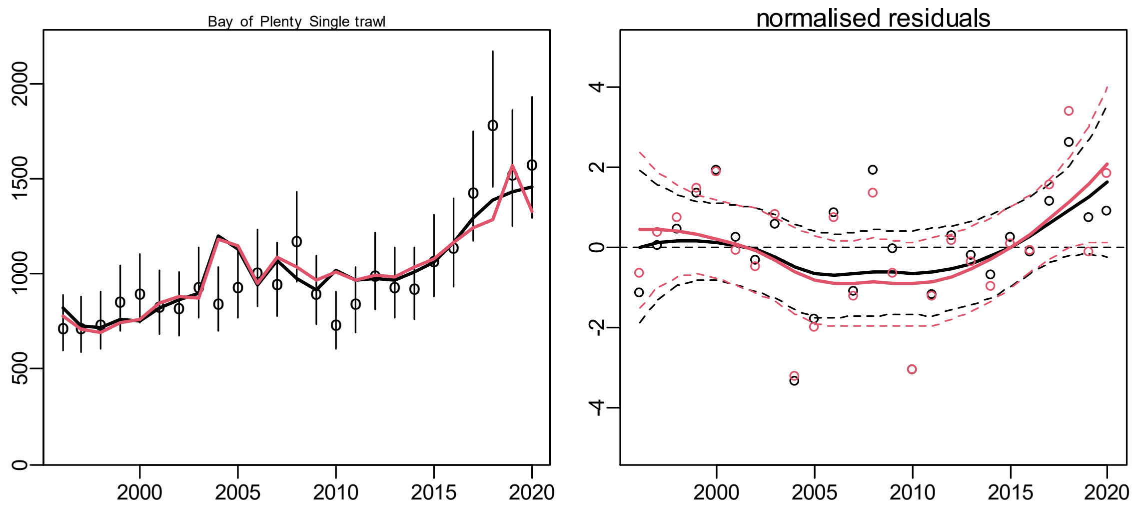


Figure 28: All-likelihood (black line) no-survey (red line) and model fits to Bay of Plenty bottom trawl CPUE.

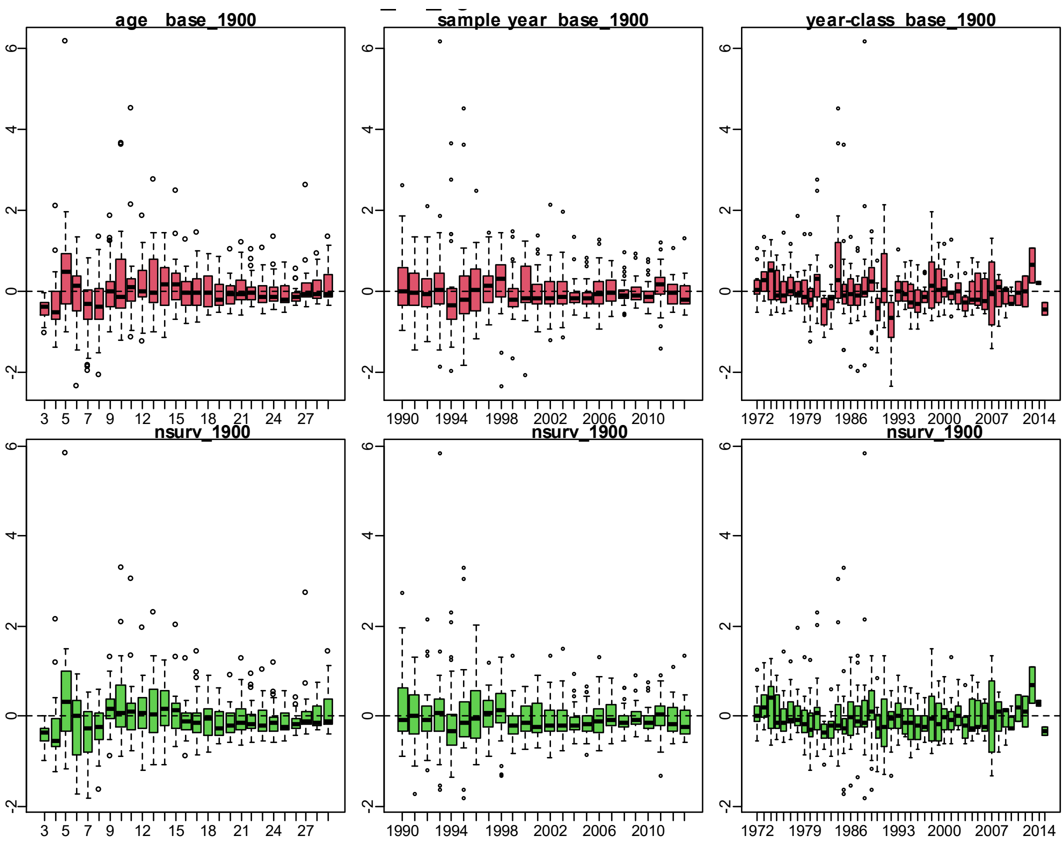


Figure 29: All-likelihood (top row) and no-survey (bottom row) model residual distributions from Hauraki Gulf longline age compositional fits. Left plots: model residual distributions aggregated by age class; middle plots: model residual distributions aggregated by survey year; right plots: model residual distributions aggregated by year-class.

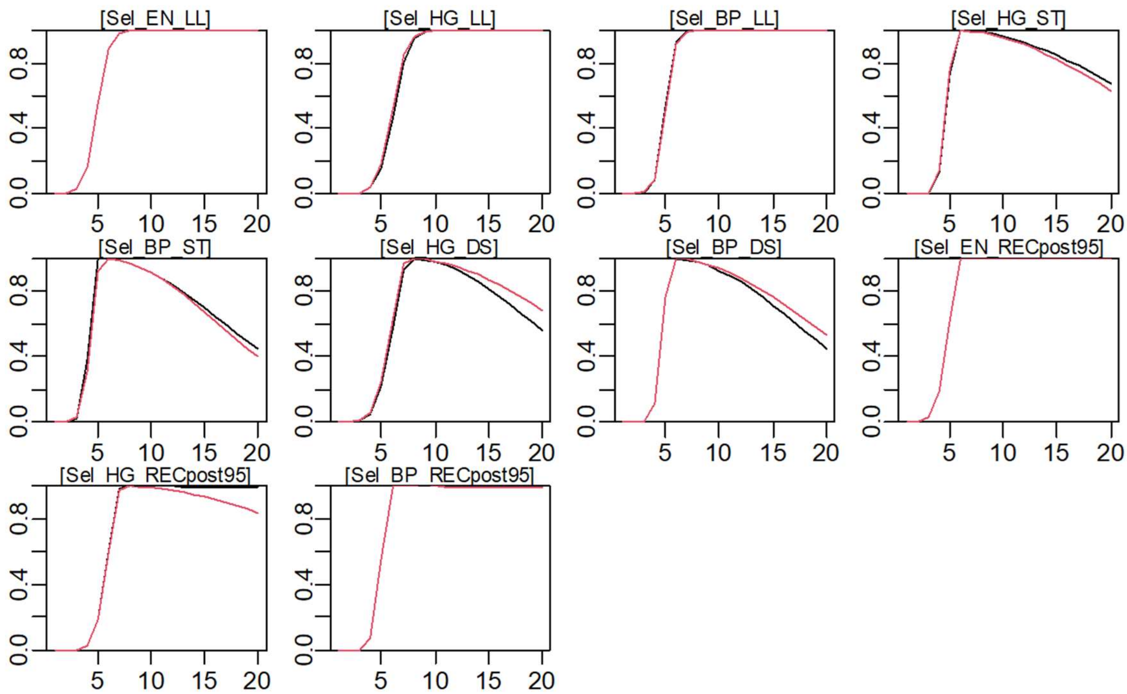


Figure 30: All-likelihood (black line) no-survey (red line) model estimated area-gear selectivities.

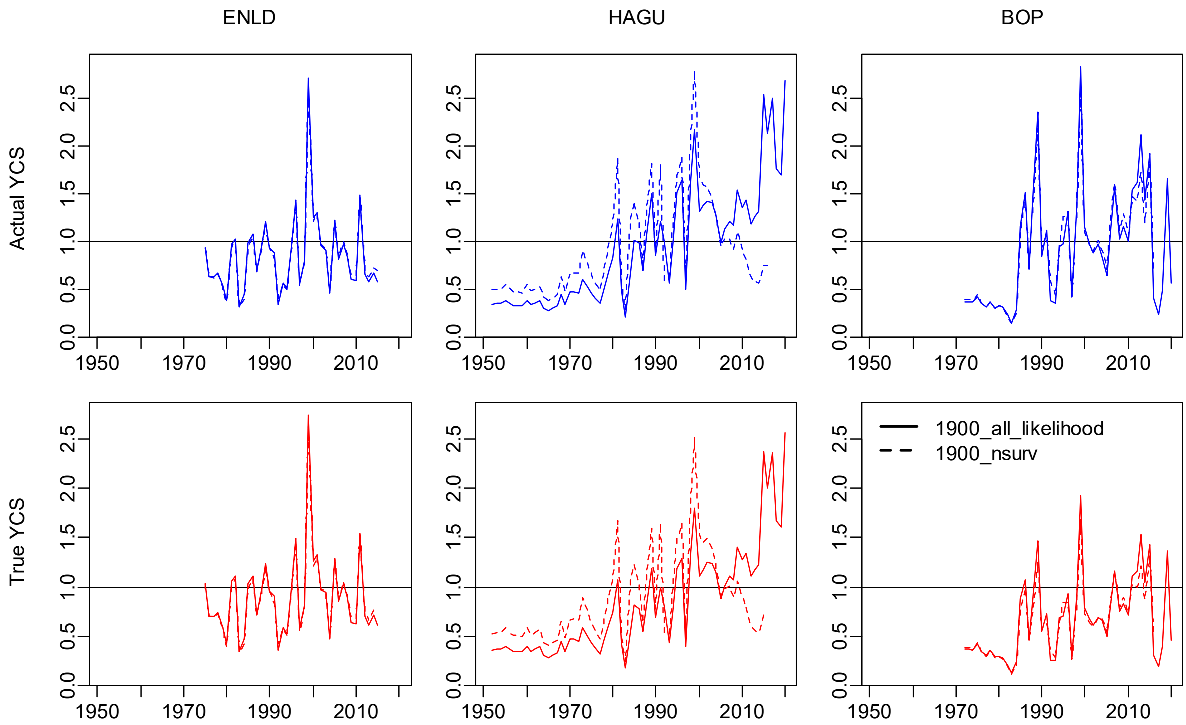


Figure 31: All-likelihood and no-survey model stock Year Class Strength (YCS) estimates. The actual YCS estimates (top row) are unadjusted for steepness (*h*).

Table 12: Model stock/area proportional movement estimates.

1900_no_survey

From home stock		EN	HG	BP
				To area
	ENLD	0.957	0.036	0.007
	HAGU	0.080	0.896	0.024
	BOP	0.026	0.386	0.588

1900_ all_likelihood

From home stock		EN	HG	BP
				To area
	ENLD	0.964	0.031	0.004
	HAGU	0.075	0.880	0.045
	BOP	0.043	0.220	0.737

Table 13: SNA 1 stock and area unexploited spawning stock biomass (B_0) model estimates.

By stock

	ENLD	HAGU	BOP
1900_no_survey	94 623	199 251	112 299
1900_ all_likelihood	89 278	310 109	101 486

By area

	EN	HG	BP
1900_no_survey_likelihood	110 191	235 178	86 539
1900_ all_likelihood	113 690	298 011	89 171

Table 14: SNA 1 stock and area current stock-status (B_{2021}/B_0) model estimates.

By stock

	ENLD	HAGU	BOP
1900_no_survey	26%	19%	11%
1900_ all_likelihood	27%	34%	10%

By area

	EN	HG	BP
1900_no_survey	23%	17%	11%
1900_ all_likelihood	26%	31%	12%

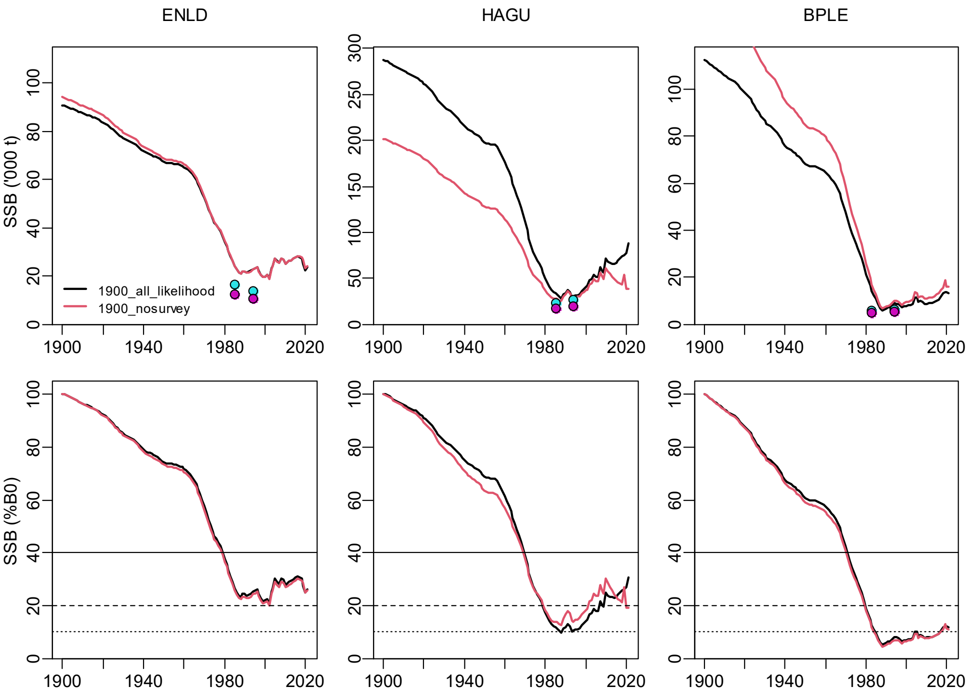


Figure 32: All-likelihood (black line) no-survey (red line) model SSB stock-status predictions. The dots are Petersen tag biomass estimates (dark blue trap-avoidance; light blue no trap-avoidance). Note: the plotted tag biomass estimates were not directly fitted in the models.

The Working Group selected the reduced-LL-CPUE model as the 2022 SNA 1 base-case assessment model principally because of longline CPUE hyperstability concerns (henceforth denoted as **base-model** in this report).

However, the Working Group requested exploration of some key model assumptions in the form of the following model MPD sensitivity runs:

1. effect of increasing the tag likelihood weightings (lowering the tag dispersion parameter value)
2. effect of assuming density dependent growth pre-1990
3. effect of commencing the model in 1970.

Each model sensitivity run was done without reweighting the base-model compositional likelihoods so that differences in individual likelihood fits could be compared.

Tag-likelihood-weight and base 1900 model MPD comparative fits and predictions:

Reweighting the base-model tagging likelihoods in accordance with the Francis approach (Appendix 7) resulted in a dispersion parameter value of 4.3 in the base model. The effect of increasing the tagging likelihood weight on model fits and predictions was explored via a series of base model runs with tag dispersion values of 4.3 (base), 1.5, and 0.75.

There were no appreciable differences in the alternate tag-weighting model fits to the compositional observational data. Except for the east Northland longline CPUE series, there were also no obvious differences in model fits to the survey abundance and Bay of Plenty longline CPUE series. Differences in model fits for the east Northland longline CPUE series were minor (Figure 33).

The base model predicted number of east Northland tag recoveries from both tag release programmes were proportionally lower than the predicted tag recoveries from the other two areas (Table 15). The model underestimate of east Northland tag recoveries was consistent with the magnitude difference in the east Northland model SSB predictions and the Petersen tag biomass pseudo-observations (Figure 26). As expected, increasing the tag likelihood relative weighting (reducing the tag dispersion value) reduced the discrepancy between the observed and model expected number of tag recoveries, with the proportional improvement in fit being highest for east Northland (Table 15).

Table 15: Tag dispersion factor model predicted tag recoveries as a percentage of observed number of tag recoveries.

			Tag dispersion factor model		
Release event year	**Release stock area**	**Observed recoveries**	**4.3(base)**	**1.5**	**0.75**
1985	EN	447	77.2%	82.1%	86.1%
	HG	1021	104.5%	103.5%	102.6%
1994	EN	144	43.1%	46.5%	50.7%
	HG	310	70.0%	71.3%	73.2%
	BP	69	87.0%	87.0%	88.4%

The model stock/area proportional movement estimates were relatively insensitive to increasing the tag likelihood weighting except for the proportional movement predictions from the Bay of Plenty stock to the Hauraki Gulf (Table 16).

Model YCS predictions were insensitive to increasing the tag likelihood weightings (Figure 34), as were model selectivity estimates (Figure 35).

Model stock productivity (B_0) predictions were minimally altered by increasing the tag likelihood weighting (Table 17).

The biggest changes in model predicted outcome in response to increasing the tag likelihood weighting were seen in the model East Northland SSB and stock-status predictions (Table 18 and Figure 36).

Table 16: Tag dispersion factor model stock/area proportional movement estimates.

Dispersion factor 4.3 (base)

		To area	
From home stock	EN	HG	BP
ENLD	0.964	0.031	0.004
HAGU	0.075	0.880	0.045
BOP	0.043	0.220	0.737

Dispersion factor 1.5

		To area	
From home stock	EN	HG	BP
ENLD	0.955	0.038	0.007
HAGU	0.078	0.877	0.046
BOP	0.035	0.271	0.694

Dispersion factor 0.75

		To area	
From home stock	EN	HG	BP
ENLD	0.949	0.042	0.010
HAGU	0.078	0.874	0.048
BOP	0.036	0.298	0.666

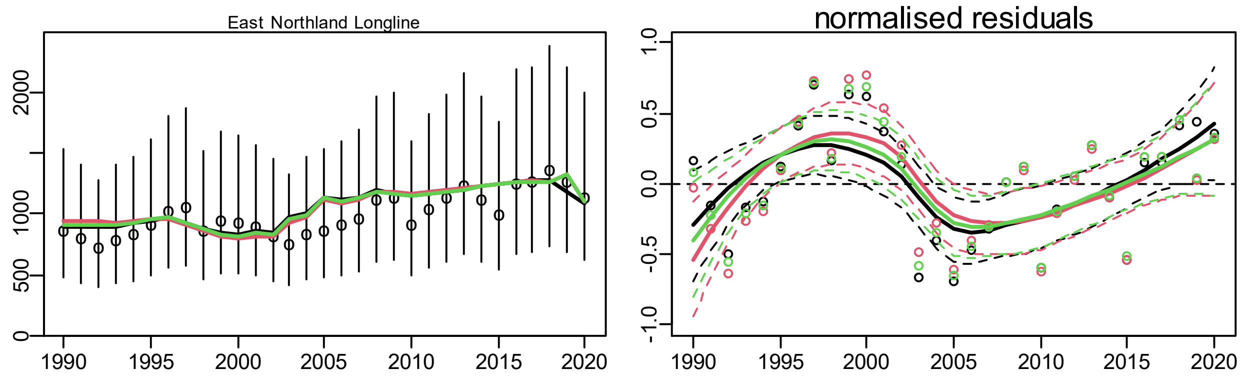


Figure 33: Tagd4.3 (black line), tagd1.5 (green line), and tagd0.75 (red line) model fits to east Northland longline CPUE.

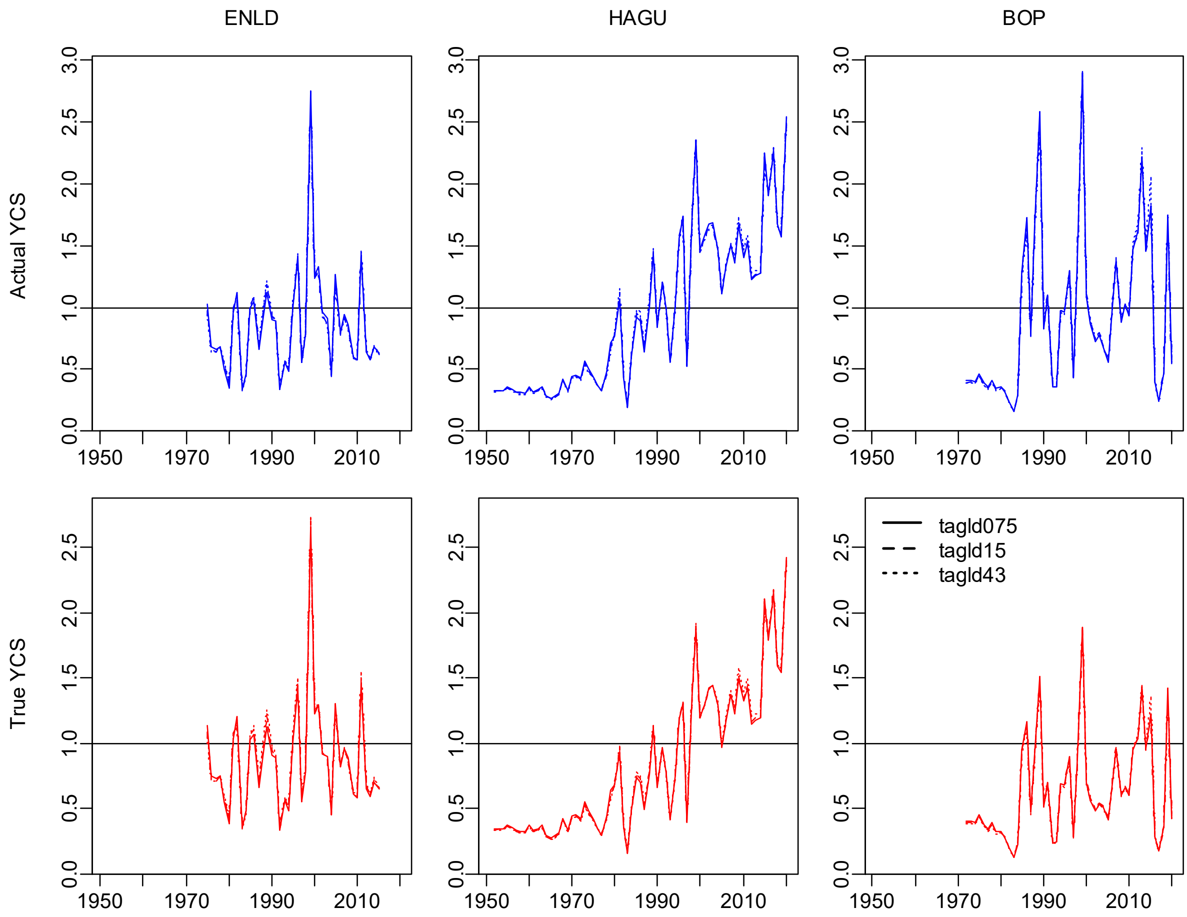


Figure 34: Effect of increasing tag likelihood weighting (lower dispersion parameter values) on model Year Class Strength (YCS) estimates. The actual YCS estimates (blue) are unadjusted for steepness (h).

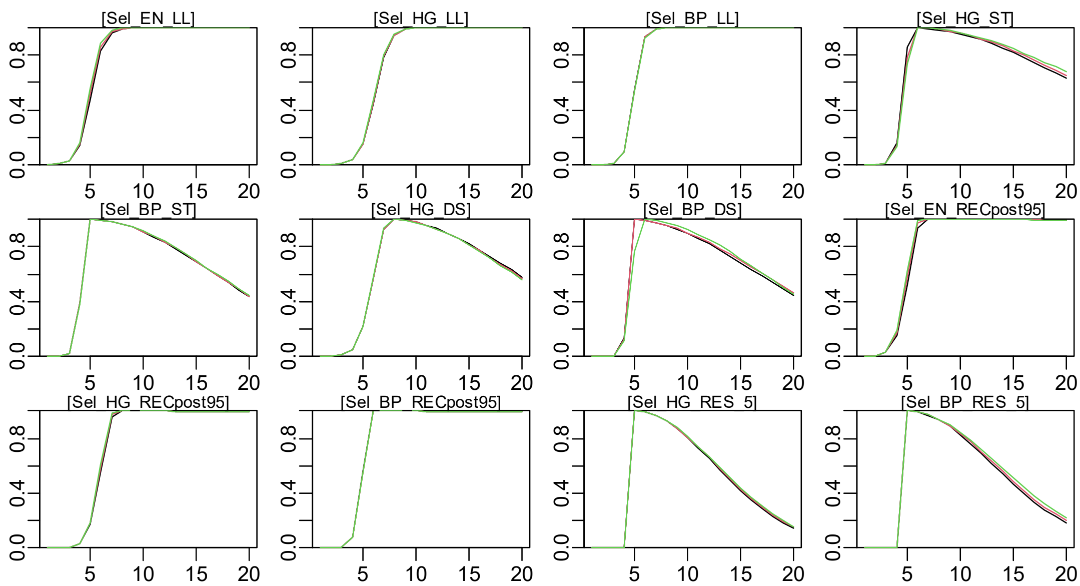


Figure 35: Tagd4.3 (black line), tagd1.5 (green line), and tagd0.75 (red line) model estimated selectivities.

Table 17: SNA 1 stock and area unexploited spawning stock biomass (B_0) model estimates.

By stock

	ENLD	HAGU	BOP
Tagld4.3(base)	89 278	310 109	101 486
Tagld1.5	88 029	305 468	104 514
Tagld0.75	86 906	304 074	105 101

By area

	EN	HG	BP
Tagld4.3	113 690	298 011	89 171
Tagld1.5	111 465	299 492	87 054
Tagld0.75	109 859	300 794	85 427

Table 18: SNA 1 stock and area current stock-status (B_{2021}/B_0) model estimates.

By stock

	ENLD	HAGU	BOP
Tagld4.3(base)	27%	34%	10%
Tagld1.5	24%	32%	10%
Tagld0.75	21%	31%	10%

By area

	EN	HG	BP
Tagld4.3(base)	26%	31%	12%
Tagld1.5	24%	29%	12%
Tagld0.75	22%	28%	12%

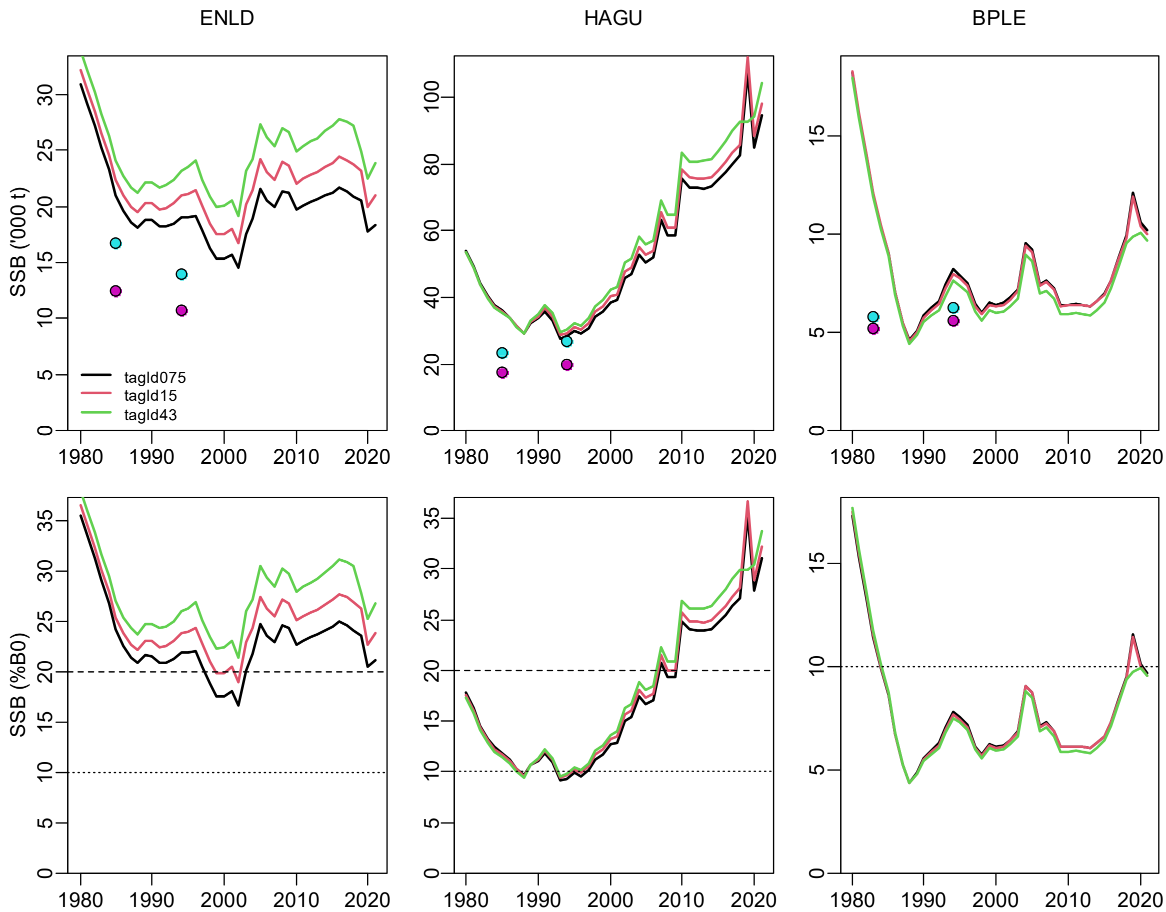


Figure 36: Tagd4.3 (black line), tagd1.5 (green line), and tagd0.75 (red line) model SSB and stock status predictions. The dots are Petersen tag biomass estimates (dark blue trap-avoidance; light blue no trap-avoidance). Note: the plotted tag biomass estimates were not directly fitted in the models.

Density-dependent-growth and base 1900 model MPD comparative fits and predictions:

The base model applies mean growth, as derived from the input growth matrices, in years for which growth is not explicitly defined by the matrices. The declining growth trends post-1990 evident in the longline catch at-age series (Appendix 5) correspond to periods of increasing biomass in all three stocks and thus the trends are consistent with density dependent growth. The Working Group requested a comparative model run which allowed for density dependent growth in each stock prior to 1990 (ddep-growth). The growth rates observed in the recent catch-at-age sampling are the slowest observed since SNA 1 age monitoring began, these rates corresponding to stock biomass levels not seen since the mid-1970s. The ddped-growth model allowed for density dependent growth back to 1975 stock biomass levels as predicted by the base model based on the growth/biomass relationship observed in the post-1990 age data series. This was achieved by extending the all the ddep-growth model growth matrices back to 1975, with the pre-1990 density dependent declining growth trends determined outside the model. As in the base model, pre-1975 growth rates in ddep-growth model were set at the mean of the observed growth rates.

The effect of specifying a density dependent growth relationship in the model over the period 1975–1990 only resulted in a minor departure from the base model SSB trajectories for this period (Figure 37); otherwise, the model fits and, B_0 and current stock-status predictions were almost identical (Table 19 and Table 20).

Table 19: SNA 1 stock and area unexploited spawning stock biomass (B_0) model estimates

By stock

	ENLD	HAGU	BOP
1900_ddepg_likelihood	90 392	311 098	100 045
1900_base_likelihood	89 278	310 109	101 486

By area

	EN	HG	BP
1900_ddepg_likelihood	114 320	297 753	90 510
1900_base_likelihood	113 690	298 011	89 171

Table 20: SNA 1 stock and area current stock-status (B_{2021}/B_0) model estimates

By stock

	ENLD	HAGU	BOP
1900_ddepg_likelihood	27%	35%	10%
1900_base_likelihood	27%	34%	10%

By area

	EN	HG	BP
1900_ddepg_likelihood	26%	32%	12%
1900_base_likelihood	26%	31%	12%

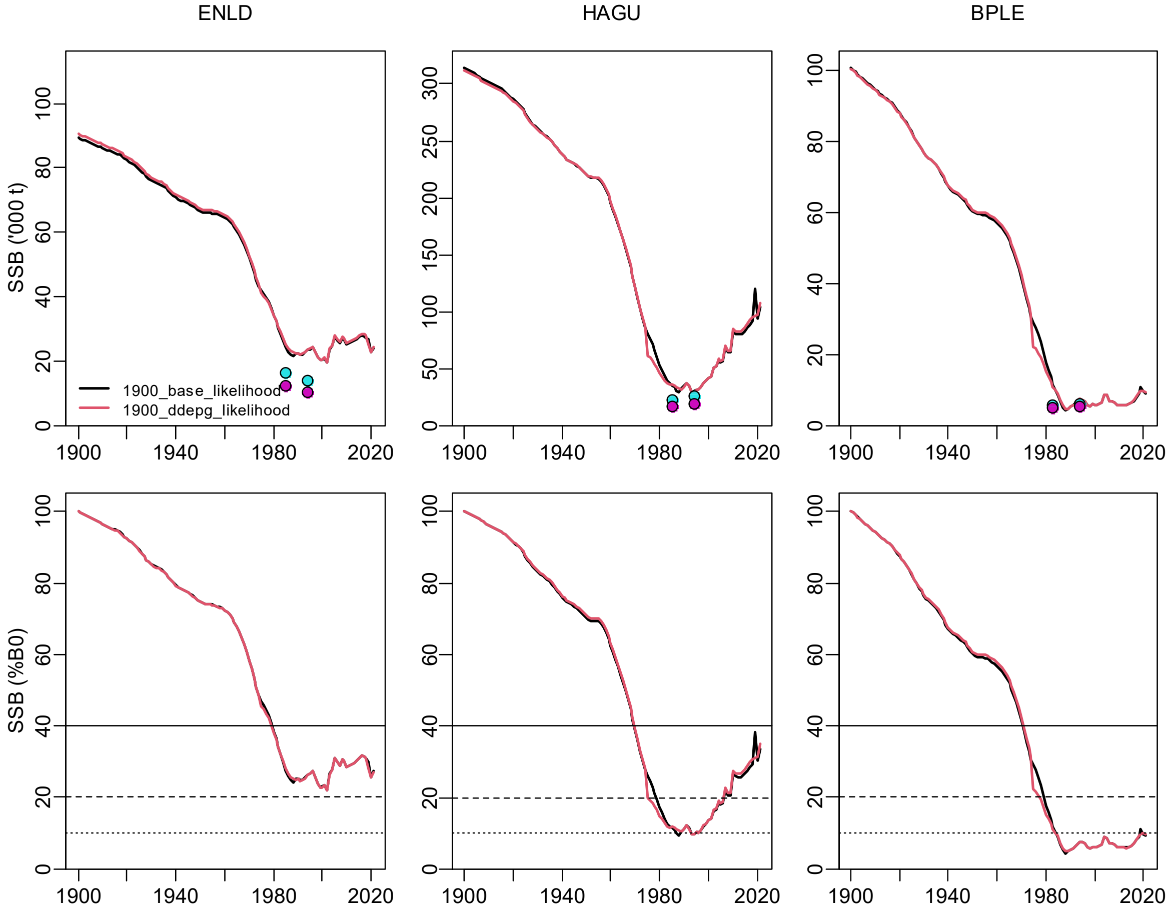


Figure 37: Base model (black line) and ddep-growth model (red line) SSB and stock-status predictions. The dots are Petersen tag biomass estimates (dark blue trap-avoidance; light blue no trap-avoidance). Note: the plotted tag biomass estimates were not directly fitted in the models.

1970 commence and base 1900 model MPD comparative fits and predictions:

SNA 1 pre-1970 catch histories are uncertain in the base 1990 model. Model runs scaling pre-1970 catch histories up and down by 20% resulted in different magnitude changes in B_0 and SSB trajectories across the three SNA 1 stocks (Table 21; Figure 38). The Hauraki Gulf model B_0 and SSB trajectories were relatively insensitive to the assumed pre-1970 catch histories, whereas differences in model productivity predictions for east Northland and Bay of Plenty stocks were more pronounced (Table 21; Figure 38). In terms of model current stock-status prediction, only the east Northland stock differed markedly (Table 22).

Table 21: SNA 1 stock and area unexploited spawning stock biomass (B_0) model estimates.

By stock

	ENLD	HAGU	BOP
1900_base_likelihood	89 278	310 109	101 486
1900_hicathist_likelihood	97 395	316 715	118 341
1900_lwcathist_likelihood	81 808	306 928	83 378

By area

	EN	HG	BP
1900_base_likelihood	113 690	298 011	89 171
1900_hicathist_likelihood	122 592	310 168	99 691
1900_lwcathist_likelihood	105 804	284 265	82 045

Table 22: SNA 1 stock and area current stock-status (B2021/B0) model estimates.

By stock

	ENLD	HAGU	BOP
1900_base_likelihood	27%	34%	10%
1900_hicathist_likelihood	29%	33%	10%
1900_lwcathist_likelihood	24%	34%	9%

By area

	EN	HG	BP
1900_base_likelihood	26%	31%	12%
1900_hicathist_likelihood	28%	31%	12%
1900_lwcathist_likelihood	25%	32%	13%

Commencing the SNA 1 base assessment model in 1970 (as was done for the 2012 SNA 1 assessment; Francis & McKenzie 2015a) avoided the issue of the model having to account for the uncertain pre-1970 catch history but alternatively required estimating three additional R_0 off-set parameters ($R_{initial}$; Table 3) in order to commence the model in 1970 in an exploited state.

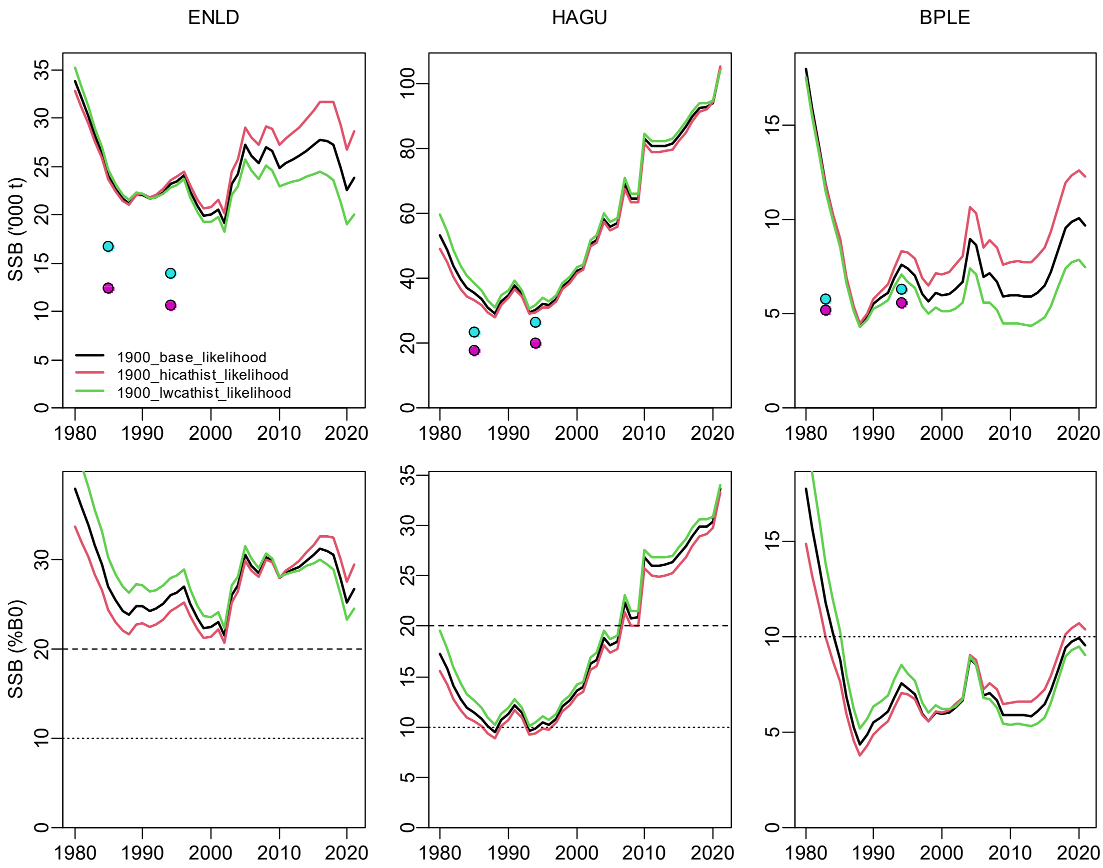


Figure 38: Base (black line), high (+20%) 1970 catch history (red line), and low (-20%) 1970 catch history (green line) model SSB and stock-status predictions. The dots are Petersen tag biomass estimates (dark blue trap-avoidance; light blue no trap-avoidance). Note: the plotted tag biomass estimates were not directly fitted in the models.

The 1970-base model achieved a 3% higher overall likelihood improvement than the 1900-base model with 15 fewer parameters (1970-base MPD total log-likelihood 7133; 1900-base MPD total log-likelihood 7347). The 1970-base model achieved a marked improvement in fit to the 2020 and 2021 Hauraki Gulf 5+ survey biomass observations (Figure 39), and a slightly improved fit to the 2020 and 2021 Bay of Plenty 5+ survey biomass observations (Figure 40). Likewise, the 1970-base model achieved a better fit to the 1983 Bay of Plenty tag biomass estimate (Figure 41). Despite not being able to explicitly account for Hauraki Gulf pre-1970 YCSs, the 1970-base model achieved comparable fits to the early Hauraki Gulf Danish seine and bottom trawl age-compositional series; in particular, most of the plus-age cohort strengths were similarly predicted by the two models (Figure 42 and Figure 43). Fits to Hauraki Gulf and Bay of Plenty survey 5+ age composition series by the two models were effectively identical (Figure 44). Overall, the base-1970 model fitted most remaining at-age compositional series marginally better than the 1900-base, although there were essentially no major differences between the two model fits to these other compositional series. The only observational series to which the 1990-base consistently fit better (although marginally) were to the tag release-recovery series (Figure 45).

It would be "unreasonable" to assume that, based on observational data fit alone, the 1970-base model provides the more "credible" assessment of the two models. The validity of both models depends on how well each could predict 1970 SNA 1 stock-status and productivity dynamics. Validity of 1900-base model stock-status predictions are proportional to the level of confidence in the pre-1970 catch histories going into the model. In the 1970-base model, uncertainty in a specified pre-1970 catch history is replaced by uncertainty in its ability to estimate the three 1970 R_0 offset parameters ($R_{initial}$). The expectation is that the 1970-base model $R_{initial}$ estimates should be predominantly informed by observational likelihood data close to 1970, more so by the compositional data (which provide information on 1970 exploitation levels), and less so by the post-1990 observational data. Observational data prior to 1985 were unavailable from the SNA 1 east Northland stock area. Likelihood profiles on the east Northland $R_{initial}$ parameter show that conflict exists between the longline compositional likelihoods and the longline CPUE and tagging likelihood, where the compositional data favours an $R_{initial}$ much lower than the abundance likelihoods suggest (Appendix 10). Hauraki Gulf Danish seine compositional data exists for the 1970s; the $R_{initial}$ predicted value from these data was consistent with the 5+ trawl abundance likelihood predicted values and the overall model MPD predicted value (Appendix 10). Observational data prior to 1983 were unavailable from the SNA 1 Bay of Plenty area. Likelihood profiles suggest that the Bay of Plenty $R_{initial}$ MPD predicted value was strongly determined by the survey 5+ age composition and the survey one year-old recruitment index, both series extending back to the mid-1980s. Not consistent with the Bay of Plenty $R_{initial}$ MPD estimated value were the tagging and longline compositional likelihoods, both favouring higher estimates (Appendix 10). The $R_{initial}$ likelihood profiles suggest that the Hauraki Gulf $R_{initial}$ estimate was probably better determined than the other two stocks.

The 1970-base model unexploited productivity stock biomass (B_0) estimates for each of the SNA 1 stocks were substantially higher than the 1900-base model estimates (Table 23). The 1970-base model Hauraki Gulf and Bay of Plenty B_0 estimates were approximately double those of the 1900-base model (Table 23). Selectivity predictions from the two models were similar (Figure 46). Both models also predicted similar patterns in YCS. However, there were marked differences in the magnitude of YCS patterns for the Hauraki Gulf and Bay of Plenty stocks, these were likely to be due to the extreme differences in base productivity predictions (B_0) between the two models (Figure 47). There were marginal differences in the movement predictions from the two models which may account for the 1970-base model's slightly degraded fit to the tag recovery data (Table 24; Figure 45). The extreme difference between the 1900-base and 1970-base Hauraki Gulf and Bay of Plenty B_0 predictions are the likely reason for the markedly divergent SSB trajectories (Figure 48). The 1970-model predicts that the Bay of Plenty stock was depleted to 2% B_0 in 1985 which the Working Group felt was highly implausible (Figure 48).

Despite the large differences in Hauraki Gulf SSB trajectories between the two models (Figure 48), both models gave similar current stock-status predictions for the Hauraki Gulf and east Northland stocks (Table 25). However, the Working Group felt that the 1970-base model Bay of Plenty current stock-status prediction of 5% (Table 25) was also highly implausible.

Overall, the Working Group felt that more work is needed to develop the 1970 model to a stage where it could be considered a viable alternative to the 1900 model.

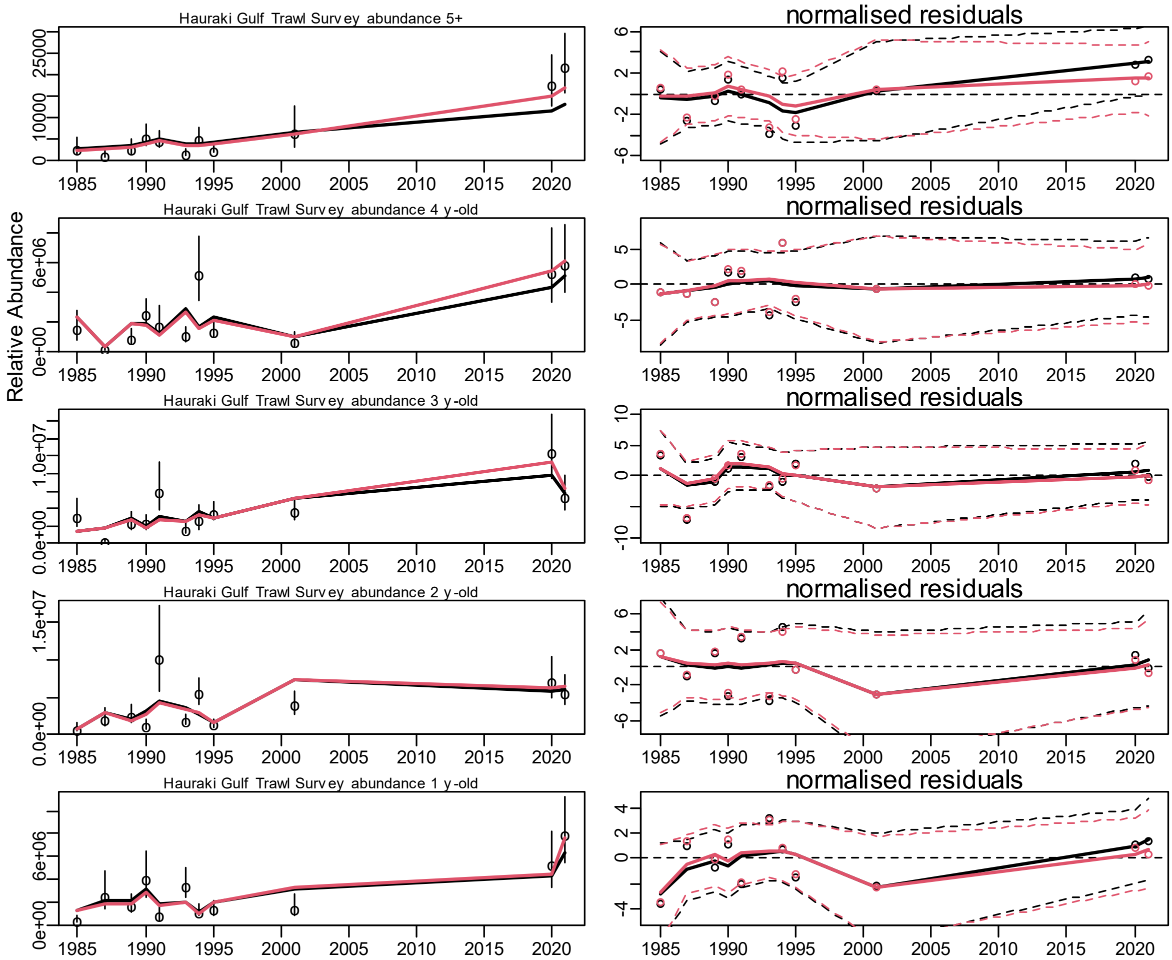


Figure 39: 1900-base-likelihood (black) and 1970-base-likelihood (red) model Hauraki Gulf trawl survey abundance comparative fits.

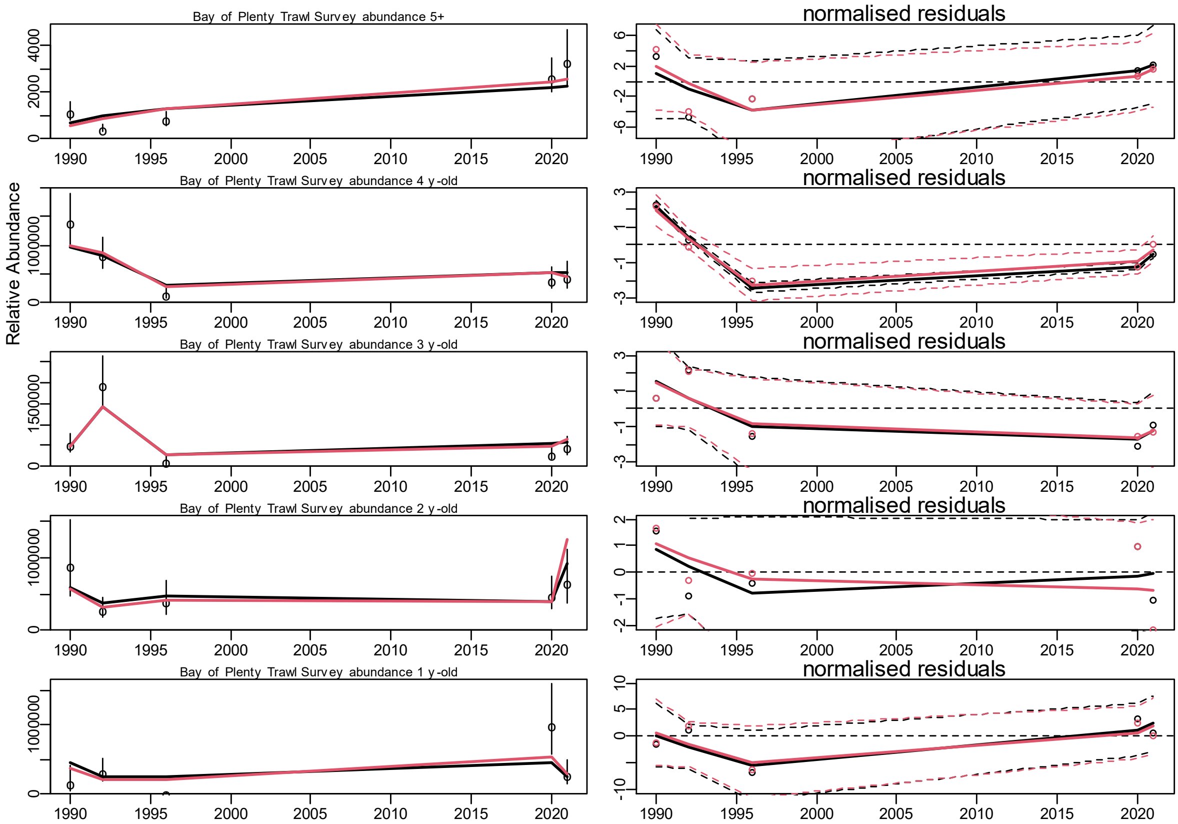


Figure 40: 1900-base-likelihood (black) and 1970-base-likelihood (red) model Bay of Plenty trawl survey abundance comparative fits.

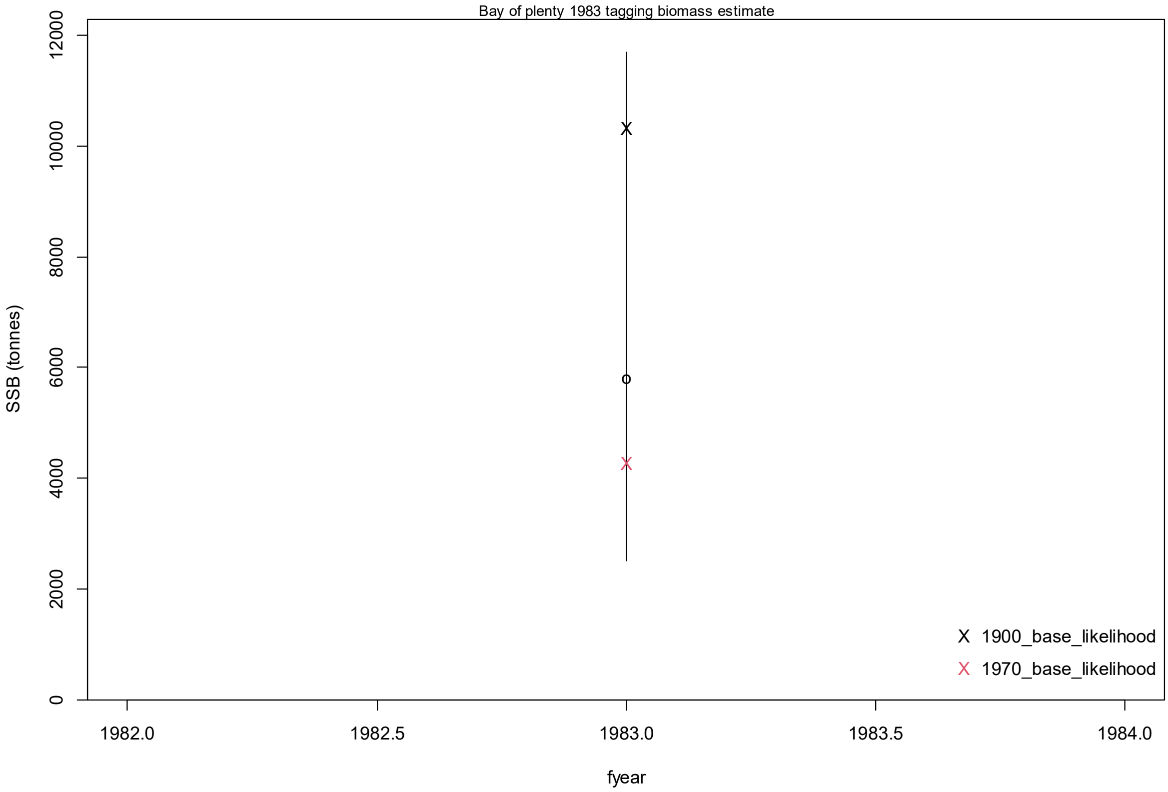


Figure 41: 1900-base-likelihood (black) and 1970-base-likelihood (red) model fits to Bay of Plenty 1983 tag recruited biomass (SSB) estimate.

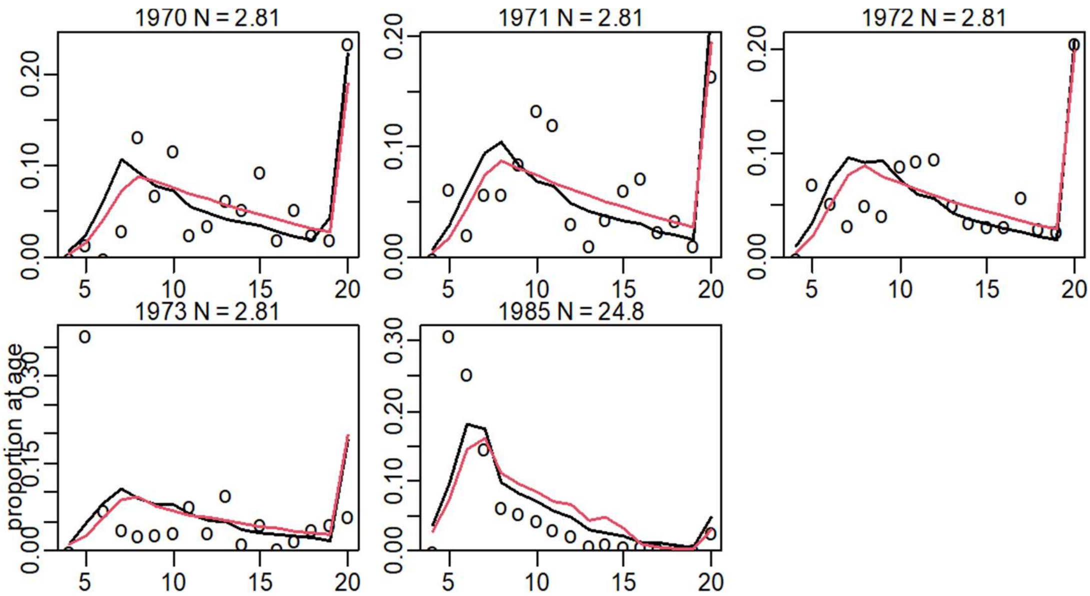
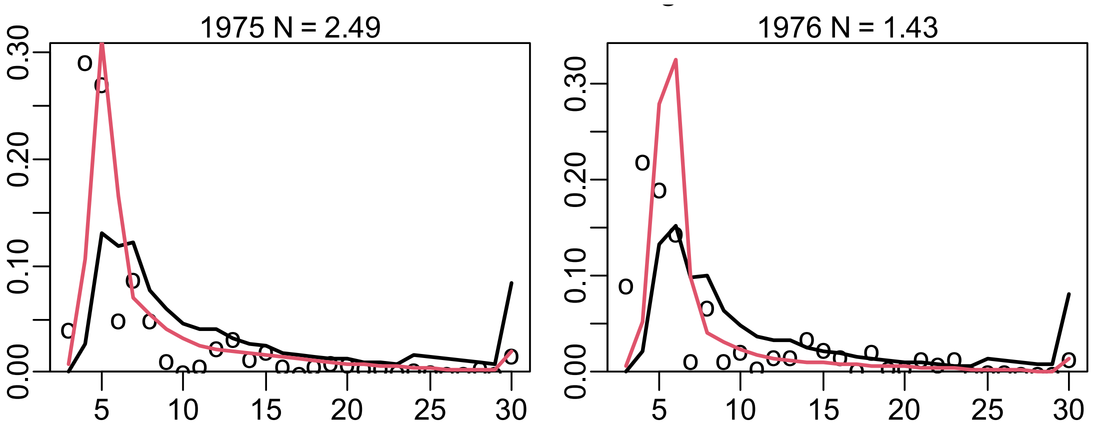


Figure 42: 1900-base-likelihood (black) and 1970-base-likelihood (red) model fits to Hauraki Gulf early Danish seine catch at-age (plus group 20+). N = effective multinomial error after likelihood reweighting.

a.



b.

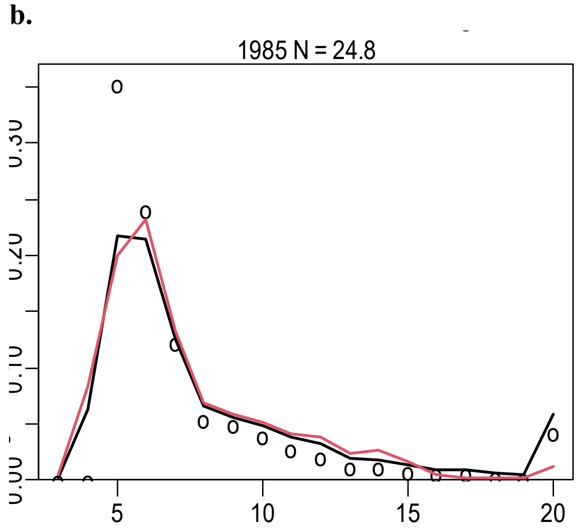
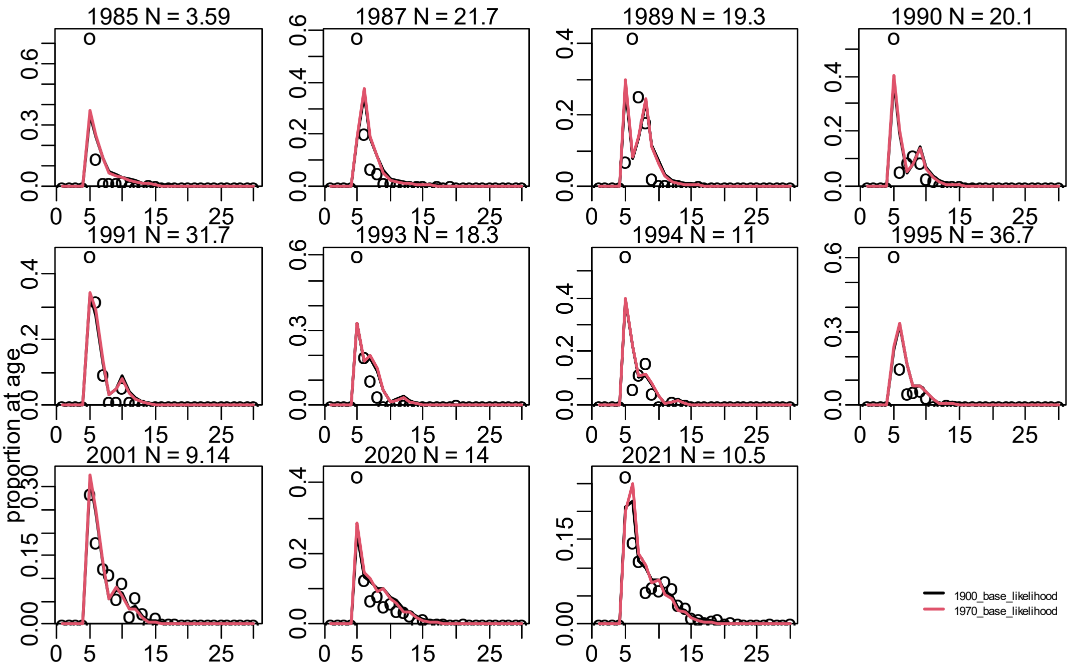


Figure 43: 1900-base-likelihood (black) and 1970-base-likelihood (red) model fits to Hauraki Gulf early bottom trawl catch at-age; a. plus group 30+, b. plus group 20+. N = effective multinomial error after likelihood reweighting.

a.



b.

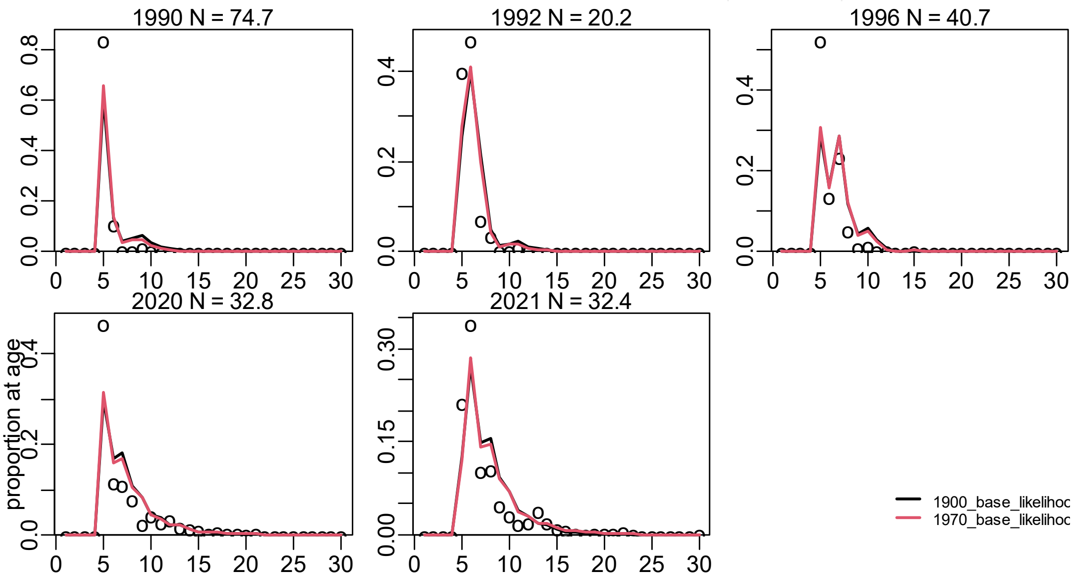


Figure 44: 1900-base-likelihood (black) and 1970-base-likelihood (red) model fits to trawl survey 5+ compositional at-age observations, a. Hauraki Gulf survey series, b. Bay of Plenty survey series. N = effective multinomial error after likelihood reweighting.

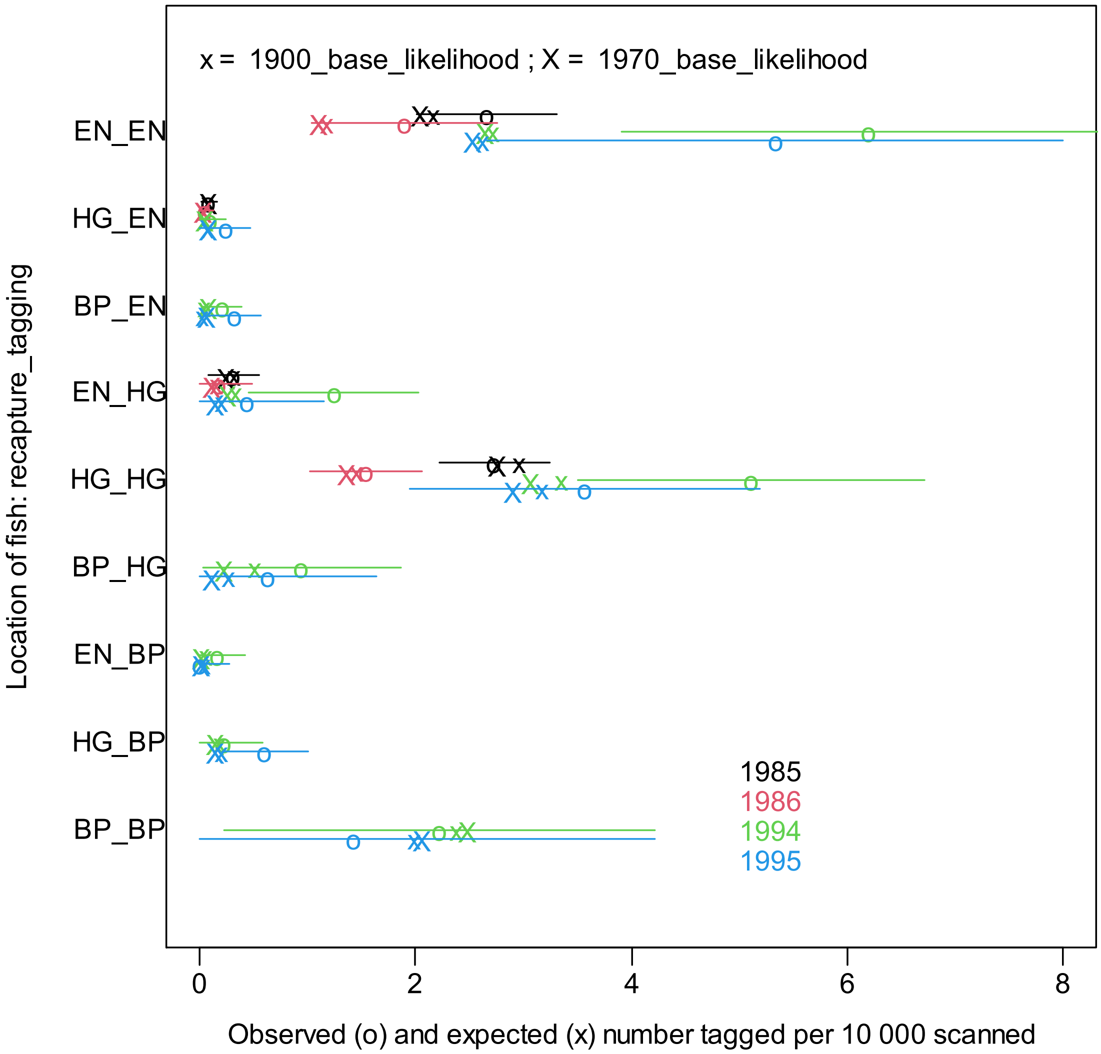


Figure 45: 1900-base-likelihood and 1970-base-likelihood model tag recovery observational fits.

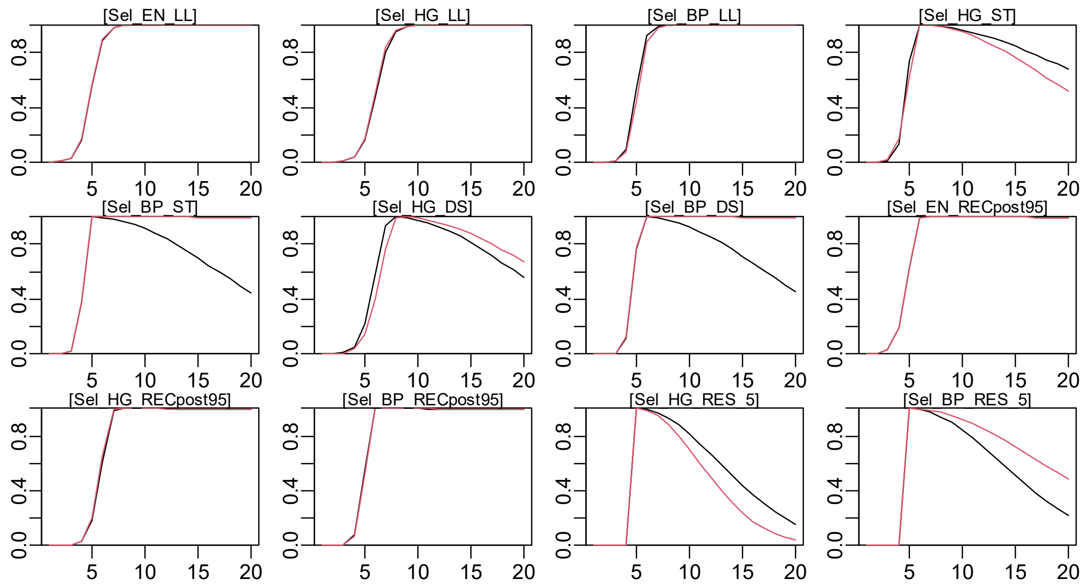


Figure 46: 1900-base-likelihood (black) and 1970-base-likelihood (red) model estimated area-gear selectivities.

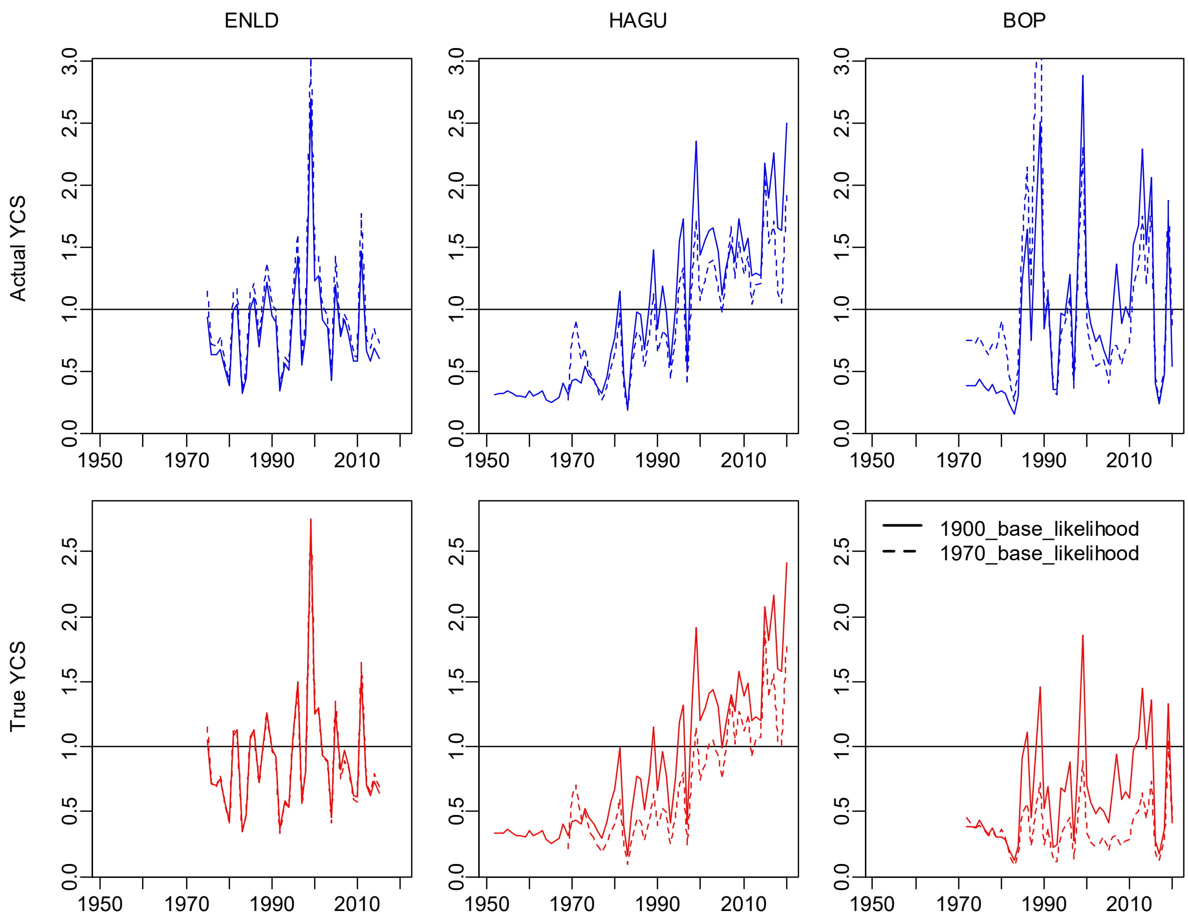


Figure 47: 1900-base-likelihood and 1970-base-likelihood model stock Year Class Strength (YCS) estimates. The actual YCS estimates (top row) are unadjusted for steepness (*h*).

Table 23: SNA 1 stock and area unexploited spawning stock biomass (B_0) model estimates.

By stock

	ENLD	HAGU	BOP
1900_base_likelihood	89 278	310 109	101 486
1970_base_likelihood	95 920	593 454	222 846

By area

	EN	HG	BP
1900_base_likelihood	113 690	298 011	89 171
1970_base_likelihood	128 020	593 489	190 710

Table 24: Model stock/area proportional movement estimates.

1900_base_likelihood

	To area		
From home stock	EN	HG	BP
ENLD	0.964	0.031	0.004
HAGU	0.075	0.88	0.045
BOP	0.043	0.22	0.737

1970_base_likelihood

	To area		
From home stock	EN	HG	BP
ENLD	0.94	0.044	0.016
HAGU	0.059	0.921	0.021
BOP	0.014	0.192	0.794

Table 25: SNA 1 stock and area current stock-status (B2021/B0) model estimates.

By stock

	ENLD	HAGU	BOP
1900_base_likelihood	27%	34%	10%
1970_base_likelihood	28	32	5

By area

	EN	HG	BP
1900_base_likelihood	26%	31%	12%
1970_base_likelihood	27%	29%	6%

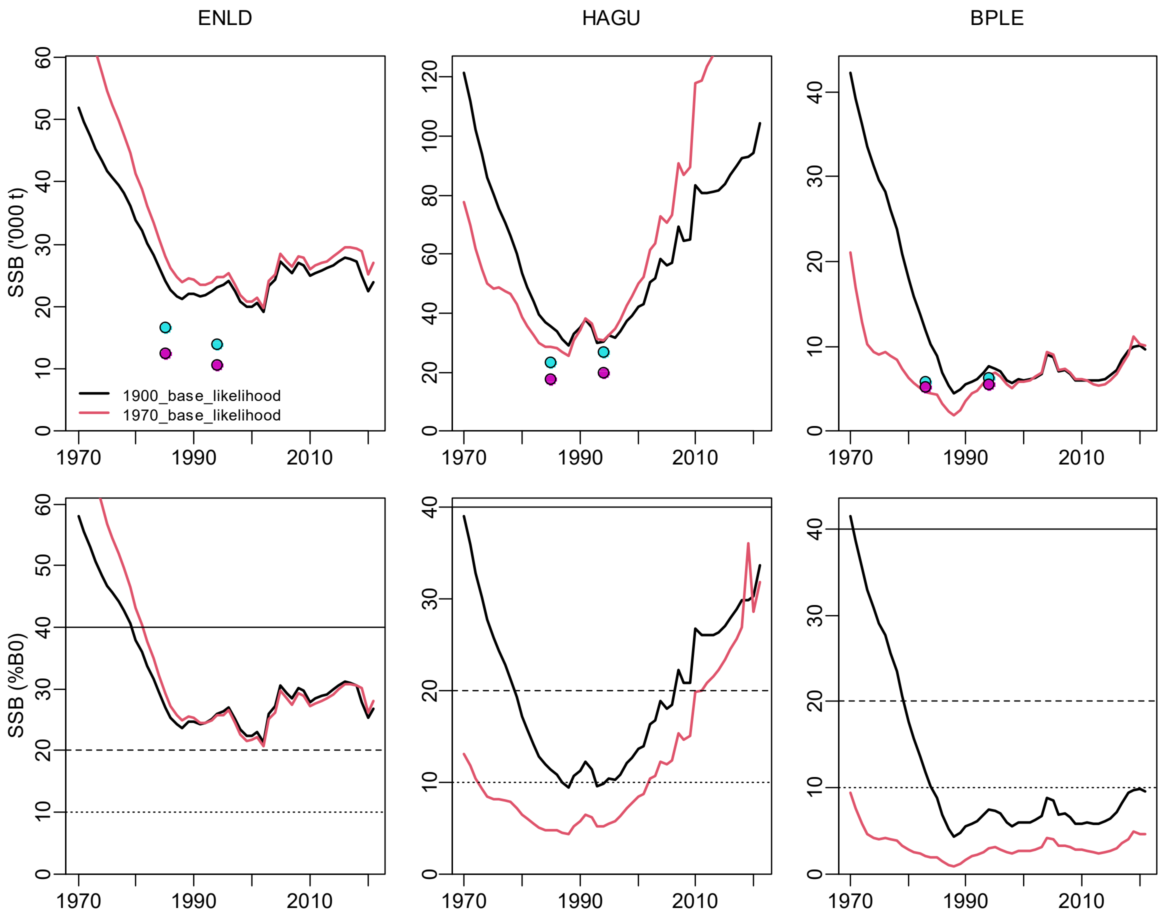


Figure 48: 1900-base-likelihood (black line) and 1970-base-likelihood (red line) model stock SSB and stock-status predictions. The dots are Petersen tag biomass estimates (dark blue trap-avoidance; light blue no trap-avoidance). Note: the plotted tag biomass estimates were not directly fitted in the models.

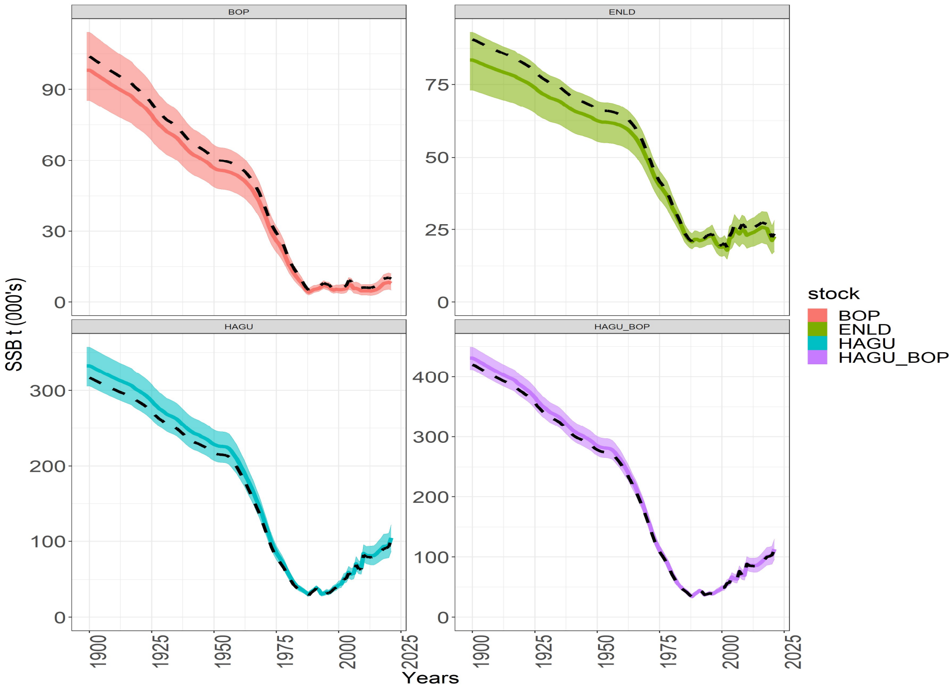
1900-base likelihood model MCMC posterior predictions:

Bayesian posteriors were generated for the 1900-base model from 3.5 million Monte Carlo Markov Chain (MCMC) parameter observations. The parameter posteriors were derived from every 1000th MCMC sample to minimise the potential for auto correlation bias. MCMC diagnostics for the model estimated parameters indicated no evidence of poor convergence (not shown).

Model MCMC 95% credible intervals on the SSB and stock-status trajectory posteriors were relatively narrow for the Hauraki Gulf and Bay of Plenty stocks, and less so for east Northland (Figure 49). Model MPD predicted trajectories “reasonably” matched the median posterior trajectories post 1985 but were mostly either higher or lower than the posterior medians prior to 1985 (Figure 49).

The MCMC posteriors on the model selectivity ogives were also narrow, which is likely to be a consequence of the large amount of compositional data going into the model (Figure 50).

MCMC posteriors on the stock-area movement parameters indicated greater uncertainty in movement from the Bay of Plenty stock than from the other two stocks (Table 26), probably being driven by the fewer number of tag recovery observations from the Bay of Plenty.



b.

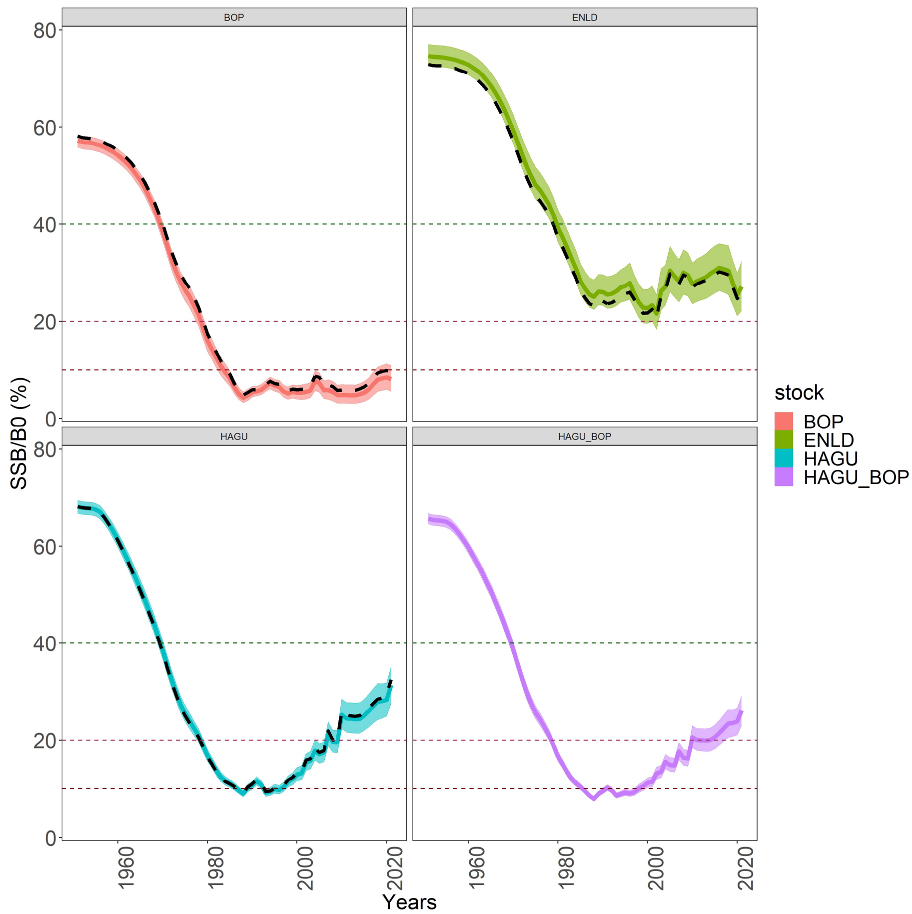


Figure 49: 1990-base likelihood model MCMC SSB (a.) and stock-status (b.) 95% posterior trajectories. HAGU_BOP 95% posteriors derived through simple addition of the model HAGU and BOP posterior estimates. Model MPD values solid lines; MCMC median values dashed lines.

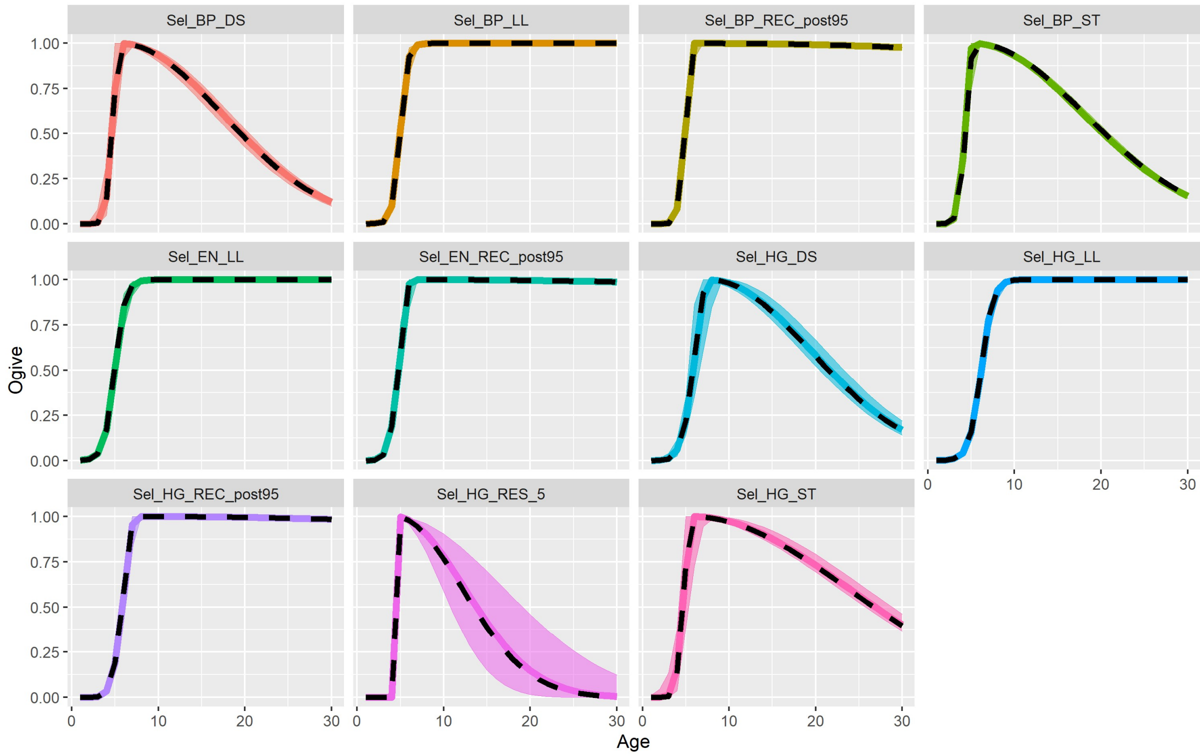


Figure 50: 1990-base likelihood model MCMC selectivity ogive 95% posteriors. Model MPD ogives solid lines; MCMC median values dashed lines.

Table 26: 1990-base likelihood model MCMC stock-area movement proportion 95% posterior ranges.

		To area			
From home stock		**EN**	**HG**	**BP**	**Sum**
ENLD	posterior 95% CI	0.935 – 0.979	0.016 – 0.056	0.012 – 0.178	-
	posterior median	0.959	0.032	0.069	1.060
	MPD predicted	0.964	0.031	0.004	1.000
HAGU	posterior 95% CI	0.074 – 0.169	0.780 – 0.877	0.038 – 0.065	-
	posterior median	0.115	0.834	0.051	1.000
	MPD predicted	0.075	0.880	0.045	1.000
BOP	posterior 95% CI	0.066 – 0.209	0.072 – 0.292	0.603 – 0.878	-
	posterior median	0.066	0.168	0.754	0.988
	MPD predicted	0.043	0.220	0.737	1.000

2.3 2022 SNA 1 Assessment Conclusions and Recommendations

The 1900-commence three-stock area home-fidelity SNA 1 assessment model, in 2013, achieved "acceptable" fits to available compositional, tag recovery, and abundance observational data sets. There were minimal likelihood conflicts between the major compositional and abundance data sets. Although the 2013 assessment model B_0 and sustainability predictions proved sensitive to the degree of weighting placed on the tagging likelihoods, the model movement predictions were only minimally affected by choice of the tag weighting (Francis & McKenzie 2015b). A new approach for appropriately weighting model tagging likelihoods was developed to the satisfaction of the Working Group (Appendix 7), and the base model assessment predictions deemed "acceptable" for management.

Difficulties have arisen applying the same three-stock area home-fidelity SNA 1 assessment model structure to SNA 1 abundance and compositional data collected since 2013. The 2022 SNA 1 HF models struggled to rationalise the observed increase in Hauraki Gulf stock abundance and possible increase in productivity (mean recruitment) occurring after 2013. The 2022 SNA 1 assessment model predicted outcomes were highly sensitive to model data weighting and model structural assumptions. The 2022 Plenary felt that more work was needed to better understand and resolve data lack-of-fit and likelihood conflicts in the assessment models.

The underlying model structural assumption issues in the 2022 SNA 1 are best illustrated by the predictive discrepancies between the 1990-base, 1970-base, 1900-Tagld0.75 (high tag weighting), and 1900-nosurvey models. Although there were no significant differences in east Northland YCS strength predictions between the models, there were marked differences between the model Hauraki Gulf and Bay of Plenty YCS predictions (Figure 51). The upward trend in Hauraki Gulf predicted YCSs after 2000, which may also indicate an upward shift mean-recruitment (R_0), was largely driven by the observed post 2000 rise in the trawl survey 5+ abundance index (Figure 51), as an YCS upward trend was not evident in the 1900-nosurvey model predictions.

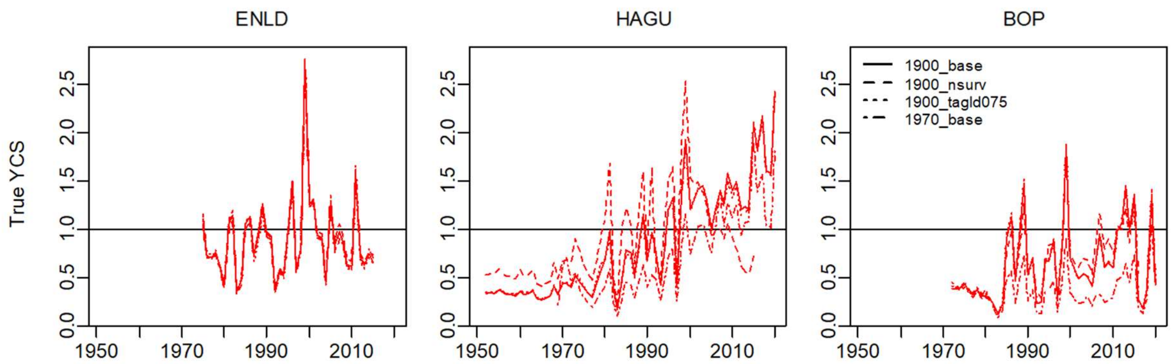


Figure 51: Comparative model SNA 1 stock 'true' (steepness adjusted) YCS estimates.

Tag movement data between the Bay of Plenty and Hauraki Gulf stock-areas are only available from the 1994 release-recapture events so there are fewer movement observations to constrain the model movement predictions between these areas. The 1900-nosurvey and 1900-Tagld0.75 models predicted higher movement from the BPLE stock to the HG region than the 1900 and 1970-base models (Table 27).

The east Northland B_0 estimates from all the models were similar although all were slightly higher than the east Northland B_0 estimates from the 2013 base-case assessment model (Figure 52). The 1970-base model Hauraki Gulf and Bay of Plenty B_0 estimates were approximately double those of all the 1900 commence models including the 2013 base-case model (Figure 52).

Understandably, the 1900-nosurvey model's east Northland SSB trajectory was largely unaffected by dropping the HG and BP survey indices (Figure 53a). Except for the 1900-Tagld0.75 model, all other 2022 assessment models produced similar east Northland SSB trajectories post-1990; these are all well above the 1985 and 1993 Petersen biomass estimates and well above the 2013 base model trajectory (Figure 53a).

The Hauraki Gulf stock SSB trajectories from all four 2022 assessment models were closer to 1994 tag biomass estimates than the 2013 base model SSB prediction (Figure 53b), which might explain why there was minimal difference in SSB trajectories between the 1900-base and 1900-Tagld0.75 models (Figure 53b). The Hauraki Gulf SSB post-2000 trajectory from the 1900-nosurvey model was markedly lower than that from the 1900-base model, being more like that predicted by the 2013 base model (Figure 53b). This result illustrates a high degree of conflict between the longline CPUE and trawl survey predictive indices, i.e. the high relative degree of Hauraki Gulf stock rebuild post-2000 exhibited by all the survey likelihood models was predominantly driven by the Hauraki Gulf survey 5+ biomass index. None of the survey models could predict the level of Hauraki Gulf relative biomass increase in 2020 and 2021 seen in the Hauraki Gulf 5+ survey index. The 1970-base model came closest to fitting the 2020 and 2021 Hauraki Gulf 5+ survey abundances (Figure 39) the outcome being a substantially higher Hauraki Gulf post-2000 SSB trajectory and current biomass prediction (Figure 53b).

The Bay of Plenty stock SSB trajectories from all four 2022 assessment models were similar post-2000 (Figure 53c). All model Bay of Plenty stock SSB trajectories were closer to the tag biomass estimates than the model predicted SSB trajectories for the other stock areas (Figure 53c). It is not immediately obvious why the 1900-nosurvey model Bay of Plenty stock SSB trajectory was higher than all other models including the 2013 base model (Figure 53c), however, this model predicted the highest proportional movement of the BPLE stock to the HG which may have had the effect of reducing direct historical fishing pressure on this stock (Table 27). The 1970-base model Bay of Plenty stock SSB predictions prior to 1990 were markedly lower than those predicted by the other models (Figure 53c), which, taken in conjunction with the high B_0 predicted by this model (Figure 52), resulted in an “implausibly” low (2% B_0) Bay of Plenty stock-status prediction for 1986 (Figure 53c).

The 2022 SNA 1 assessment Working Group and Plenary review process identified the following primary uncertainty areas that would need further investigation in the 2023 assessment modelling:

- spatial stock structure and degree of stock-area interchange;
- the strength of the relative abundance change seen in the Hauraki Gulf and Bay of Plenty 5+ trawl survey indices;
- the validity of using longline CPUE as a measure of east Northland relative abundance change
- stock pre-1970 catch histories;
- stock pre-1975 growth rates;
- the model assumption that commercial area-method selectivities have remained unchanged over the entire model catch history period;
- the assumption that stock mean recruitment (R_0) was constant over the years that stock YCS were estimated by the models.

Table 27: 1990-base, 1970-base, 1900-Tagld0.75 (high tag weighting), and 1900-nosurvey stock/area proportional movement estimate comparisons. Colour shading show similar Bay of Plenty to Hauraki Gulf predicted movement.

1900-base

			To area
From home stock	EN	HG	BP
ENLD	0.964	0.031	0.004
HAGU	0.075	0.880	0.045
BOP	0.043	0.220	0.737

1900-Tagld0.75

			To area
From home stock	EN	HG	BP
ENLD	0.949	0.042	0.010
HAGU	0.078	0.874	0.048
BOP	0.036	0.298	0.666

1900-nosurvey

			To area
From home stock	EN	HG	BP
ENLD	0.957	0.036	0.007
HAGU	0.080	0.896	0.024
BOP	0.026	0.386	0.588

1970-base

			To area
From home stock	EN	HG	BP
ENLD	0.940	0.044	0.016
HAGU	0.059	0.921	0.021
BOP	0.014	0.192	0.794

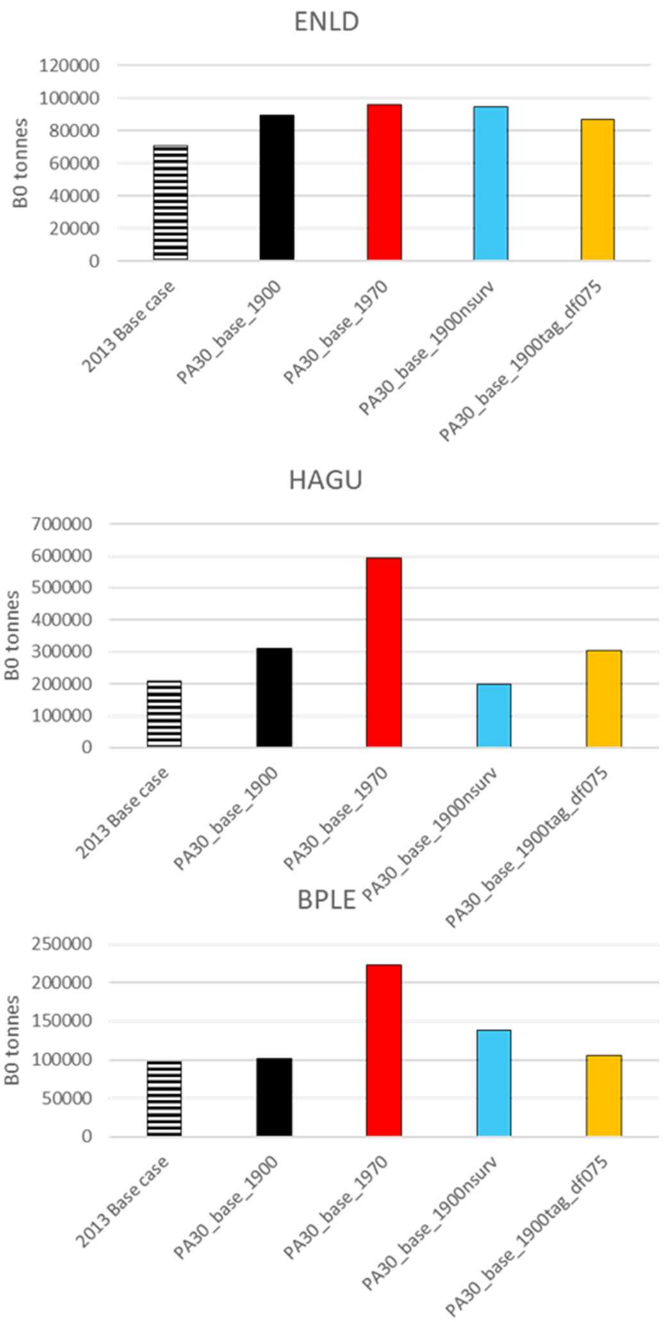


Figure 52: SNA 1 stock B_0 comparative model predictions. 2013 base-case assessment model B_0s shown for comparison.

a.

b.

c.

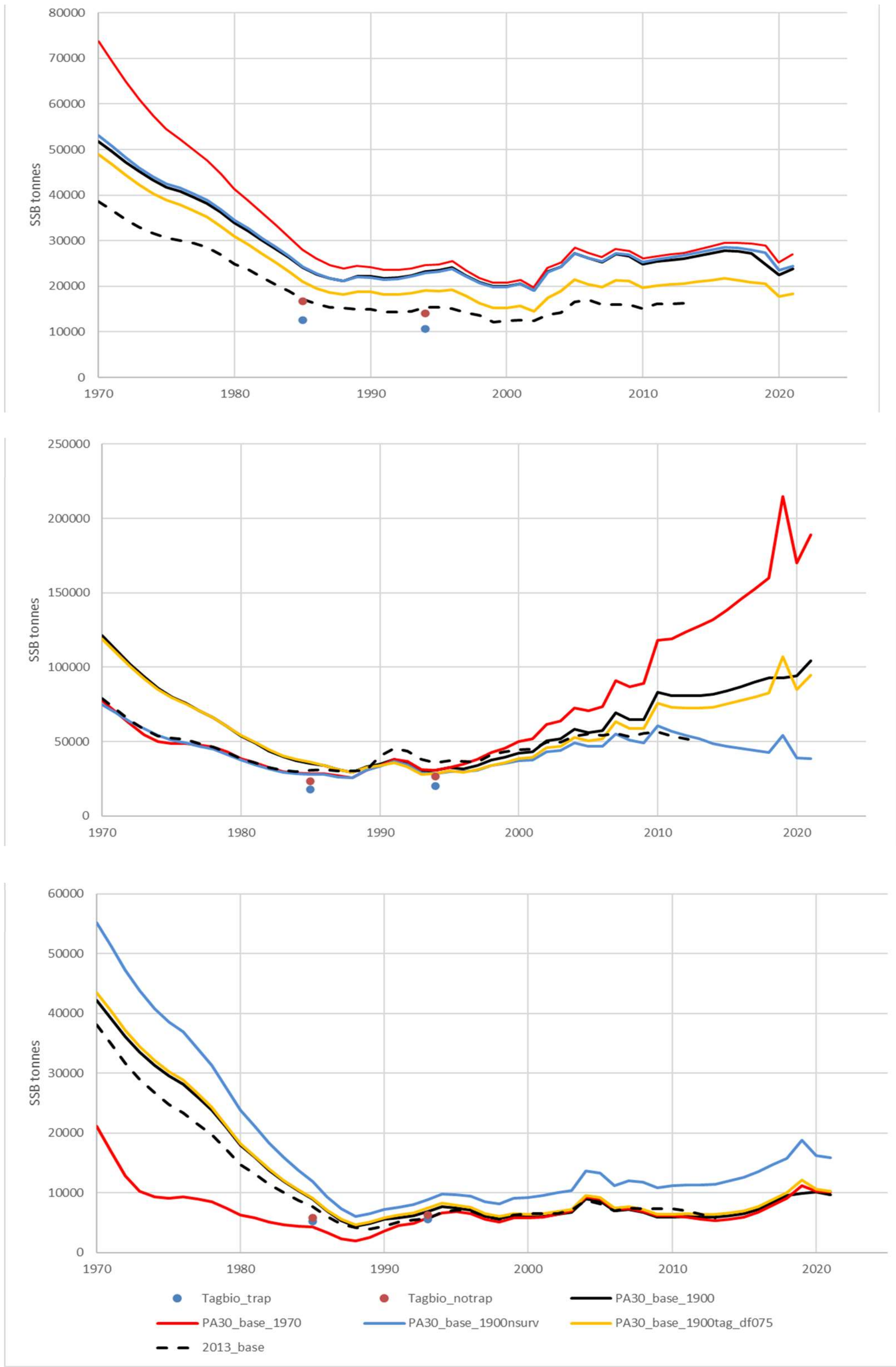


Figure 53: SNA 1 stock comparative model SSB trajectories. 2013 base-case assessment model B0s shown for comparison; a. east Northland; b. Hauraki Gulf, c. Bay of Plenty.

The 2022 SNA 1 assessment Working Group and Plenary made the following recommendations for the 2023 SNA 1 assessment.

1. Revise and simplify assessment SNA 1 2023 model structure.

The Working Group felt that there was insufficient power in the available observational data (particularly the tagging observational data) to reliably estimate movement across the SNA 1 three-stock complex within a single model framework. In the light of there being minimal tag movement between east Northland and the other two SNA 1 stock areas, it was recommended that: (1) the east Northland stock be assessed and modelled as a standalone stock; while (2) the Hauraki Gulf and Bay of Plenty SNA 1 stocks still be assessed as a linked stock complex using a two-area HF modified version of the 2022 SNA 1 model.

The Plenary recommended continuing to explore the start-1970 modelling approaches to get around reliance on highly uncertain pre-1970 SNA 1 catch histories to inform B_0 and also having to make assumptions as to pre-1970 growth rates. For all new 1900 model variants it was recommended that all commercial pre-1960 catches are assumed to have been taken by bottom trawl.

2. Review the Hauraki Gulf and Bay of Plenty trawl survey data series for catchability issues.

There was concern that changes in Hauraki Gulf and Bay of Plenty adult snapper distributional patterns may have affected trawl survey catchability (q). It was therefore recommended that the survey series data be investigated for evidence of spatio-temporal distributional changes. It was also recommended that the minimum age of the survey adult abundance indices be increased to age 6+ and that the abundance indices going into the models be expressed as numbers not biomass.

3. Investigate the utility of bottom trawl CPUE as relative abundance measures for Hauraki Gulf and east Northland (as a replacement to the current longline CPUE series).

Snapper is one of several species taken by bottom trawlers in SNA 1, so it was thought that bottom trawl CPUE may be less prone to hyperstability than snapper target longline fisheries.

4. Review current SNA 1 spatial stock boundary assumptions.

The Plenary recommended reevaluating the SNA 1 stock boundary assumptions by conducting spatial-temporal analyses of available abundance, compositional and tagging data.

5. Reanalysis of the 1985 and 1993 tagging programme mark-recapture data.

The Plenary recommended that the 2023 SNA 1 new assessment models should not be fitted to release-recovery observational data directly as was done by the 2022 SNA 1 models. Instead, the 2023 SNA 1 models should be fitted to independently derived biomass and movement parameter values from Petersen-type estimators.

3 SNA 1 SPATIAL STOCK STRUCTURE REVIEW

The SNA 1 spatial stock structure was reviewed for the 2013 assessment (Francis & McKenzie 2015b). Spatial differences seen in age-structure, growth rates and abundance (longline CPUE) resulted in the three sub-stock hypothesis being reaffirmed. There was less certainty, however, about the validity of the purported SNA 1 sub-stock boundaries (Francis & McKenzie 2015b). Prior to the 2023 SNA 1 assessment, spatio-temporal models were fitted to longline CPUE and CPUE-at-age data to re-examine the three sub-stock hypothesis, as well as to understand seasonal ecological patterns in SNA 1. Bottom trawl CPUE and longline catch at-age analyses were also carried out to further explore the validity of the assumed sub-stock boundaries.

3.1 SNA 1 VAST stock structure analyses

Methods

Generalised linear mixed models implemented using R package "VAST" (Thorson, 2019) were fitted to SNA 1 commercial longline data to gain an improved understanding of stock spatio-temporal dynamics (Grüss et al. 2023). Two types of SNA 1 longline data were used in the analyses: CPUE data for 2008–2020, for all snapper ages combined; and CPUE-at-age data for the most recent years during which longline catch at-age sampling occurred, i.e., 2008, 2009, 2010, 2013, 2018 and 2020.

Specifically, the VAST spatio-temporal modelling was aimed at fulfilling two objectives: (1) to better understand seasonal ecological patterns in SNA 1; (2) to assess the validity of the current SNA 1 sub-stock spatial boundaries (Figure 1). The VAST analytical work also generated indices of relative abundance and proportion-at-age estimates for the ENLD, HAGU and BOP sub-stocks; these were compared to indices of relative abundance and proportion-at-age estimates for SNA 1 generated using standard approaches and can be found in Grüss et al. 2023.

Objective 1 required spatio-temporal investigations of the following VAST model predicted quantities: median log-density across all years, interannual variability in log-density, and long-term abundance trend (derived from the models fitted to longline CPUE data); and median mean age across all years, and long-term trend in mean age (derived from the models fitted to longline CPUE-at-age data). These five quantities were computed for each cell of a 1 km × 1 km prediction grid constructed for the SNA 1 region. The analysis involved seeing whether the spatial patterns of these quantities and their distribution across the three strata (ENLD, HAGU and BOP) differed largely between seasons (spring, summer, autumn, winter) and between semesters (spring-summer, autumn-winter).

For Objective 2, the five above-mentioned quantities were further analysed, and hierarchical clustering analyses were performed on them (Grüss et al. 2023). Pairwise spatial distances between the cells of the prediction grid were ignored in the analyses, to obtain groups (clusters) that reflect only ecological distances between prediction grid cells. Hierarchical clustering analyses were only performed for semesters, i.e., spring-summer and autumn-winter, as two of the VAST quantities (median mean age and long-term trend in mean age) were available for semesters but not for seasons.

Results

Objective 1 - Understanding seasonal ecological patterns in the SNA 1 stock

The estimated spatial patterns of median log-density largely differed between spring and summer and autumn and winter (Figure 54). More precisely, median log-density was predicted to be significantly higher in HAGU in spring and summer, but not in autumn and winter where high median log-density values were more widespread among the HAGU, ENLD and BOP strata (Figure 54). Thus, the median log-density predictions suggested the existence of migrations between HAGU and ENLD at the end of summer and at the end of winter, but also the existence of migrations from HAGU to BOP at the end of summer and from BOP to HAGU at the end of winter.

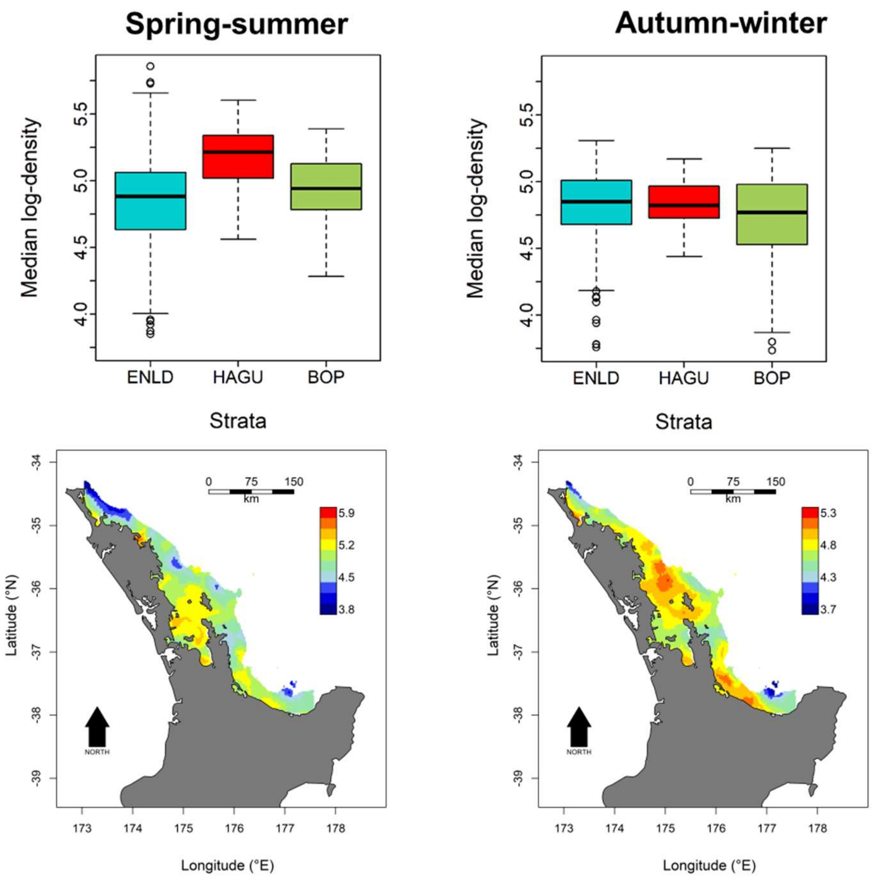


Figure 54: Median log-densities predicted by the spatio-temporal models fitted to the snapper bottom longline catch-per-unit-effort data collected in spring-summer and autumn-winter. The top panels show the distribution of the median log-densities estimated for East Northland (ENLD), Hauraki Gulf (HAGU) and Bay of Plenty (BOP), while the bottom panels show the spatial patterns of median log-density predicted by the spatio-temporal models.

The maps of stable high-density areas (which can be interpreted as "core areas") and variable low-density areas (which can be interpreted as "transition areas") also suggested the existence of migrations from HAGU to ENLD and BOP at the end of summer and from ENLD and BOP to HAGU at the end of winter (Figure 55 and figure 4 of Grüss et al. 2023). Relatively clear transition areas were predicted between HAGU and ENLD and between HAGU and BOP in all seasons (Figure 55 and figure 4 of Grüss et al. 2023). The spatial distribution of the core areas within each of the three strata (ENLD, HAGU and BOP) largely differed between spring and summer and autumn and winter, with, in particular, the extent of core areas in HAGU decreasing in autumn (and increasing in spring) and the extent of core areas in BOP increasing in autumn (and decreasing in spring) (figure 4 of Grüss et al. 2023). Similar seasonal patterns were also seen in the CPUE-at-age data (Grüss et al. 2023).

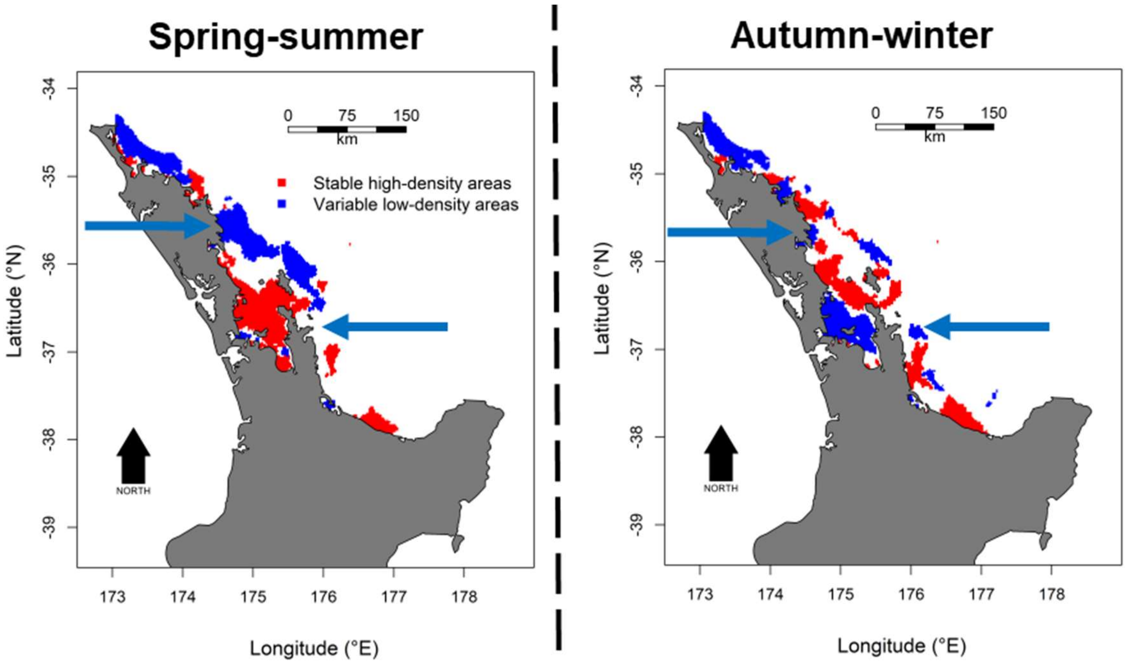


Figure 55: Stable high-density areas (in red) and variable low-density areas (in blue) predicted by the spatio-temporal models fitted to the snapper bottom longline catch-per-unit-effort data collected in spring- summer and autumn-winter. Blue arrows indicate the variable low-density areas located between East Northland (ENLD) and Hauraki Gulf (HAGU) and between HAGU and Bay of Plenty (BOP), which can be interpreted as "transition areas".

Objective 2 - Evaluating current hypotheses about the structure of the SNA 1 stock

Dendrograms resulting from the hierarchical clustering analyses were cut into three clusters and the resulting outcomes evaluated (Figure 56). For both spring-summer and autumn-winter, the great majority of HAGU and BOP cells fell within Cluster 1, the great majority of Cluster 2 cells fell within the HAGU stratum, and the great majority of Cluster 3 cells fell within the ENLD stratum. The derived quantities for Cluster 3 tended to reflect the derived quantities estimated for ENLD (highest interannual variability in log-density and smallest long-term abundance trends compared to the other clusters, larger long-term trends in mean age), while it was less clear whether the derived quantities for Clusters 1 and 2 reflected the derived quantities estimated for BOP and HAGU, respectively (Figure 56). All these results, as well as the spatial distribution of the three clusters, suggested that ecological patterns in ENLD are significantly different from those in the HAGU and BOP strata, and that ecological differences are less marked between HAGU and BOP (Figure 56).

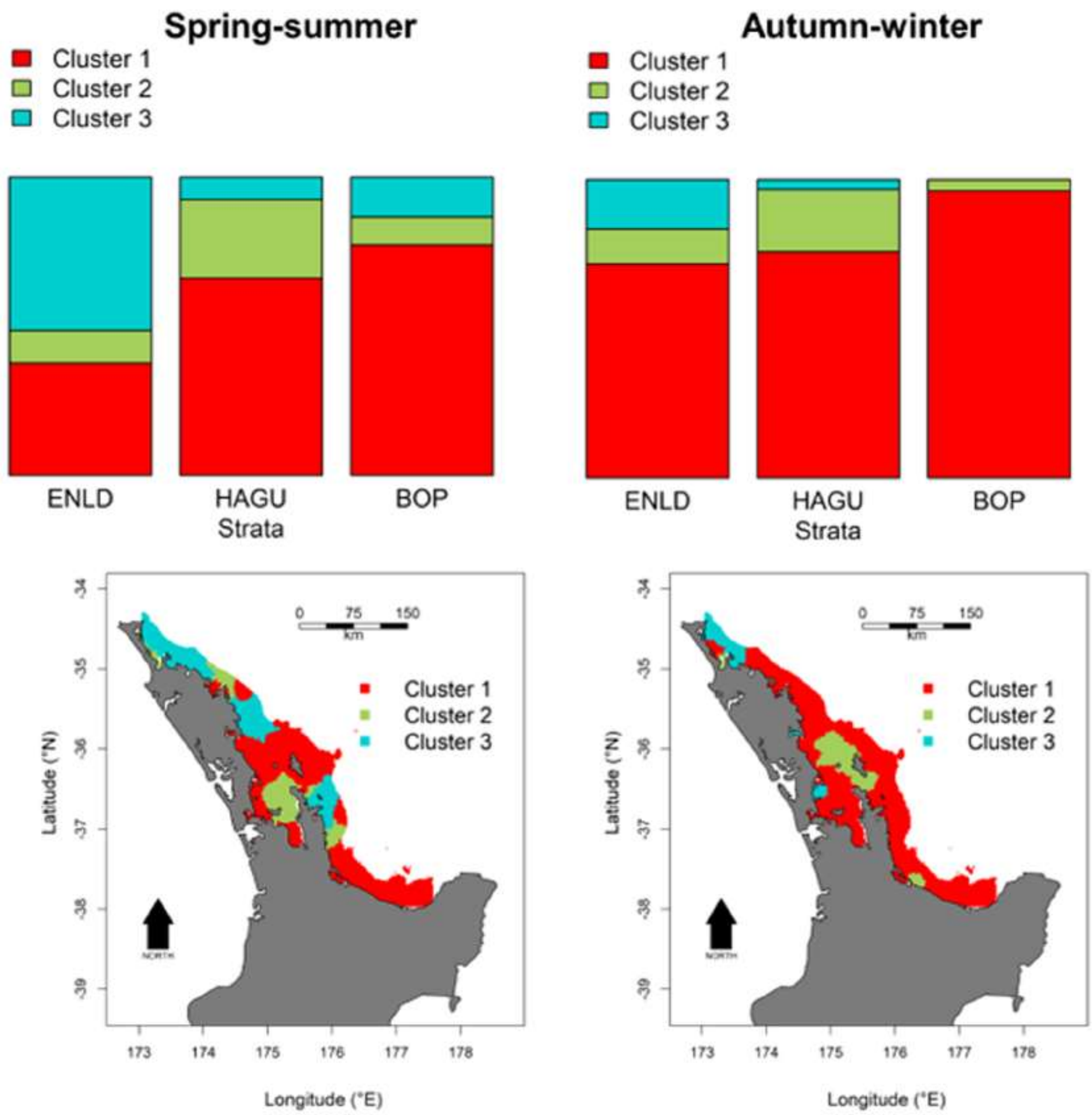


Figure 56: Results of the hierarchical clustering analyses when cutting the dendrograms into three groups, leading to the definition of three clusters. The top panels show the proportion of East Northland (ENLD), Hauraki Gulf (HAGU) and Bay of Plenty (BOP) grid cells falling into each of the three clusters, while the bottom panels show the spatial distribution of the three clusters in the study region.

Conclusions

Clear evidence of seasonal distributional changes (migrations) in SNA 1 were seen in the VAST analysis results. Several spatio-temporal model products (indices of relative abundance, median log-densities, and maps of stable-high density and variable low-density areas) indicated the existence of migrations between ENLD and HAGU and between HAGU and BOP at the end of summer and at the end of winter. The VAST analyses identified variable low-density areas located between the ENLD and HAGU and between HAGU and BOP sub-stock regions which may correspond to transition boundary zones (Figure 55).

The analysis of the five quantities derived from spatio-temporal model predictions (median log-density, interannual variability in log-density, long-term abundance trends, median mean age, and long-term trends in mean age) confirmed that it is reasonable to distinguish between the ENLD, HAGU and BOP sub-stocks in the SNA 1 stock assessment model (Grüss et al. 2023).

The results from the three-group hierarchical clustering analyses indicated that ecological differences were more marked between ENLD and the HAGU and BOP strata than between HAGU and BOP. This result concurs with historical stock structure evidence (Section 2.2.1).

3.2 Bottom trawl CPUE (see also Langley 2023)

Spatial analyses of SNA 1 bottom trawl CPUE were also undertaken using standard GLM modelling approaches to separately model the occurrence of snapper catches (presence/absence) and the magnitude of positive snapper catches (Langley 2023). The dependent variable of the catch magnitude CPUE models was the natural logarithm of catch. The positive catch CPUE models assumed a lognormal error structure. The presence/absence of snapper catch was modelled based on a binomial distribution.

The Langley (2023) study focused on the component of the trawl fishery within the East Northland and Hauraki Gulf areas of SNA 1. These areas were defined by Statistical Areas 002–006[5] (Figure 1). The East Northland and Hauraki Gulf areas accounted for about 50–60% of the annual trawl catch from SNA 1, with the remainder of the catch taken from the Bay of Plenty (Statistical Areas 008–010). Langley partitioned Statistical Area 003 into northern and southern regions at latitude 35° 30’ S (north of Tutukaka), corresponding to a discontinuity seen in the distribution of trawl effort.

Methods

The SNA 1 bottom trawl data were limited to a set of (core) vessels based on the continuity criteria of a minimum of 20 trawls per year and a minimum annual snapper catch of 100 kg for at least five years. The core fleet accounted for 89.7% of the total snapper catch included in the initial data set. Snapper is taken by the SNA 1 bottom trawl fishers in conjunction with red gurnard, John dory, tarakihi, and trevally.

GLM analyses were based on individual event trawl catch and effort records from 1995–96 to 2020–21 for the spring-summer period. This data set consisted of Trawl Catch Effort and Processing Return (TCEPR), Trawl Catch Effort Return (TCER) and Electronic Reporting Systems (ERS) trawl-based catch and effort records. Catch reporting was standardised between reporting formats by restricting snapper catch records to be amongst the five largest estimated species catches from an individual trawl (‘top-5 species’). For each trip, the landed catch of snapper was apportioned amongst the individual trawl records in proportion to the (top 5) estimated catches of snapper. Snapper landed catches from trips without corresponding estimated catches were distributed equally amongst trawl records.

A stepwise fitting procedure was implemented to configure each of the CPUE models. The fitting procedure considered the range of potential explanatory variables (Table 28) with the continuous variables typically parameterised as a third order polynomial function. Spatial variation in snapper catch rates was incorporated in the CPUE models by allocating individual trawl records to 0.5-degree latitude/longitude grid cells (16) based on the start position of the trawl. Variables in addition to fishing-year (Table 28) were included in the model until the improvement in the Nagelkerke pseudo-R^2 was less than 0.5%.

[5] Note: bottom trawl method is prohibited in Statistical Area 007 and part of 006.

Table 28: Variables offered in the SNA 1 bottom trawl GLM standardisations (from Langley 2023).

Variable	Definition	Data type	Range
Vessel	Fishing vessel category	Categoric	
FishingYear	Fishing year	Categoric	1996–2021
Month	Month	Categoric	1–12
StatArea	Statistical Area	Categoric	002–006
Latlong5	0.5 degree lat/long cell	Categoric	
Depth	Trawl depth (start) (m)	Continuous	5–200
Duration	Natural logarithm of trawl duration (hours)	Continuous	1–6
Speed	Trawl speed (knots)	Continuous	2–5
Distance	Natural logarithm of trawl distance (Speed×Duration)	Continuous	
StanTime	Trawl start time	Continuous	
GearWidth	Wingspread of trawl gear (m)	Continuous	
GearHeight	Headline height of trawl gear (m)	Continuous	1–25
SNAcatch	SNA trawl catch (kg)	Continuous	0–5000
SNAbin	Presence (1) or absence (0) of SNA catch in trawl	Categoric	

Results and conclusions

The implied coefficient trends for the two Hauraki Gulf statistical areas (005 and 006) and the southern part of 003 closely matched the overall model CPUE trend (Figure 57). The implied coefficient trends from Statistical Area 002 and the northern part of 003 markedly differed to each other and to the overall model predicted trend (Figure 57). This is strong evidence that at least the southern part of 003 should be part of the Hauraki Gulf sub-stock. It is ambiguous from the GLM results which sub-stock the northern part of 003 belongs to, and it more likely encompasses a zone of mixing. The Statistical Area 004 implied coefficient results are largely irrelevant as very little SNA 1 catch was taken from this region and the CPUE data was likewise scant (Figure 57).

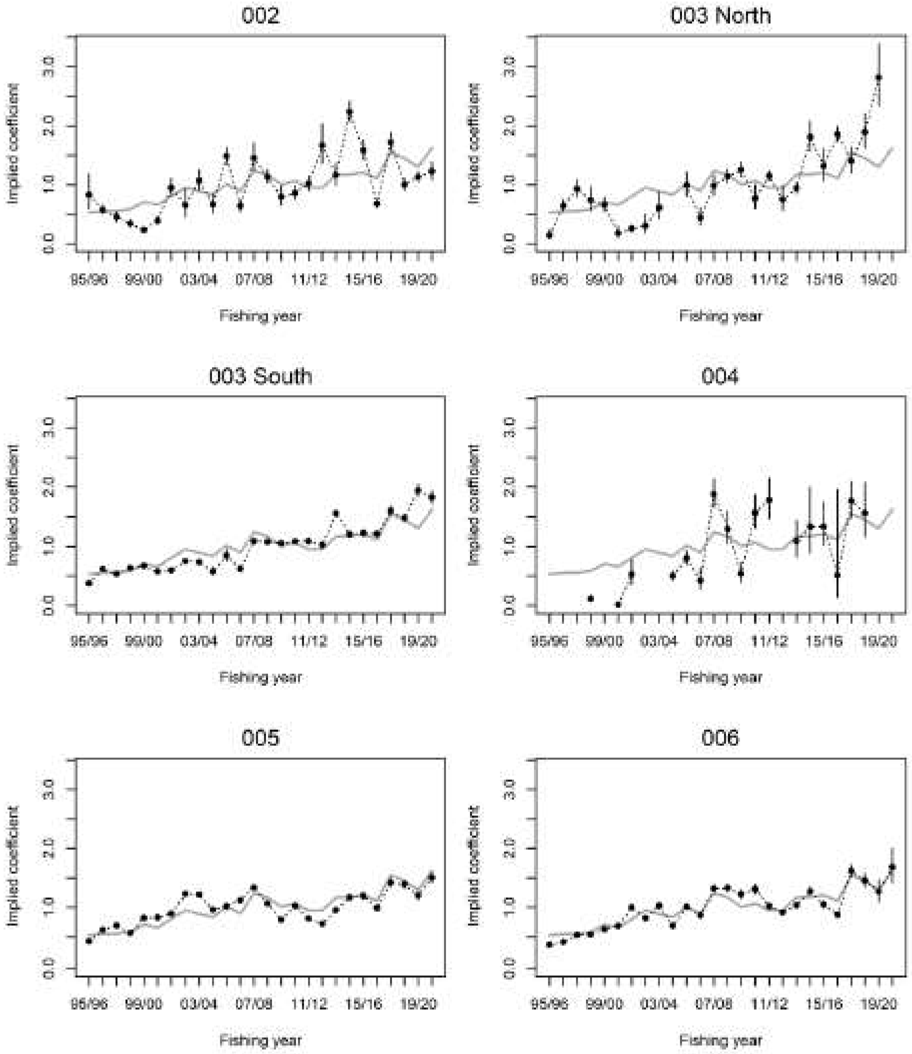


Figure 57: Annual implied coefficients (points) derived for spring-summer (October–March) for the individual Statistical Areas from the positive catch GLM fitted to bottom trawl data. Statistical Area 003 is partitioned into northern and southern areas. The grey line represents the annual CPUE indices derived from the positive catch CPUE model. The confidence intervals represent the standard error of the annual residuals (reproduced from Langley 2023).

3.3 Age structure spatial evidence

Longline catch at-age sampling data sufficient to spatially disaggregate the Statistical Area 002 and 003 components of the East Northland region of SNA 1 are available since the 1995–96 fishing year. Proportional at-age plots were produced for Statistical Areas 002, 003 and the Hauraki Gulf (004–006) representing all currently available sampling years since 1995–96 (Figure 58; Appendix 11). It can be concluded from the catch at-age time series that Statistical Area 002 consistently had a broader age range than the Hauraki Gulf statistical areas and a greater accumulation of age classes older than nineteen (Figure 58; Appendix 11). The Statistical Area 003 age compositions often appeared intermediary in age structure to the other two regions (Figure 58; Appendix 11). A Pearson correlation analysis of YCSs from each of the three areas as derived from catch curve analysis suggests a lack-of-similarity between east Northland 002 and the Hauraki Gulf statistical area YCSs and the intermediary similarity of east Northland 003 YCS (Table 29).

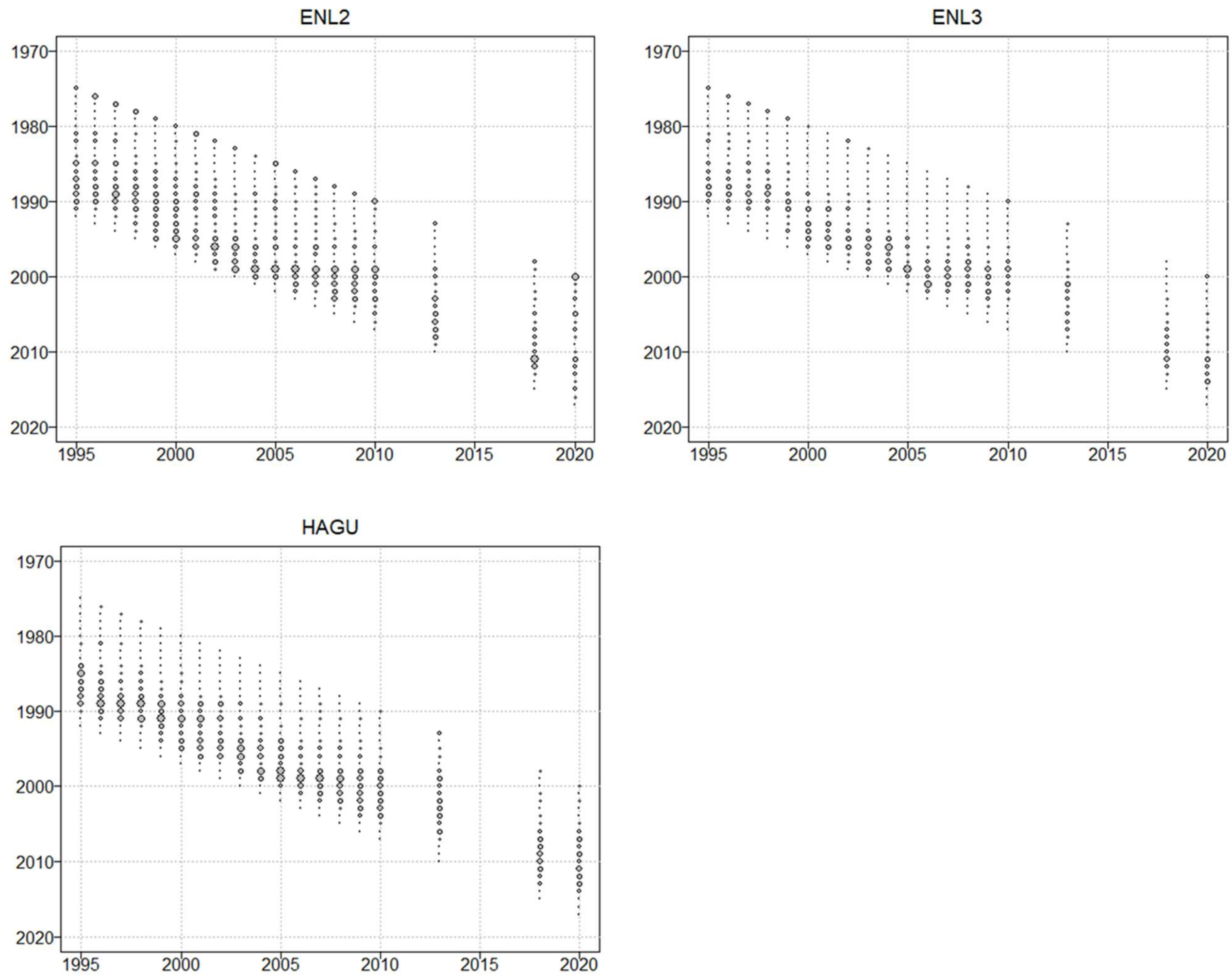


Figure 58: Time series of age frequency distributions by year class and year from the east Northland 002 (ENL2), 003 (ENL3) and Hauraki Gulf bottom longline spring-summer fisheries from 1994–95 to 2019–20. Symbol area is proportional to the proportion at-age. The proportion of the oldest year class in each year is represented by an aggregate (over 19 years) age group.

Table 29: Pearson correlation coefficients for catch curve residuals of year class strength for the 6–19 age classes in the east Northland 002 (ENL2), 003 (ENL3) and Hauraki Gulf bottom longline spring-summer fisheries from 1994–95 to 2019–20 subject to constraint that each age class used in the analysis must have appeared at least ten times in the data. Significant correlations are bolded.

	EN 003	HG	
EN 002	**0.88**	0.43	Coeff
	<0.001	0.14	p(Coeff = 0)
EN 003		**0.8**	Coeff
		<0.001	p(Coeff = 0)

3.4 Growth rate spatial evidence

Mean weight at-age trends derived from longline age sampling data from Statistical Areas 002, 003 and the Hauraki Gulf (004–006) all showed declining growth rate trends (Figure 59). East Northland Statistical Area 003 growth rates were clearly intermediary to the other two region growth rates (Figure 59).

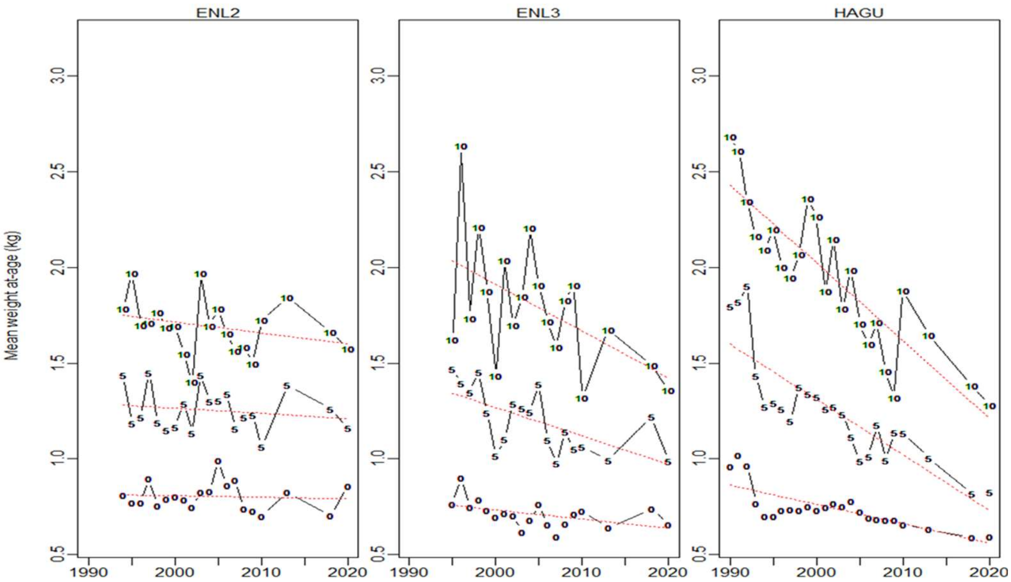


Figure 59: Mean weight at-age (binned by 5 cm age class) for east Northland 002 (ENL2), 003 (ENL3), and Hauraki Gulf bottom longline spring-summer fisheries from 1994–95 to 2019–20. The plotting symbols identify the age-class bin (e.g., '5' = 5–9). Mean weight trends are shown by regression lines (red dotted lines).

3.5 Conclusions and Recommendations

The SNA 1 longline VAST, bottom trawl CPUE, and longline at-age analyses all have shown that the past assumption of Statistical Area 003 being solely part the east Northland sub-stock region was likely to have been flawed. The bottom trawl CPUE analysis suggests that snapper south of latitude 35° 30' S (north of Tutukaka) in Statistical Area 003 more likely belong to the Hauraki Gulf stock complex. Where the snapper biomass residing in the northern region of Statistical Area 003 belongs to is unknown; both the VAST and bottom trawl analyses suggest that this area is likely to be a mixing or stock transition zone. For pragmatic reasons, the Working Group decided that the northern 003 catch history should also be assigned to the Hauraki Gulf for the purposes of the 2023 SNA 1 assessment. This decision was made simply because it was not feasible to subdivide the Statistical Area 003 catch history prior to 2007 due to the lack of spatial resolution in the catch report data prior to the 2007 fishing year. It would also not be possible to subdivide the at-age and tagging observational data series at scales finer than the statistical areas.

Therefore, for the purposes of the 2023 SNA 1 assessment the stock spatial definitions were as follows: east Northland Statistical Area 002; Hauraki Gulf Statistical Areas 003, 004, 005, 006, 007; Bay of Plenty Statistical Areas 008, 009, 010. These revised area definitions necessitate rederiving east Northland and the Hauraki Gulf commercial and recreational catch histories back to 1900.

The VAST analyses reaffirmed the occurrence of seasonal migration within the SNA 1 stock complex. The lack of accounting for seasonal movement in all past SNA 1 stock assessments is a long-acknowledged source of uncertainty. However, the available SNA 1 observational time series lacked sufficient temporal resolution to support seasonal migration estimation in the assessment. Thus, for the

2023 SNA 1 assessment, it was again infeasible to explicitly incorporate seasonal stratification in the models.

4 2023 SNA 1 ASSESSMENT REVISED CATCH HISTORIES

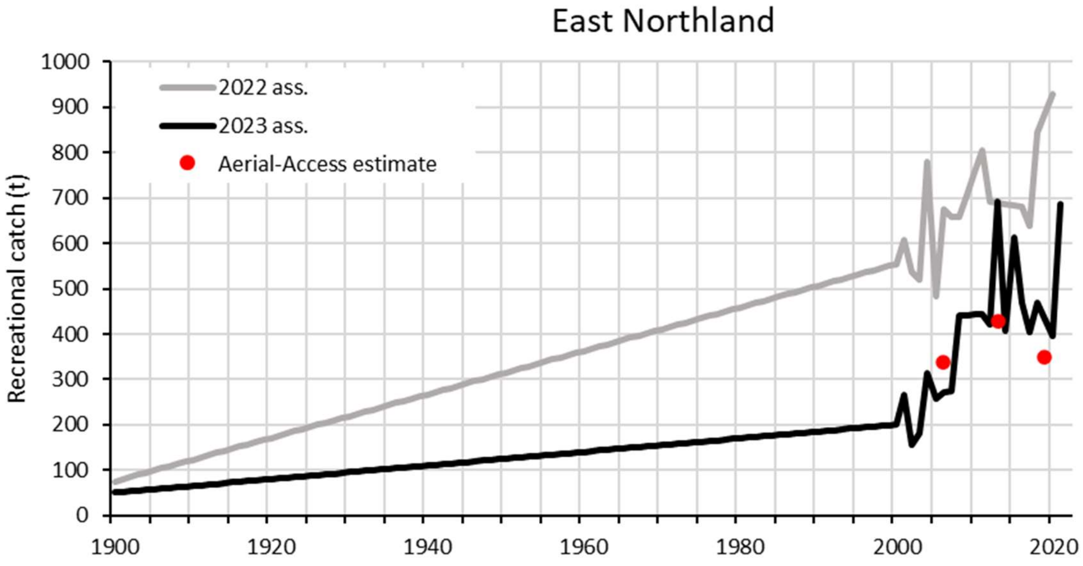
4.1 Commercial Catch

Including Statistical Areas 003 and 004 into the Hauraki Gulf stock region required regenerating the Hauraki Gulf and east Northland commercial catch histories back to 1900 with the new boundary definition. The Bay of Plenty commercial catch history compiled for the 2022 assessment remained unchanged. The commercial catch histories for all three sub-stocks were also updated to include the 2021–22 fishing year catches (Appendix 12).

It was infeasible to derive catch history profiles with the new east Northland/Hauraki Gulf boundary before 1982–83, when catch reporting against the modern statistical area definitions commenced. The reasons for this along with a description of how new east Northland and Hauraki Gulf catch histories were derived are given in Appendix 12.

4.2 Recreational catch

East Northland and Hauraki Gulf recreational catch histories were re-estimated with the revised boundary definition (Appendix Figure 61), using methods described in Appendix 3 and Appendix 13. East Northland and Hauraki Gulf revised catch histories are shown in Figure 60 and are also given in Appendices 13 and 14. The Bay of Plenty recreational catch history was unchanged from that compiled for the 2022 assessment (Figure 4).



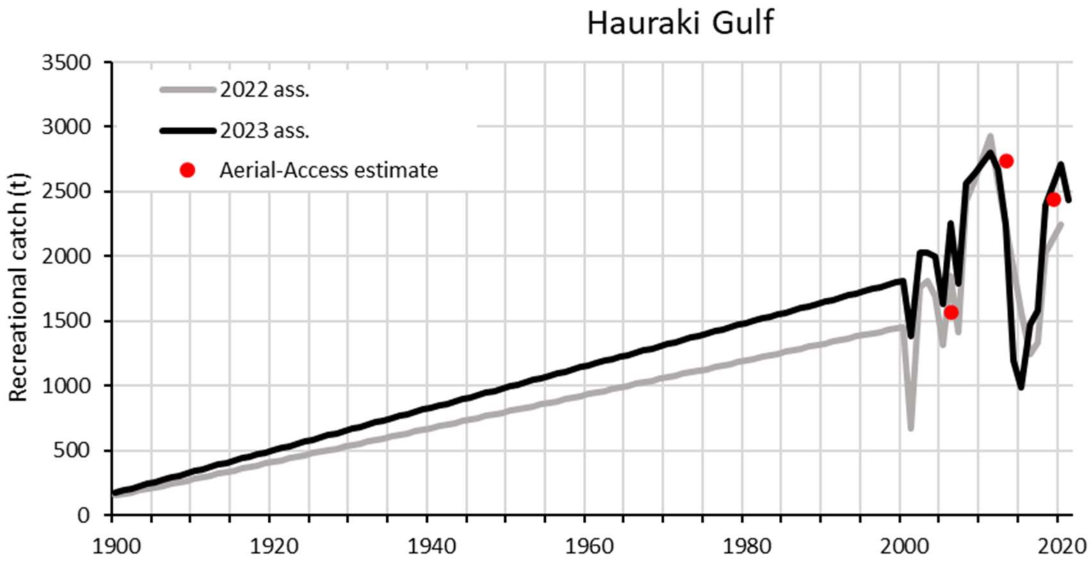


Figure 60: SNA 1 regional annual recreational harvest 1900–01 to 2020–21. Post 2000–01 estimates derived with methods given in Appendix 3 and Appendix 14. Estimates back to 1900–01 were derived by ramping back from the regional 2000–01 estimated values to assumed 1900–01 catch values of: 50 t for East Northland; 175 t for Hauraki Gulf; 75 t for Bay of Plenty. Grey lines show catch histories assumed in the 2022 SNA 1 assessment.

5 2023 SNA 1 ASSESSMENT REVISED OBSERVATIONAL DATA

5.1 Tag biomass and tag movement estimation

Consistent with the recommendations in Section 2.3, the 1985 and 1994 tagging data were not fitted directly within the 2023 SNA 1 assessment models. Instead, sub-stock tag-biomass and tag movements estimates were independently derived for input to the models by fitting these data within Petersen tag estimator models.

Methods

Petersen tag estimator models, developed in R under Ministry of Fisheries project SNA2010-07 to validate SNA 1 agent-based simulation models (McKenzie et al. 2018), were applied to the 1985 and 1994 SNA 1 tagging data for the purposes of estimating sub-stock population-size and annual movement. The specific portion of the SNA 1 stock complex the tagging programmes were designed to estimate were the total number of snapper 25 cm and above that resided in each sub-stock at the time of tagging.

It was possible to reconfigure the 1994 tagging programme datasets to conform to the revised east Northland/Hauraki Gulf boundary definitions as the recovery data could be disaggregated to statistical reporting area resolution (i.e. 002 recoveries being specific to the new east Northland model definition). It was, however, not possible to restructure the 1985 tagging data to conform to the new sub-stock boundary definition. The approach taken for the 1985 tagging data was to reanalyse these data with the original sub-stock boundary definitions. The 1985 SNA 1 tagging programme did not include the Bay of Plenty sub-stock so the population estimate derived was the combined total for the east Northland/ Hauraki Gulf stock complex. The 1985 combined population tag estimate was then prorated to each sub-stock in proportion to east Northland/Hauraki population ratio as derived from the revised 1994 Petersen tagging analysis.

Only the 1994 tagging programme data (where tagging had occurred in all three sub-stocks) could be used to derive estimates of annual sub-stock proportional movement. A necessary assumption to applying these estimates in the 2023 SNA 1 assessment models was that movement rates had not changed significantly over the model history.

As discussed in McKenzie et al. (2011), the SNA 1 Petersen tagging estimates were derived specific to the time of release. Because the recovery of tagged fish occurred over subsequent 15-month periods in both the 1985 and 1994 tagging programmes several time-related factors could have altered the initial population mark-ratios, the main ones being initial mortality, tag-loss, trap-avoidance, under-detection, growth, and movement (McKenzie & Davies 1996; McKenzie et al. 2011). The tagging data used in the Petersen analyses were adjusted for tag-loss and initial mortality as described in Francis & McKenzie (2015a). Unlike the 2013 and 2022 SNA 1 assessments, the tagging data were not adjusted for trap-avoidance bias for the 2023 SNA 1 assessment as per the recommendation of the Working Group. The Petersen tag estimators were able to adjust for tag recovery under-detection using the 2013 SNA 1 assessment estimates (Francis & McKenzie 2015a). Due to the 15-month recovery phase required for both tagging programmes, it was highly likely that the initial population mark-ratios would have been altered by sub-25 cm (at the time of tagging) fish subsequently growing into the tagged population length-range. The Petersen estimators could allow for post-release growth by back-projecting the length composition of the examined catches (Appendix 14; McKenzie et al. 2011). To do this, the Petersen estimators used growth-increment observations from the recovered tagged fish to estimate the necessary von Bertalanffy growth parameters for growth back-projections (Appendix 14; McKenzie et al. 2011). The Petersen estimators were specifically designed to estimate, and adjust for, post-release tag movement between sub-stocks (Appendix 14; McKenzie et al. 2011). It was shown in McKenzie et al. (2011) that the tag population estimates for the right-hand tail of the population length distribution tend to be positively biased, this is simply due to the lower number of tag recoveries from the larger length classes. The Working Group thus recommended limiting the SNA 1 1985 and 1994 Petersen population estimation analyses to the 25–40 cm length-range.

The performance of the Petersen tag estimator model was validated using simulated data generated by the agent-based SNA 1 operating model developed by McKenzie et al. (2018) (see Appendix 14).

Biomass or numbers?

Most mark-recapture estimators provide population estimates in terms of numbers not biomass, the Petersen estimator being no exception to this. The Petersen estimator used for the 2023 SNA 1 assessment was, however, capable of providing biomass estimates by application of length-weight conversion parameters. To do this conversion the Petersen estimator needed to be provided with the "true" population relative length composition within each length-bin category in the analysis. These length compositions coming from scanned data relative length-frequencies. There was potential for bias in this process when the analytical bins were broad and the length composition of the examined catch within the bin did not match that of the "true" population (i.e. non-uniform selectivity in the recovery samples). A key assumption in the Petersen analysis is that the length composition of the released tags within each length-bin category were proportional to the true population at the time of release. If this is achieved, then the Petersen population estimates in terms of numbers will be relatively unbiased even under non-uniform size selection during the recovery phase. However, if the recovery length samples are not proportional to the true population, the Petersen derived biomass estimates are likely to be biased even though the population estimates in numbers are not. For this reason, it was decided to fit Petersen sub-stock population estimates in the 2023 SNA 1 assessment models as numbers not biomass.

Results

1994 tagging programme

The Petersen model fits to the 1994 revised boundary east Northland tag recovery data were not as good as the original boundary fits whereas the overall fit to the Bay of Plenty sub-stock was improved (Figure 61). It is important to note that the 1994 tagging programme was not designed to provide SNA 1 population estimates at smaller spatial resolutions than the original sub-stock areas. Post-hoc analysis of a smaller east Northland area resulted in substantially fewer tag recoveries available to the model for estimation (42 vs 118 Table 30). Despite no tag movement being observed between east Northland and Bay of Plenty sub-stocks with the new boundary definitions, the Petersen estimators produced similar movement estimates relative to the original and new boundary definitions (Table 31). Despite there being fewer tag observations to estimate the east Northland sub-stock population size and movement, the combined SNA 1 population estimates from the two Petersen models were similar as were the Bay of Plenty estimates (Table 30).

Table 30: Petersen 1994 SNA 1 tagging programme 25–40 cm sub-stock population estimates (numbers of fish).

Substock	Number tagged	Number scanned	Recovered tags	Population estimate	L 95%	U 95%
original boundaries						
East Northland	6 761	214 148	118	11 639 370	9 414 049	14 583 577
Hauraki Gulf	11 797	580 193	264	25 264 102	21 938 438	29 446 064
Bay of Plenty	3 212	195 897	62	12 013 558	7 998 989	16 796 000
Total	21 770	990 238	444	48 917 030	39 351 476	60 825 641
new boundaries						
East Northland	1 864	107 167	42	4 851 992	3 533 340	6 888 259
Hauraki Gulf	16 694	687 174	340	31 534 555	27 109 322	36 570 464
Bay of Plenty	3 212	195 897	62	12 284 935	8 670 094	16 993 375
Total	21 770	990 238	444	48 671 482	39 312 756	60 452 098

Table 31: Petersen 1994 SNA 1 tagging programme sub-stock area annual proportional movement estimates (number of tag recoveries).

original boundaries

	Recovery area		
Release area	east Northland	Hauraki Gulf	Bay of Plenty
east Northland	0.87 (107)	0.11 (7)	0.02 (4)
Hauraki Gulf	0.02 (18)	0.87 (232)	0.11 (14)
Bay of Plenty	0.07 (2)	0.19 (20)	0.74 (58)

new boundaries

	Recovery area		
Release area	east Northland	Hauraki Gulf	Bay of Plenty
east Northland	0.89 (39)	0.1 (3)	0.01 (0)
Hauraki Gulf	0.05 (16)	0.84 (306)	0.11 (18)
Bay of Plenty	0.09 (0)	0.2 (22)	0.71 (40)

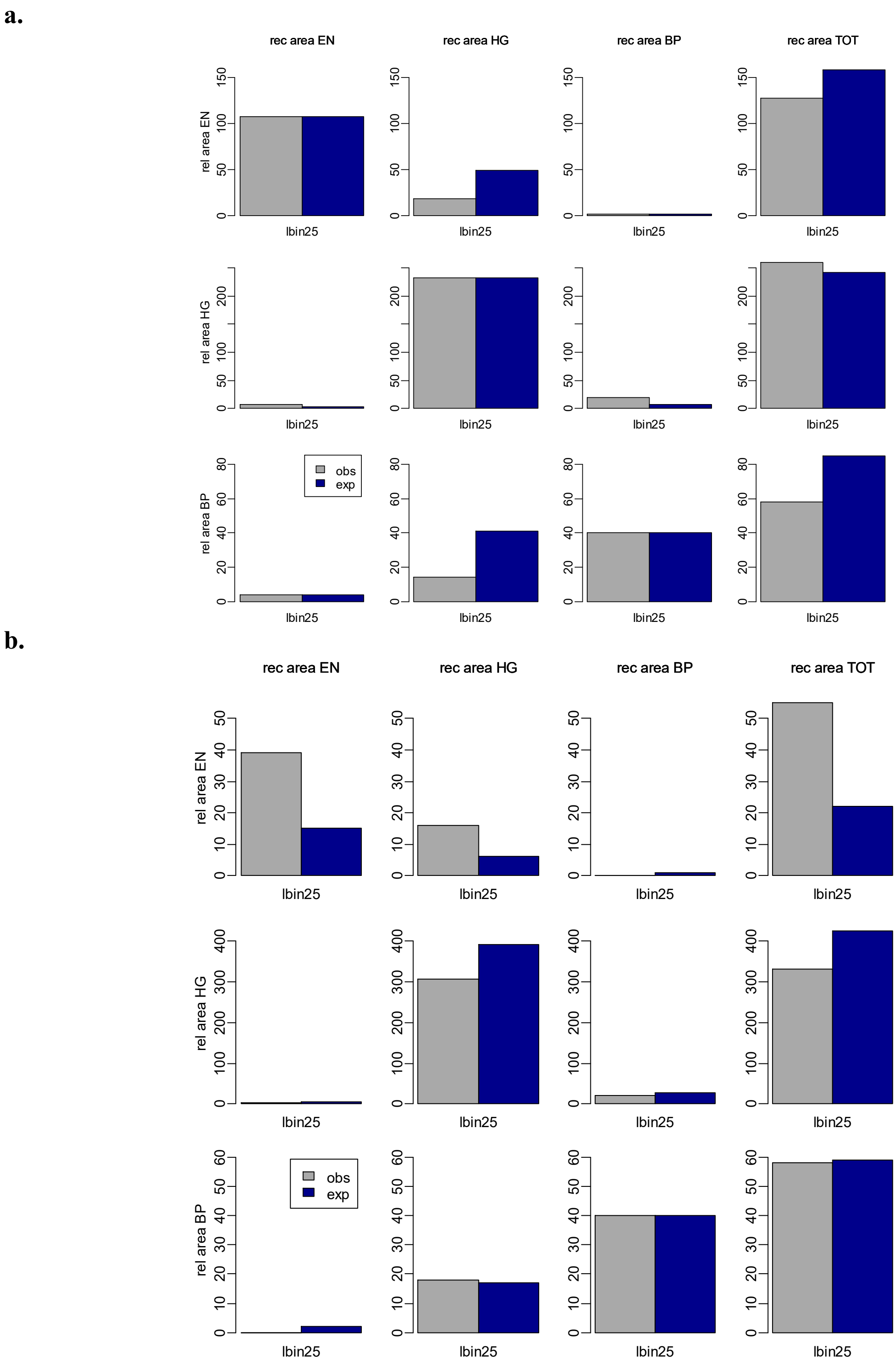


Figure 61: Petersen model fits to 1994 SNA 1 total observed tag snapper recoveries for the 25–40 cm length-bin class. a. original sub-stock boundary analysis, b. revised sub-stock boundary analysis.

1985 tagging programme

The Petersen model fits to the 1985 original boundary east Northland/Hauraki Gulf tag recovery data were reasonable (Figure 62). Applying the new boundary east Northland/Hauraki Gulf 1994 population ratio from Table 30 to the combined 1985 population estimate in Table 32 gave 1985 new boundary 25–40 cm population estimates of respectively 4 443 637 and 29 396 763 for east Northland and Hauraki Gulf respectively.

Table 32: Petersen 1985 SNA 1 tagging programme 25–40 cm sub-stock population estimates (numbers of fish).

Substock	number tagged	number scanned	recovered tags	population estimate	L 95%	U 95%
original boundaries						
east Northland	4 433	708 053	343	10 525 413	9 430 108	11 741 390
Hauraki Gulf	9 900	1 728 353	839	23 314 988	21 708 253	25 040 021
Total	14 333	2 436 406	1182	33 840 401	31 138 361	36 781 411

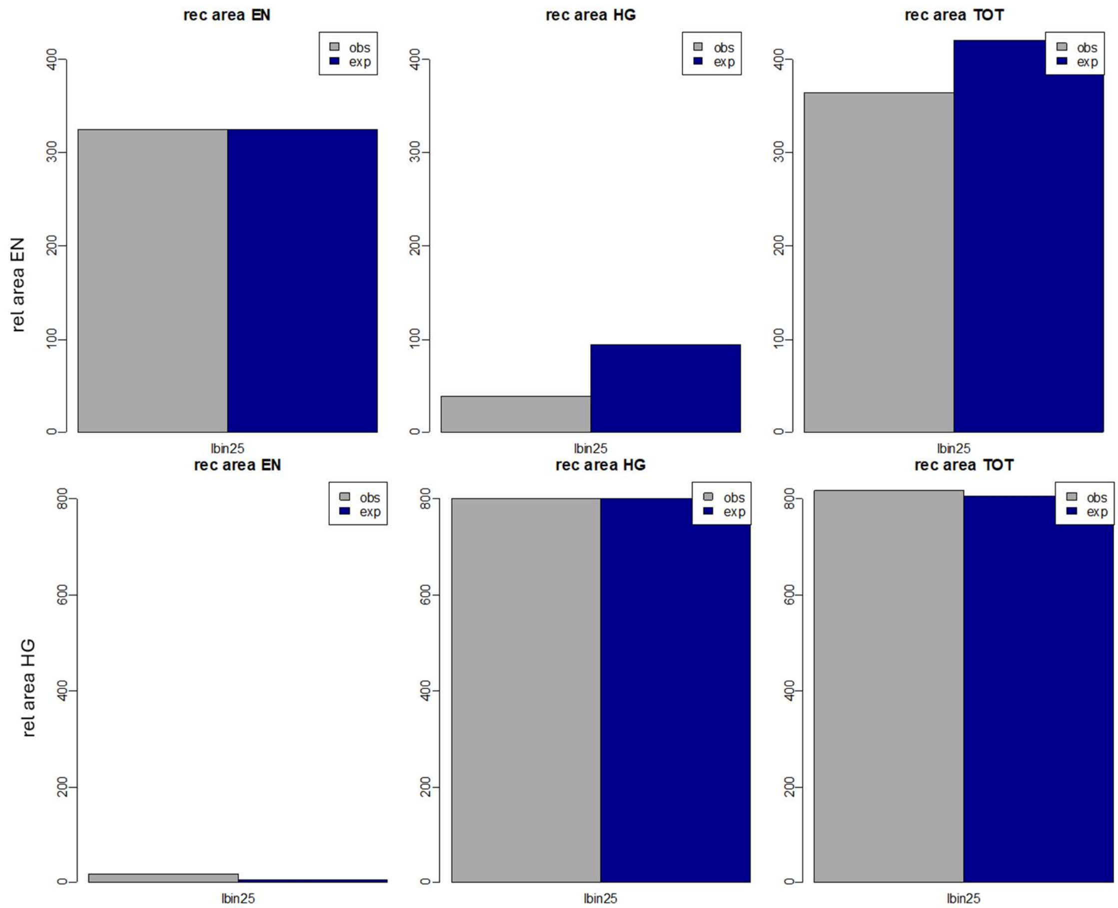


Figure 62: Petersen model fits to 1985 SNA 1 total observed tag snapper recoveries for the 25–40 cm length-bin class.

5.2 Relative Abundance data

5.2.1 Bottom trawl CPUE

New bottom trawl CPUE indices were derived for east Northland (Statistical Area 002 only) and the Hauraki Gulf (005, 006, 007) for the fishing-year period 1995–96 to 2020–21. The Bay of Plenty bottom trawl series used in the 2022 SNA 1 assessment was updated to include the 2020–21 fishing year.

The east Northland bottom trawl combined delta-lognormal index (Appendix 15) shows a pronounced increase after 2004–05, being relatively flat prior to this (Figure 63). The post 2005 increase was largely driven by the trend in the binomial index (Figure 63). Abundance is indicated to decline after 2014–15, this trend being predominantly driven by the log-normal index (Figure 63).

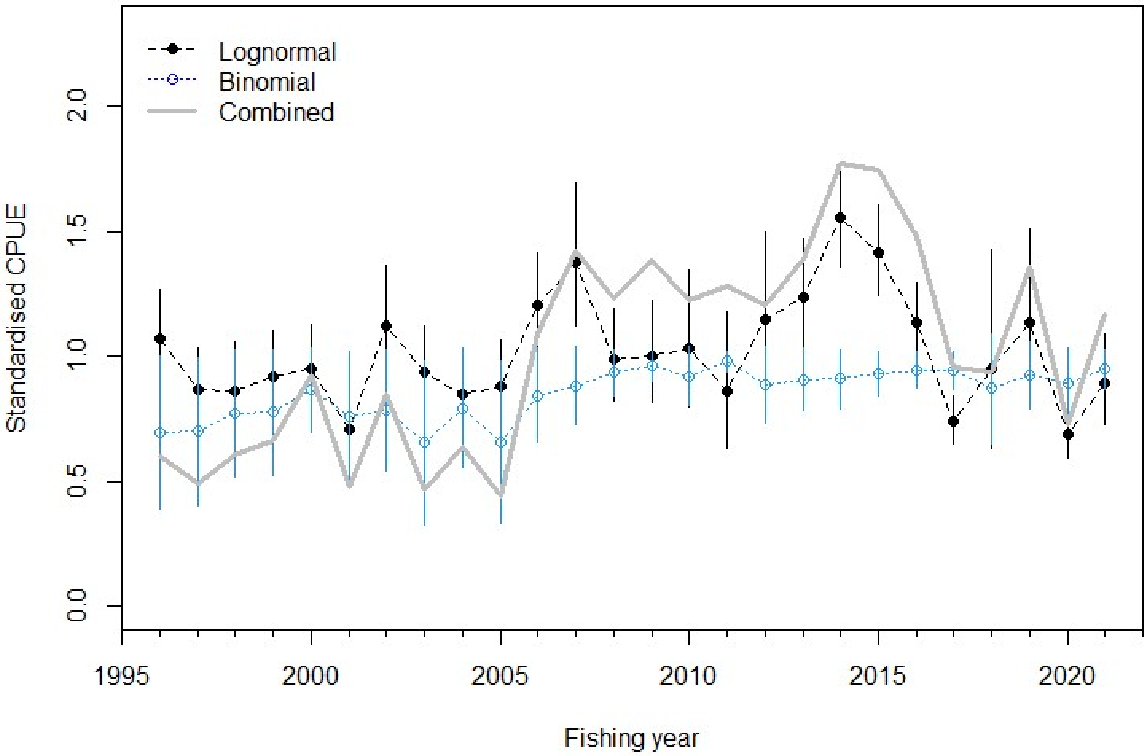


Figure 63: East Northland bottom trawl lognormal, binomial, and combined delta-lognormal indices.

The Hauraki Gulf bottom trawl combined delta-lognormal index (Appendix 15) shows a progressively increasing trend with very little effect from the binomial index (Figure 64).

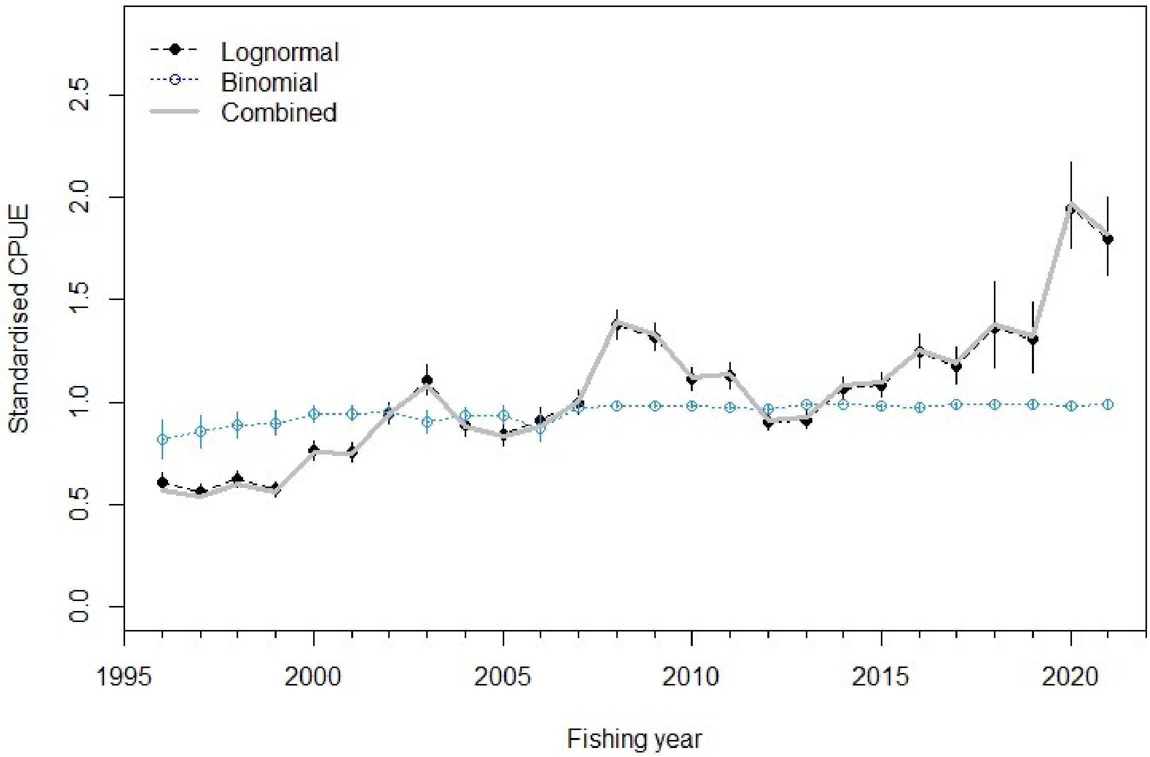


Figure 64: Hauraki Gulf bottom trawl lognormal, binomial, and combined delta-lognormal indices.

The Bay of Plenty bottom trawl combined delta-lognormal index (Appendix 15) shows a pronounced increase after 2015–16, being relatively flat prior to this (Figure 65). The trend in the binomial index was minimal and as a result the combined delta index closely matched the lognormal (positive catch) index (Figure 65).

The Hauraki Gulf and Bay of Plenty CPUE indices were "reasonably" consistent with the trawl survey relative 5+ indices (Figure 66).

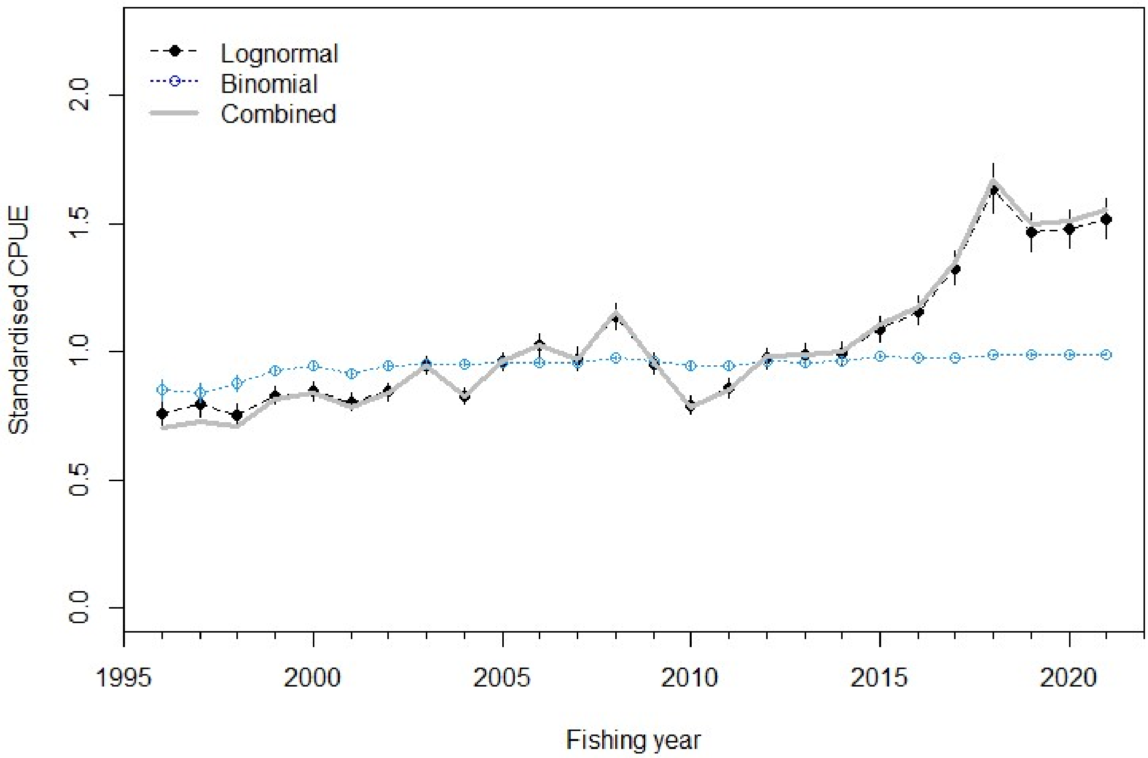


Figure 65: Bay of Plenty bottom trawl lognormal, binomial, and combined delta-lognormal indices.

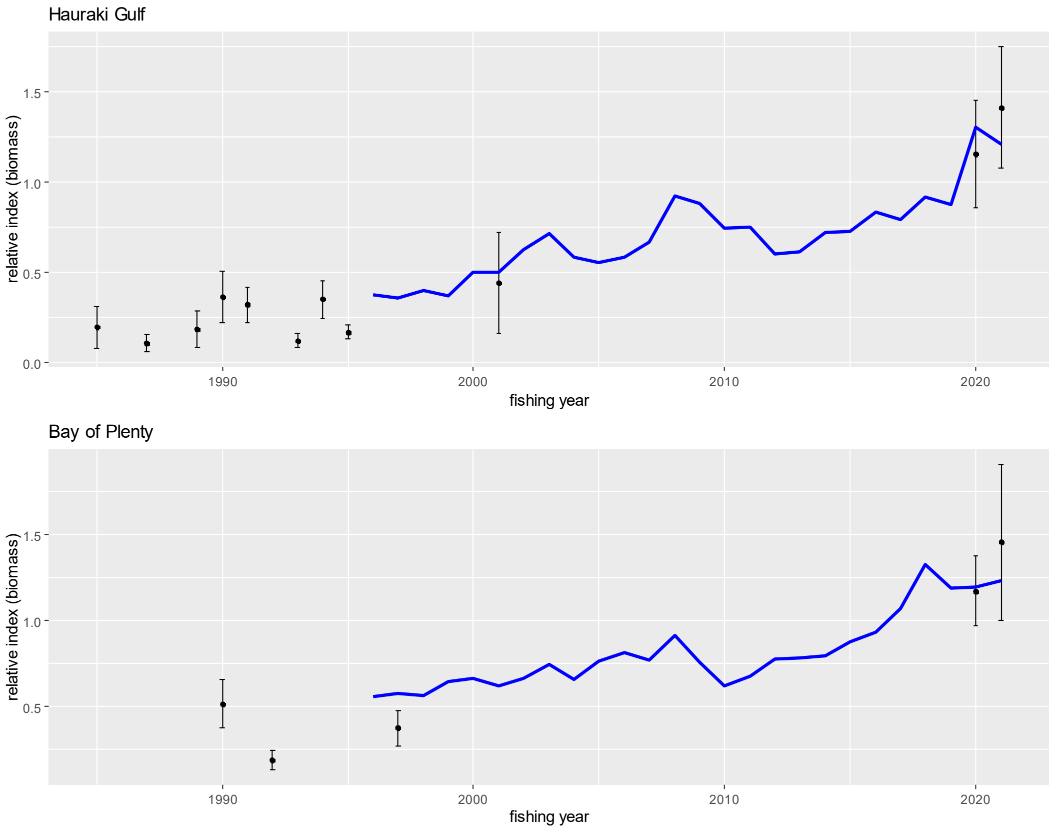


Figure 66: Hauraki Gulf and Bay of Plenty CPUE indices (blue lines) compared to the trawl survey 5+ biomass indices (black dots + 95% CIs) when plotted on the same relative scales.

5.2.2 Trawl survey revised indices

No new survey data were available for the 2023 SNA 1 assessment however slight changes were made in the way in which these data were fitted in the 2023 SNA 1 assessment models. For the 2022 SNA 1 assessment both the Hauraki Gulf and Bay of Plenty survey series data had been input to the models as five separate indices; there were four relative indices for each age class from one to four as numbers and a fifth index for ages five and above as biomass (Section 2.2.2). For the 2023 assessment six survey indices were used; five relative indices for each age class from one to five as numbers and a sixth index for ages six and above as biomass. The age one through four survey indices used in the 2023 SNA 1 assessment models were identical to those shown in Figure 5 and Figure 6. The new indices are shown in Figure 67 and Figure 68.

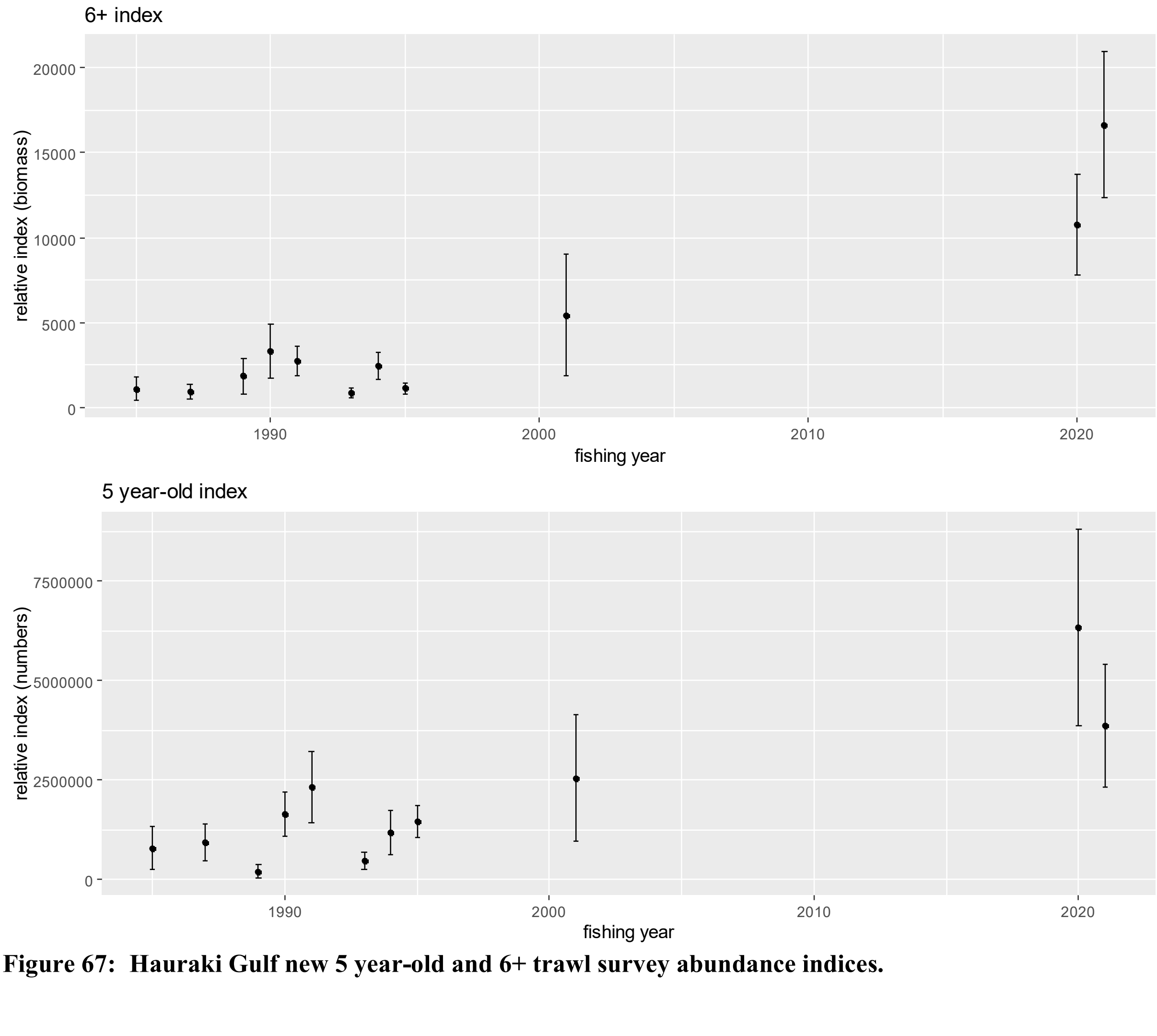


Figure 67: Hauraki Gulf new 5 year-old and 6+ trawl survey abundance indices.

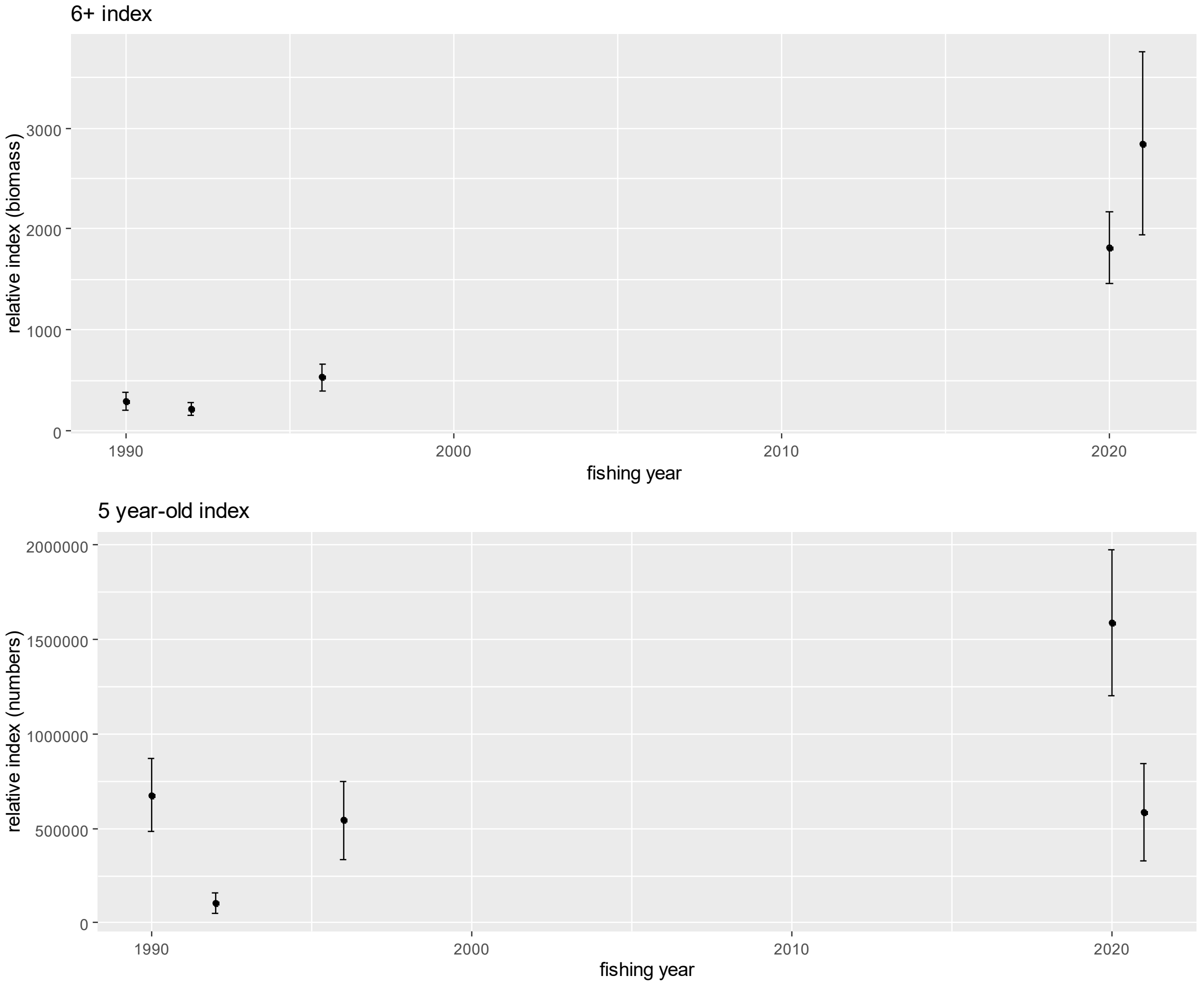


Figure 68: Bay of Plenty new 5 year-old and 6+ trawl survey abundance indices.

5.3 Compositional data

5.3.1 Commercial

No new commercial catch at-age data were available for the 2023 SNA 1 assessment. The east Northland/Hauraki Gulf boundary change did not require a reanalysis of the Hauraki Gulf and Bay of Plenty series. However, the Working Group recommended excluding the 1975 and 1976 Hauraki Gulf Danish seine at-age data from the 2023 SNA 1 assessment because of sampling representativeness concerns. All the available east Northland commercial compositional series required reanalysis to exclude samples that were not unique to Statistical Area 002, with the resultant loss of the 1985 longline and 2020 MHS datasets.

5.3.2 Recreational

Additional recreational length frequency data were available for the 2019–20 fishing year from all three new-boundary sub-stock regions. As with the commercial at-age data, only the east Northland sub-stock area at-age series required reanalysis by reapplication of the Statistical Area 002 recreational length data to 002 commercial longline age-length keys, again, there were no fishing-year data losses. Additional recreational at-age observations were also generated for the 2020 fishing year from all three sub-stocks.

6 2023 SNA 1 ASSESSMENT MODELLING OVERVIEW

The 2023 SNA 1 assessment models were built using NIWA's generic stock assessment package Casal2 (Casal2 Development Team 2022). In addition to having a faster more efficient code-base than its predecessor CASAL (Bull et al. 2012), Casal2 offered two important new functionality features that were to prove critical to the 2023 assessment:

1. the ability to perform parameter transformations prior to estimation, this is done to minimise poor MCMC convergence due to parameter correlation.
2. the ability to commence the models in a non-virgin state.

In accordance with model structural recommendations (Section 2.3), two Casal2 assessment models were developed to assess the status of the SNA 1 stock complex in 2023:

1. the east Northland sub-stock was assessed using a single-area stock model that assumed no interchange between it and the other two SNA 1 sub-stocks;
2. the Hauraki Gulf and Bay of Plenty sub-stocks were assessed using a two-area stock model that, like the 2013 and 2022 assessment models, could accommodate home-fidelity interchange between the two sub-stock areas.

The assessment model estimation periods were extended to include the 2021–22 fishing year, the CPUE and sub-stock catch histories accordingly extended to 2020–21 (Section 5.2.1).

Differences between the 2022 and 2023 SNA 1 assessment model catch histories and observational input data sets were described in Sections 4 and 5. Both the 2022 and 2023 assessments used age-structured catch history models that employed same gradient minimisers (MPD) and MCMC processes. The same mean length at-age sub-stock growth matrices developed for the 2022 assessment (Appendix 5), were also applied in the 2023 assessment models. Mean growth rates were applied outside the period defined by the growth matrices in the 2023 base models which differed from the nearest-neighbour approach used in the 2022 base models (Section 2.2).

R_0 was the equilibrium productivity parameter estimated by the 2022 assessment models whereas B_0 was the productivity parameter estimated by the 2023 assessment models. The 2022 assessment models made use of R_0 offset parameters ($R_{initial}$; Section 2.2.2) to commence the sub-stocks in non-virgin exploited states. For the 2023 assessment, sub-stock non-virgin starting states were modelled by application of an initial mortality rate parameter ($F_{initial}$), and an associated selectivity, to the estimated virgin state population and iterating this until the required exploited equilibrium state was established.

The $F_{initial}$ parameters were estimated in all the 2023 assessment models, however, the associated selectivity parameters could be fixed or estimated. Due to observed high estimation correlation between the B_0 and $F_{initial}$ parameters these were subsequently estimated in all 2023 assessment models via application of orthogonal transformations (Casal2 Development Team 2022). Transformations also proved necessary for estimating some 2023 model selectivity parameters (described below).

7 2023 EAST NORTHLAND SUB-STOCK ASSESSMENT

7.1 Base Model

The east Northland sub-stock was assessed using a single area model that assumed no interchange with the other SNA 1 sub-stocks[6]. The abundance and compositional data fitted in the east Northland assessment models are given in Table 33. Model estimable and fixed parameters are given in Table 34 and Table 35.

No east Northland bottom trawl and MHS compositional data were available to estimate selectivity for these methods specific to east Northland; the fixed selectivity parameter estimates for these methods used in the east Northland assessment models were the 2023 Hauraki Gulf and Bay of Plenty base model estimates (Table 35).

Table 33: 2023 east Northland base assessment model observational data inputs.

Type	Likelihood	Source	Range of years	No. of years
Relative abundance (CPUE)	Lognormal	Bottom trawl	1996–2021	26
Absolute population numbers (25–40cm)	Lognormal	Tagging	1985 & 1994	2
Age composition	Multinomial	longline	1994–2020	20
		recreational fishing	1994–2020[1]	14

[1]All age composition data sets were split into pre-1995 (2 years), post-1995 (11 years) and post-2015 because recreational selectivity was assumed to change in 1995 and in 2015 due to minimum-legal-size changes

Table 34: 2023 east Northland base assessment model estimated parameters.

Type	Description	No. of parameters	Prior
B_0	Mean unfished Spawning Stock Biomass	1	uniform[1]
$F_{initial}$	1968 commence model initial exploitation parameter	1[2]	uniform[1]
YCS	Year-class strengths by year and stock	40[3]	lognormal[4]
Selectivity	long line (logistic)	2	uniform
	Recreational pre-1995 (double-normal)	3	uniform[5]
	Recreational 1995–2014 (double-normal)	3	uniform[5]
	Recreational post-2014 (double-normal)	3	uniform[5]
q	Bottom trawl catchability	1	uniform-log
		53(54[2])	

[1] B_0 and $F_{initial}$ parameters estimated as an orthogonal transformation in 1968 commence models
[2]1968 commence models only
[3]YCSs were estimated for years 1975–2014
[4]With mean 1 and coefficient of variation 0.6
[5]Parameter transformations necessary

[6] Note: interchange with the other SNA 1 sub-stocks was factored into the Peterson 1985 and 1994 Peterson population estimated fitted in the model (see Section 5.1).

Table 35: 2023 east Northland base assessment model fixed parameters.

Natural mortality	0.075 y^{-1}
Stock-recruit steepness	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]	$a = 3.49 \times 10^{-5}$, $b = 2.870$
Mean lengths at-age	provided for years 1989–2021
Coefficients of variation for length at-age	0.10 at-age 1, 0.20 at age 20
Selectivity	
Bottom trawl (double normal)[1]	$a_1 = 5.64$ y, $\sigma_L = 0.95$ y, $\sigma_R = 19.7$ y
MHS trawl (double normal)[2]	$a_1 = 8.12$ y, $\sigma_L = 2.2$ y, $\sigma_R = 145.8$ y
Pair trawl (double-normal)	$a_1 = 6$ y, $\sigma_L = 1.5$ y, $\sigma_R = 30$ y
$F_{initial}$ (uniform)	knife-edged at 25 cm
Petersen tag population estimates (double normal plateau)	$a_1 = 25$cm, $a_2 = 15$cm $\sigma_L = 0.001$ y, $\sigma_R = 0.001$

1 as estimated from the 2023 Hauraki Gulf assessment model as no east Northland ST compositional data available
2 as estimated from the 2023 Bay of Plenty assessment model as no east Northland MHS compositional data available

7.2 Model likelihoods, priors, penalties, and weighting

Bottom trawl CPUE assumed error

The east Northland bottom trawl CPUE abundance index was fitted with an assumed CV of 0.31 according to the 2022 SNA 1 base assessment model.

Compositional likelihood error

All compositional datasets were first assigned a multinomial error value as calculated from their derived analytical CVs, this being a standard approach in New Zealand stock assessments.

Tagging population estimates

The Petersen tag population estimates were fitted with lognormal error CVs of 0.3 (1985) and 0.2 (1994). The respective CVs were as agreed to by the Working Group and were based on Hessian matrix derived confidence intervals from the Peterson analyses (Table 30 and Table 32) with due regard for additional process error (e.g. trap avoidance, heterogeneous tag mixing).

Priors and Penalties

Except for the model year-class parameters, model parameter priors were either uniform or uniform-log (Table 34). Year-class priors were assumed to be log-normally distributed with a mean of one and a CV of 0.6 (Table 34). Strong likelihood penalties were applied in the model if the predicted biomass available to a fishery in any given year was less than the “true” catch history. Strong penalties were also applied when the mean of the predicted year-class strengths (YCSs) did not equal to one.

Model likelihood weighting

The Francis TA1.8 reweighting process was used to down-weight the individual compositional likelihoods relative to assumed error on the abundance likelihoods (Francis 2011).

7.3 1968 base model MPD results

Model fits

The east Northland base model decision came down to a choice between the 1900 commence and 1968 commence models. Both models achieved relatively equivalent fits to the observational data and almost identical likelihood scores under identical weighting (1900: 686.27; 1968: 686.93). The Working Group accepted the 1968 start model as the preferred base because of greater certainty in the catch history going into this model.

The 1968 base model captured the overall abundance trend seen in the east Northland bottom trawl CPUE but was unable to replicate the predicted peak in 2014 and 2015 (Figure 69). The 1968 base model over-estimated both the 1985 and 1994 Petersen 25–40 cm population estimates although the expected population values were within the 95% confidence bounds of observed (Figure 70).

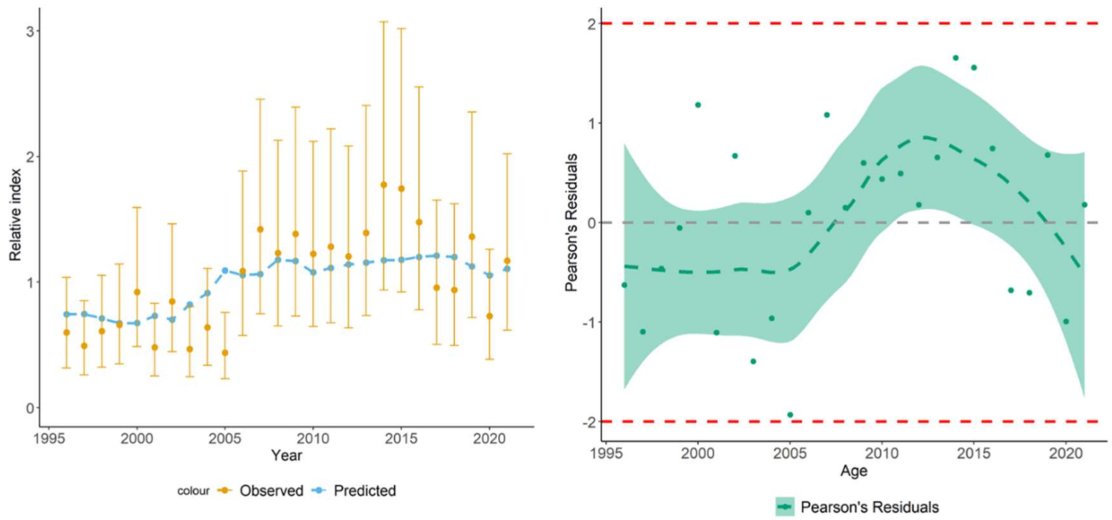


Figure 69: 1968 base model fit to the east Northland bottom trawl CPUE index; error bars are the 95% lognormal confidence intervals.

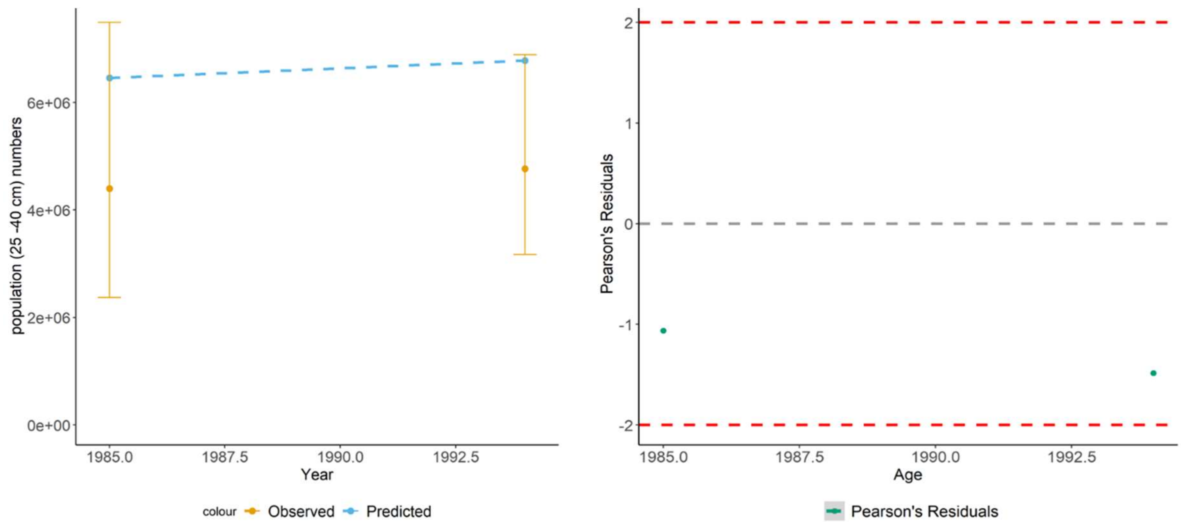


Figure 70: 1968 base model fit to the east Northland 1985 and 1994 Petersen 25–40 cm population estimates (numbers), error bars are 95% lognormal confidence intervals.

Overall, the 1968 base model longline at-age compositional data fits were "reasonable" across all age ranges and survey years (Appendix Figure 97; Figure 71). YCS in the longline data appeared well estimated by the model for the year range 1979 to 2004, however more recent YCS were less well estimated, possibly because there were fewer observations of these year classes (Figure 71 centre plot).

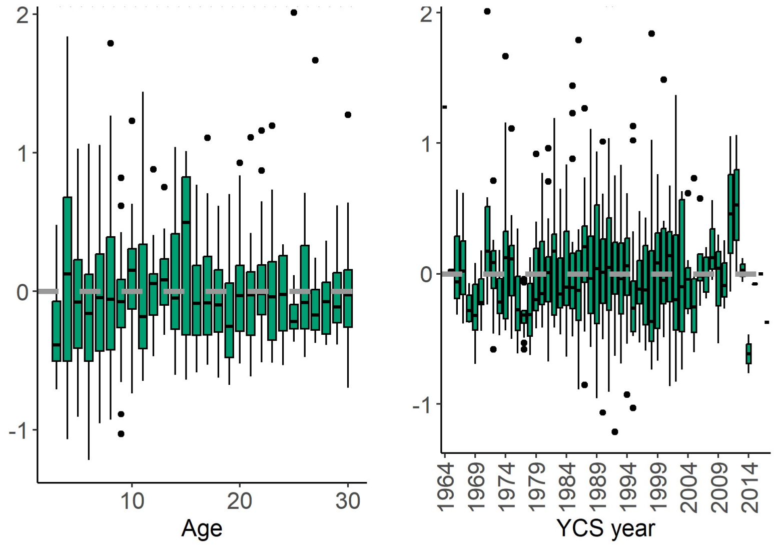


Figure 71: 1968 base model residual distributions from the longline age compositional fits. Left plot: model residual distributions aggregated by age class; middle plot: model residual distributions aggregated by year-class; right plot: model residual distributions aggregated by survey year.

Model fits to the post-1995 recreational at-age data were also reasonable for most years and length classes (Figure 72). Model YCS predictions in the post-95 recreational data were not as good as the longline YCS predictions, this is likely to be due to there being fewer sample years in this series (Appendix Figure 99; Figure 72 middle plot).

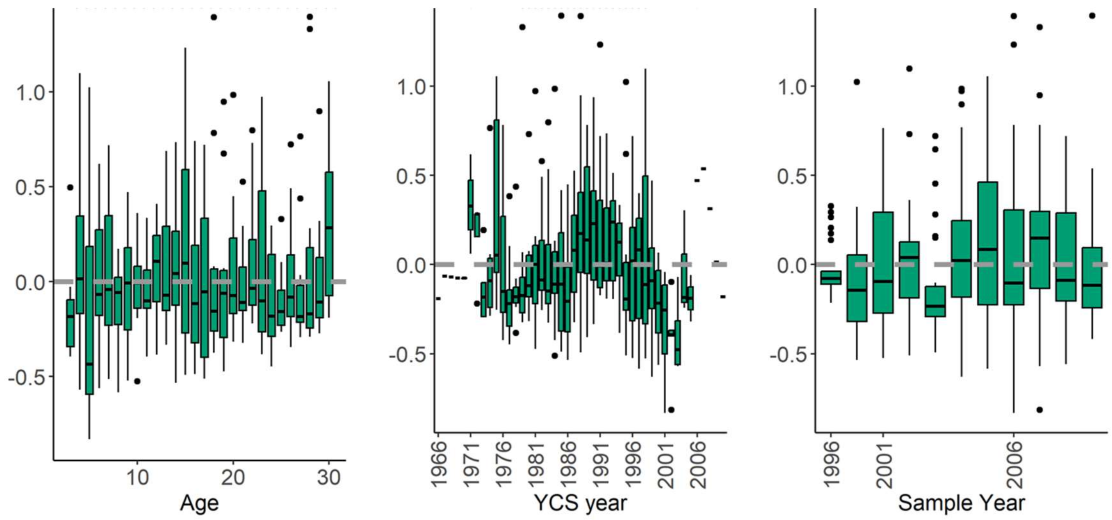


Figure 72: 1968 base model residual distributions from the post-1995 recreational line age compositional fits. Left plot: model residual distributions aggregated by age class; middle plot: model residual distributions aggregated by year-class; right plot: model residual distributions aggregated by survey year.

Model fits to the pre-1995 and post-2015 recreational line age data were also "reasonable" (Appendix 16).

Further evidence that the base 1968 model compositional data fits were sound is seen in the good correspondence between model mean length at-age prediction values estimated from the data (Figure 73).

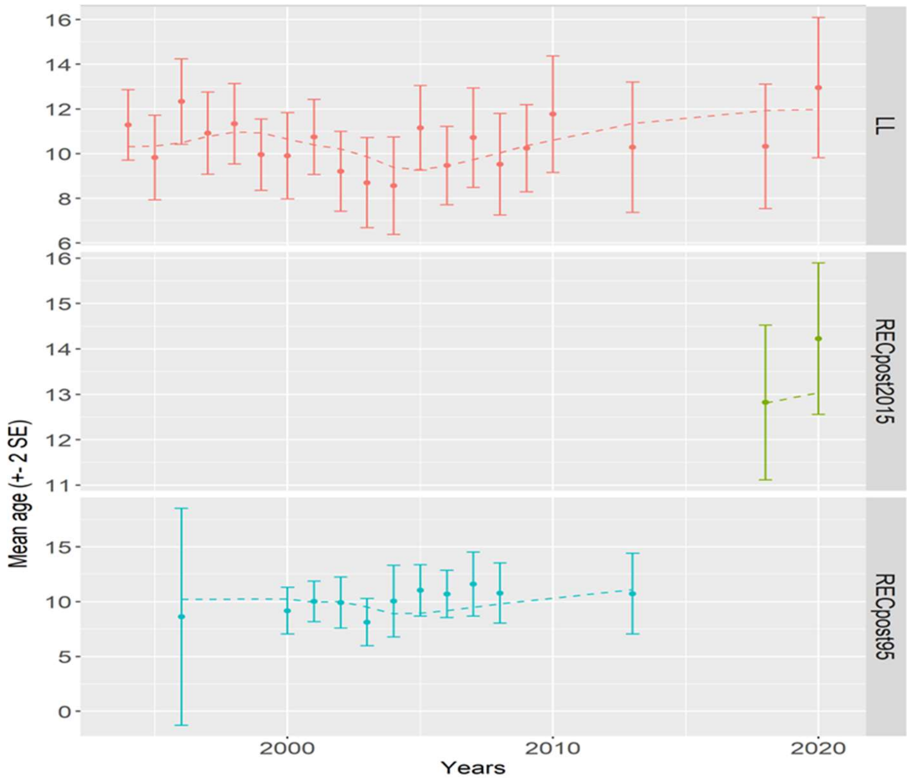


Figure 73: 1968 base model mean length at-age predictions (dotted line) compared to observational data estimates, error bars represent 95% confidence intervals.

Model derived quantities

Likelihood profiles on the model B_0 and $F_{initial}$ indicate that these parameters were well informed by the observational data (Appendix 17). The upper-bound on B_0 being informed by the Petersen tag population estimates and longline line compositional age data, the lower-bound by the bottom trawl CPUE (Appendix Figure 101). The upper and lower bounds on $F_{initial}$ informed by both the bottom trawl CPUE and longline compositional age data (Appendix Figure 102).

The estimated 1968 base model selective ogives for longline and recreational data collected post 1995 were all strongly ‘logistic”, whereas the pre-1995 recreational selectivity was markedly domed (Figure 74).

Model predicted YCS shows a slight increase in mean recruitment after 1995 with stronger year-classes occurring after this time (Figure 75). The strong 1999 year-class model prediction, although seemingly anomalous, was strongly informed by the longline post-95 recreational compositional data (Appendix Figure 103).

The 1968 base model projected SSB trajectory shows a strongly increasing trend after 2000 followed by a minor decline after 2018 (Figure 76). The 1968 base model B_0 estimate (54 989 tonnes) equated to a predicted 2021–2021 stock-status of 37% B_0 (Figure 76).

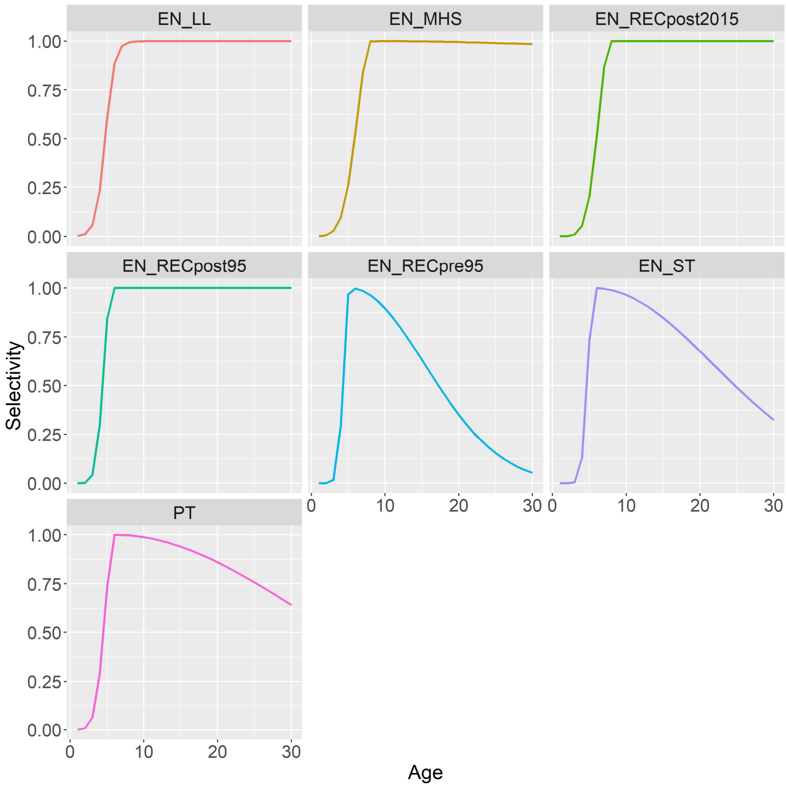


Figure 74: 1968 base model selectivity ogives. Estimated: longline (LL), pre-95, post-95, post-2015 recreational (REC) line. Fixed: Pair trawl (PT), bottom trawl (ST), MHS.

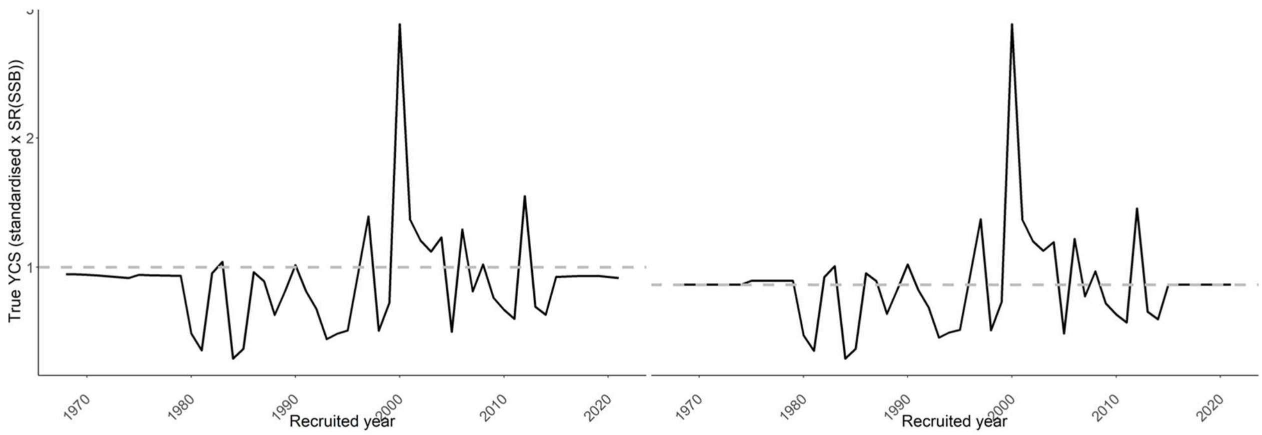


Figure 75: 1968 base model Year Class Strength (YCS) estimates. The actual YCS estimates (right) are unadjusted for steepness (left). The strong predicted peak is the 1999 year-class.

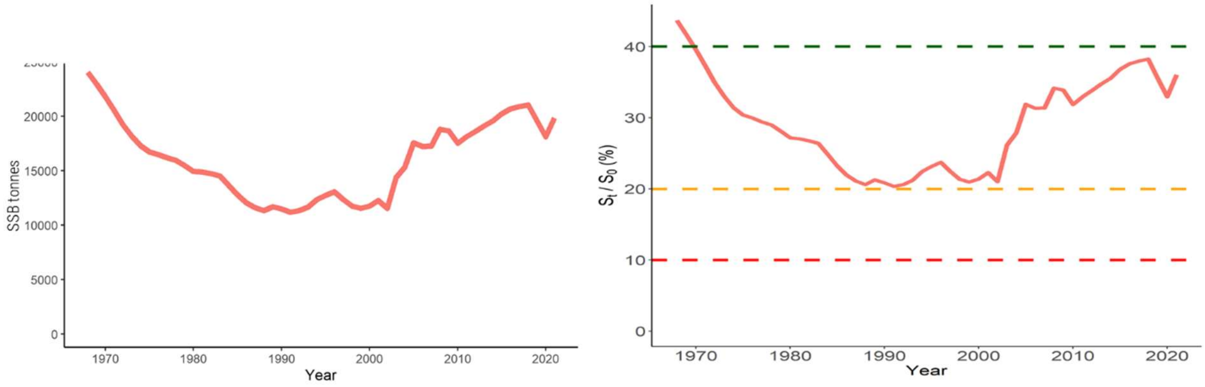


Figure 76: 1968 base model SSB and stock-status predictions.

7.4 MCMC stock assessment and projection results

Three MCMC chains of 2 million samples each were run using the 1968 base east Northland model. All the MCMC chains were commenced at the MPD parameter values. The burn-in period on each chain was set at 400 000 with step size adjustments occurring at 40 000, 80 000, 100 000, 200 000, 300 000, and 400 000 samples. After 400 000 samples every 500th sample was retained to generate the final MCMC posterior parameter set.

Successful MCMC convergence was not possible when the pre-95 recreational line selectivity parameters were set as free parameters; these parameters were therefore fixed in the MCMCs at the MPD estimated values.

The relative improvement in the respective MCMC chain acceptance rates began to asymptote after 400 000 samples indicating that the designated burn-in period was likely to be appropriate (Figure 77 left plot). The objective function values forming each MCMC chain were strongly overlapping with no obvious departures in trend or pattern (Figure 77 right plot).

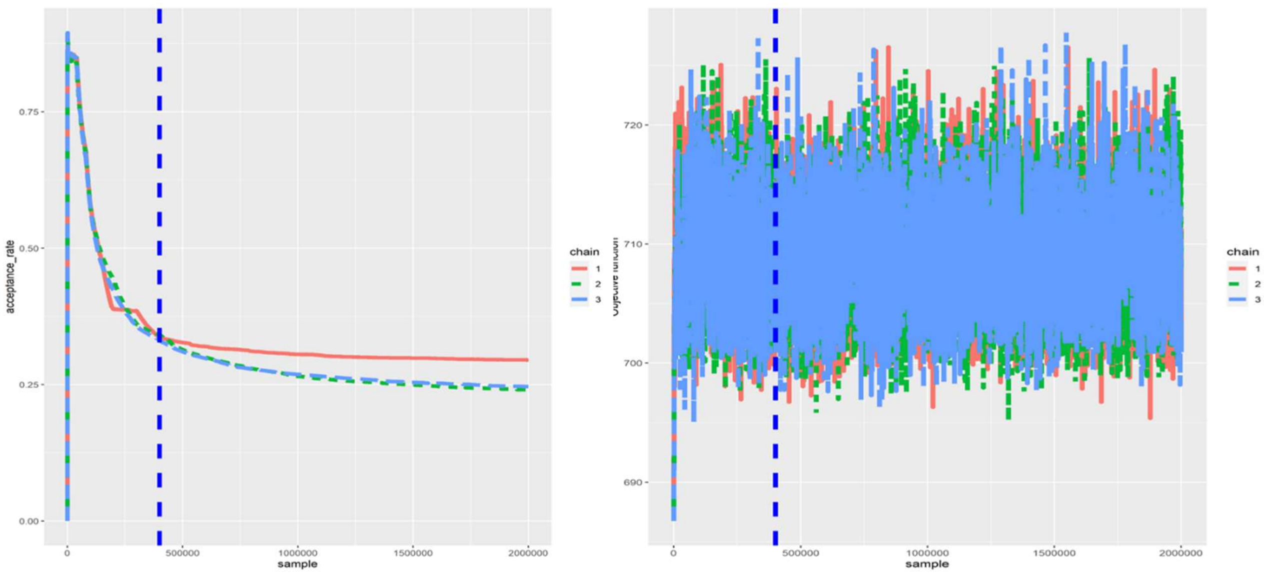


Figure 77: 1968 base model objective function acceptance rate improvement for each MCMC chain (left plot), and full MCMC chain objective function values overlaid (right plot).

$\hat{R}$ (Gelman & Rubin 1992) convergence diagnostics on the three MCMC chains indicated that acceptable MCMC convergence had been achieved on all free model parameters (Appendix Figure 104). The post-2015 recreational line selectivity parameters $y\sigma_L$ and ya_1 (estimated as orthogonal transformations) had the worst R-hat convergence values (Appendix Figure 104). Further MCMC diagnostics conducted on these parameters also showed "acceptable" convergence (Appendix Figure 105 and Appendix Figure 106). The inference being that if the worst $\hat{R}$ score parameters had converged so had those with better $\hat{R}$ scores.

MCMC convergence diagnostics for the B_0 and $F_{initial}$ model parameters (estimated as orthogonal transformations) were strongly indicative of successful convergence (Appendix Figure 107 and Appendix Figure 108), indicative also that the MCMC posterior densities for these parameters were well described.

The MCMC selectivity parameter posterior densities resulted in relatively narrow logistic selectivity derivations with the medians being virtually identical to the MPD derived ogives (Figure 78).

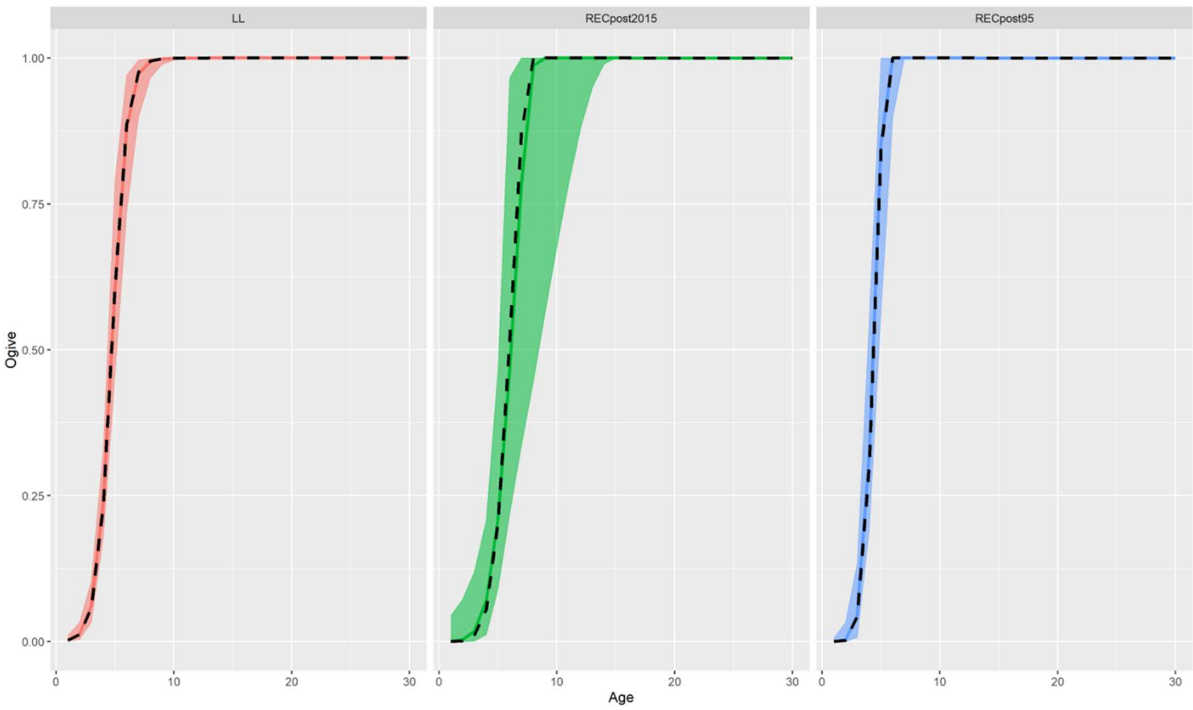


Figure 78: 1968 base model MCMC selectivity predictions for longline, post-95 and post 2015 recreational ogives. Shaded areas are the MCMC 95% CI density ranges, coloured lines MCMC density medians, dashed lines are MPD predicted values.

MCMC median YCS predicted values closely matched MPD predicted values (Figure 79). YCS posteriors between 1980 and 2000 were relatively narrow, probably due to there being multiple observations of these year-classes, those after 2000, where repeat year-class observations were fewer, (recent productivity) were less precisely estimated (Figure 79).

The MCMC median SSB and stock-status predictions again matched to MPD predicted values (Figure 80). Uncertainty in MCMC predicted trajectories progressively increased after 2004–05, probably due to there being fewer YCS observations after this date (Figure 80).

The median predicted status of the east Northland sub-stock in 2021–22 was 38% B_0 with a 29% probability of the sub-stock being above the 40%B_0 management target (Table 36). There was a 100% probability of the sub-stock being above the 20%B_0 soft-limit in 2021–22 (Table 36).

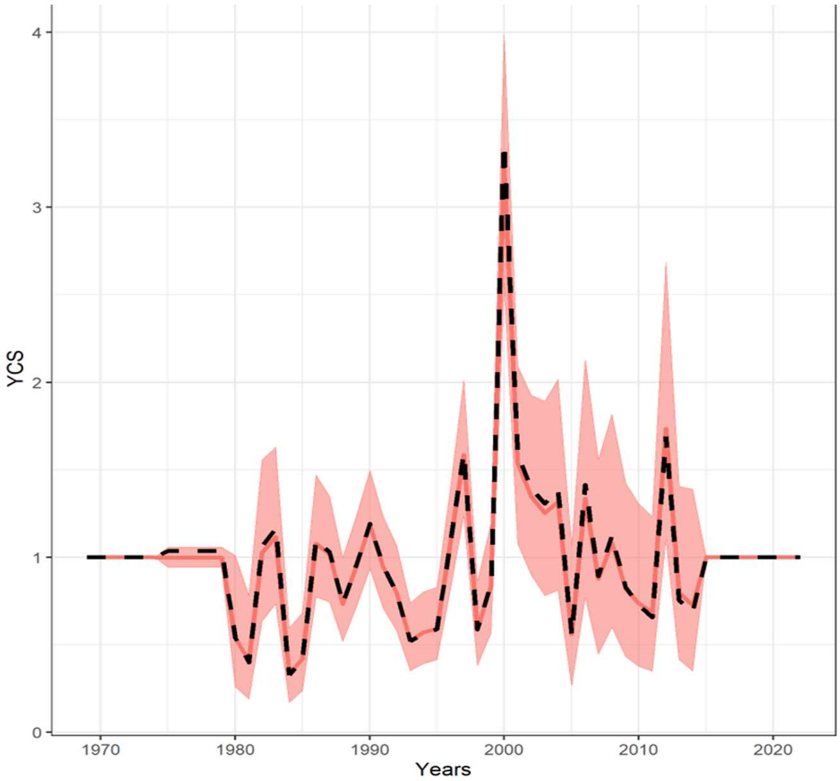


Figure 79: 1968 base model MCMC Year Class Strength (YCS) estimates unadjusted for steepness. The shaded area is the MCMC 95% CI density range, redline MCMC density medians, dashed line MPD predicted YCSs.

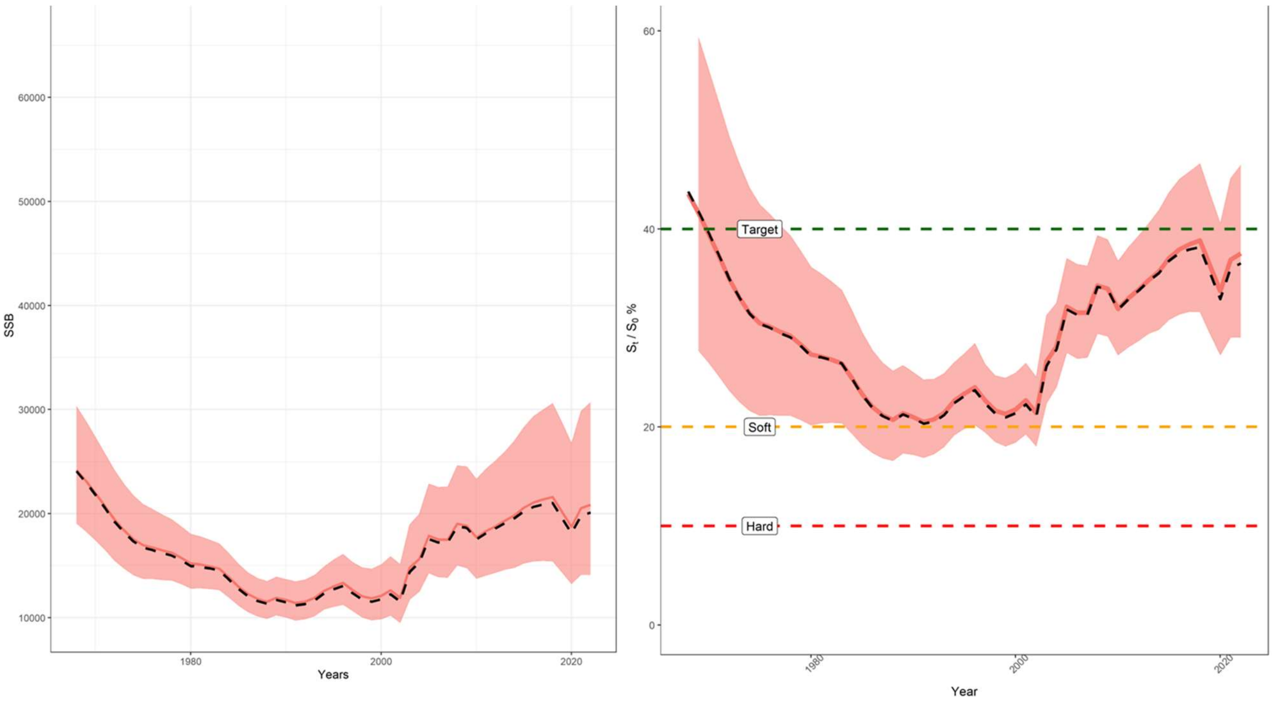


Figure 80: 1968 base model MCMC SSB and stock-status predictions. Shaded area is the MCMC 95% CI density range, redline MCMC density medians, dashed line MPD predicted value.

Table 36: East Northland 1968 base model 2021–22 MCMC predicted status probabilities.

Substock-status factor	Probability
$p[B_{2022} > 40\%B_0]$	29%
$p[B_{2022} > 20\%B_0]$	100%
Median B_{2022} $\%B_0$	38% (95% CI 29 – 46%)
Median B_0	55 873 (95% CI 50 953 – 61 892)

The derived target fishing-pressure (U; refer Appendix 19) corresponding to the 40%B_0 equilibrium biomass was 0.052 ($U_{SSB\ B40\%}$; Table 37). The MCMC median U estimate for 2021–22 (0.057; Table 37) was higher than the $U_{SSB\ B40\%}$ deterministic target. The probability of U being below $U_{SSB\ B40\%}$ in 2021–22 was only 26% (Table 37).

Table 37: East Northland 1968 base model 2021–22 MCMC predicted fishing-pressure (U) status.

Exploitation factor	Value
$U_{SSB\ B40\%}$	0.052
Median U_{2022}	0.057 (95% CI 0.039 – 0.085)
$U_{SSB\ B40\%}$ catch	1 120 t
$p[U_{2022} > U_{SSB\ B40\%}]$	74%
$p[U_{2022} < U_{SSB\ B40\%}]$	26%

The MCMC status predictions show the east Northland substock as having been mostly within the over-fishing/over-fished quartile ranges since 1972 (Figure 81).

MCMC projections of the east Northland 1968 base model were undertaken for the year range 2022–23 to 2026–27. Two projections were undertaken in respect to post–2014 YCS variability: one resampling the full period of estimable year-class parameters (1980–2014); the other resampling estimable year-classes only from the most recent 10 years (2005–2014). Both sets of projections were undertaken with post 2021–22 recreational and commercial catches set to the model 2021–22 values. The projection probability of the east Northland sub-stock being above 40% B_0, under both resampling scenarios, slightly declined with current catch removals (Table 38; Figure 82). Overall, there was very little difference in projected stock-status between the two YCS resampling scenarios (Table 38; Figure 82). Higher variability in the recent YCSs appears to have resulted in wider ranges between positive and negative projected outcomes compared to the full YCS period resampling scenario (Table 38). There was 0.00% probability of the east Northland sub-stock being below 20% B_0 in 2021–22, however both projection scenarios showed a small, but increasing, probability of this occurring over the subsequent five years (Table 38).

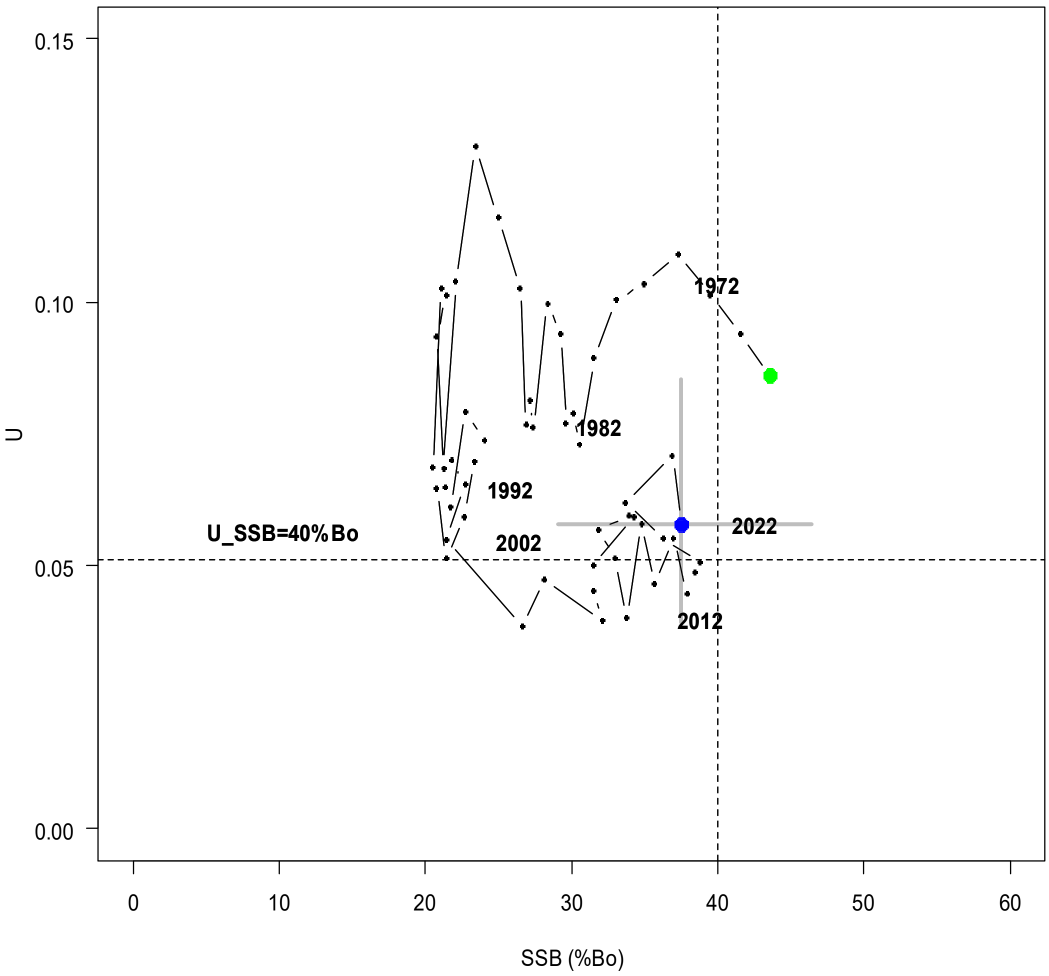


Figure 81: 1968 base model MCMC median trajectory over time of fishing-pressure (U) and spawning biomass (% B_0), grey lines are 95% confidence intervals on SSB %B_0 and U.

Table 38: East Northland 1968 base model MCMC post-2022 five-year projection status.

	Status	2023	2024	2025	2026	2027
1980 – 2014 YCS resampling						
	< 20% B_0	0.01%	0.01%	0.07%	0.17%	0.22%
	< 40% B_0	69.45%	70.51%	71.28%	71.38%	72.15%
	> 40% B_0	30.55%	29.49%	28.72%	28.62%	27.85%
2005 – 2014 YCS resampling						
	< 20% B_0	0.00%	0.01%	0.09%	0.23%	0.55%
	< 40% B_0	68.98%	69.47%	70.01%	70.12%	70.60%
	> 40% B_0	31.02%	30.53%	29.99%	29.88%	29.40%

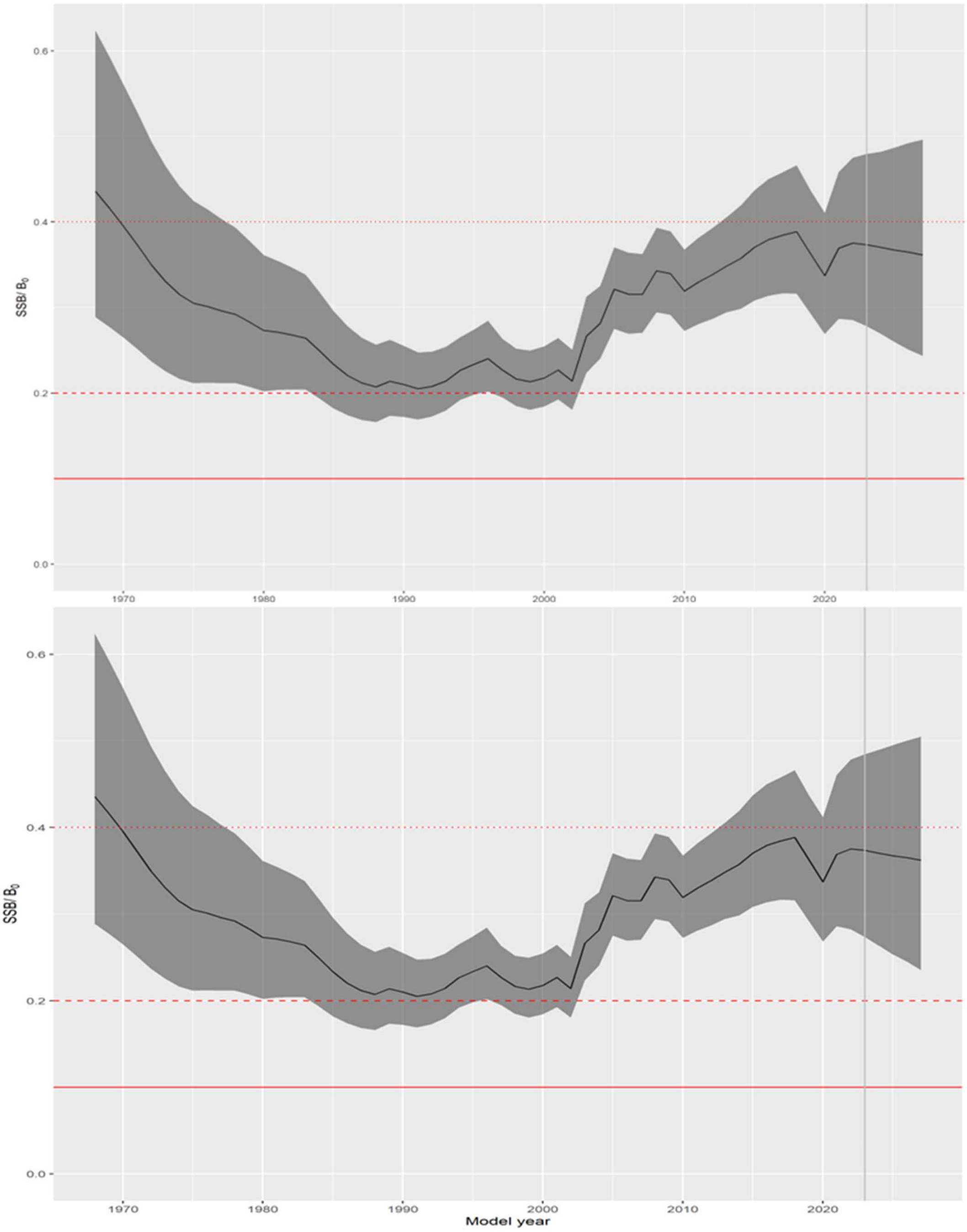


Figure 82: East Northland 1968 base model MCMC post-2022 five-year projections, top 1980–2014 YCS resampling, bottom 2005–2014 YCS resampling. Horizontal lines are the target (dotted), soft (dashed), and hard limit (solid) SSB/ B_0 Fisheries New Zealand sustainability ratios.

7.5 Base 1968 model MPD sensitivity model results

The Working Group recommended the following four alternative model configurations as sensitivities to the base model assessment:

1. Lower natural mortality constant of 0.06 cf. 0.075;
2. Nearest neighbour growth applied outside the growth matrix year range as was done in the 2013 and 2022 base assessment models;
3. High pre-1984 commercial catch (+20%);
4. 1900 commence at virgin exploitation.

The nearest-neighbour and high pre-1984 catch resulted in minimal change in SSB and stock status trajectories (Table 39, Figure 83).

The low M scenario, although predicting a similar post-2000 SSB trajectory to the base model, predicted a much lower stock-status outcome to the base model (Table 39, Figure 83). The lower stock-status prediction was likely to have been driven by the need for a higher B_0 to offset lower productivity associated with the lower M, a result is typical for this type of sensitivity (Table 39).

The difference in stock-status prediction between the 1968 commence and 1900 commence models, needs consideration as both models fitted to the observational data similarly and the post 1968 catch histories are identical. The 1985 and 1994 Petersen tag population estimates served to constrain both models to predict similar SSB values over the interim tag survey years (Figure 83). The departure of model SSB trajectories outside the 1980s and 1990s (Figure 83) is driven by differences in the B_0 estimates, the lower B_0 of the 1900 model driven by the pre-1968 catch history. The decision as to which model prediction is closer to the underlying "truth" depends on our confidence in the pre-1968 model catch history.

Table 39: Sensitivity model stock-status comparisons

Model	B_{2022} (t)	B_{2022} %B_0	B_0 (t)
1968 commence base	**20 091**	**37%**	**54 989**
M 0.06	21 154	29%	73 496
nearest neighbour growth	18 928	35%	54 130
pre 84 catch + 20%	20 787	37%	55 779
1900 commence	16 832	32%	51 799

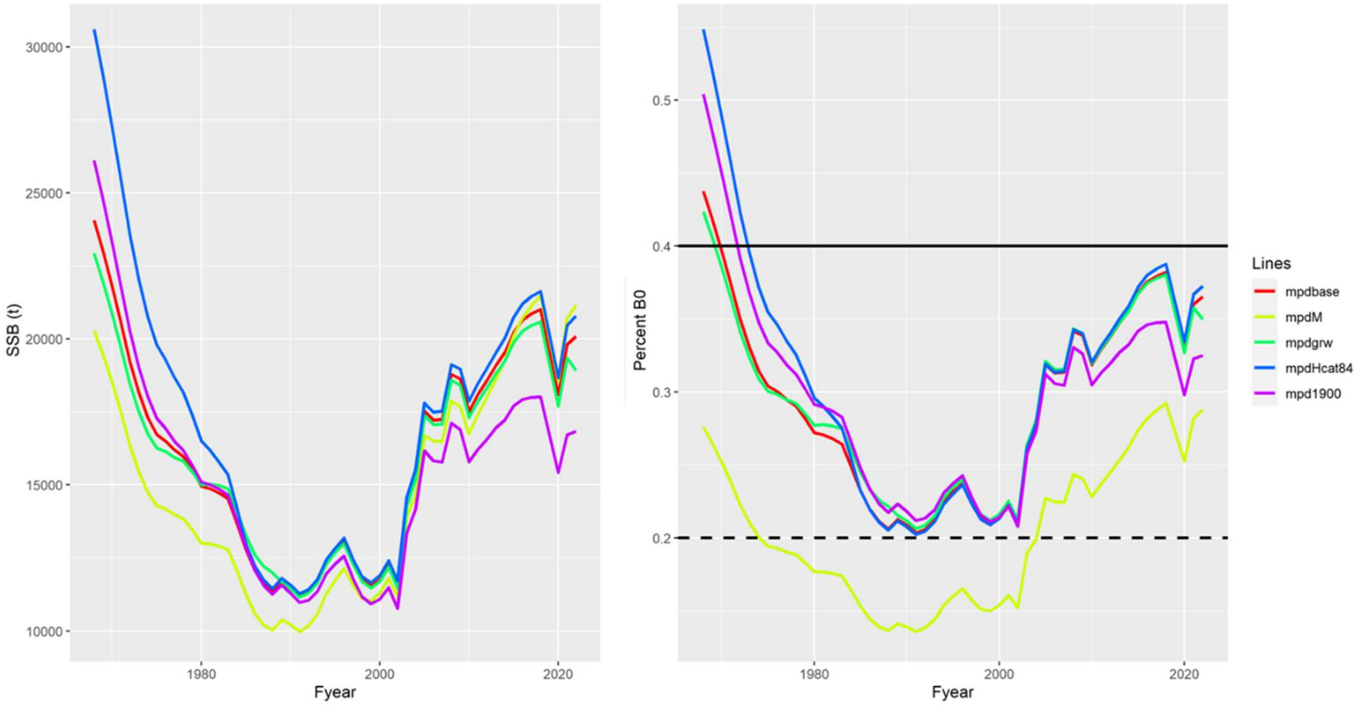


Figure 83: East Northland 1968 base model SSB and stock-status model sensitivity comparisons.

8 2023 HAURAKI GULF/BAY OF PLENTY SUB-STOCK-COMPLEX ASSESSMENT

8.1 1900 and 1968 Base Model structures

The Hauraki Gulf/Bay of Plenty stock complex was assessed initially using a two-area home-fidelity model, similar to the three-area 2022 SNA 1 assessment model. Unlike the 2022 SNA 1 assessment model, model movement parameters were not estimated but fixed equivalent to the 1994 Petersen estimator new-boundary movement estimates (Table 31). In accordance with the home-fidelity movement dynamic, 100% of model migrating fish were moved back to their home sub-stock area before the start of the next fishing year and after fishing had occurred in the current fishing year.

The abundance and composition data fitted in the Hauraki Gulf/Bay of Plenty assessment models are given in Table 40. Model estimable and fixed parameters are given in Table 41 and Table 42.

Table 40: 2023 Hauraki Gulf/Bay of Plenty base assessment model observational data inputs.

Type	Likelihood	Area	Source	Range of years	No. of years
Absolute biomass	Lognormal	BP	1984 tagging	1983	1
Absolute numbers[1]	Lognormal	HG	1984 & 1995 tagging	1984,1995	2
Absolute numbers[1]	Lognormal	BP	1995 tagging	1995	1
Relative biomass[2]	Lognormal	HG	bottom trawl CPUE	1996–2021	26
		BP	bottom trawl CPUE	1996–2021	26
		HG	research survey age-6+	1985–2021	11
		BP	research survey age-6+	1990–2021	5
Relative numbers[3]	Lognormal	HG	research survey age-1	1985–2021	11
		HG	research survey age-2	1985–2021	11
		HG	research survey age-3	1985–2021	11
		HG	research survey age-4	1985–2021	11
		HG	research survey age-5	1985–2021	11
		BP	research survey age-1	1990–2021	5
		BP	research survey age-2	1990–2021	5
		BP	research survey age-3	1990–2021	5
		BP	research survey age-4	1990–2021	5
		BP	research survey age-5	1990–2021	5
Age composition	Multinomial	HG	longline	1990–2010	19
		BP	longline	1985–2010	18
		BP	MHS	2020	1
		HG	Danish seine	1970–2020	12
		BP	Danish seine	1995–2020	2
		HG	bottom trawl	1975–2020	7
		BP	bottom trawl	1990–2020	6
		HG	research survey	1985–2021	11
		BP	research survey	1990–2021	5
		EN	recreational fishing	1994–2018[4]	13
		HG	recreational fishing	1991–2018[4]	14
		BP	recreational fishing	1991–2018[4]	14
		HG	research survey age-6+	1985–2021	11
		BP	research survey age-6+	1990–2021	5

[1] Petersen population estimates as numbers for length range 25–40 cm
[2] CPUE (catch per unit effort) or bottom trawl research survey
[3] Bottom trawl research survey
[4]All length composition data sets were split into pre-1995 (2 years), post-1995 (11 years) and post-2015 because recreational selectivity was assumed to change in 1995 and in 2015 due to minimum-legal-size changes

Table 41: 2023 Hauraki Gulf/Bay of Plenty assessment model estimated parameters.

Type	Description	No. of parameters	Prior
B_0	Mean unfished Spawning Stock Biomass	2	uniform-log[1]
$F_{initial}$	1968 commence model initial exploitation parameter	2[2]	uniform[1]
YCS	Year-class strengths by year and stock	118 (100[2])[3]	lognormal[4]
Selectivity	Hauraki Gulf long line (logistic)	2	uniform
	Bay of Plenty long line (logistic)	2	uniform
	Hauraki Gulf bottom trawl (double-normal)	3	uniform
	Bay of Plenty bottom trawl (double-normal)	3	uniform
	Hauraki Gulf Danish seine pre 1973 (double-normal)	3	uniform
	Hauraki Gulf Danish seine post 1973 (double-normal)	3	uniform
	Bay of Plenty Danish seine (double-normal)	3	uniform
	Bay of Plenty MHS (double-normal)	3	uniform[5]
	Hauraki Gulf Recreational pre-1995 (double-normal)	3	uniform[5]
	Hauraki Gulf Recreational 1995–2014 (double-normal)	3	uniform[5]
	Hauraki Gulf Recreational post-2014 (double-normal)	3	uniform[5]
	Bay of Plenty Recreational pre-1995 (double-normal)	3	uniform[5]
	Bay of Plenty Recreational 1995–2014 (double-normal)	3	uniform[5]
	Bay of Plenty Recreational post–2014 (double-normal)	3	uniform[5]
	Hauraki Gulf trawl survey age 6+ (double exponential[5])	2	uniform
	Bay of Plenty trawl survey age 6+ (double exponential[5])	2	uniform
q	Catchability (for relative biomass observations)	16	uniform-log
		180(164[2])	

[1] B_0 and $F_{initial}$ parameters estimated as an orthogonal transformation in 1968 commence models
[2]1968 commence models only
[3]YCSs were estimated for years 1952–2020 (or 1970–2020) for HAGU, and 1972–2020 for BOP
[4]With mean 1 and coefficient of variation 0.6
[5]Only the x_2 and y_2 double exponential selectivity parameters were estimated (Casal2 Development Team 2022).

Table 42: 2023 Hauraki Gulf/Bay of Plenty base assessment model fixed parameters.

Natural mortality	0.075 y^{-1}
Stock-recruit steepness	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]	
Hauraki Gulf	$a = 4.94 \times 10^{-5}$, $b = 2.771$
Bay of Plenty	$a = 4.30 \times 10^{-5}$, $b = 2.813$
Mean lengths at-age	provided for years 1989–2021
Coefficients of variation for length at-age	0.10 at age 1, 0.20 at age 20
Selectivity	
$F_{initial}$ (uniform)	knife-edged at 25 cm
Petersen tag population estimates (double normal plateau)	a_1 = 25cm, a_2 = 15cm σ_L = 0.001 y, σ_R = 0.001
Hauraki Gulf trawl survey age 6+ (double exponential[1])	x_1= 4.5, x_0 =5, y_0=1, y_1 = 0.0001
Bay of Plenty trawl survey age 6+(double exponential[1])	x_1= 4.5, x_0 =5, y_0=1, y_1 = 0.0001
Movement	
Hauraki Gulf to Bay of Plenty	0.11
Bay of Plenty to Hauraki Gulf	0.206

[1]The x_2 and y_2 double exponential selectivity parameters were estimated (Casal2 Development Team 2022).

8.2 Model likelihoods, priors, penalties, and weighting

Trawl survey abundance assumed error

A process error CV value of 0.1 on all trawl survey indices was assumed by the model in addition to analytical CVs as derived external to the model (after Parsons & Bian 2022).

Bottom trawl CPUE assumed error

The bottom trawl CPUE abundance indices were fitted with an assumed CV of 0.31 as in the 2022 SNA 1 base assessment model.

Compositional likelihood error

All compositional datasets were first assigned a multinomial error value as calculated from their derived analytical CVs, this being a standard approach in New Zealand stock assessments.

Tagging population estimates

The Petersen tag population estimates were fitted with lognormal error CVs of 0.3 (1985) and 0.2 (1994). The respective CVs were by the Working Group and are based on Hessian matrix derived confidence intervals (Table 30 and Table 32) with due regard for additional process error (e.g. trap avoidance, heterogeneous tag mixing).

Priors and Penalties

Except for the model year-class parameters, model parameter priors were either uniform or uniform-log (Table 41). Year-class priors were assumed to be log-normally distributed with a mean of one and a CV of 0.6 (Table 41). Strong likelihood penalties were applied in the model if the predicted biomass available to a fishery in any given year was less than the "true" catch history. Strong penalties were also applied when the mean of the predicted year-class strengths (YCSs) did not equal to one.

Model likelihood weighting

The Francis TA1.8 reweighting process was used to down-weight the individual compositional likelihoods relative to assumed error on the abundance likelihoods (Francis 2011).

8.3 Base model decision process

Difficulty in fitting the pre-1973 Hauraki Gulf Danish seine at-age data resulted in a decision to estimate pre and post 1973 selectivity ogives for this fishery. Similarly, difficulties in fitting the six and seven year-old cohorts in the Hauraki Gulf and Bay of Plenty trawl survey at-age data resulted in the adoption of double-exponential selectivity ogives (Casal2 Development Team 2022) for these surveys (Table 41 and Table 42).

It proved difficult to develop a 1968 commence model that could also accommodate mixing between the Hauraki Gulf and Bay of Plenty sub-stock areas. A high degree of correlation between the Bay of Plenty B_0 and $F_{initial}$ parameters was the main issue with the 1968 commence model. The Bay of Plenty $F_{initial}$ parameter in the 1968 commence model was found to be poorly determined by the observational data with the result that it would always converge at the pre-determined upper-bound value (the model was able to accommodate high $F_{initial}$ values by increasing B_0). Application of an informative prior on the Bay of Plenty $F_{initial}$ parameter, although fixing the convergence issue, meant that the final assessment outcome was then largely determined by the choice of prior. There were no bounding issues on any B_0 and $F_{initial}$ 1968 commence model parameters with movement set to zero (i.e., under the independent sub-stocks assumption). For this reason, the Working Group chose the no-movement version of the 1968 commence model as a candidate base-case. However, ignoring movement in the 1968 commence model may have meant that the individual sub-stock productivity estimates would have been alternately positively and negatively biased to some degree. The lack of need for $F_{initial}$ parameters in the 1900 commence model meant that this model did not suffer from convergence issues with movement fixed at the 1994 Petersen tag estimated values.

The 1900 and 1968 commence models produced similar B_0 and status estimate for the Hauraki Gulf, whereas the Bay of Plenty B_0 and B_{2022} SSB estimates were dissimilar (Table 43, Figure 84). The 1900 and 1968 model SSB estimates between 1985 and 1995 were similar for both sub-stocks, probably due to the constraints imposed by the Petersen tag absolute abundance observations. The two models' marked departure in their Bay of Plenty SSB estimates after 1995 was likely to be a consequence of the difference in the B_0 estimates (and by inference R_0), as the post 1995 YCSs estimated by the two models were of similar pattern and magnitude.

Table 43: 1900 and 1968 Hauraki Gulf/Bay of Plenty model B_0 and status predictions.

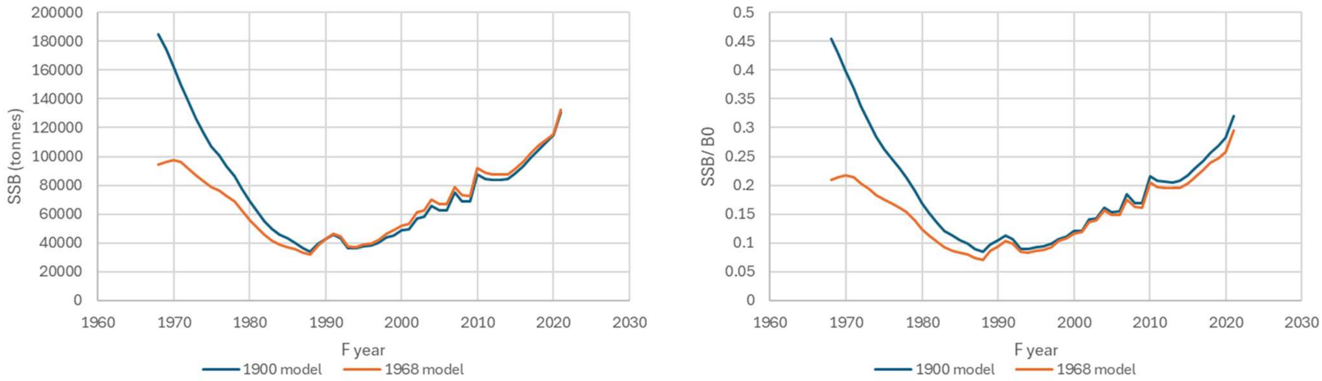
		Hauraki Gulf	Bay of Plenty
1900 commence			
	B_0	407 078 t	84 669 t
	B_{2022}/B_0	0.32	0.15
	B_{2022}	130 264 t	12 700 t
1968 commence			
	B_0	449 476 t	222 603 t
	B_{2022}/B_0	0.32	0.14
	B_{2022}	143 832 t	31 164 t

There was little to differentiate between 1900 and 1968 models based on observational data fits, and model reweighting differences made direct likelihood comparisons difficult.

The Working Group strongly disfavoured the 1900 model on the grounds that the model's Bay of Plenty B_0 estimate was largely determined by the long period of highly uncertain pre-1970 catch histories going into the model. The 1968 commence model was therefore selected as the base; and this decision was also ratified by the 2023 Plenary.

Setting the movement to zero in the 1968 commence model effectively resulted in assessing each sub-stock separately. The 2023 Hauraki Gulf/Bay of Plenty sub-stock complex assessment is first presented in this report as two individual sub-stock assessments, then overall assessment conclusions are provided based on the combination of the two individual sub-stock assessments. It was reasoned by the Working Group that potential positive and negative biases in the individual sub-stock assessment results due to not accounting for movement would be ameliorated in the final combined sub-stock estimates.

a.



b.

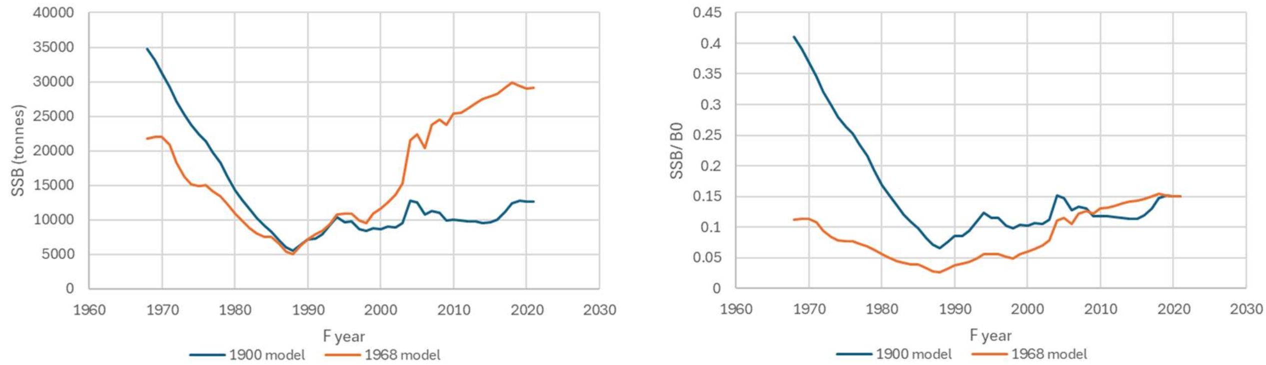


Figure 84: 1900 and 1968 model SSB and stock-status predictions, a. Hauraki Gulf, b. Bay of Plenty.

8.4 Hauraki Gulf base 1968 model MPD results

The 1968 base model captured the overall abundance trend seen in the Hauraki Gulf bottom trawl CPUE and was mostly within the central confidence range of the data (Figure 85).

The 1968 base model under-estimated both the 1985 and 1994 Petersen 25–40 cm population estimates although the expected population values were within the 95% confidence bounds of the observed values (Figure 86).

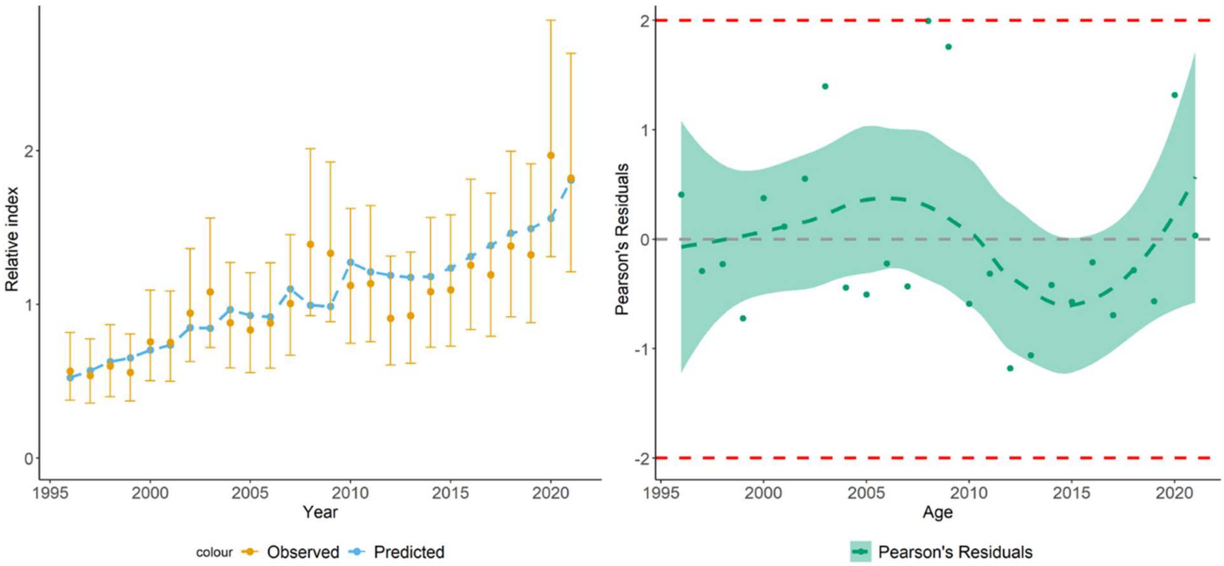


Figure 85: Hauraki Gulf 1968 base model fit to the bottom trawl CPUE index; error bars are the 95% lognormal confidence intervals.

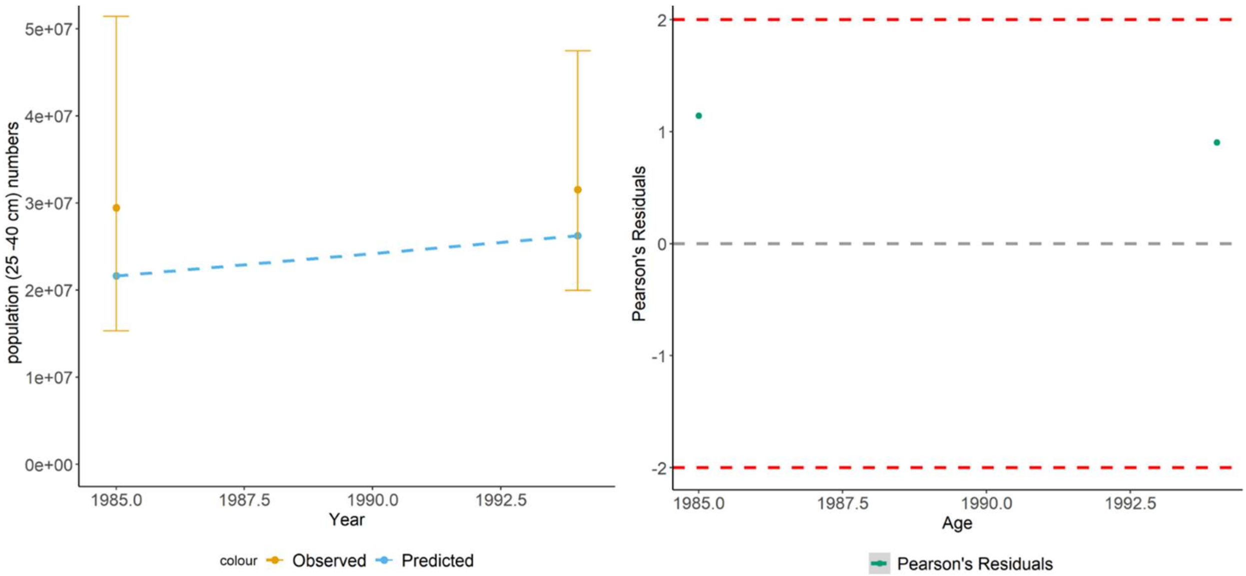


Figure 86: Hauraki Gulf 1968 base model fit to the 1985 and 1994 Petersen 25–40 cm population estimates (numbers), error bars are 95% lognormal confidence intervals.

As with the 2022 assessment, the model was unable to fit the Hauraki Gulf trawl survey 2020 and 2021 age+ (5+ 2022 6+ 2023) group biomass estimates (Figure 87). Despite this, the model was able to capture the Hauraki Gulf trawl survey overall increasing abundance trend including fitting the observed strong 2015 year-class (Figure 87).

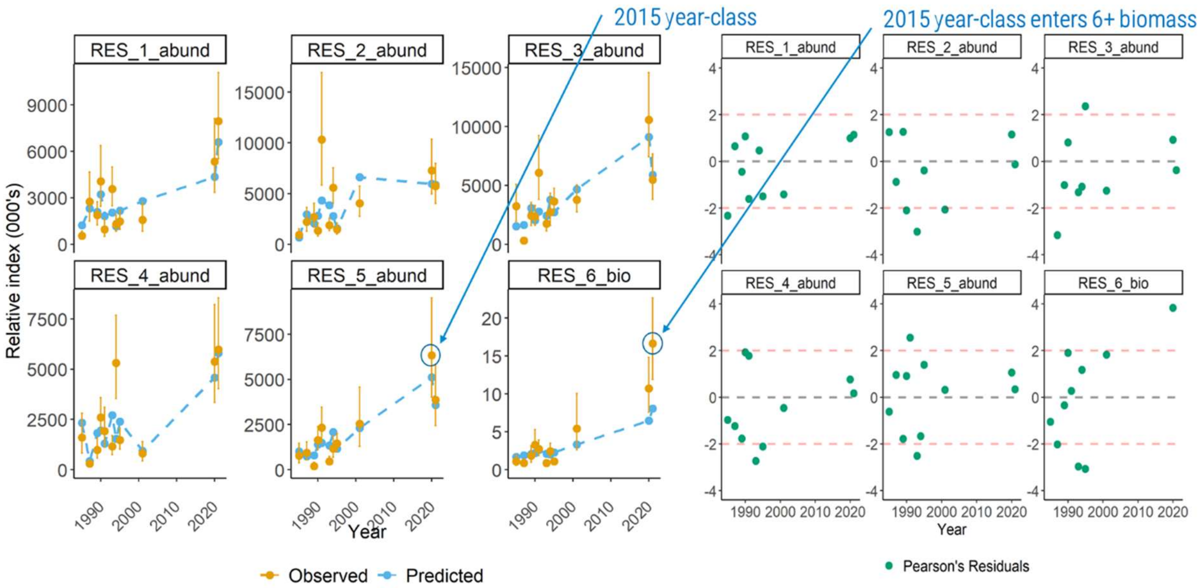


Figure 87: Hauraki Gulf 1968 base model fit to the trawl survey 1 – 5 age cohorts and 6+ biomass indices. Data points that include a strong 2015 year-classs are indicated.

The 1968 base model fits to the Hauraki Gulf longline age compositional data were "reasonable" amalgamated by age and survey-year (Figure 88, Appendix Figure 109). YCS in the longline data appear well estimated except for the earliest and most recent year-classes (Figure 88 centre plot).

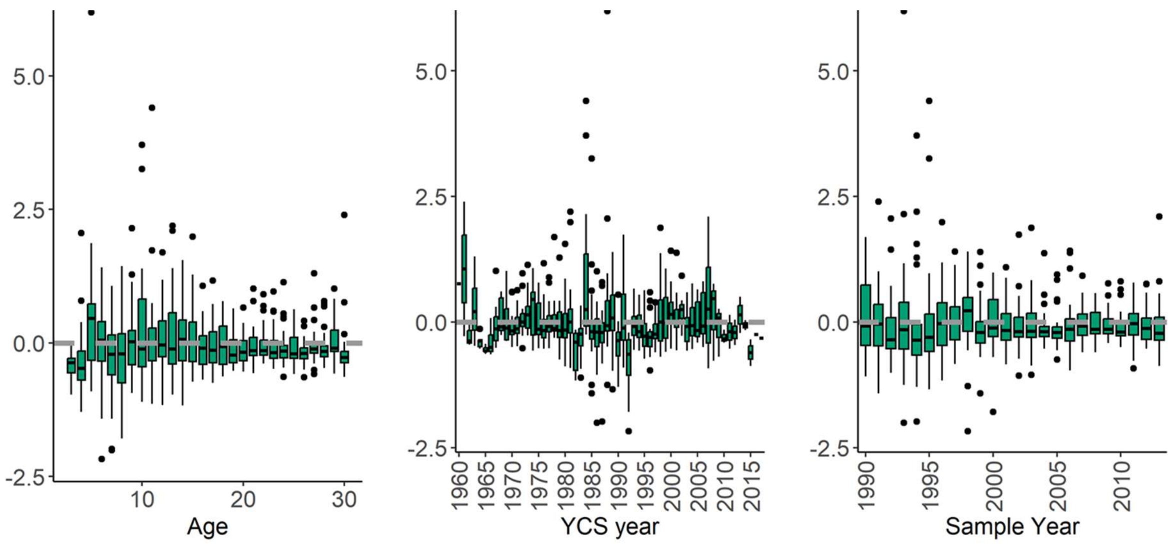
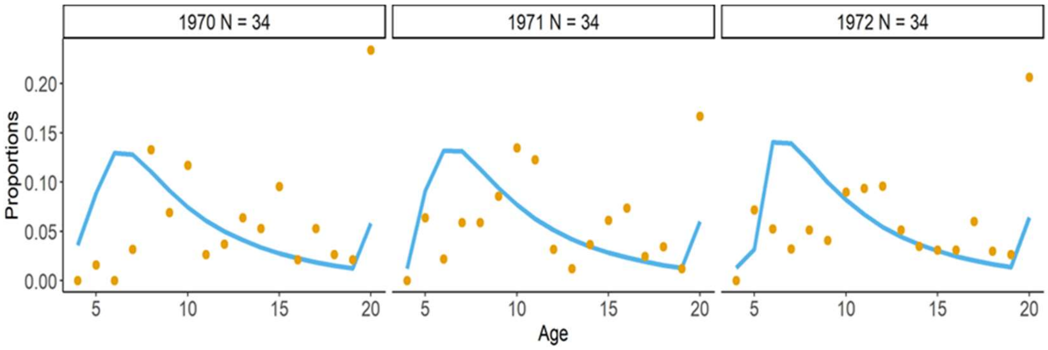


Figure 88: Hauraki Gulf 1968 base model residual distributions from the longline age compositional fits. Left plot: model residual distributions aggregated by age class; middle plot: model residual distributions aggregated by year-class; right plot: model residual distributions aggregated by survey year.

The 1968 base model was unable to achieve a good fit to the pre-1973 Hauraki Gulf Danish seine at-age data (Figure 89). The lack of fit was partially due to the model not being able to estimate pre-1968 year-classes, however, the lack of fit to the 20+ cohorts was a concern. The Working Group noted that the sampling representativeness of these and the 1973 Dainish seine data could not be verified. The model, however, achieved good fits the post 1990 Danish seine at-age data (Figure 89).

a.



b.

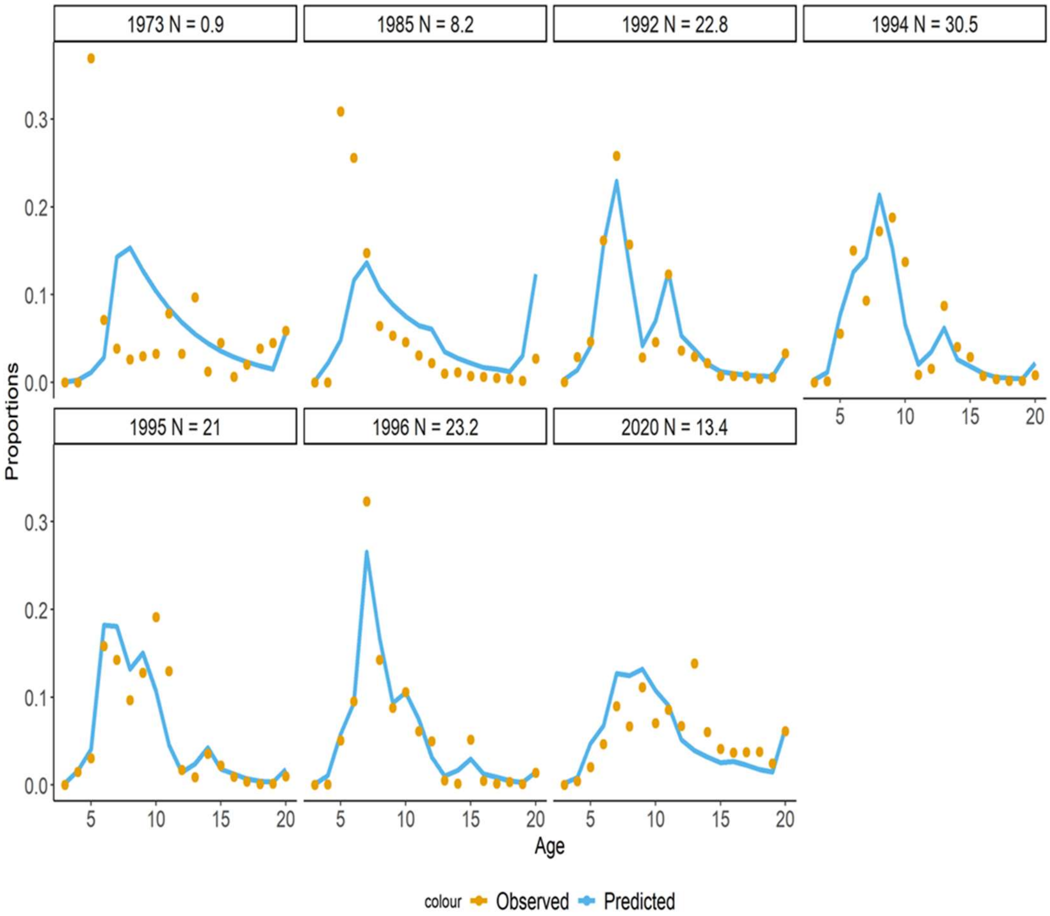


Figure 89: Hauraki Gulf 1968 model fit to Danish seine at-age data: a. pre-1973, b. post 1973. N= effective multinomial error after likelihood reweighting.

The model was also not able to replicate some of the strong younger age classes seen in the 1970s Hauraki Gulf bottom trawl at-age data, again this was most likely due to it not being able to estimate pre 1968 year-classes (Figure 90). However, unlike the 1970s Danish seine at-age fits, the model was able to match the strength of the 20+ cohort in the 1970s Hauraki Gulf bottom trawl at-age data, and the fit to the post 1990 bottom trawl at-age data was also reasonable (Figure 90 and Figure 91).

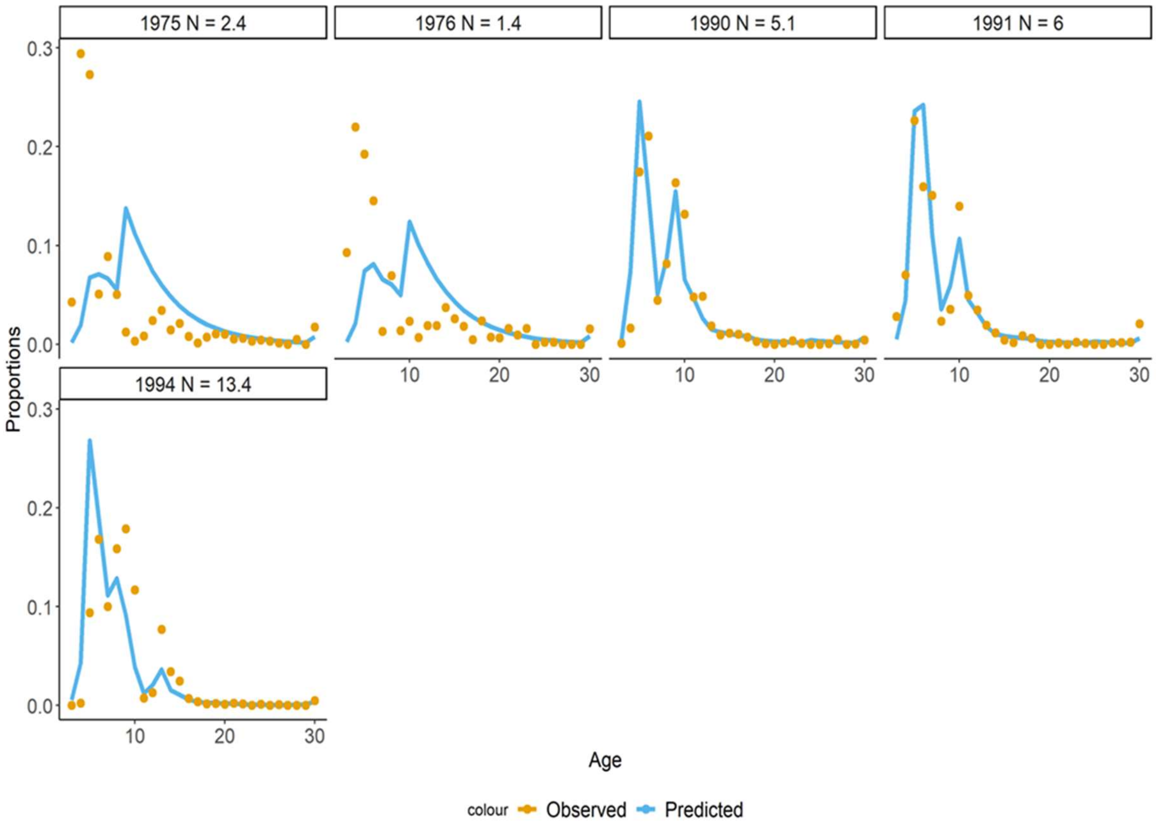


Figure 90: Hauraki Gulf 1968 model fit to bottom trawl at-age data. N= effective multinomial error after likelihood reweighting.

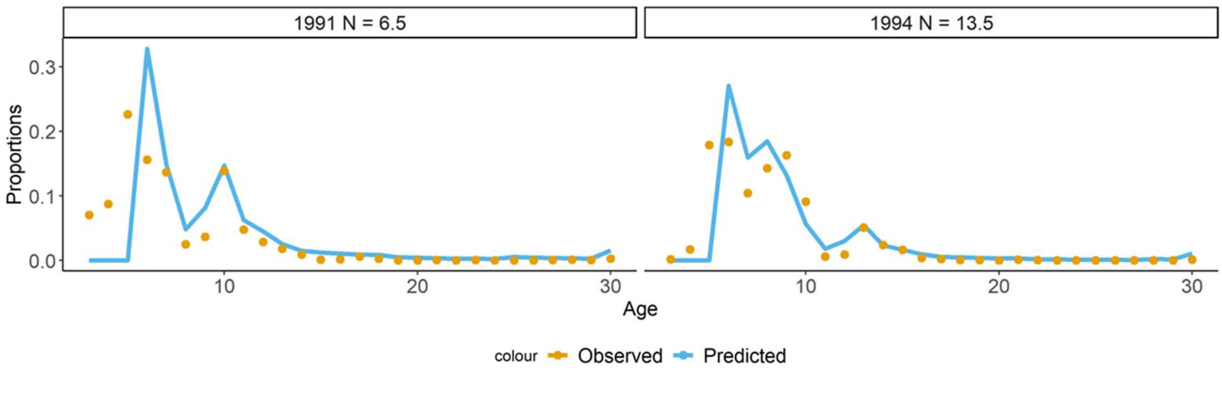


Figure 91: Hauraki Gulf 1968 model fit to pre-1995 recreational line at-age data. N= effective multinomial error after likelihood reweighting.

The model also achieved "reasonable" fits to the pre-1995, post-1995, and post-2015 Hauraki Gulf recreational line at-age data (Figure 91, Figure 92, Figure 93, Appendix Figure 110).

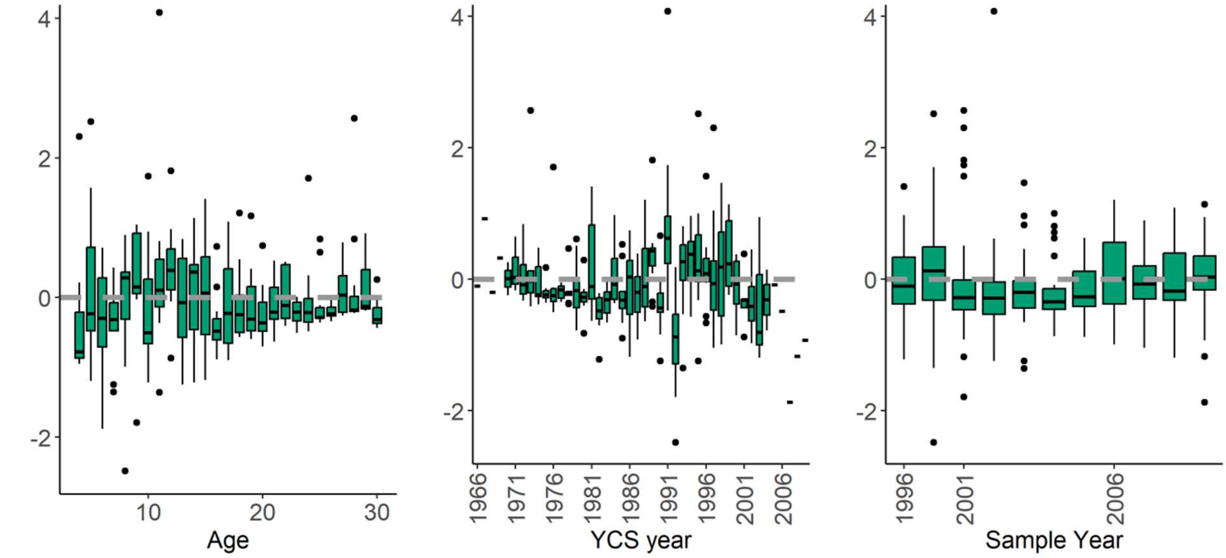


Figure 92: Hauraki Gulf 1968 base model residual distributions from the post-1995 recreational line age compositional fits. Left plot: model residual distributions aggregated by age class; middle plot: model residual distributions aggregated by year-class; right plot: model residual distributions aggregated by survey year.

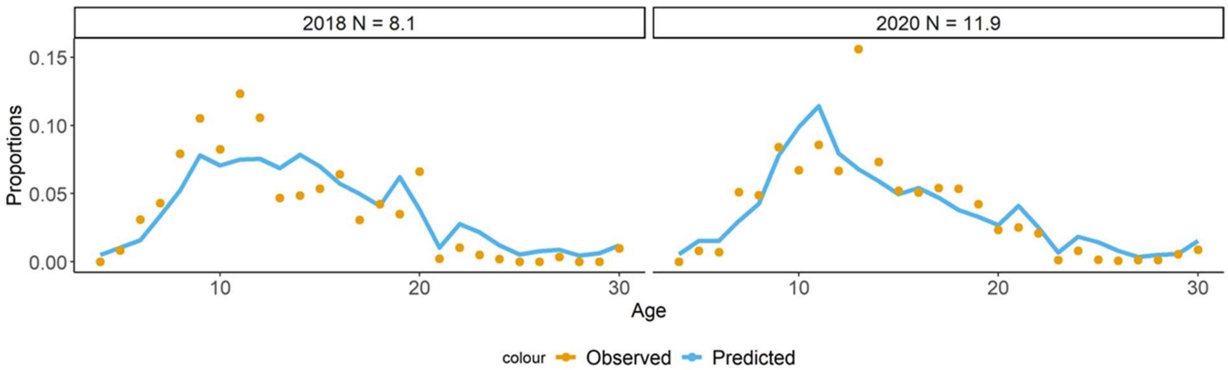


Figure 93: Hauraki Gulf 1968 model fit to post-2015 recreational line at-age data. N= effective multinomial error after likelihood reweighting.

After adoption of the double-exponential selectivity ogive, the model achieved better fits to the, occasionally strong, six and seven-year-old age-classes in the 6+ Hauraki Gulf trawl survey at-age series (Figure 94). The model fits to the trawl survey observed older age classes were also “reasonable (Figure 94).

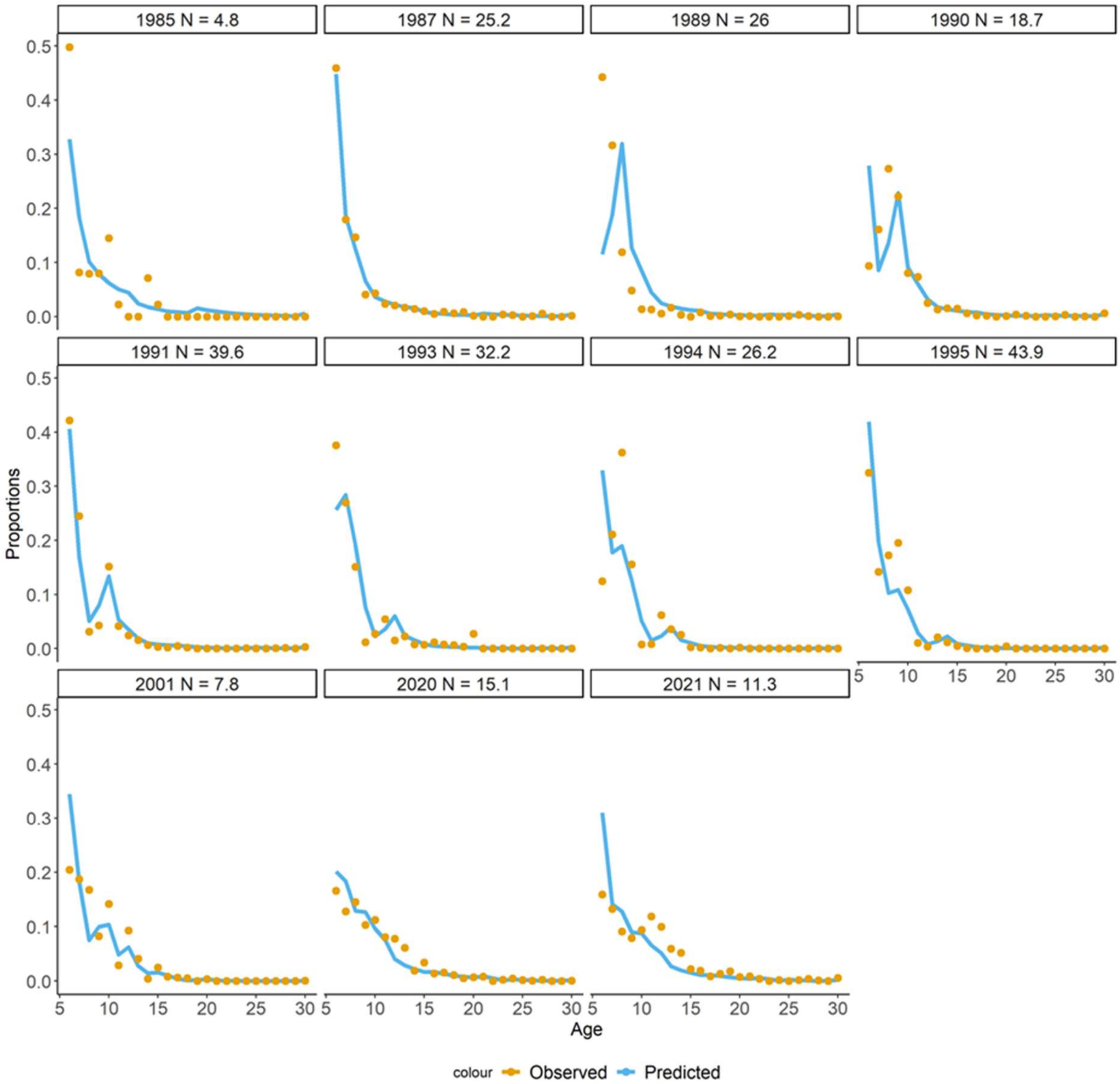


Figure 94: Hauraki Gulf 1968 model fit to trawl survey 6+ at-age data. N= effective multinomial error after likelihood reweighting.

Except for the pre-1973 Danish seine at-age data, the model was able to capture the underlying growth variability to all the other Hauraki Gulf age compositional series as shown in Figure 95.

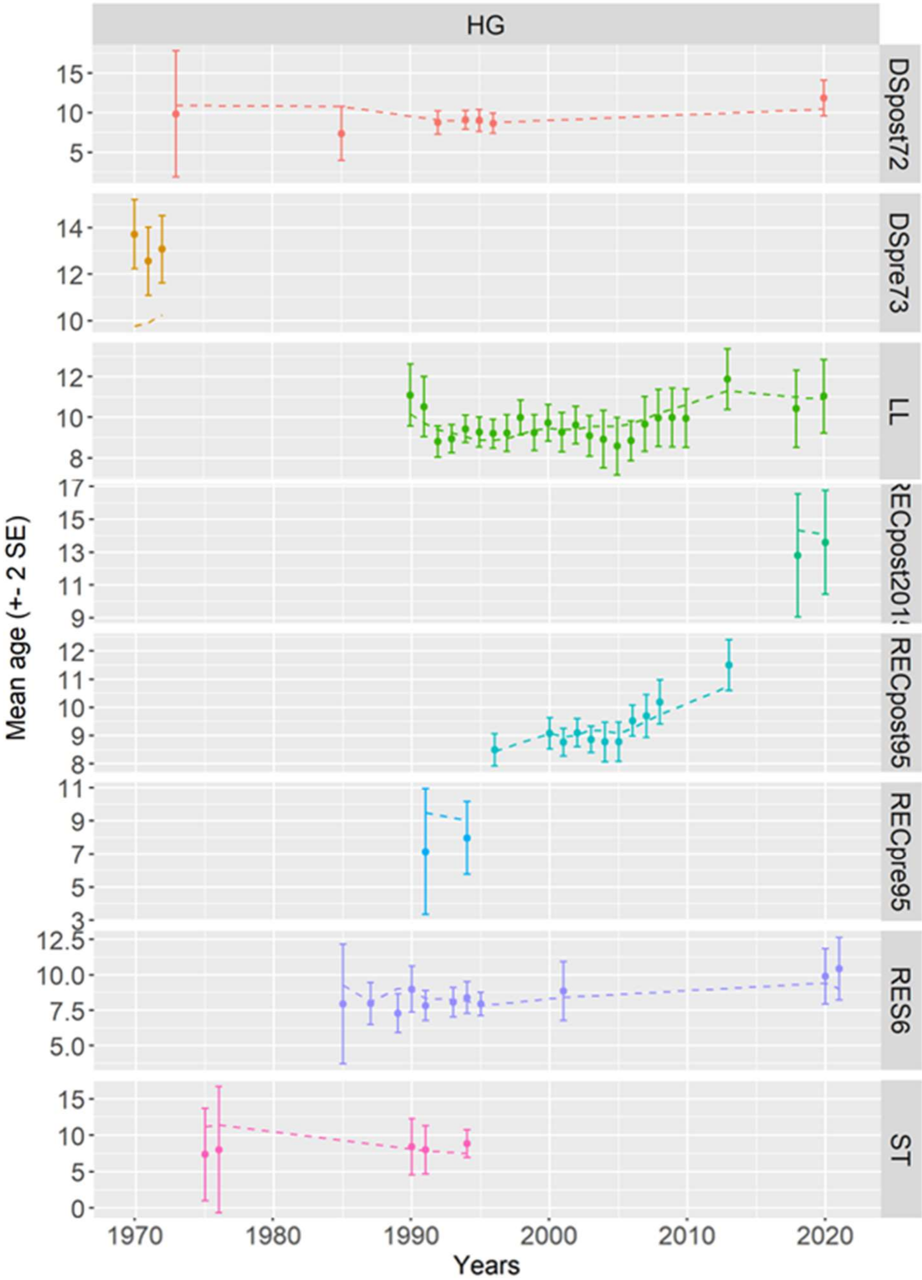


Figure 95: Hauraki Gulf 1968 base model mean length at-age predictions (dotted line) compared to observational data estimates, error bars represent 95% confidence intervals.

The estimated 1968 Hauraki Gulf base model selective ogives for pre-1973 Danish seine were effectively logistic in contrast to a domed post-1973 selectivity (Figure 96). A progressive temporal right-shift in the age of maximum selectivity is seen in the recreational line selectivity curves. This is consistent with the progressive increase in minimum legal size (Figure 96).

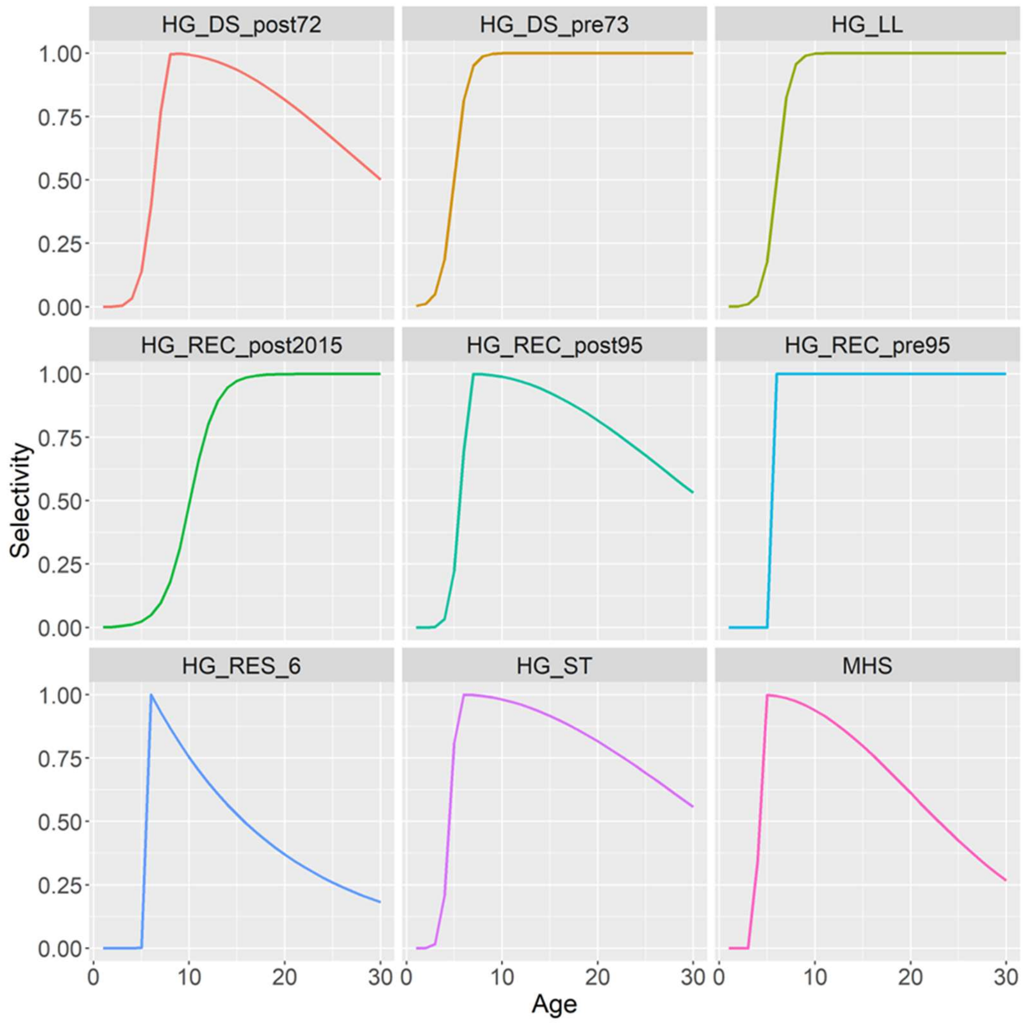


Figure 96: Hauraki Gulf 1968 base model estimated selectivity ogives.

Model predicted YCSs show the same progressive increasing trend as estimated by the 2022 SNA 1 assessment model (Figure 47, Figure 97). The only observations as to the strength of the 2015 year-class were the Hauraki Gulf trawl survey data where it is first seen in the five-year-old index from the 2020 survey (Figure 87). The 2015 year-class likelihood profiles show the Hauraki Gulf survey five-year-old likelihood as having the strongest influence on this parameter. Hauraki Gulf survey 6+ biomass likelihood favours an even higher estimate for the 2015 year-class, likely to better fit the strong biomass signal in 2021 (Figure 87). However, the 2015 year-class as seen in the six-year-old cohort in the 2021 Hauraki Gulf survey 6+ at-age data did not match model prediction (Figure 94).

The model prediction of a weak 1977 year-class (Figure 97) was adequately informed by the Hauraki Gulf longline, post-73 Danish seine, and trawl survey 6+ at-age compositional series (Appendix Figure 112).

The 1968 base model predicted SSB trajectory shows a strongly increasing trend after 1995 (Figure 98). The 1968 base model B_0 estimate (449 476 t) equated to a predicted 2021–22 stock-status of 32% B_0 (Table 43; Figure 98).

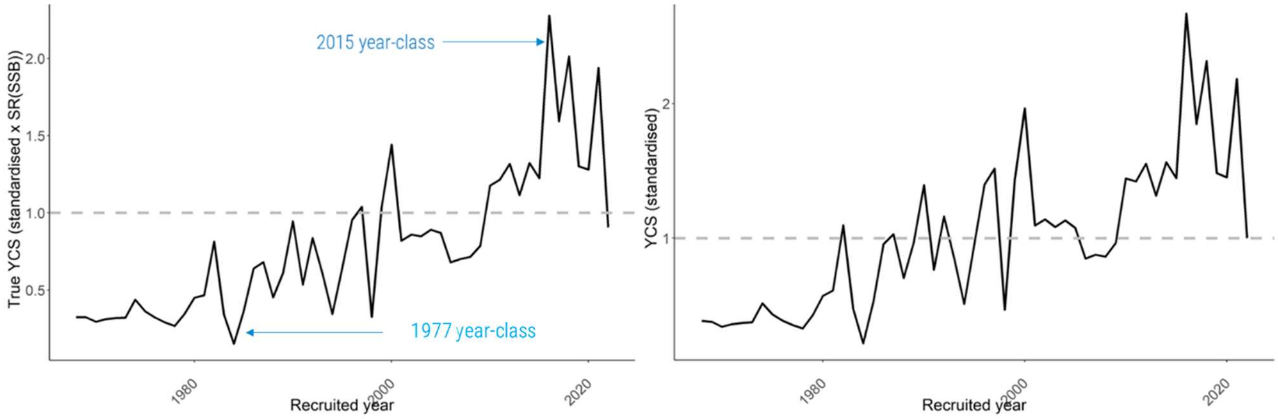


Figure 97: Hauraki Gulf 1968 base model Year Class Strength (YCS) estimates. The actual YCS estimates (right) are unadjusted for steepness (left). Years corresponding to the strongest and weakest year-classes are shown.

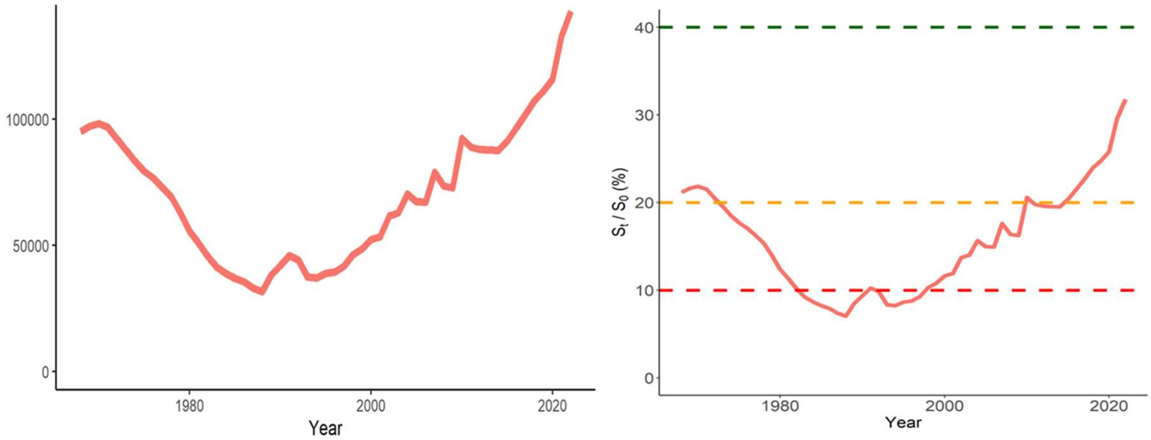


Figure 98: Hauraki Gulf 1968 base model SSB and stock-status predictions.

8.5 Hauraki Gulf base 1968 MCMC stock assessment and projections

Three MCMC chains of 2 million samples each were run using the Hauraki Gulf 1968 base model. All the MCMC chains were commenced at the MPD parameter values. The burn-in period on each chain was set at 200 000 with step size adjustments occurring at 20 000, 40 000, 50 000, 100 000, 150 000, 200 000. After 200 000 samples every 500th sample was retained thus generating the final MCMC posterior parameter sets.

Successful MCMC convergence was not possible when the pre-95 recreational line and pre-73 Danish seine selectivity parameters were set as free parameters, these parameters were therefore fixed in the MCMCs at the MPD estimated values.

The relative improvement in the respective MCMC chain acceptance rates were minimal after 200 000 samples indicating that the designated burn-in period was appropriate (Figure 99 right plot). The objective function values from each MCMC chain were strongly overlapping with no obvious departures in trend or pattern (Figure 99 left plot).

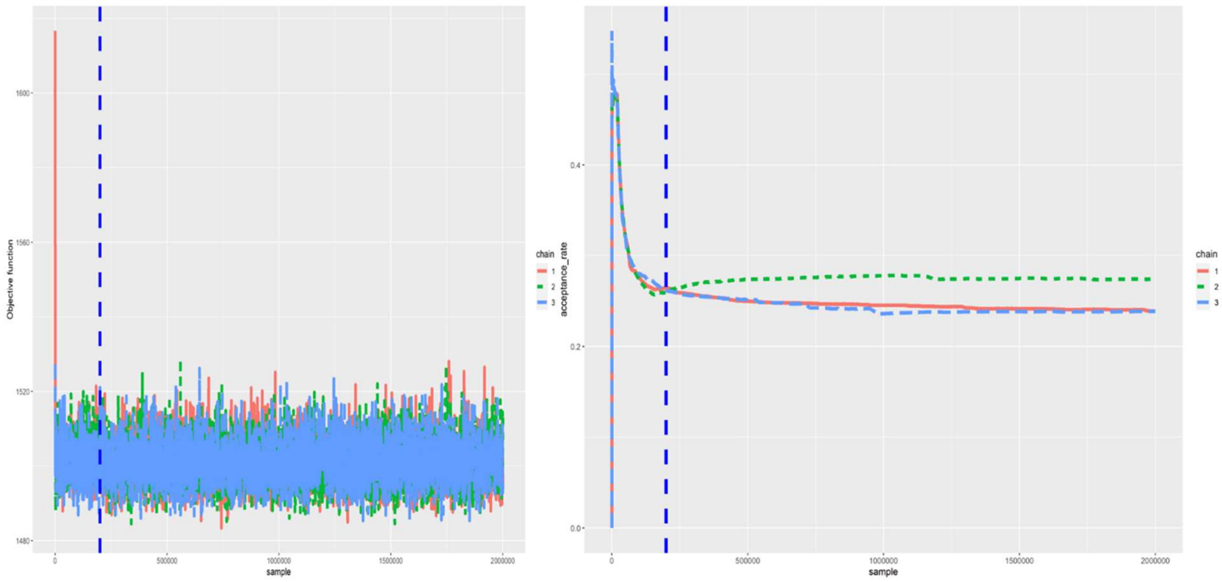


Figure 99: Hauraki Gulf 1968 base model objective function acceptance rate improvement for each MCMC chain (right plot), and full MCMC chain objective function values overlaid (left plot).

$\hat{R}$ (Gelman & Rubin 1992) convergence diagnostics on the three MCMC chains indicated acceptable MCMC convergence had been achieved on all free model parameters (Appendix Figure 113). The Hauraki Gulf bottom trawl selectivity parameters $y\sigma_L$ and ya_1 (estimated as orthogonal transformations) had the worst $\hat{R}$ convergence values (Appendix Figure 113). Further MCMC diagnostics conducted on these parameters also showed "acceptable" convergence (Appendix Figure 114, Appendix Figure 115). The inference was that if the worst $\hat{R}$ score parameters had converged so had those with better $\hat{R}$ scores.

MCMC convergence diagnostics for the B_0 and $F_{initial}$ model parameters (estimated as orthogonal transformations) were strongly indicative of successful convergence (Appendix Figure 116, Appendix Figure 117), indicative also that the MCMC posterior densities for these parameters were well described.

The MCMC selectivity parameter posterior densities for longline and post-95 recreational line were very tightly predicted. The posterior densities on the other Hauraki Gulf method selectivity ogives were markedly broader (Figure 100), notably, the right-hand limbs on the post-73 Danish seine and bottom trawl ogives varied between logistic and domed.

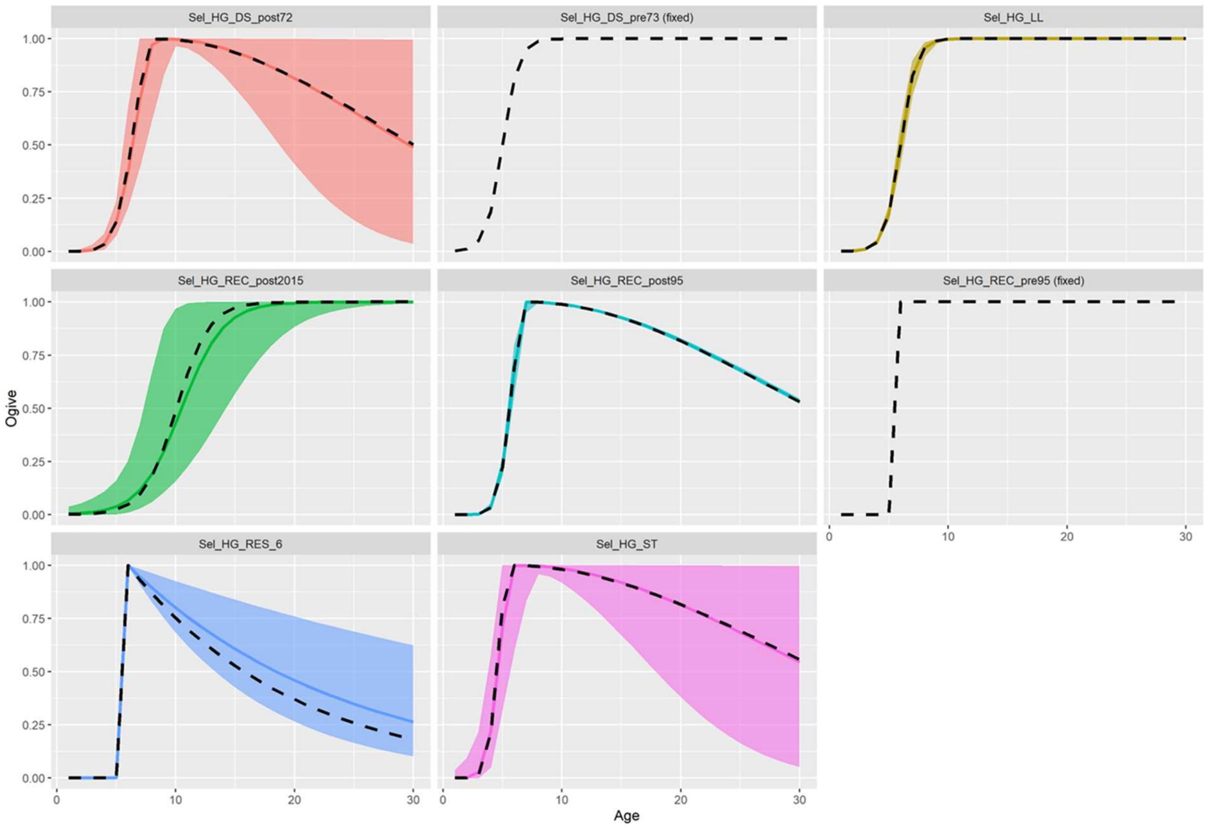


Figure 100: Hauraki Gulf 1968 base model MCMC selectivity predictions. Shaded areas are the MCMC 95% CI density ranges, colour lines are MCMC density medians, dashed lines are MPD predicted values.

MCMC median YCS predicted values closely matched MPD predicted values (Figure 101). As with the east Northland sub-stock MCMCs, YCS posteriors between 1980 and 2000 were relatively narrow, most likely due to there being multiple observations of these year-classes, those after 2000, where repeat year-class observations were fewer, (representing recent productivity) were less precisely known (Figure 101).

The MCMC median SSB and stock-status predictions again matched to MPD predicted values (Figure 102). Uncertainty in MCMC predicted trajectories progressively increases after 2004–05 probably due to there being fewer YCS observations after this date (Figure 102).

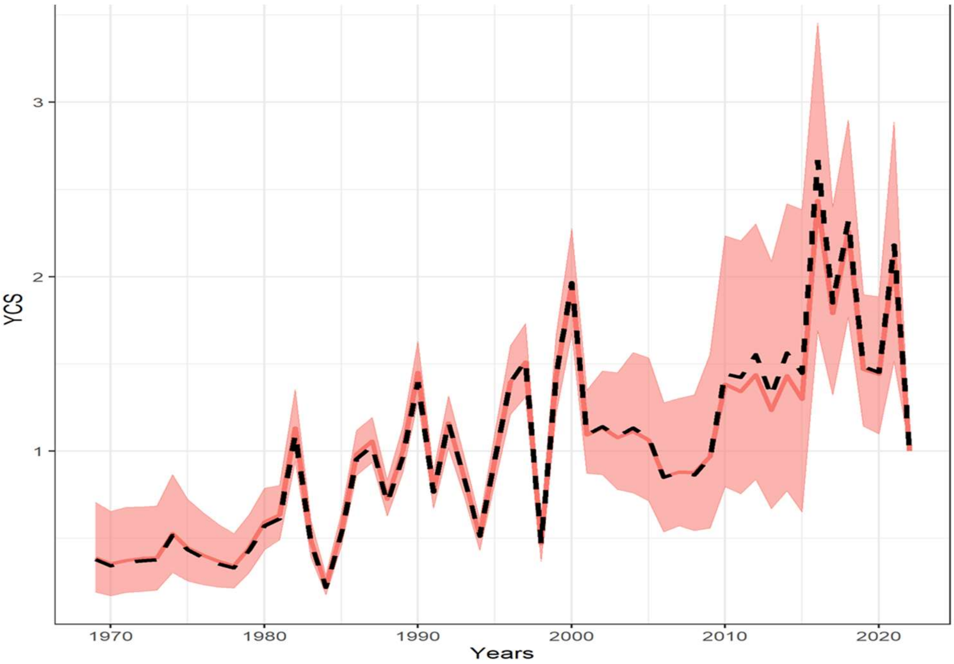


Figure 101: Hauraki Gulf 1968 base model MCMC Year Class Strength (YCS) estimates unadjusted for steepness. Shaded area is the MCMC 95% CI density range, redline MCMC density medians, dashed line MPD predicted YCSs.

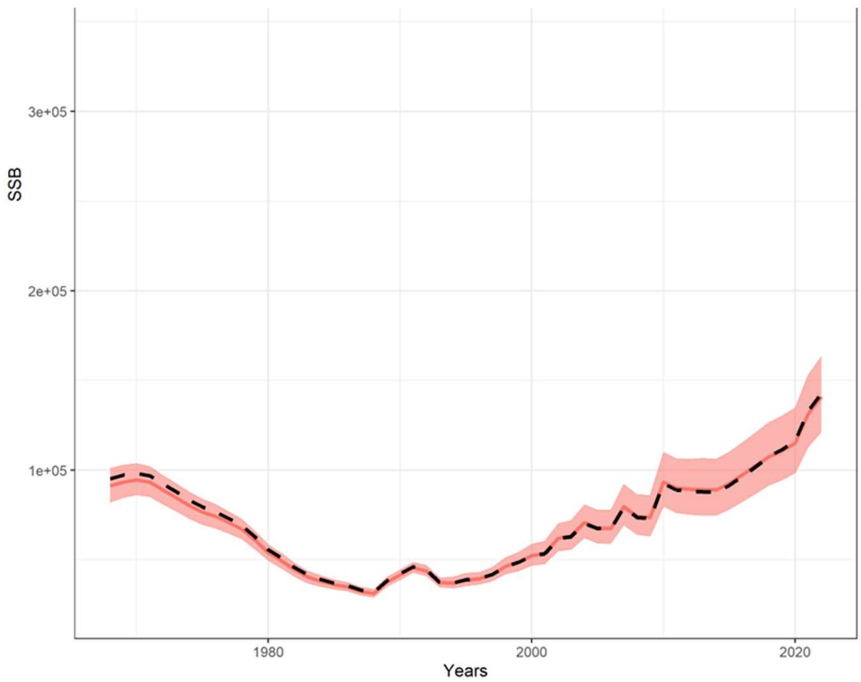


Figure 102: Hauraki Gulf 1968 base model MCMC SSB (tonnes) predictions. Shaded area is the MCMC 95% CI density range, redline MCMC density medians, dashed line MPD predicted value.

The derived target fishing-pressure (U; refer Appendix 19) corresponding to the 40% B_0 equilibrium biomass was 0.049 ($U_{SSB\ B40\%}$; Table 44). The MCMC median U estimate for 2021–22 (0.031;Table 44) was lower than the $U_{SSB\ B40\%}$ deterministic target. The probability of U being below $U_{SSB\ B40\%}$ in 2021–22 was 100% (Table 44).

Table 44: Hauraki Gulf 1968 base model 2021–22 MCMC predicted fishing-pressure (U) status.

Exploitation factor	Value
$U_{SSB\ B40\%}$	0.049
Median U_{2022}	0.031 (95% CI 0.027 – 0.036)
$U_{SSB\ B40\%}$ catch	8 802 t
p[$U_{2022} > U_{SSB\ B40\%}$]	0.0%
p[$U_{2022} < U_{SSB\ B40\%}$]	100.0%

8.6 Hauraki Gulf 1968 base model MPD sensitivity model results

The Working Group recommended the following four alternative model configurations as sensitivities to the base model assessment:

1. Lower natural mortality constant of 0.06 cf. 0.075;
2. Nearest neighbour growth applied outside the growth matrix year range as was done in the 2013 and 2022 base assessment models;
3. High pre-1984 commercial catch (+20%);
4. 1900 commence at virgin exploitation.

Post 1980 SSB trajectory predictions from all sensitivity models were similar to the 1968 base model (Figure 103).

The low M scenario, although predicting a similar post-1980 SSB trajectory to the base model, predicted a much lower stock-status outcome to the base model (Table 45; Figure 103). The lower stock-status prediction was most likely driven by the need for a higher B_0 to offset lower productivity associated with the lower M, a result that is typical for this type of sensitivity (Table 45).

Table 45: Hauraki Gulf 1968 base model stock-status sensitivity comparisons.

Model	B_{2022} (t)	B_{2022} %B_0	B_0 (t)
1968 commence base	**142 878**	**32%**	**449 476**
M 0.06	127 568	21%	615 109
nearest neighbour growth	126 433	31%	403 737
pre 84 catch + 20%	145 237	32%	455 778
1900 commence	130 264	32%	407 078

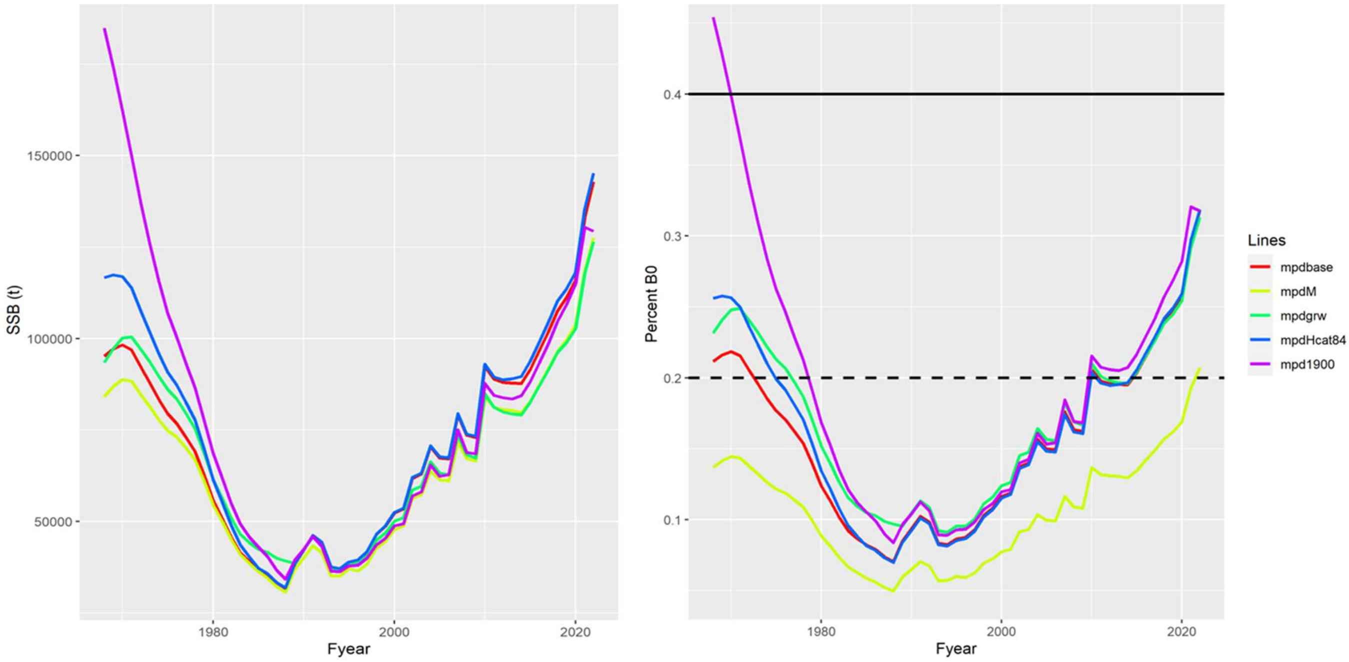


Figure 103: Hauraki Gulf 1968 base model SSB and stock-status model sensitivity comparisons.

8.7 Bay of Plenty base 1968 model MPD results

The Bay of Plenty 1968 base model consistently under-fit the 1996 to 2003 portion of the Bay of Plenty bottom trawl CPUE index and consistently over-fit the index between 2008 and 2016 (Figure 104). Despite the under and over fitting, the Bay of Plenty 1968 base model predicted trend was mostly with the 95% confidence intervals of the Bay of Plenty bottom trawl CPUE index (Figure 104).

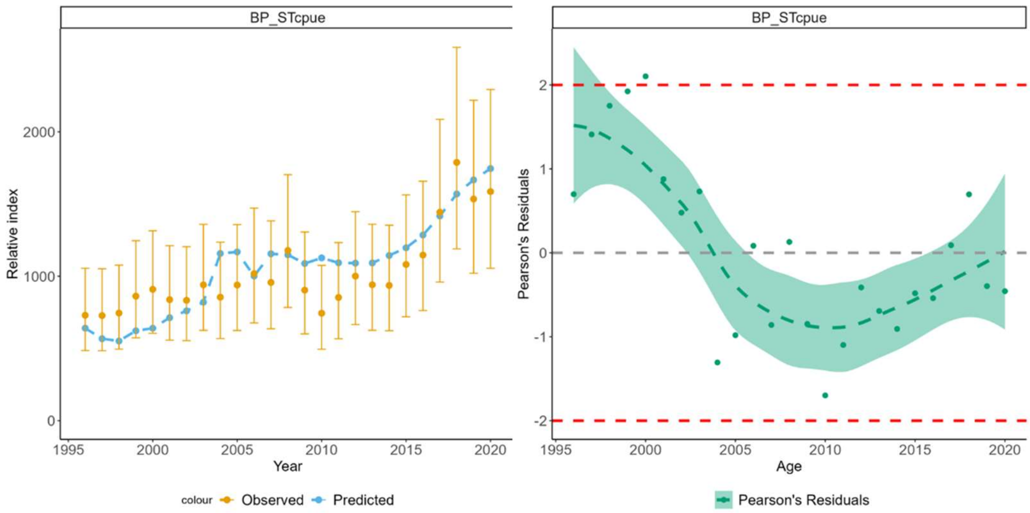


Figure 104: Bay of Plenty 1968 base model fit to the bottom trawl CPUE index; error bars are the 95% lognormal confidence intervals.

The Bay of Plenty 1968 base model also achieved good fits to the 1983 tag SSB estimate and 1994 Petersen 25–40 cm population estimates (Figure 105).

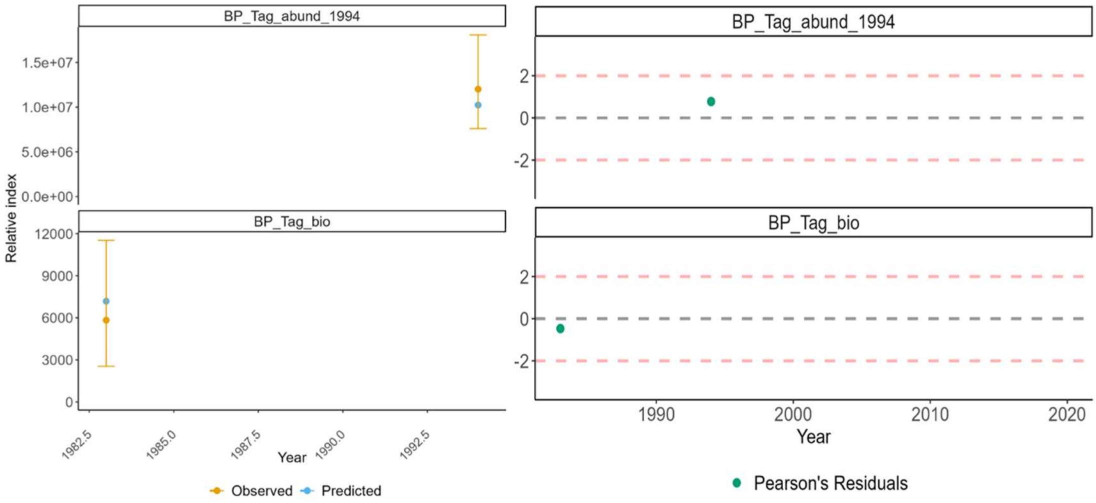


Figure 105: Bay of Plenty 1968 base model fit to the 1983 tag SSB estimate and 1994 Petersen 25–40 cm population estimates (numbers), error bars are 95% lognormal confidence intervals.

The Bay of Plenty 1968 base model fits to the Bay of Plenty trawl survey abundance series were mostly reasonable (Figure 106). The model was unable to fit the marked 6+ biomass increase predicted by the 2021 survey (Figure 106). The model was also unable to fit the strong one year-old cohort seen in the 2020 survey data (Figure 106).

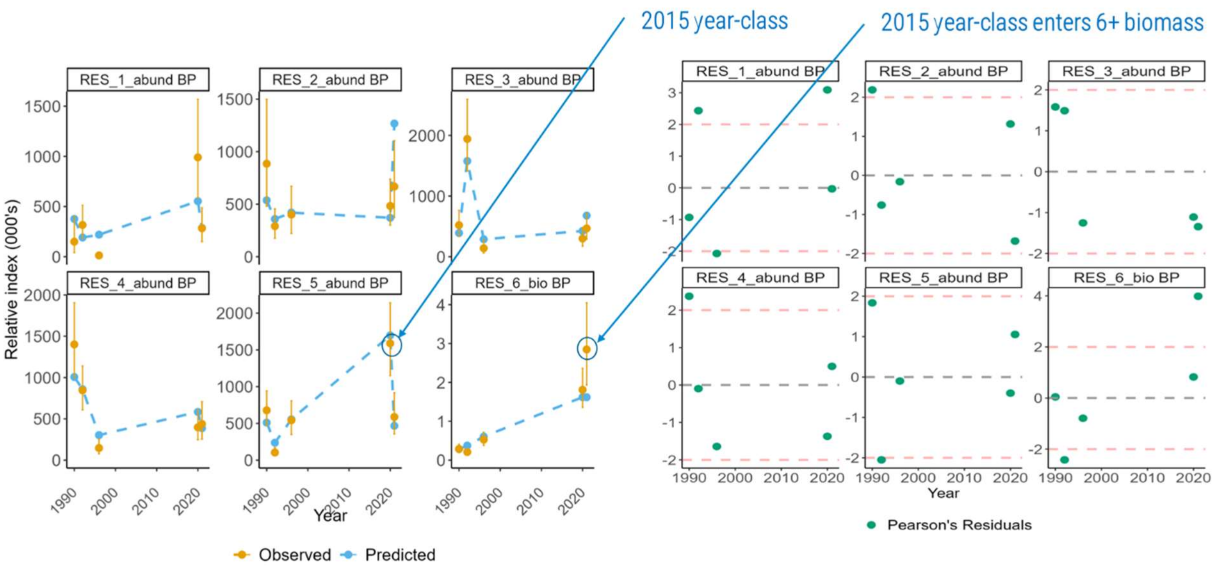


Figure 106: Bay of Plenty 1968 base model fit to the trawl survey 1–5 age cohorts and 6+ biomass indices. Data points that include a strong 2015 year-classs are indicated.

The Bay of Plenty 1968 base model fits to the Bay of Plenty longline age compositional data were generally "reasonable" amalgamated by age and survey-year (Figure 107, Appendix Figure 118). YCS in the longline data appear well estimated for most year-classes (Figure 107 centre plot).

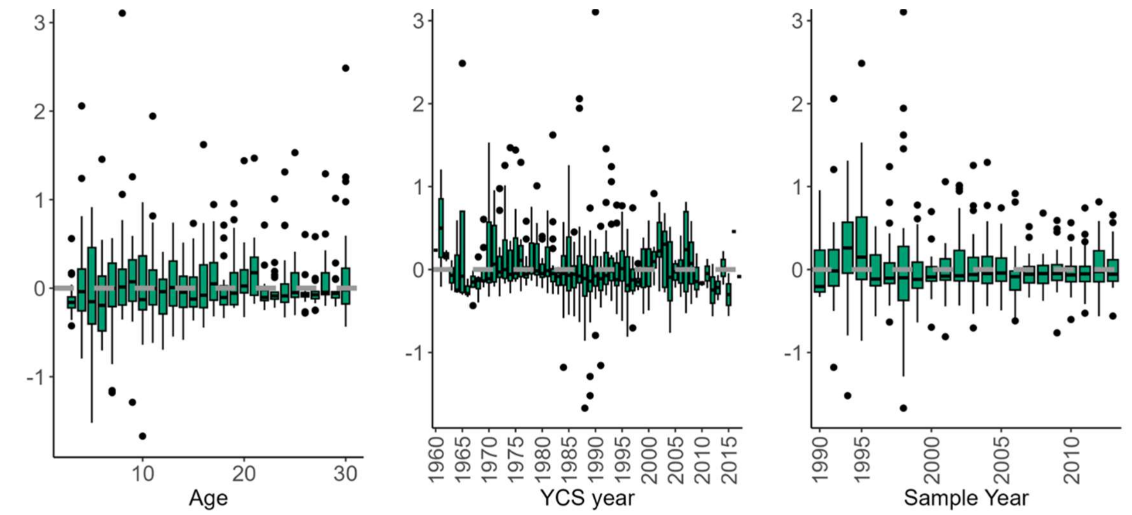


Figure 107: Bay of Plenty 1968 base model residual distributions from the longline age compositional fits. Left plot: model residual distributions aggregated by age class; middle plot: model residual distributions aggregated by year-class; right plot: model residual distributions aggregated by survey year.

The Bay of Plenty 1968 base model also achieved good fits to the Bay of Plenty Danish seine at-age data (Figure 108) and the 2020 MHS at-age data (Figure 109).

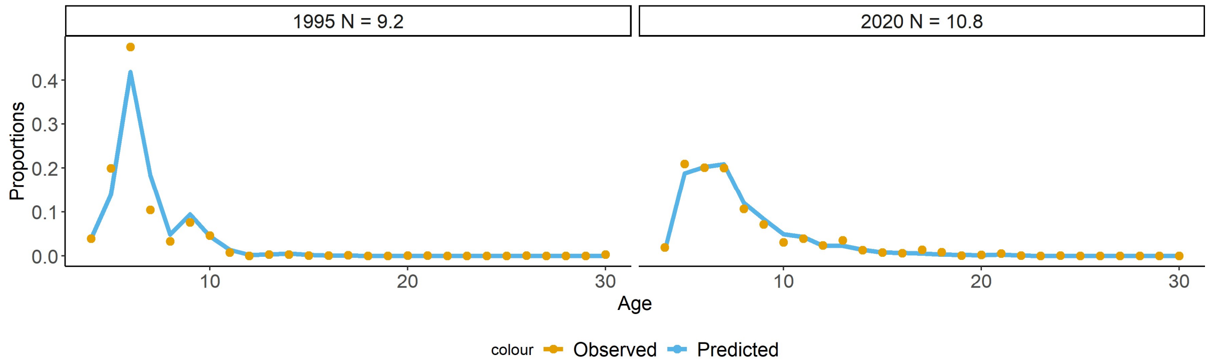


Figure 108: Bay Plenty 1968 base model fit to Danish seine at-age data. N = effective multinomial error after likelihood reweighting.

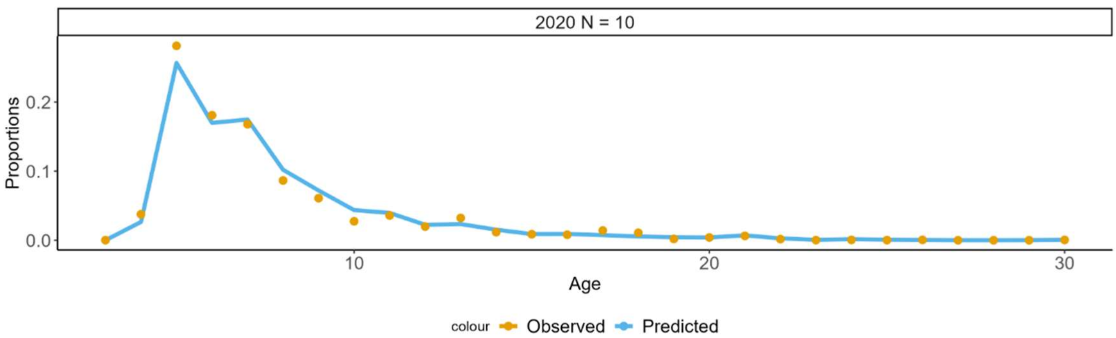


Figure 109: Bay Plenty 1968 base model fit to 2020 MHS at-age data. N = effective multinomial error after likelihood reweighting.

The Bay of Plenty 1968 base model achieved reasonable fits to the Bay of Plenty bottom trawl at-age data series (Figure 110).

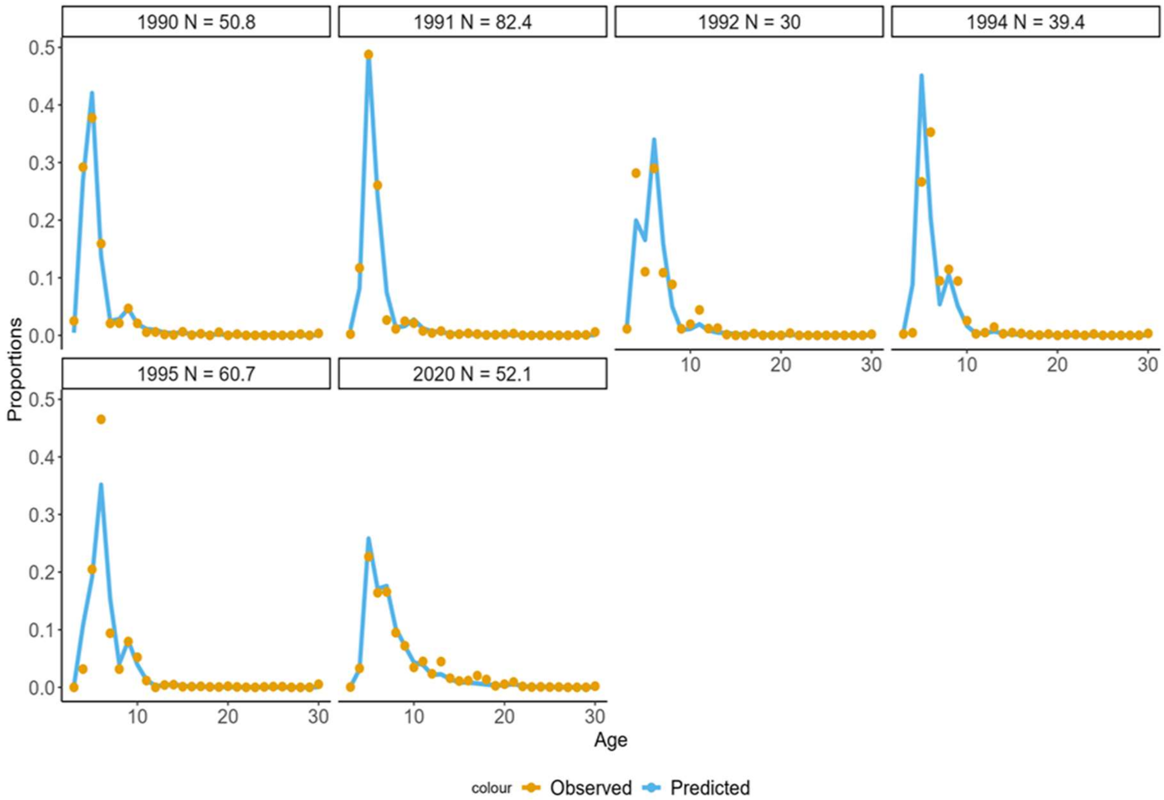


Figure 110: Bay of Plenty 1968 base model fit to bottom trawl at-age data. N = effective multinomial error after likelihood reweighting.

The Bay of Plenty 1968 base model also achieved reasonable fits to the pre-1995, post-1995, and post-2015 Bay of Plenty recreational line at-age data (Figure 111, Figure 112, Figure 113, Appendix Figure 119), but over/under patterns in predicted YCS between 1985 and 2000 were evident in model fits to the post-1995 age data series (Figure 112 centre plot).

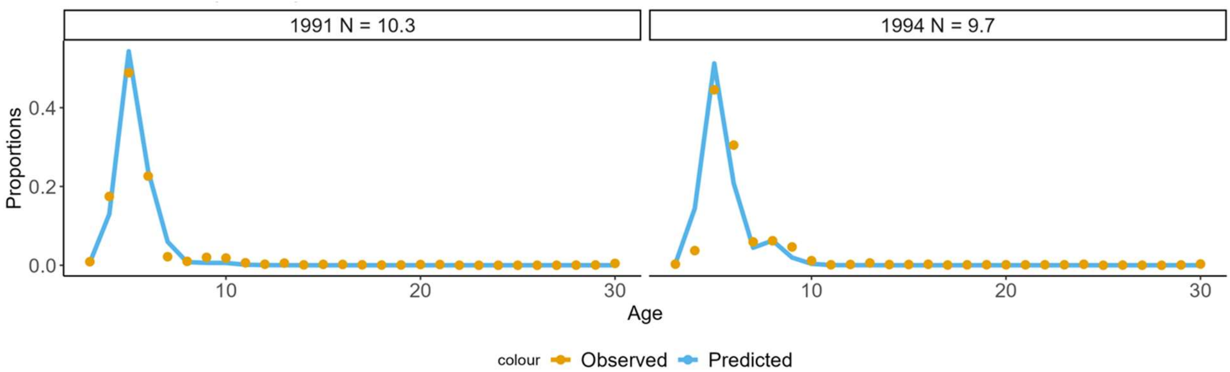


Figure 111: Bay of Plenty 1968 base model fit to pre-1995 recreational line at-age data. N = effective multinomial error after likelihood reweighting.

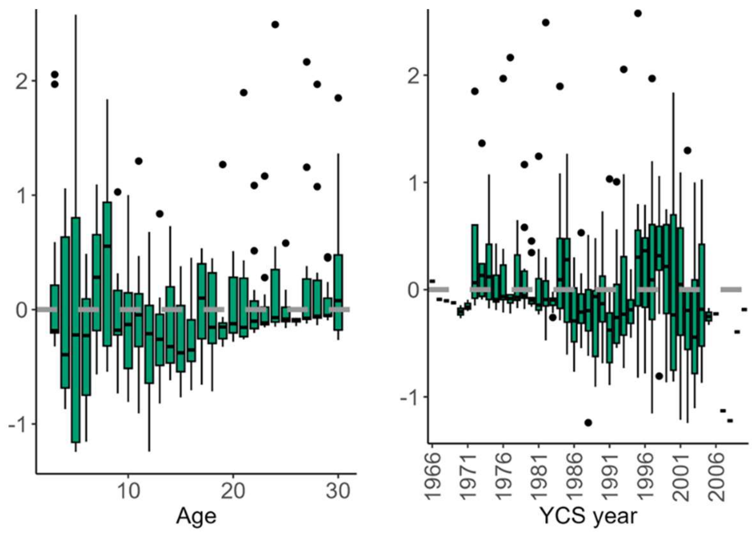


Figure 112: The Bay of Plenty 1968 base model residual distributions from the post-1995 recreational line age compositional fits. Left plot: model residual distributions aggregated by age class; middle plot: model residual distributions aggregated by year-class; right plot: model residual distributions aggregated by survey year.

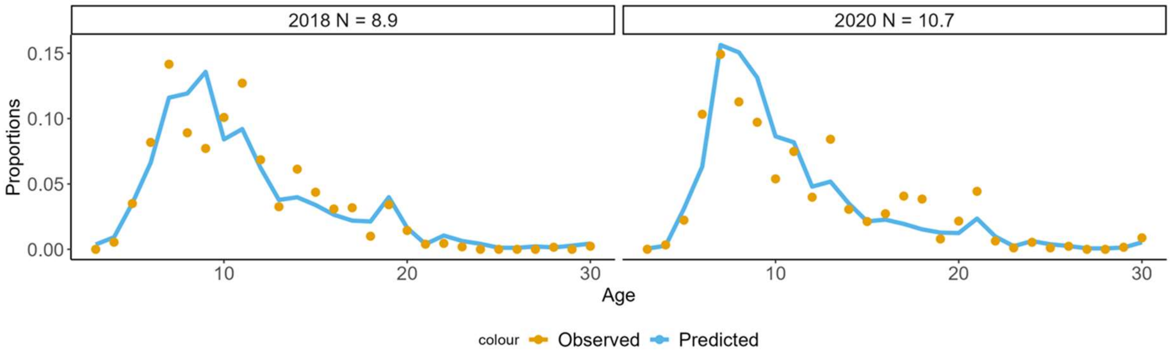


Figure 113: The Bay of Plenty 1968 base model fit to post-2015 recreational line at-age data. N = effective multinomial error after likelihood reweighting.

The Bay of Plenty 1968 base model fits to the 6+ Bay of Plenty trawl survey at-age series improved over most age classes by adoption of the double-exponential selectivity ogive, however, the model still consistently under-estimated the six-year-old age cohorts in the series (Figure 114).

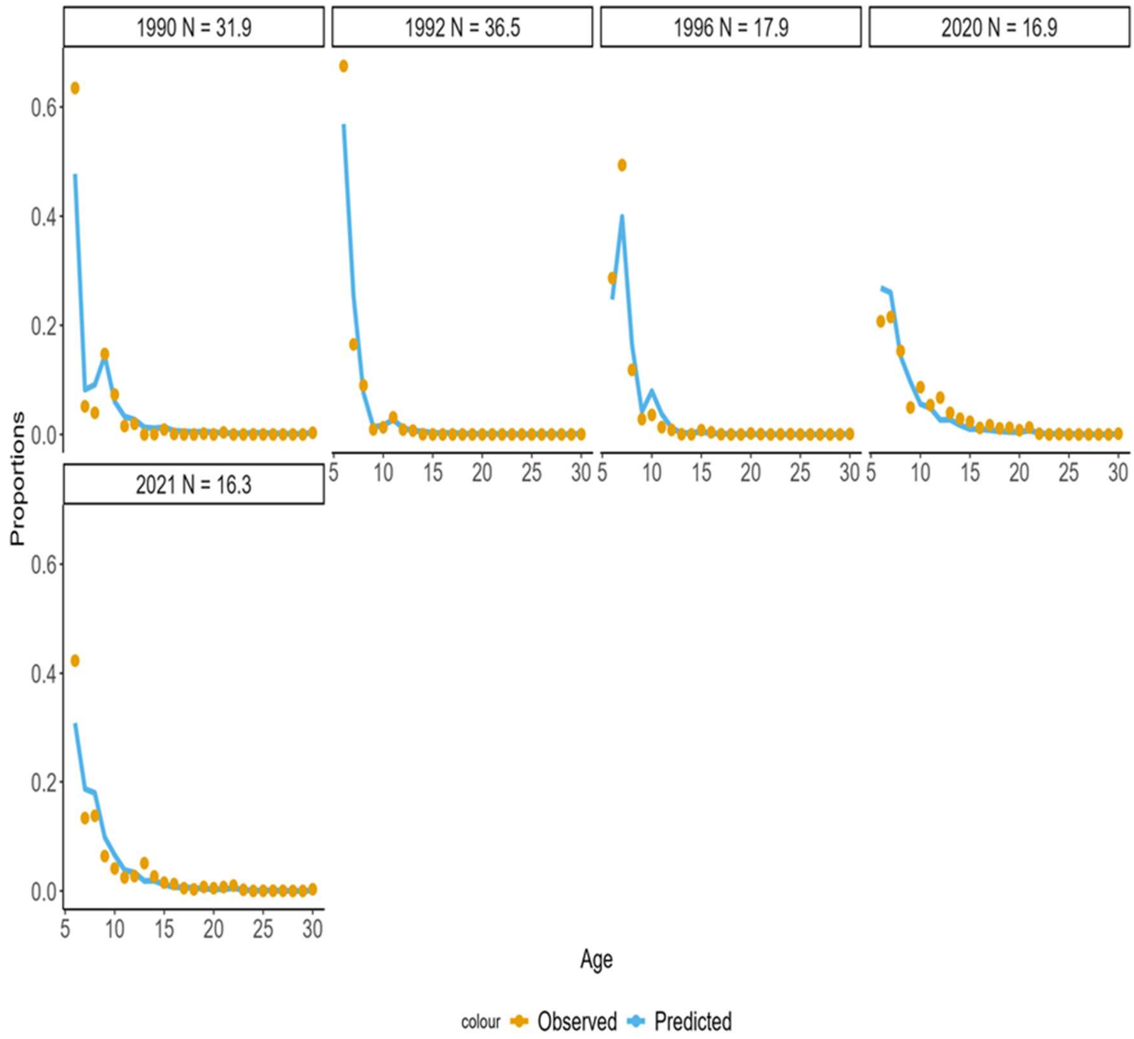


Figure 114: Bay of Plenty 1968 base model fit to trawl survey 6+ at-age data. N = effective multinomial error after likelihood reweighting.

The Bay of Plenty 1968 base model was able to capture the underlying growth variability to all Bay of Plenty age compositional series as evidenced in Figure 115.

The estimated Bay of Plenty 1968 base model selectivity ogives for all the non-line methods were domed (Figure 116). A progressive temporal right-shift in the age of maximum selectivity is seen in the recreational line selectivity curves which is consistent with the progressive increase in minimum legal size (Figure 116).

The Bay of Plenty 1968 base model predicted YCSs show a marked stock recruitment (steepness) adjustment effect (Figure 117) due to low 1980s predicted SSBs (Figure 118). There was evidence of an increasing trend in YCS through the series (Figure 117) but this trend was not as pronounced as the trend seen in the Hauraki Gulf 1968 base model YCS predictions (Figure 97).

The 1968 base model predicted SSB trajectory shows a strongly increasing trend after 1990 (Figure 118). The 1968 base model B_0 estimate (222 603 t) equated to a predicted 2021–22 stock-status of 14% B_0 (Table 43; Figure 118). Note: the model predicts the Bay of Plenty stock status in 1990 was about 5% B_0 (Figure 118) which some members of Working Group felt was implausible.

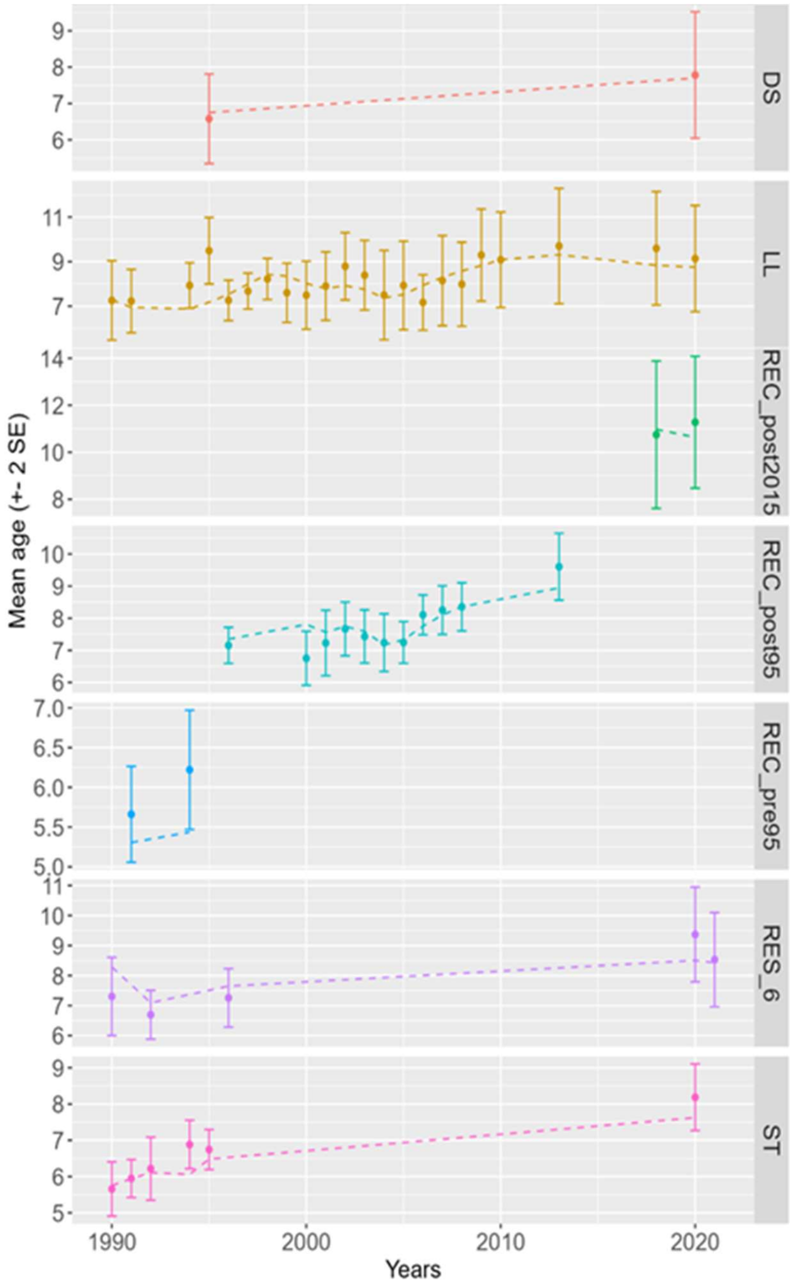


Figure 115: Bay of Plenty 1968 base model mean length at-age predictions (dotted line) compared to observational data estimates, error bars represent 95% confidence intervals.

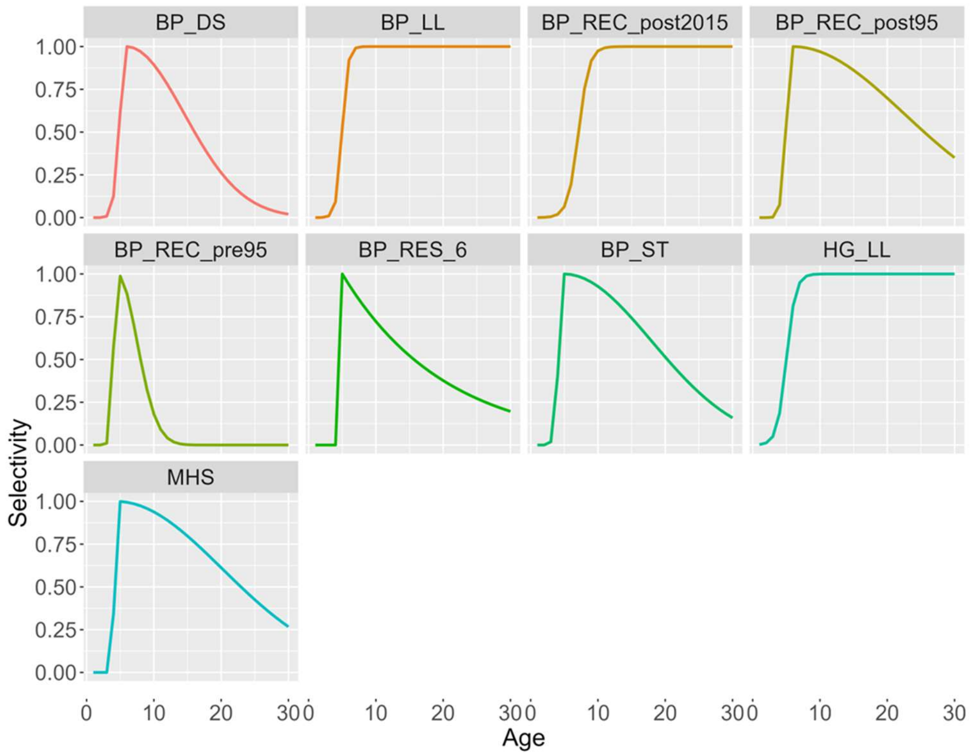


Figure 116: Bay of Plenty 1968 base model estimated selectivity ogives.

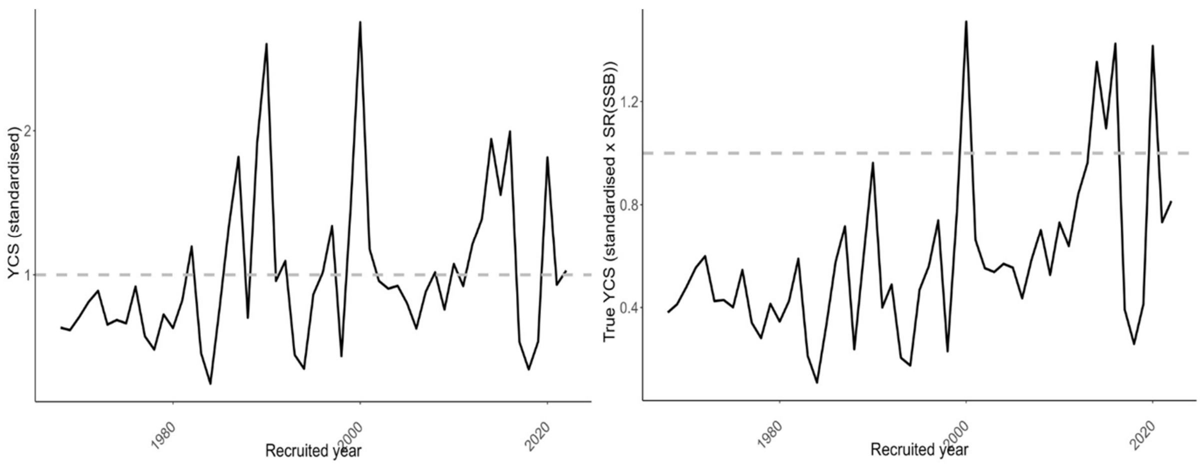


Figure 117: Bay of Plenty 1968 base model Year Class Strength (YCS) estimates. The actual YCS estimates (right) are unadjusted for steepness (left).

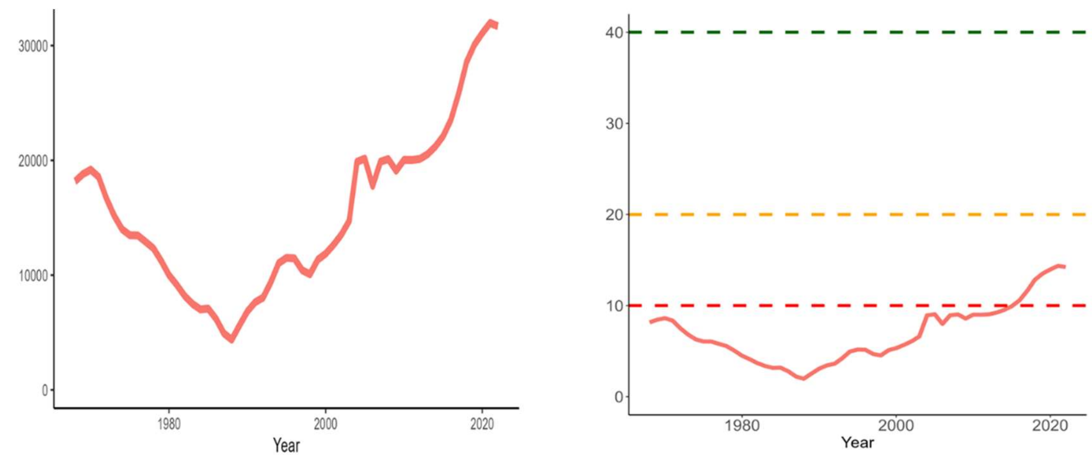


Figure 118: Bay of Plenty 1968 base model SSB and stock-status predictions.

8.8 Bay of Plenty 1968 base model MCMC stock assessment and projections

Three MCMC chains of eight million samples each were run using the Bay of Plenty 1968 base model. All the MCMC chains were commenced at the MPD parameter values. The burn-in period on each chain was set at 200 000 with step size adjustments occurring at 20 000, 40 000, 50 000, 100 000, 150 000, 200 000. After 200 000 samples every 500th sample was retained to generate the final MCMC posterior parameter set.

Successful MCMC convergence was not possible when the post-2015 recreational line and MHS selectivity parameters were set as free parameters, these parameters were therefore fixed in the MCMCs at the MPD estimated values.

The relative improvement in the respective MCMC chain acceptance rates were minimal after 200 000 samples indicating that the designated burn-in period was likely to be appropriate (Figure 119 right plot). The objective function values form each MCMC chain were strongly overlapping with no obvious departures in trend or pattern (Figure 119 left plot).

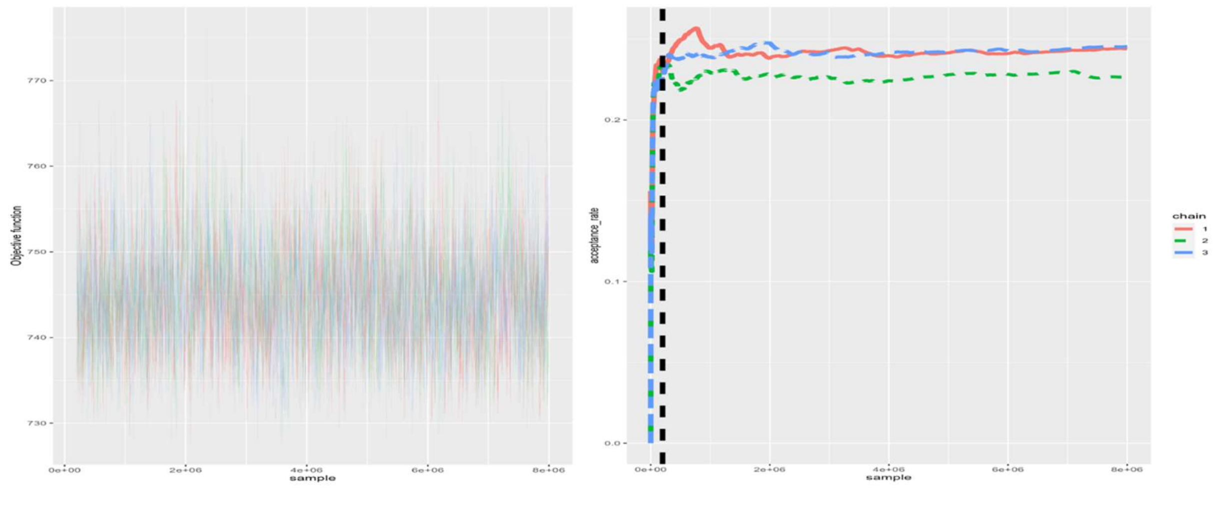


Figure 119: Bay of Plenty 1968 base model objective function acceptance rate improvement for each MCMC chain (left plot), and full MCMC chain objective function values overlaid as three colours (right plot).

$\hat{R}$ (Gelman & Rubin 1992) convergence diagnostics on the three MCMC chains indicated acceptable MCMC convergence had been achieved on all free model parameters (Appendix Figure 120).

MCMC convergence diagnostics for the B_0 and $F_{initial}$ model parameters (estimated as orthogonal transformations), although not ideal, were indicative of successful convergence (Appendix Figure 121; Appendix Figure 122).

The MCMC selectivity Bay of Plenty method parameter predictions, except for Danish seine and 6+ trawl survey methods, were very tightly predicted (Figure 120).

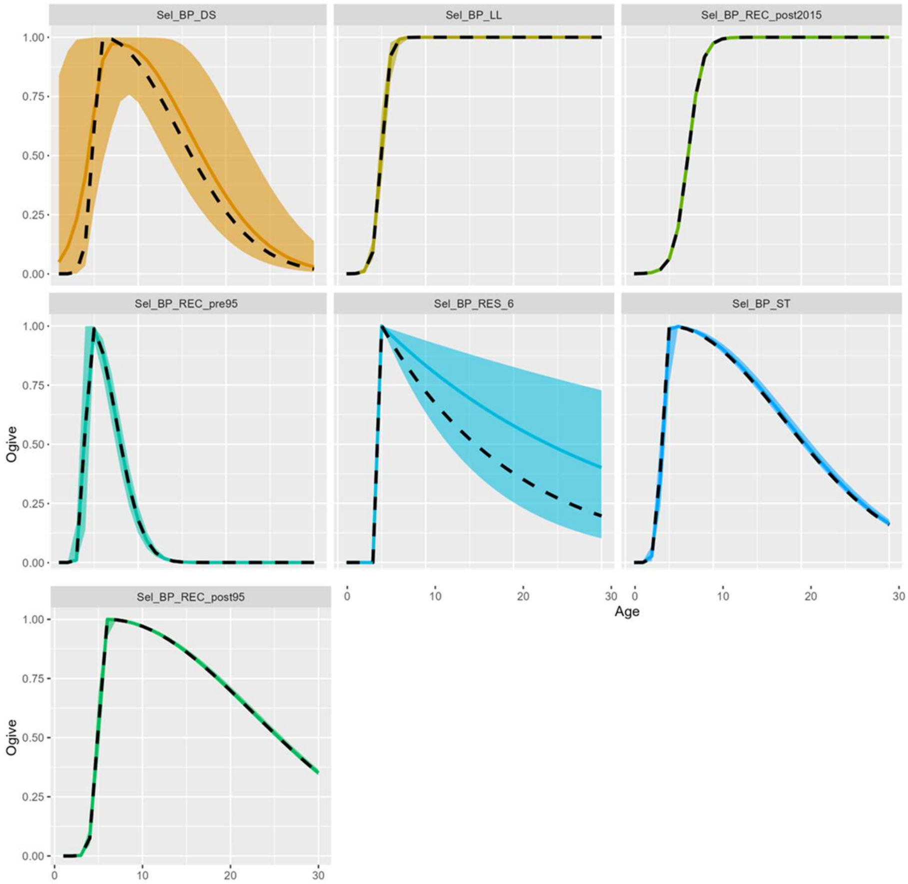


Figure 120: Bay of Plenty 1968 base model MCMC selectivity. Shaded areas are the MCMC 95% CI density ranges, coloured lines are MCMC density medians, dashed lines are MPD predicted values.

MCMC median YCS predicted values closely matched MPD predicted values (Figure 121). YCS posteriors between 1980 and 2000 were relatively narrow most likely due to there being multiple observations of these year-classes, whereas those between 2000 and 2014, where repeat year-class observations were fewer, (recent productivity) were less precise (Figure 121). Model post 2014 YCS predictions are only based on the 2020 and 2021 Bay of Plenty trawl survey at-age data, the tighter posteriors on these parameters suggest that recent YCS seen in each of the two surveys were similar (Figure 121).

The MCMC median SSB and stock-status predictions again matched to MPD predicted values (Figure 122). Uncertainty in MCMC predicted SSB trajectories progressively increased after 2004–05 (Figure 122).

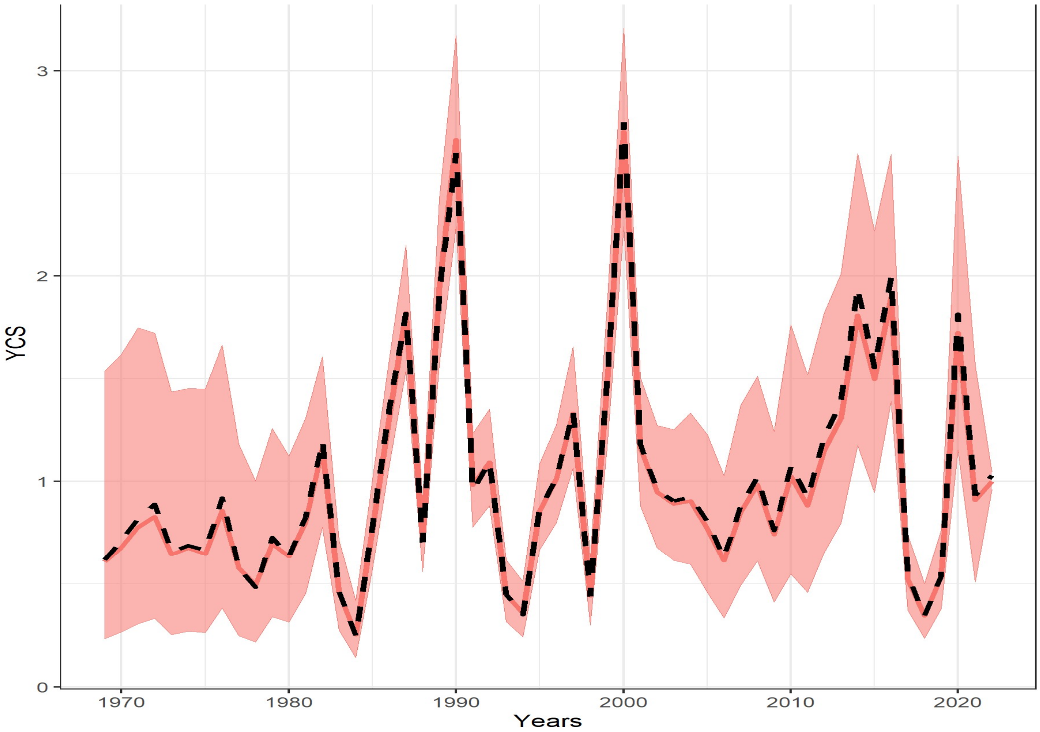


Figure 121: Bay of Plenty 1968 base model MCMC Year Class Strength (YCS) estimates unadjusted for steepness. Shaded area is the MCMC 95% CI density range, redline MCMC density medians, dashed line MPD predicted YCSs.

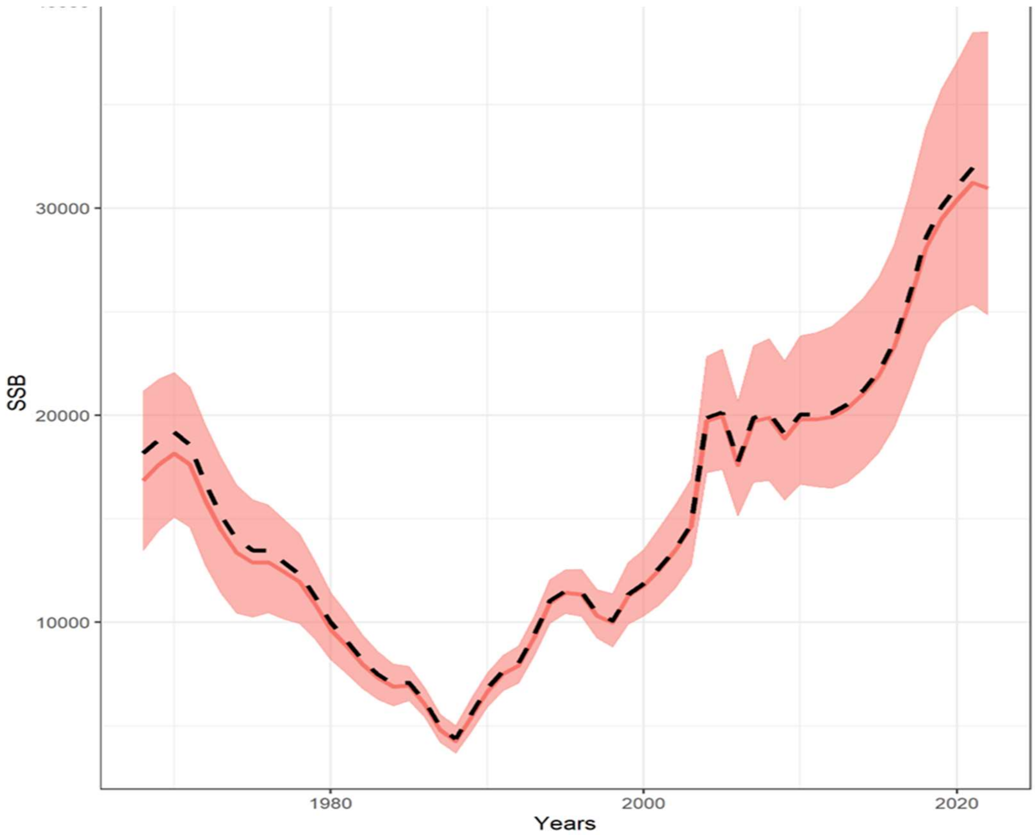


Figure 122: Bay of Plenty 1968 base model MCMC SSB (tonnes) predictions. Shaded area is the MCMC 95% CI density range, redline MCMC density medians, dashed line MPD predicted value.

The derived target fishing-pressure (U; refer Appendix 19) corresponding to the 40% B_0 equilibrium biomass was 0.049 ($U_{SSB\ B40\%}$; Table 46). The MCMC median U estimate for 2021–22 (0.08; Table 46) was higher than the $U_{SSB\ B40\%}$ deterministic target. The probability of U being below $U_{SSB\ B40\%}$ in 2021–22 was 0% (Table 46).

Table 46: Bay of Plenty 1968 base model 2021–22 MCMC predicted fishing-pressure (U) status.

Exploitation factor	Value
$U_{SSB\ B40\%}$	0.049
Median U_{2022}	0.08 (95% CI 0.07 – 0.11)
$U_{SSB\ B40\%}$ catch	3 437 t
p[$U_{2022} > U_{SSB\ B40\%}$]	100.0%
p[$U_{2022} < U_{SSB\ B40\%}$]	0.0%

8.9 Bay of Plenty 1968 base model MPD sensitivity model results

The Working Group recommended the following four alternative model configurations as sensitivities the base model assessment:

1. Lower natural mortality constant of 0.06 cf. 0.075;
2. Nearest neighbour growth applied outside the growth matrix year range as was done in the 2013 and 2022 base assessment models;
3. High pre-1984 commercial catch (+20%);
4. 1900 commence at virgin exploitation.

Post 1980 SSB trajectory predictions from all sensitivity models except the 1900 commence model were similar to those from the 1968 base model (Figure 123).

The low M scenario, although predicting a similar post-1980 SSB trajectory to the base model, predicted a much lower stock-status outcome to the base model (Table 47; Figure 103). The lower stock-status prediction was most likely driven by the need for a higher B_0 to offset lower productivity associated with the lower M, a result that is typical for this type of sensitivity (Table 47).

Table 47: Bay of Plenty 1968 base model stock-status sensitivity comparisons.

Model	B_{2022} (t)	B_{2022} %B_0	B_0 (t)
1968 commence base	**31 685**	**14%**	**222 603**
M 0.06	30 902	8%	398 364
nearest neighbour growth	31 432	15%	207 860
pre 84 catch + 20%	31 742	14%	225 461
1900 commence	19 562	16%	123 224

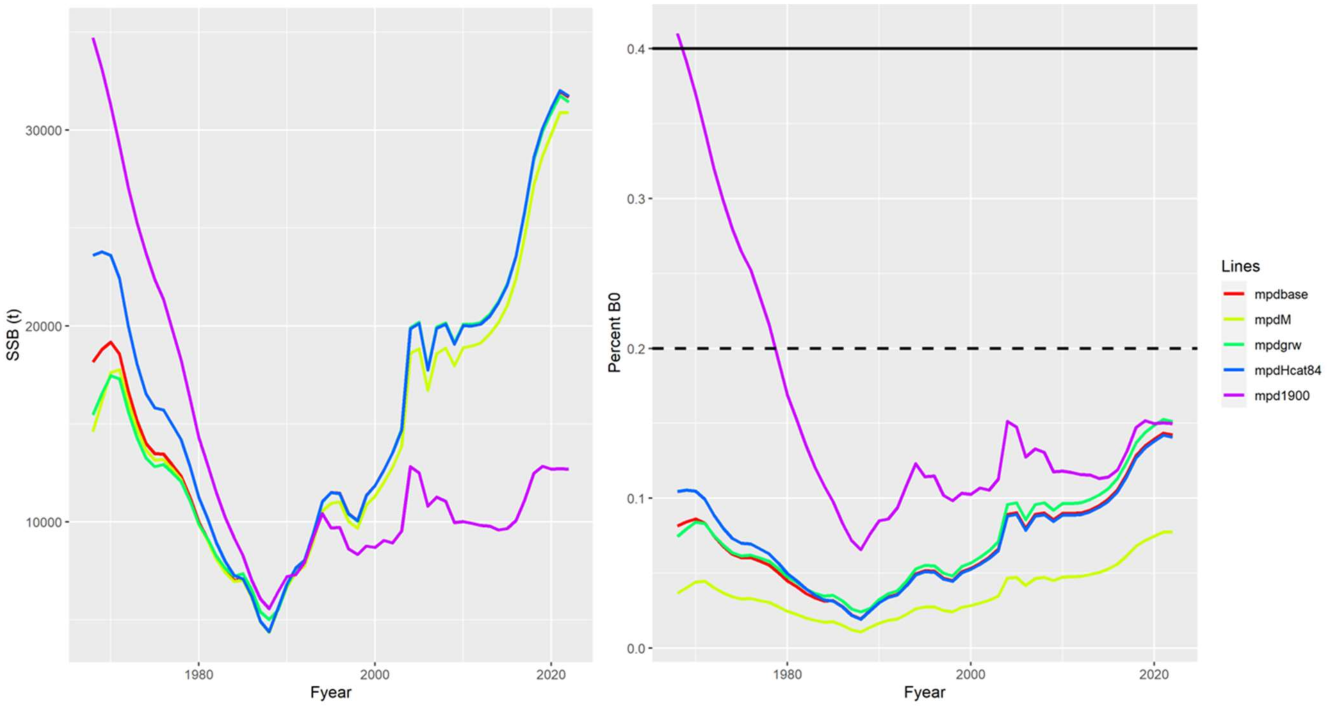


Figure 123: Bay of Plenty 1968 base model SSB and stock-status model sensitivity comparisons.

8.10 Hauraki Gulf/Bay of Plenty combined model stock status and projections

As discussed, the above independent assessments of the Hauraki Gulf and Bay of Plenty are likely to be biased because they did not account for known interchange between the two sub-stock areas as evidenced from tagging. The 2023 Plenary recommended combining the results of the two assessments for the purposes of management advise under the assumption that any individual assessment biases would likely cancel out, or at least partially.

The 2023 Plenary concluded that the strong upward trend in YCS seen in Hauraki Gulf 1968 base model predictions was evidence of a shift in sub-stock productivity (B_0) after 2000 (Figure 97). Although the same upward trend in YCS was less evident in the Bay of Plenty sub-stock model predictions (Figure 117), the 2023 Plenary concluded that an increasing B_0 would still feature in combined sub-stock productivity dynamics. There is growing evidence from the fisheries research literature as to the "inappropriateness" of equilibrium B_0 reference points for fisheries management under changing productivity as might be expected under climate change (see Marsh et al. 2024 for review). Marsh et al. (2024) showed that, if it is suspected that productivity has changed over the assessment period, exploitation-based (F-based) reference measures are likely to be less biased than B_0 reference measures.

The 2023 Plenary was not confident in the B_0 estimates from the Hauraki Gulf and Bay of Plenty assessment models but was confident in the model SSB predictions. The 2023 Plenary therefore accepted the U-based assessment findings for the Hauraki Gulf/Bay of Plenty sub-stock complex. $U_{SSB40\%}$ estimates for each of the three SNA 1 sub-stocks were similar (0.052, 0.049, 0.049) despite differences in model B_0s. The 2023 Plenary therefore accepted 0.05 as the $U_{SSB40\%}$ sustainability reference value for the Hauraki Gulf/Bay of Plenty sub-stock complex.

The Hauraki Gulf/Bay of Plenty combined mode SSB trajectory shows a continuing upward trend after the late 1980s (Figure 124).

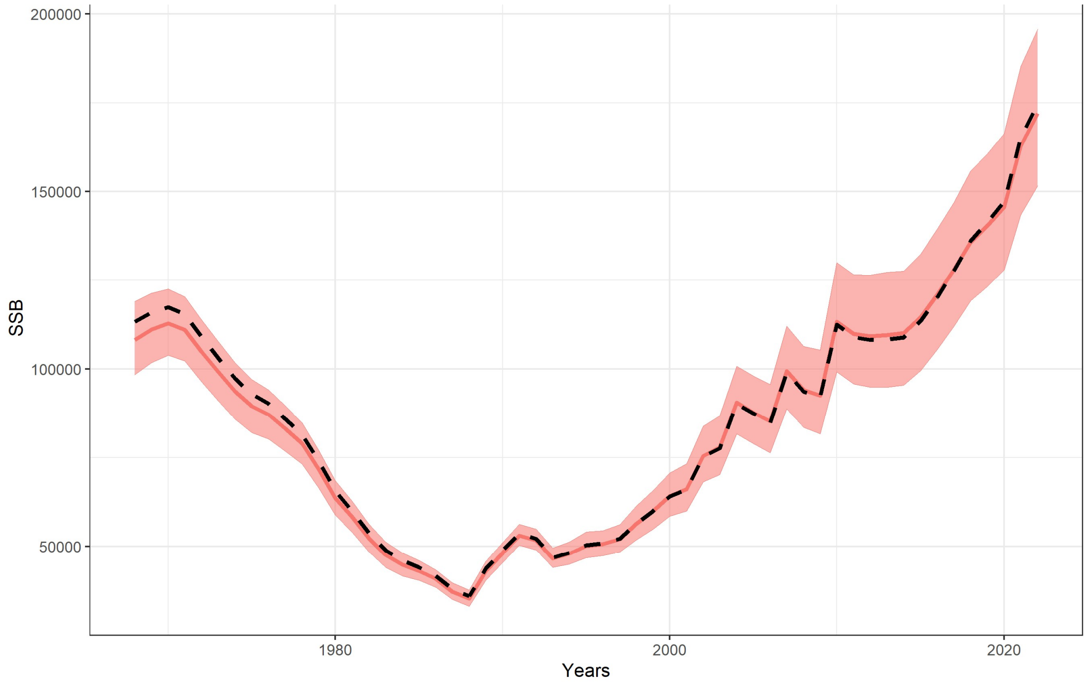


Figure 124: Hauraki Gulf/Bay of Plenty combined model MCMC SSB (tonnes) predictions. Shaded area is the MCMC 95% CI density range, redline MCMC density medians, dashed line MPD predicted value.

The Hauraki Gulf/Bay of Plenty combined model MCMC median U estimate for 2021–22 was lower than the $U_{SSB\ B40\%}$ reference value (0.041; Table 48). The probability of U being above $U_{SSB\ B40\%}$ in 2021–22 was 0.02% (Table 48).

Table 48: Hauraki Gulf/Bay of Plenty combined model 2021–22 MCMC predicted fishing-pressure (U) status.

Exploitation factor	Value
$U_{SSB\ B40\%}$	0.050
Median U_{2022}	0.041 (95% CI 0.036 – 0.046)
$U_{SSB\ B40\%}$ catch	12 240 t
p[$U_{2022} > U_{SSB\ B40\%}$]	0.02%
p[$U_{2022} < U_{SSB\ B40\%}$]	99.98%

MCMC projections of the Hauraki Gulf/Bay of Plenty combined model were undertaken for the year range 2022–23 to 2026–27. Two projections were undertaken in respect to post-2014 YCS variability: one resampling the full period of estimable year-class parameters (1975–2021), the other resampling estimable year-classes only from the most recent 10 years (2011–2021). Both sets of projections were undertaken with post 2021–22 recreational and commercial catches set to the model 2021–22 values. There was 0.00% probability of the Hauraki Gulf/Bay of Plenty U going above that of the $U_{SSB\ B40\%}$ reference value between 2023 and 2027 under either recruitment projection scenario (Table 49, Figure 125).

Table 49: Hauraki Gulf/Bay of Plenty combined model MCMC post-2022 five-year projection $U_{SSB\ B40\%}$ reference status.

	Status	2023	2024	2025	2026	2027
1975 – 2021 YCS resampling						
	U< $U_{SSB\ B40\%}$	100%	100%	100%	100%	100%
2011 – 2021 YCS resampling						
	U< $U_{SSB\ B40\%}$	100%	100%	100%	100%	100%

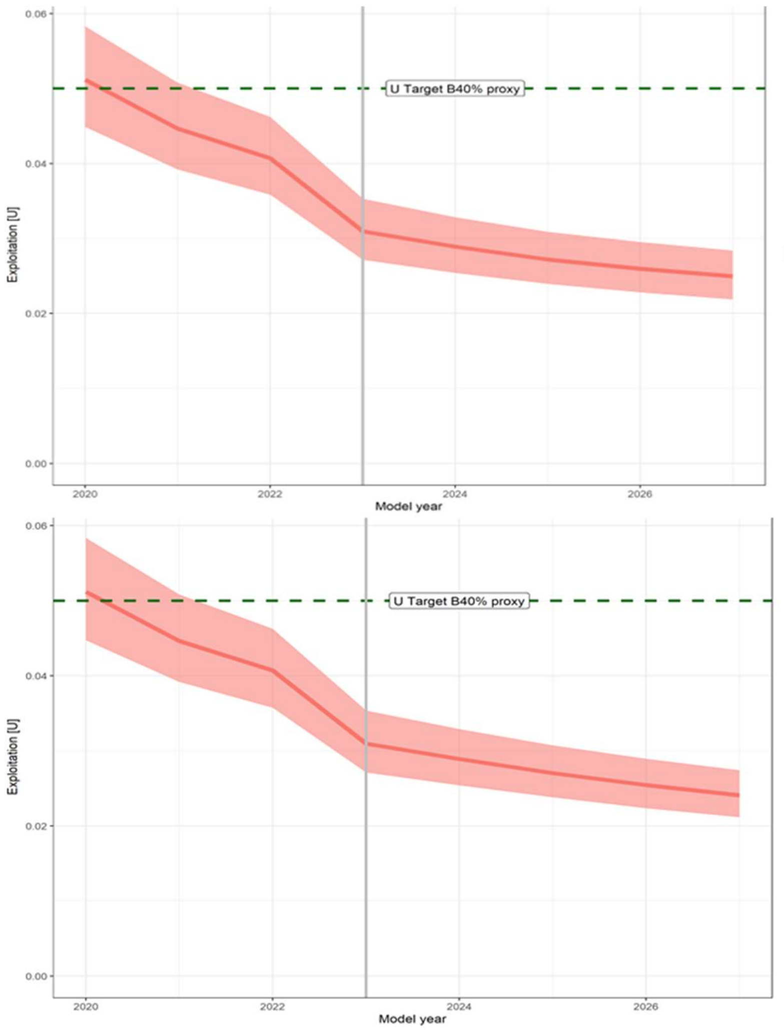


Figure 125: Hauraki Gulf/Bay of Plenty combined model status ($U_{SSB\ B40\%}$) projections. MCMC medians solid line, shaded region 95% confidence intervals. Top 1975–2021 YCS resampling, bottom 2011–2021 YCS resampling.

9 DISCUSSION

The 2022 and 2023 SNA 1 assessments necessitated a thorough review of historical monitoring and catch information available for this stock complex. The work has reaffirmed our belief in the presence of three stock productivity units (sub-stocks) within the SNA 1 QMA and improved our understanding of the spatial extent of the east Northland and Hauraki Gulf sub-stocks. The VAST analysis provided further evidence of seasonal migration and mixing into and out of the central Hauraki Gulf sub-stock area. The VAST analysis also showed, as long suspected, that SNA 1 sub-stock boundaries are labile and broadly diffuse, the existence of which is a challenge for stock assessment modelling and management. The 2022 and 2023 SNA 1 stock assessment models were unsuccessful in attempts to explicitly account for sub-stock mixing and movement; the available observational data were of insufficient power to estimate this. It is uncertain to what degree the 2023 SNA 1 assessment results would have been biased by ignoring movement.

There were investigations made as part of the 2022–23 SNA 1 assessment process as to possible linkages between the Bay of Plenty sub-stock and snapper residing in the northern region of the SNA 2 QMA (Figure 1). A derived SNA 2-north bottom trawl CPUE index showed a similar magnitude upward trend to the Bay of Plenty bottom trawl index. However, age-structure comparisons between snapper from the more western Bay of Plenty and SNA 2-north were inconclusive. Further data is needed to better understand the relationship between Bay of Plenty and SNA 2-north, specifically the collection of at-age data from the eastern Bay of Plenty region.

The likely occurrence of an upward productivity shift in the Hauraki Gulf/Bay of Plenty sub-stock complex after 2000 was another important conclusion from the 2022–23 SNA 1 assessment process. The acceptance of this by the 2023 Plenary has meant that traditional equilibrium B_0 reference points are likely to be inappropriate for Hauraki Gulf/Bay of Plenty sub-stock complex management (Marsh et al. 2024). The 2023 Plenary recommended assessing the Hauraki Gulf/Bay of Plenty sub-stock complex against exploitation-based reference points (F-based); the ratio of total annual catch to mid-year SSB (U) being chosen for this. The independent 2023 assessments of the three SNA 1 sub-stocks produced very similar equilibrium $U_{SSB\ B40\%}$ ratio values (~0.05) despite each sub-stock model producing very different B_0 estimates. This means that, despite uncertainty as to current Hauraki Gulf/Bay of Plenty productivity ($B_{0current}$), the current fixed $U_{SSB\ B40\%}$ sustainability reference value is unlikely to be significantly altered by future productivity changes. The reason for this is that $U_{SSB\ B40\%}$ is essentially a per-recruit reference point meaning that the model R_0 (mean recruitment) value is largely immaterial to its derivation. A shift to $U_{SSB\ B40\%}$ sustainability measures for SNA 1 means that reliable estimates of current sub-stock SSBs are now critical for setting TACs. It was seen in the 2022 and 2023 SNA 1 sub-stock assessments that the tag derived absolute abundance estimates from the mid-1980s and 1990s were highly influential on the post-2000 SSB predictions from the various models. Most of the Hauraki Gulf and Bay of Plenty assessment model variants derived similar post-2000 SSB trajectories, as all were constrained by the tagging likelihoods to predict similar 1985–1995 SSB values. For this reason, the 2023 Plenary was confident in the SNA 1 base assessment model SSB predictions, despite the lack of confidence in Hauraki Gulf and Bay of Plenty model B_0 estimates. Future SNA 1 stock assessments will become increasingly reliant on relative abundance measures to estimate current-SSBs, so the need for new absolute abundance estimates for the SNA 1 sub-stocks is likely to become more critical.

Incidental mortality is a significant issue that has not been addressed, as this was not explicitly accounted for in the 2023 and all previous SNA 1 assessments. This is because incidental mortality has proven both difficult and costly to estimate for snapper (McKenzie et al. 2024). An assumption in all previous SNA 1 assessments has been that incidental mortality is implicit in the abundance data observations going into the models such that model yield predictions (e.g. sustainable catch removal recommendations) implicitly include an associated level of incidental mortality. This assumption is most likely violated if the exploitation demographics of the fishery change, such that there is a significant shift to a method with a greater or lower associated incidental mortality level than past methods. Explicit inclusion of incidental mortality in future SNA 1 assessments needs careful consideration, as it is essentially an all or nothing decision, and incidental mortality estimates will be not only be required for all current fishing methods and practices but for all those in the past as well. The recent decision by Fisheries New Zealand to now require most commercial methods to land all snapper caught regardless of size or survival condition will likely force the need to explicitly account incidental mortality in future SNA 1 stock assessments, as has been the European experience (Tom Catchpole ICES stock assessment scientist pers. comm.).

10 FUTURE RESEARCH RECOMMENDATIONS

The 2022–23 SNA 1 stock assessment process provided further insight into the biological complexities of the SNA 1 sub-stock complex. We know the SNA 1 stock complex comprises three sub-stocks of differing productivity and exploitation status. We know the boundaries between these sub-stocks are diffuse and expand and contract on seasonal cycles. We know the levels of interchange between the Hauraki Gulf and Bay of Plenty sub-stocks are higher than between these sub-stocks and the east Northland sub-stock. We now know the southern region of Statistical Area 003 to be part of the Hauraki Gulf sub-stock range. We suspect that some degree of mixing also occurs between the eastern Bay of Plenty and the northern region of SNA 2. We know the productivity potential ($B_{0current}$) of the SNA 1 sub-stocks has progressively changed over last 30 years as evidenced by lowering growth-rates and increasing recruitment strengths. Because of this, we know caution should be exercised in using model B_0 (as derived based on long-term productivity dynamics) as sustainability measures for the Hauraki Gulf/Bay of Plenty sub-stock complex. We suspect that the relative levels of incidental fishing mortality have changed through time such that incidental mortality should ideally be explicitly factored into future SNA 1 assessments.

Currently we lack the monitoring data to adequately describe, estimate, and account for many of these dynamics in SNA 1 stock assessments. Also, some of methods used in the past to monitor SNA 1 sub-stock status may longer be viable or possible to use in the future, examples being: the Hauraki Gulf and Bay of Plenty trawl surveys, due to concerns about impacts of bottom trawling; catch at-age monitoring using commercial longline at-age sampling, due to possible changing selectivity; and bottom trawl CPUE, due to possibly changing catchability.

Taking all the above into consideration, we make the following future research recommendations:

1. Conduct simulation modelling to identify and prioritise SNA 1 stock monitoring and assessment needs.

Given that the level of monitoring investment required to adequately account for all the SNA 1 stock dynamics is likely to exceed the total annual New Zealand research budget, the first research question that should be asked is: to what extent is our ability to sustainably manage the SNA 1 sub-stock complex compromised by our inability to model all the known SNA 1 sub-stock dynamics in assessments? Simulation modelling offers a relatively inexpensive way of assessing the efficacy of alternative monitoring and assessment strategies, using operating models of varying “real-world” assumed complexity. Complex operating modelling platforms already been developed for SNA 1 and SNA 8 under previous Fisheries New Zealand projects (McKenzie et al. 2018; Marsh et al. 2024).

2. Investigate the utility of fishery independent longline and juvenile netting surveys for monitoring SNA 1 abundance, recruitment, and adult age composition as alternatives to research trawl.

The continued use of trawl surveys to monitor pre-recruit and adult abundance in the Hauraki Gulf and Bay of Plenty sub-stocks is uncertain due to increasing public concern about bottom trawling. Also, research trawl surveys have proven to be unsuitable for monitoring the east Northland sub-stock due to the high proportion of untrawlable ground.

As longlines can be applied across nearly all the SNA 1 spatial extent with low associated environmental impact, SNA 1 fishery independent longline surveys are a potential alternative to trawl surveys for monitoring adult age composition and abundance in SNA 1 and should be investigated.

In addition, preliminary investigations have shown that net sampling of juvenile (1+) snapper in harbours and estuaries is likely to be able to provide pre-recruit YCS estimates for SNA 1 sub-stocks, again offering viable alternative to the research trawl pre-recruit indices.

3. Reconsider the use of tagging for estimating of SNA 1 sub-stock absolute abundance.

The power of the 1985 and 1994 tag absolute abundance estimates to inform current SNA 1 management was again seen in the 2023 SNA 1 assessments. The most recent SNA 1 tag abundance estimates are now 30 years old. The move to U-based reference points for managing the Hauraki Gulf/ Bay of Plenty sub-stock complex now makes the need for more recent absolute abundance estimates a management imperative. Currently mark-recapture methods are the only proven way of estimating absolute abundance within SNA 1. Reconsideration of tagging for the purpose of SNA 1 absolute abundance estimation is strongly recommended.

4. Investigate options for estimating seasonal mixing and movement within and between SNA 1 sub-stock areas.

A new SNA 1 tag biomass programme would also provide further observations of sub-stock interchange within SNA 1. However, other less expensive methods for estimating movement within SNA 1 should also be considered, these include limited tagging from research surveys, sampling for sub-stock specific morphometric or genetic markers.

5. Further investigation of Bay of Plenty and SNA 2-north sub-stock relationship.

Simultaneous at-age sampling of snapper in the eastern Bay of Plenty and northern region of SNA 2 for the purposes of year-class-strength comparisons should be a research priority for both snapper QMAs.

6. Investigate the utility and feasibility of explicitly incorporating incidental mortality (i.e., both surface-release and through-mesh) in SNA 1 stock assessment.

Changes to SNA 1 fishing practices over the last ten years, for example the introduction of new gears such as MHS and the 2015 increase to the recreational MLS, have almost certainly altered the level of fishing-related incidental mortality on SNA 1 sub-stocks. However, the direction and magnitude of incidental mortality shifts are largely unknown. Voluntary use of larger mesh nets to avoid catching lower market value small snapper has occurred in SNA 1. Although apparently beneficial, mesh size increases can result in higher associated mortality due to greater numbers of snapper passing through the meshes. In some areas, increasing the mesh-size results in most of the snapper encountering the gear passing through the nets, in such instances the associated incidental mortality can increase despite through-mesh mortality being low (~5%).

As mentioned in Section 9, proposed changes to the SNA 1 commercial discard rules requiring most fishers to land all snapper caught regardless of size or condition would probably require explicit consideration of incidental mortality in future SNA 1 assessments.

11 ACKNOWLEDGEMENTS

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13 APPENDICES

Appendix 1: 2012 and 2013 SNA 1 Assessment Commercial catch history derivation

The SNA 1 commercial catch histories for the various method area fisheries after 1989–90 were derived from the Fisheries New Zealand catch effort reporting database (*warehou*); catches for method and area between 1981–82 and 1989–90 were constructed based on data contained in archived Fisheries New Zealand databases.

Commercial catch histories for the period 1915 through to 1982 were derived from two sources as follows:

- 1915–73: 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.
- 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 (although this had little effect for snapper given that it is typically a major species in SNA 1 ports).

No commercial catch records are available prior to 1915; therefore, for the purposes of the current assessment the 1915 catch totals were applied back to 1900.

The only information available on the spatial distribution of SNA 1 landings before 1983 comes from "The Wetfish Report" (Ritchie et al. 1975) in which snapper landings for old statistical areas were provided by year and month for the period 1960–1970. The boundaries of the old Statistical Areas 2, 3 and 4 are similar to those for the East Northland, Hauraki Gulf and Bay of Plenty sub-stocks. However, Area 4 is smaller than the Bay of Plenty sub-stock, whereas Area 2 is larger than East Northland and Area 3 is larger than Hauraki Gulf. Nevertheless, the match between old statistical areas and sub-stock boundaries is likely to be close enough to use the catch split from "The Wetfish Report" to apportion SNA 1 landings among sub-stocks. The percentage split by statistical area varied little over the 11-year period 1960–73:

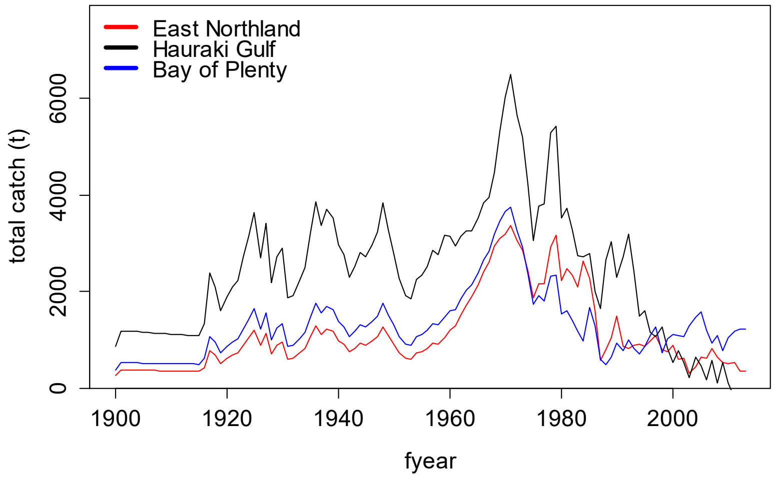
Area 2: 17–20% (mean 19%)
Area 3: 54–59% (mean 56%)
Area 4: 22–29% (mean 25%).

The mean percentages for Areas 2, 3 and 4 were used to apportion 1960–70 SNA 1 landings among East Northland, Hauraki Gulf and Bay of Plenty respectively. In the absence of any information on the spatial distribution of catches before 1960, the same percentages were applied to SNA 1 landings for 1900–1959 (Appendix Figure 1).

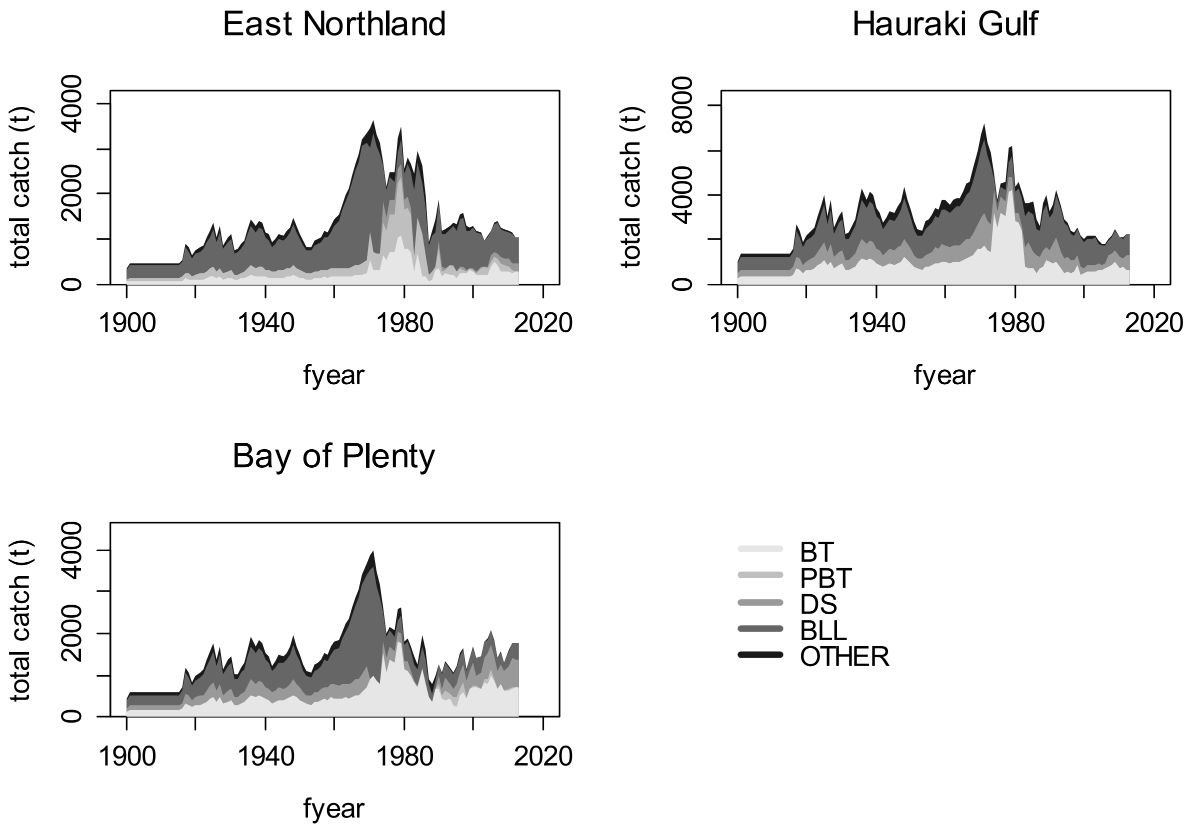
The historical SNA 1 commercial catch time-series was divided into four method fisheries: bottom longline (BLL or LL in text and figures); single bottom trawl (BT or ST in text and figures); pair bottom trawl (PBT or PT in figures); and Danish seine (DS). Catches from "other" commercial methods (predominantly setnet) were not explicitly modelled but the catch totals were pro-rated across the fisheries in the same area. Information on specific catching methods becomes increasingly less reliable prior to 1973 so the area catch method splits from the early 1970s were applied back to 1900 (Appendix Figure 2).

In the 1997–98 SNA 1 assessment (Davies 1999), the foreign (Japanese longline) catch was assumed to have occurred between 1960 and 1977, with cumulative total removals over the period at three alternative levels: 20 000 t, 30 000 t and 50 000 t. The assumed pattern of catches increased linearly to a peak in 1968 and then declined linearly to 1977; the catch was split evenly between east Northland and the Hauraki Gulf/Bay of Plenty. For the 2013 assessment the base case level of total foreign catch between 1960 and 1977 was assumed to be 30 000 t, this catch apportioned among the three sub-stocks in the ratio 50% East Northland, 10% Hauraki Gulf and 40% Bay of Plenty and added to the domestic longline method totals (Appendix Figure 1; Appendix Figure 2).

The level of illegal catch in SNA 1 since 1970 is largely unknown but unlikely to be zero. As was done in previous assessments (Gilbert et al. 2000, Francis & McKenzie 2015a); commercial catch totals prior to the 1986 QMS year were adjusted upwards to account for an assumed 20% level of under-reporting. Catch totals post 1986 QMS were likewise scaled assuming 10% under-reporting (Appendix Figure 1; Appendix Figure 2).



Appendix Figure 1: Commercial catch histories by area (adjusted for under-reporting) plus foreign catch.



Appendix Figure 2: Commercial catch histories split by method and area.

Appendix 2: 2022 SNA 1 assessment model catch histories

Table Appendix 1: East Northland 2022 assessment model catch history (tonnes)

Fish Year	LL	PT	BT	MHS	REC	Fish Year	LL	PT	BT	MHS	REC	Fish Year	LL	PT	BT	MHS	REC
1900	233	58	50	0	75	1941	744	191	158	0	271	1982	890	956	821	0	466
1901	311	79	66	0	80	1942	637	157	140	0	275	1983	1714	389	333	0	471
1902	311	79	66	0	85	1943	695	171	149	0	280	1984	1357	866	747	0	476
1903	311	79	66	0	89	1944	765	191	163	0	285	1985	1324	1107	195	0	481
1904	311	79	66	0	94	1945	744	185	162	0	290	1986	1202	578	180	0	485
1905	311	79	66	0	99	1946	801	202	172	0	295	1987	698	151	83	0	490
1906	311	79	66	0	104	1947	865	217	187	0	299	1988	861	219	92	0	495
1907	311	79	66	0	108	1948	1007	251	218	0	304	1989	963	88	369	0	500
1908	311	79	66	0	113	1949	879	220	190	0	309	1990	943	495	428	0	505
1909	311	79	66	0	118	1950	770	192	166	0	314	1991	856	131	194	0	509
1910	311	79	66	0	123	1951	649	163	140	0	318	1992	876	89	264	0	514
1911	311	79	66	0	127	1952	570	144	123	0	323	1993	855	214	230	0	519
1912	311	79	66	0	132	1953	557	141	118	0	328	1994	943	206	217	0	524
1913	311	79	66	0	137	1954	650	163	140	0	333	1995	1011	144	155	0	528
1914	311	79	66	0	142	1955	673	167	145	0	337	1996	1157	104	266	0	533
1915	311	79	66	0	147	1956	718	179	154	0	342	1997	1200	108	254	0	538
1916	372	93	79	0	151	1957	798	199	172	0	347	1998	976	16	285	0	543
1917	617	153	132	0	156	1958	779	194	167	0	352	1999	875	45	324	0	547
1918	551	138	117	0	161	1959	872	218	188	0	357	2000	949	46	298	0	552
1919	436	109	95	0	166	1960	1043	212	183	0	361	2001	915	56	210	0	607
1920	508	127	109	0	170	1961	1167	197	170	0	366	2002	763	144	237	0	538
1921	552	138	119	0	175	1962	1387	205	176	0	371	2003	565	207	198	0	519
1922	588	147	126	0	180	1963	1583	208	179	0	376	2004	680	143	235	0	780
1923	703	175	152	0	185	1964	1753	205	176	0	380	2005	629	125	445	0	484
1924	805	201	173	0	190	1965	1989	218	188	0	385	2006	676	123	568	0	676
1925	922	230	199	0	194	1966	2233	233	200	0	390	2007	771	153	483	0	657
1926	704	176	152	0	199	1967	2432	237	203	0	395	2008	727	213	307	0	658
1927	870	218	188	0	204	1968	2723	264	227	0	400	2009	702	178	323	0	707
1928	587	147	126	0	209	1969	2769	314	270	0	404	2010	727	131	329	0	756
1929	715	179	153	0	213	1970	2142	704	606	0	409	2011	780	88	281	0	805
1930	759	191	162	0	218	1971	2856	416	358	0	414	2012	707	0	337	0	691
1931	522	130	113	0	223	1972	2593	393	337	0	419	2013	707	0	337	0	689
1932	532	133	114	0	228	1973	2416	390	335	0	423	2014	1072	0	528	0	686
1933	607	153	132	0	232	1974	996	927	791	0	428	2015	1081	0	473	0	684
1934	671	166	145	0	237	1975	750	760	653	0	433	2016	1141	0	617	33	682
1935	838	208	182	0	242	1976	601	1004	861	0	438	2017	1219	0	506	223	639
1936	992	246	214	0	247	1977	511	1053	908	0	442	2018	1297	0	224	457	845
1937	879	224	187	0	252	1978	451	1504	1289	0	447	2019	1425	0	303	372	887
1938	956	244	202	0	256	1979	658	1521	1306	0	452	2020	1293	0	381	184	929
1939	920	228	201	0	261	1980	660	1020	878	0	457	2021	1275	0	406	254	778
1940	794	199	171	0	266	1981	824	1067	917	0	462						

TableAppendix 2: Hauraki Gulf 2022 assessment model catch history (tonnes)

Fish Year	LL	BT	DS	MHS	REC	Fish Year	LL	BT	DS	MHS	REC	Fish Year	LL	BT	DS	MHS	REC
1900	474	311	223	0	150	1941	1514	994	712	0	635	1982	1291	2574	276	0	1120
1901	632	414	298	0	162	1942	1295	849	609	0	647	1983	1702	891	1019	0	1132
1902	632	414	298	0	174	1943	1408	924	661	0	659	1984	1576	814	1221	0	1144
1903	632	414	298	0	185	1944	1551	1018	729	0	671	1985	1970	826	894	0	1156
1904	632	414	298	0	197	1945	1513	993	711	0	682	1986	1391	607	911	0	1168
1905	632	414	298	0	209	1946	1627	1068	765	0	694	1987	1228	747	601	0	1179
1906	632	414	298	0	221	1947	1758	1154	827	0	706	1988	1927	828	845	0	1191
1907	632	414	298	0	233	1948	2044	1342	961	0	718	1989	2103	1245	638	0	1203
1908	632	414	298	0	245	1949	1787	1173	840	0	730	1990	1617	1123	538	0	1215
1909	632	414	298	0	256	1950	1562	1025	734	0	742	1991	1576	1033	982	0	1227
1910	632	414	298	0	268	1951	1318	866	620	0	753	1992	1978	1099	1164	0	1239
1911	632	414	298	0	280	1952	1158	760	545	0	765	1993	1948	713	830	0	1250
1912	632	414	298	0	292	1953	1132	742	532	0	777	1994	1654	509	744	0	1262
1913	632	414	298	0	304	1954	1321	867	621	0	789	1995	1527	570	681	0	1274
1914	632	414	298	0	316	1955	1366	896	643	0	801	1996	1219	497	677	0	1286
1915	632	414	298	0	327	1956	1459	957	685	0	813	1997	1219	585	529	0	1298
1916	754	494	354	0	339	1957	1621	1064	762	0	824	1998	1205	901	461	0	1310
1917	1249	820	587	0	351	1958	1583	1039	744	0	836	1999	1375	468	342	0	1321
1918	1118	734	526	0	363	1959	1772	1162	833	0	848	2000	1204	523	264	0	1333
1919	887	583	418	0	375	1960	1787	1148	822	0	860	2001	1305	591	290	0	664
1920	1030	676	484	0	387	1961	1713	1073	769	0	872	2002	1284	629	285	0	1721
1921	1124	738	528	0	398	1962	1834	1126	807	0	884	2003	1226	603	319	0	1746
1922	1195	784	562	0	410	1963	1908	1148	823	0	895	2004	981	673	327	0	1826
1923	1428	937	671	0	422	1964	1929	1137	814	0	907	2005	878	638	298	0	1279
1924	1634	1073	768	0	434	1965	2083	1213	868	0	919	2006	810	720	267	0	1820
1925	1874	1230	881	0	446	1966	2254	1299	931	0	931	2007	726	830	485	0	1355
1926	1431	939	673	0	458	1967	2332	1325	949	0	943	2008	800	862	534	0	2311
1927	1768	1160	831	0	469	1968	2602	1476	1057	0	955	2009	909	1049	525	0	2484
1928	1193	783	560	0	481	1969	2981	1748	1252	0	966	2010	859	770	501	0	2657
1929	1451	952	682	0	493	1970	3421	1785	1500	0	978	2011	900	778	405	0	2830
1930	1542	1012	726	0	505	1971	3645	1931	1623	0	990	2012	963	660	646	0	2555
1931	1060	696	499	0	517	1972	3221	1710	1436	0	1002	2013	963	660	646	0	2228
1932	1079	709	508	0	529	1973	2986	1598	1342	0	1014	2014	873	644	427	0	1901
1933	1235	811	581	0	540	1974	536	3320	1093	0	1026	2015	714	678	571	0	1574
1934	1365	895	641	0	552	1975	430	2666	701	0	1037	2016	696	479	468	110	1247
1935	1703	1118	801	0	564	1976	454	3332	745	0	1049	2017	721	336	406	188	1352
1936	2013	1321	947	0	576	1977	555	3306	740	0	1061	2018	557	63	389	232	2098
1937	1790	1175	841	0	588	1978	749	4652	688	0	1073	2019	564	163	381	123	2408
1938	1942	1275	913	0	600	1979	1062	4568	597	0	1085	2020	616	285	337	0	2719
1939	1870	1228	879	0	611	1980	1032	2974	351	0	1097	2021	631	265	396	131	1965
1940	1612	1058	758	0	623	1981	1206	2911	444	0	1108						

TableAppendix 3: Bay of Plenty 2022 assessment model catch history (tonnes)

Fish Year	LL	BT	DS	MHS	REC	Fish Year	LL	BT	DS	MHS	REC	Fish Year	LL	BT	DS	MHS	REC
1900	211	139	100	0	75	1941	676	444	318	0	254	1982	525	1047	125	0	433
1901	282	185	133	0	79	1942	578	380	272	0	258	1983	457	979	27	0	437
1902	282	185	133	0	84	1943	629	412	295	0	263	1984	431	798	38	0	442
1903	282	185	133	0	88	1944	693	455	326	0	267	1985	578	1347	40	0	446
1904	282	185	133	0	92	1945	675	443	318	0	271	1986	643	936	15	0	451
1905	282	185	133	0	97	1946	726	477	341	0	276	1987	365	546	0	0	455
1906	282	185	133	0	101	1947	784	514	368	0	280	1988	288	508	0	0	459
1907	282	185	133	0	106	1948	913	599	429	0	285	1989	194	771	0	0	464
1908	282	185	133	0	110	1949	797	523	375	0	289	1990	274	746	244	0	468
1909	282	185	133	0	114	1950	698	458	328	0	293	1991	392	489	195	0	472
1910	282	185	133	0	119	1951	588	386	276	0	298	1992	428	516	397	0	477
1911	282	185	133	0	123	1952	517	339	243	0	302	1993	397	503	277	0	481
1912	282	185	133	0	127	1953	506	331	237	0	306	1994	422	369	267	0	485
1913	282	185	133	0	132	1954	589	387	277	0	311	1995	496	309	424	0	490
1914	282	185	133	0	136	1955	610	400	286	0	315	1996	482	604	430	0	494
1915	282	185	133	0	140	1956	652	427	307	0	320	1997	423	707	529	0	499
1916	337	221	158	0	145	1957	723	475	340	0	324	1998	226	483	420	0	503
1917	558	366	262	0	149	1958	707	464	333	0	328	1999	314	684	425	0	507
1918	499	328	235	0	154	1959	791	519	372	0	333	2000	351	751	564	0	512
1919	396	260	186	0	158	1960	930	508	364	0	337	2001	453	731	231	0	139
1920	460	302	217	0	162	1961	1028	471	337	0	341	2002	419	681	367	0	416
1921	502	329	236	0	167	1962	1211	492	353	0	346	2003	413	890	510	0	316
1922	533	350	250	0	171	1963	1374	500	358	0	350	2004	341	841	694	0	438
1923	637	418	300	0	175	1964	1511	493	353	0	354	2005	405	1056	634	0	525
1924	730	478	343	0	180	1965	1708	524	376	0	359	2006	383	892	551	0	750
1925	837	549	393	0	184	1966	1912	560	401	0	363	2007	325	672	426	0	629
1926	639	419	300	0	189	1967	2076	571	408	0	368	2008	298	799	466	0	648
1927	790	518	371	0	193	1968	2325	635	454	0	372	2009	199	650	464	0	672
1928	532	349	250	0	197	1969	2383	756	542	0	376	2010	374	659	561	0	697
1929	648	425	304	0	202	1970	2885	1005	0	0	381	2011	365	681	714	0	721
1930	689	452	324	0	206	1971	2895	1087	0	0	385	2012	367	723	672	0	429
1931	473	311	222	0	210	1972	2525	957	0	0	389	2013	367	723	672	0	389
1932	482	317	227	0	215	1973	2269	890	0	0	394	2014	321	724	317	0	349
1933	552	362	260	0	219	1974	718	1600	287	0	398	2015	415	647	349	0	309
1934	609	400	286	0	223	1975	530	1108	341	0	402	2016	319	499	427	59	268
1935	760	499	357	0	228	1976	431	1444	298	0	407	2017	413	613	307	149	300
1936	899	590	422	0	232	1977	361	1426	286	0	411	2018	435	504	377	488	832
1937	799	524	376	0	237	1978	321	1999	258	0	416	2019	440	587	315	206	705
1938	867	569	408	0	241	1979	442	1902	272	0	420	2020	518	844	387	62	579
1939	835	548	392	0	245	1980	415	1198	203	0	424	2021	425	609	363	193	537
1940	720	472	338	0	250	1981	489	1178	219	0	429						

Appendix 3: 2022 Preliminary SNA 1 assessment recreational catch history derivation

Historical SNA 1 annual recreational catch estimates are only available for a small number of recent aerial-access surveys (Hartill et al. 2007, 2013, 2019) and National panel surveys (Wynne-Jones et al. 2014, 2019) (Table Appendix 4).

Table Appendix 4: Aerial-access (A-A) and National panel survey (NPS) estimates of the recreational harvest tonnage taken from the SNA 1 stock, by region, by fishing year. Coefficients of variation are given for each estimate in brackets.

Region	2004–05		2011–12		2017–18	
	A-A	NPS	A-A	NPS	A-A	NPS
East Northland	557 (0.13)	–	705 (0.14)	909 (0.12)	720 (0.10)	761 (0.12)
Hauraki Gulf	1 345 (0.10)	–	2 465 (0.08)	2 381 (0.11)	2 068 (0.07)	1 578 (0.11)
Bay of Plenty	516 (0.10)	–	534 (0.12)	691 (0.12)	680 (0.10)	627 (0.12)
SNA 1	2 419 (0.06)	–	3 704 (0.06)	3 981 (0.08)	3 468(0.05)	2 967 (0.07)

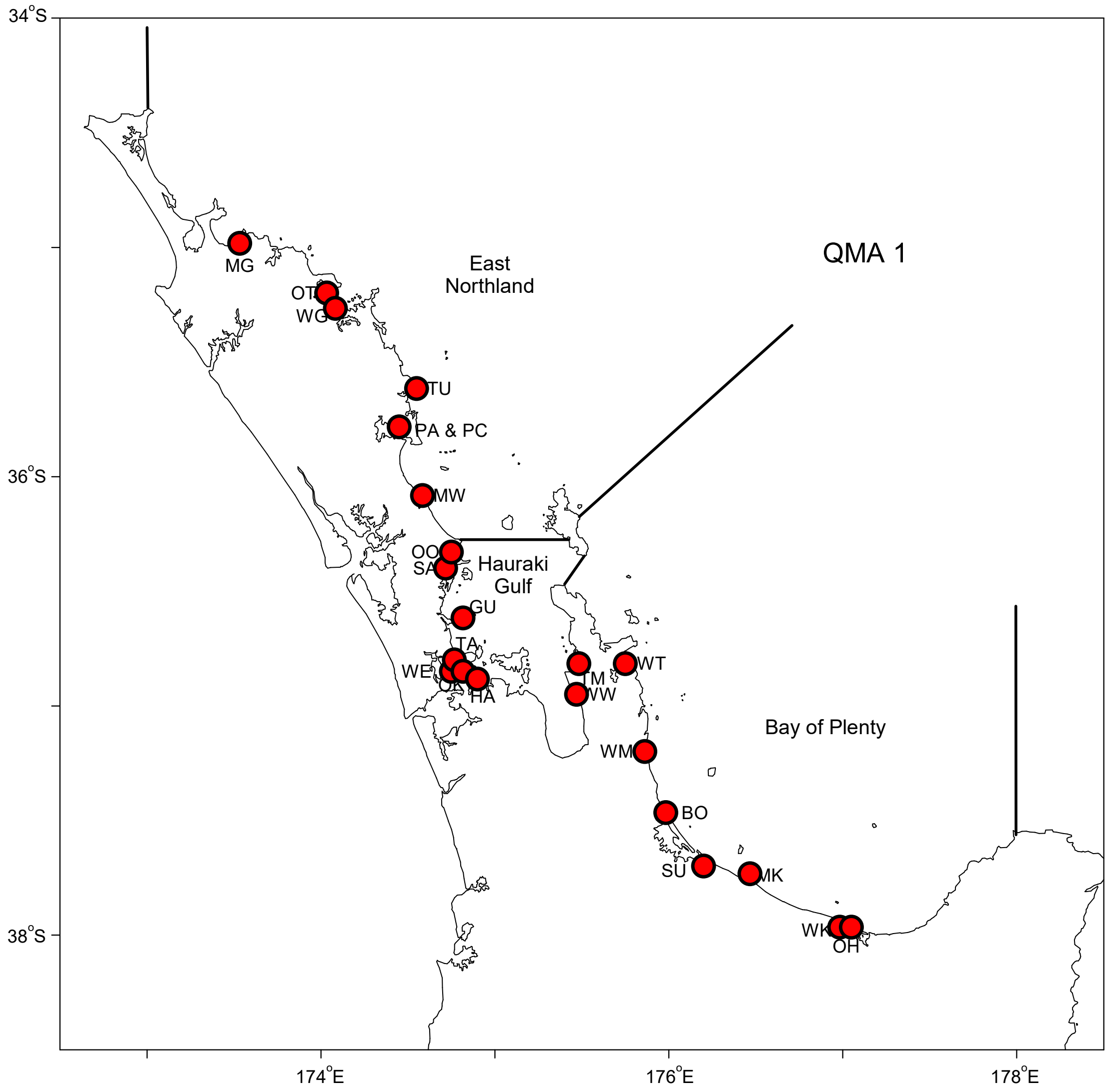
Recreational catch sampling at various SNA 1 regional boat ramps has occurred intermittently since 1990–91 (Appendix Figure 3). These data were used to develop regional relative recreational catch indices back to 1990–91 which were then fitted to the aerial-access and National panel survey absolute catch estimates (Table Appendix 4), thereby increasing the available number of annual SNA 1 recreational harvest estimates. Before the annual boat-ramp catch totals could be used, these data needed to be scaled up to account for periods within the sampled year when samplers were not present at the ramps. This was achieved using zero inflated negative binomial (ZINB) generalised linear predictive models. The ZINB model covariates and coefficients were identified and derived through fitting the models to the observed number of snapper landed hourly (the explanatory variable) at a subsample of boat ramps that have been regularly surveyed in each region since 1990–91.

Data for a fishing year were removed from each regional dataset when fewer than three boat ramps had been surveyed in that fishing year. A summary of the number of ramps surveyed in each year, and number of complete hours when interviewers were present at these ramps, is given in Table Appendix 5.

Preliminary analyses suggested that hourly landing rate data conformed to a ZINB distribution, with the high incidence of zero landing hours (~70%) often associated with unfishable weather and times of the day and year when little fishing took place. The ZINB models are two component models, where variables are offered separately to both a left-hand negative binomial model and a right-hand model that is used to estimate excess zeros that are not predicted by the left-hand negative binomial model. The ZINB models were implemented using the R package *mgcv*.

The response variables offered to each regional model were temporal factors (ramp, fishing year, month, weekday type, and hour of day) and environmental factors (wind speed, wind direction, and tidal state) for each observed hour. All the response variables were categorised as factors because there was no available way of fitting smoothers to ZINB models implemented in R and, consequently, response variable interaction terms (Table Appendix 6).

The ZINB models predicted the total number of snapper landed, these values were converted to weight by multiplying the predicted numbers by the mean weight of snapper sampled at the ramps in each region and each year.



East Northland

MG Mangonui
MW Mangawai
OT Opito Bay, Kerikeri
PA Parua Bay (public ramp)
PC Parua Bay (club ramp)
TU Tutukaka
WG Waitangi

Hauraki Gulf

GU Gulf Harbour
HA Half Moon Bay
OK Okahu Bay
SA Sandspit
TA Takapuna
TM Te Kouma
WE Westhaven
OO Ohama
WW Waikawau

Bay of Plenty

BO Bowentown
SU Sulphur Point, Tauranga
WK Whakatane
WT Whitianga
MK Maketu
OH Ohope
WM Whangamata

Appendix Figure 3: Location of boat ramps where recreational catch and effort data have been collected and used to provide estimates of the number of snapper landed per completed surveyed hour, since 1991.

Table Appendix 5: Summary of boat ramp interview data used to inform regional models that were used to predict the number of snapper landed at indicator ramps throughout the day, for the fishing years in which at least three ramps were surveyed in each region.

	East Northland			Hauraki Gulf			Bay of Plenty		
Fishing year	No. ramps	No. months	No. hours	No. of ramps	Months surveyed	Hours surveyed	No. of ramps	Months surveyed	Hours surveyed
1990–91	4	7	641	5	7	422	6	8	525
1991–92	—	—	—	—	—	—	—	—	—
1992–93	—	—	—	—	—	—	—	—	—
1993–94	4	6	583	5	6	373	5	6	1 085
1994–95	—	—	—	—	—	—	—	—	—
1995–96	5	10	348	6	9	429	6	9	184
1996–97	—	—	—	—	—	—	—	—	—
1997–98	—	—	—	—	—	—	—	—	—
1998–99	—	—	—	—	—	—	—	—	—
1999–00	—	—	—	—	—	—	—	—	—
2000–01	7	6	273	6	6	981	7	6	683
2001–02	7	4	337	6	4	857	7	4	676
2002–03	7	4	372	6	4	883	7	4	687
2003–04	7	4	315	6	10	832	6	4	2 398
2004–05	7	10	2 297	6	12	2 666	6	10	2 762
2005–06	7	6	663	6	6	1 148	6	6	977
2006–07	7	4	371	6	12	811	6	4	1 770
2007–08	7	4	417	6	4	866	6	4	1 510
2008–09	—	—	—	—	—	—	—	—	—
2009–10	—	—	—	—	—	—	—	—	—
2010–11	6	12	439	8	12	1 082	6	12	703
2011–12	6	12	3 082	7	12	3 135	6	12	3 636
2012–13	—	—	—	—	—	—	—	—	—
2013–14	—	—	—	—	—	—	—	—	—
2014–15	—	—	—	—	—	—	—	—	—
2015–16	6	12	553	7	12	1 036	6	12	1 084
2016–17	6	12	543	7	12	1 000	6	12	1 047
2017–18	6	12	3 078	7	12	3 137	6	12	3 655
2018–19	—	—	—	—	—	—	—	—	—
2019–20	3	5	625	5	6	247	5	5	471

Table Appendix 6: Continuous variable categories offered to the ZIBN models.

Fishing year (fyear)	cat 17: 1991–92, 1993–94, 1995–96, 2001–2008, 2011–2021
Time-of day (hour)	cat 10: 0700–0900,1000, 1100,…1800,1900–2200
Day-type	cat 2: weekend/holidays vs workdays
Ramp	cat 22:
Month-of-year	cat 12; 1 = Oct etc
Wind-speed (WS)	cat 4: 0–4.9, 5–10,11–18, 19+
Wind-direction	cat 2: on/off-shore
Average monthly sea surface temperature	cat 7: <15o,15o,16o,17o,18o,19o,20o+
Tidal-state (hourly)	cat 4: High, Out (going), Low, In(coming)

Results:

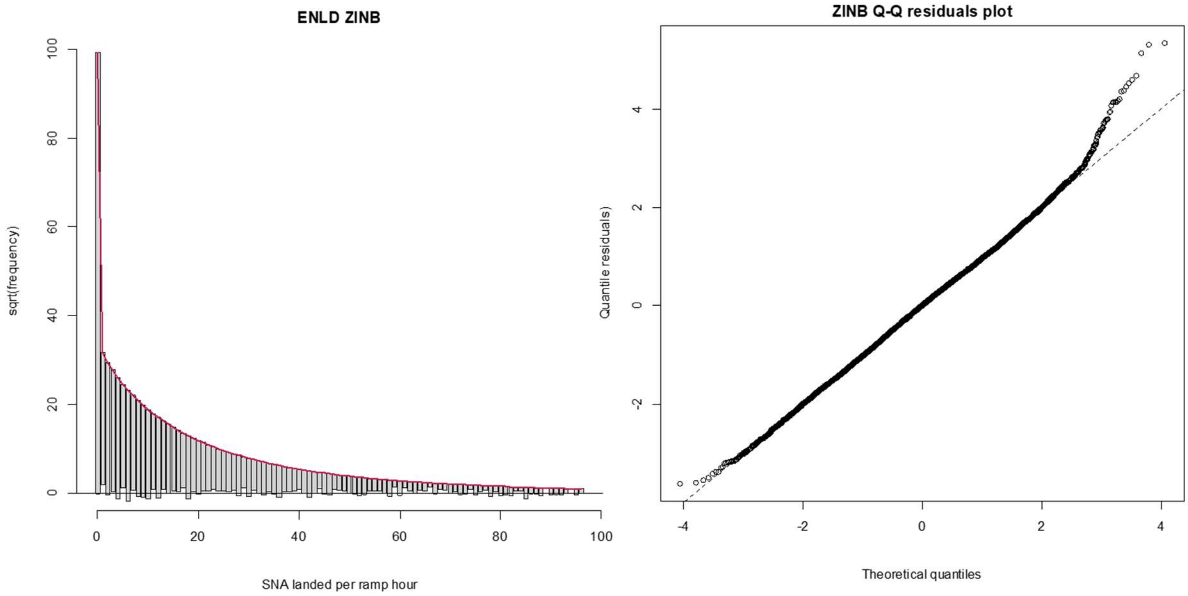
Marked differences in the predicted proportion of zero catches in the 1990s boat ramp data suggested that these surveys differed from subsequent surveys. This led to the three 1990s survey years being dropped from the models.

East Northland

The final East Northland fitted ZINB model parameterisation was:

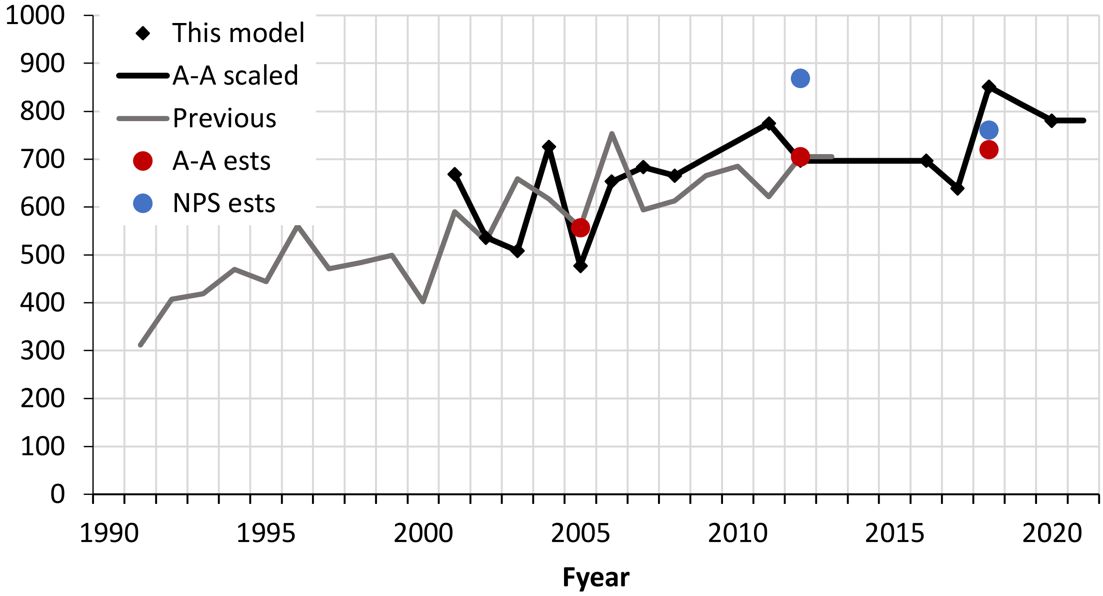
Numbers/hr^{-1} ~ month + hour + ramp + wind-speed + fyear + day-type | hour + ramp.

Rootogram and QQ diagnostics suggest the model fit to the data was "acceptable" (Appendix Figure 4).



Appendix Figure 4: East Northland ZINB model fit diagnostic plots. Right: rootogram (Kleiber & Zeileis 2016) of predicted and observed snapper catch per hour. Left: ZINB model QQ normality residuals.

The final predicted East Northland recreational snapper catches post 2000–01 derived by fitting the ZINB model predicted catch index to the geometric mean of the aerial-access estimate years is given in Appendix Figure 5.



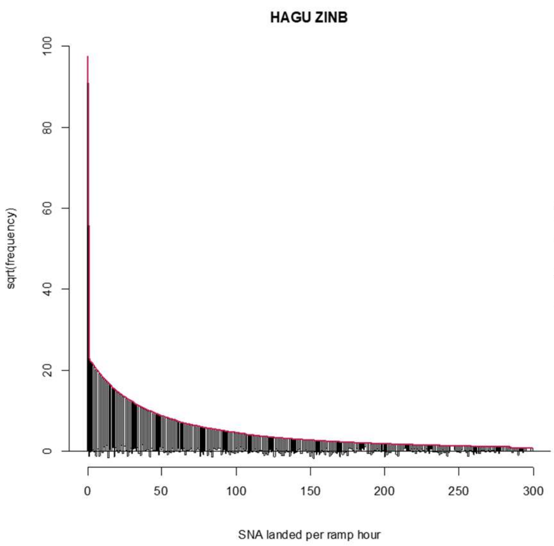
Appendix Figure 5: East Northland post 2000–01 ZINB model predicted recreational snapper harvest estimates. Note: catches for years with no survey data are interpolated. Grey line shows recreational catch estimates used in the 2013 SNA 1 assessment.

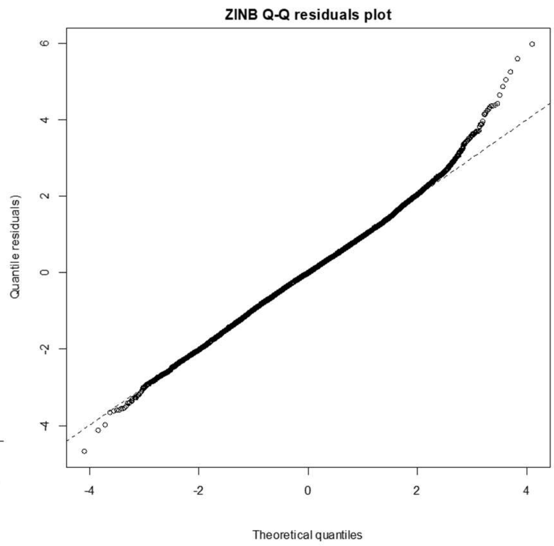
Hauraki Gulf

The final Hauraki Gulf fitted ZINB model parameterisation was:

Numbers/hr^{-1} ~ month + hour + ramp + wind-speed + fyear + day-type | hour + ramp.

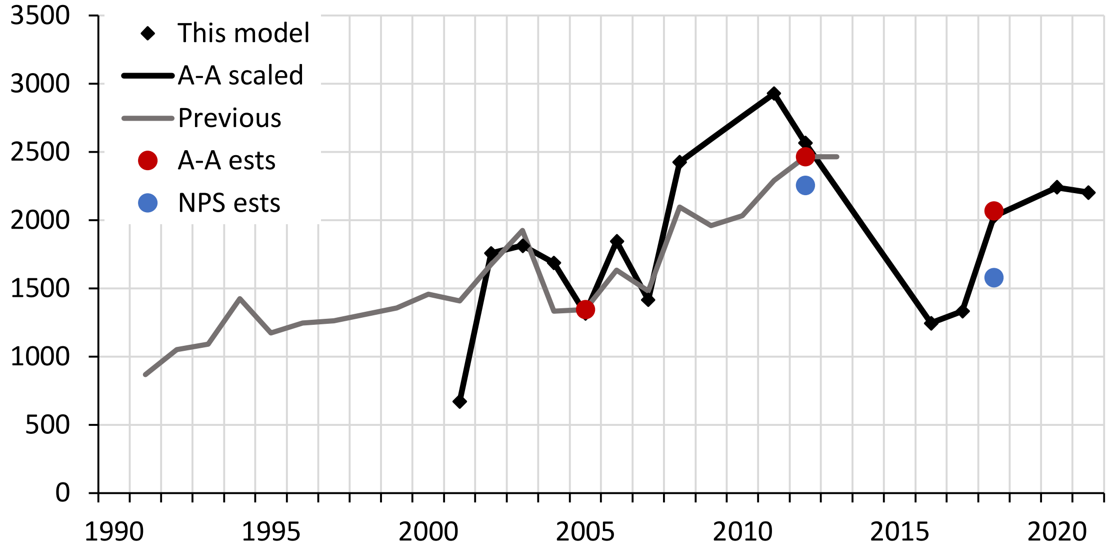
Rootogram and QQ diagnostics suggest the model fit to the data was “acceptable” (Appendix Figure 6).





Appendix Figure 6: Hauraki Gulf ZINB model fit diagnostic plots. Right: rootogram (Kleiber & Zeileis 2016) of predicted and observed snapper catch per hour. Left: ZINB model QQ normality residuals.

The final predicted Hauraki Gulf recreational snapper catches post 2000–01 derived by fitting the ZINB model predicted catch index to the geometric mean of the aerial-access estimate years is given in Appendix Figure 7.



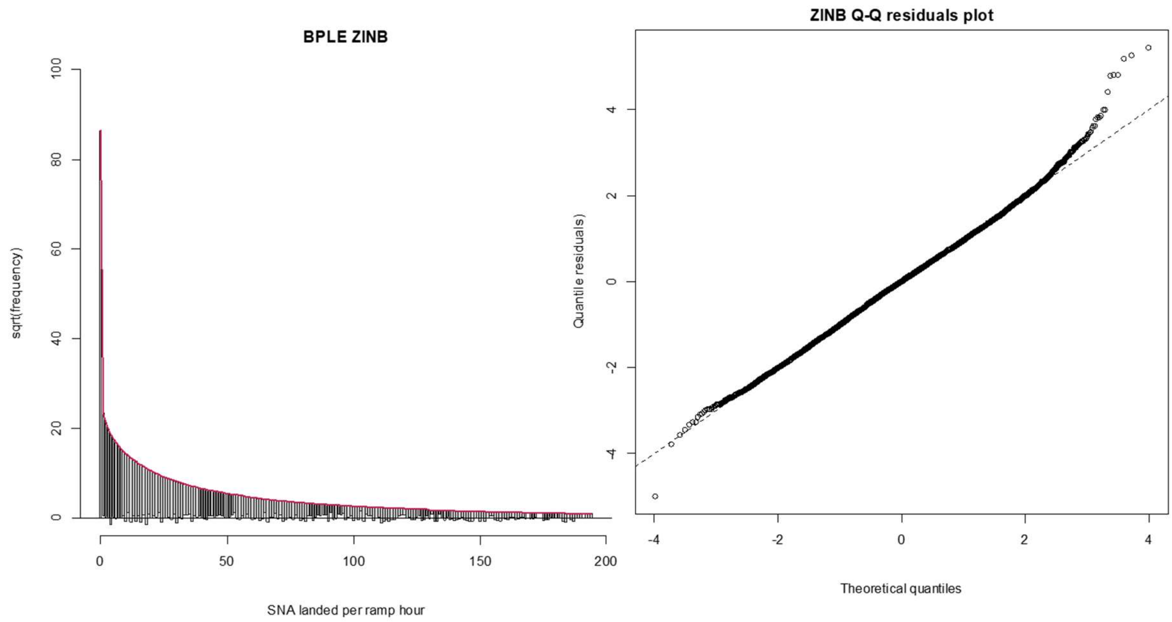
Appendix Figure 7: Hauraki Gulf post 2000–01 ZINB model predicted recreational snapper harvest estimates. Note: catches for years with no survey data are interpolated. Grey line shows recreational catch estimates used in the 2013 SNA 1 assessment.

Bay of Plenty

The final Bay of Plenty fitted ZINB model parameterisation was:

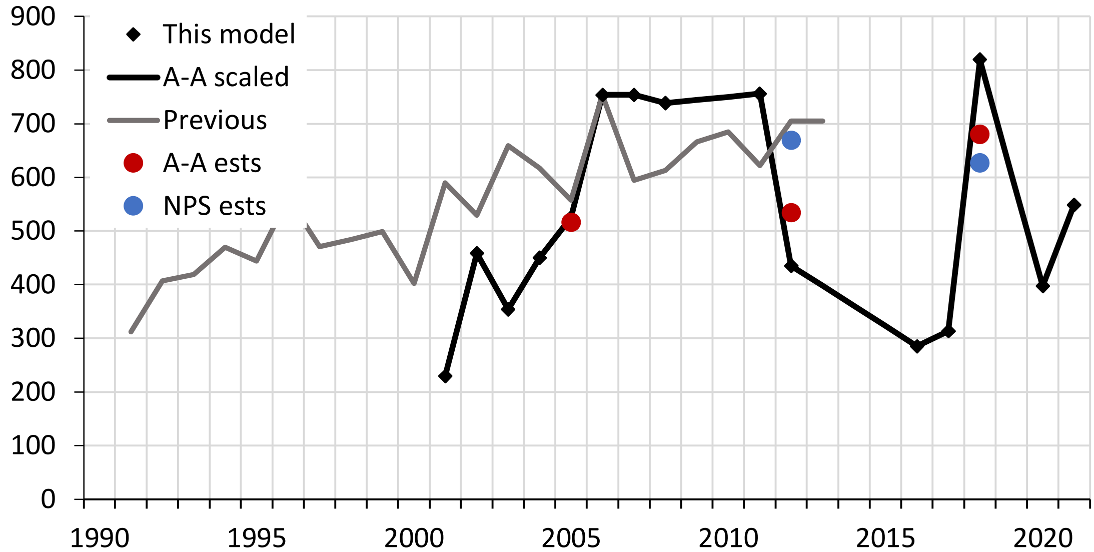
Numbers/hr^{-1} ~ month + hour + ramp + wind-speed + fyear + day-type | hour + ramp.

Rootogram and QQ diagnostics suggest the model fit to the data was “acceptable” (Appendix Figure 8).



Appendix Figure 8: Bay of Plenty ZINB model fit diagnostic plots. Right: rootogram (Kleiber & Zeileis 2016) of predicted and observed snapper catch per hour. Left: ZINB model QQ normality residuals.

The final predicted Bay of Plenty recreational snapper catches post 2000–01 derived by fitting the ZINB model predicted catch index to the geometric mean of the aerial-access estimate years is given in Appendix Figure 9.



Appendix Figure 9: Bay of Plenty post 2000–01 ZINB model predicted recreational snapper harvest estimates. Note: catches for years with no survey data are interpolated. Grey line shows recreational catch estimates used in the 2013 SNA 1 assessment.

Appendix 4: 2022 Preliminary SNA 1 assessment commercial longline and bottom trawl updated CPUE series

Longline CPUE series

Standardisation of the SNA 1 regional longline CPUE data series was undertaken using generalised linear modelling as done for the 2013 assessment (Francis & McKenzie 2015b). Before standardisation the longline CPUE data needed to be adjusted to account for differences in Fisheries New Zealand reporting requirements and form-type changes that had occurred since 1990. The most significant longline reporting change occurred at the start of the 2007–08 fishing year when fishers were required to report event based CPUE as opposed to the daily aggregated CPUE they had previously reported. The other reporting change at this time was a requirement for fishers to report the top eight species caught per event where previously they had only been required to report catch and effort for the top five species caught per day. These changes required "rolling up" the post 2007–08 fishing event data to the day level and discarding data for species ranking below the top five daily aggregated catches.

Zero CPUE records made up less than 1% of the data in any given year and were, therefore, discarded from the analyses. The response variable in the GLM standardisation was log-catch. Fishing-year was always included in the models as a categorical variable, other covariate terms offered to the models are given in Table Appendix 7. Covariant terms were added stepwise to the GLMs, the stopping rule being when the addition of another model term resulted in a less than 1% improvement in residual sums-of-squares (R^2).

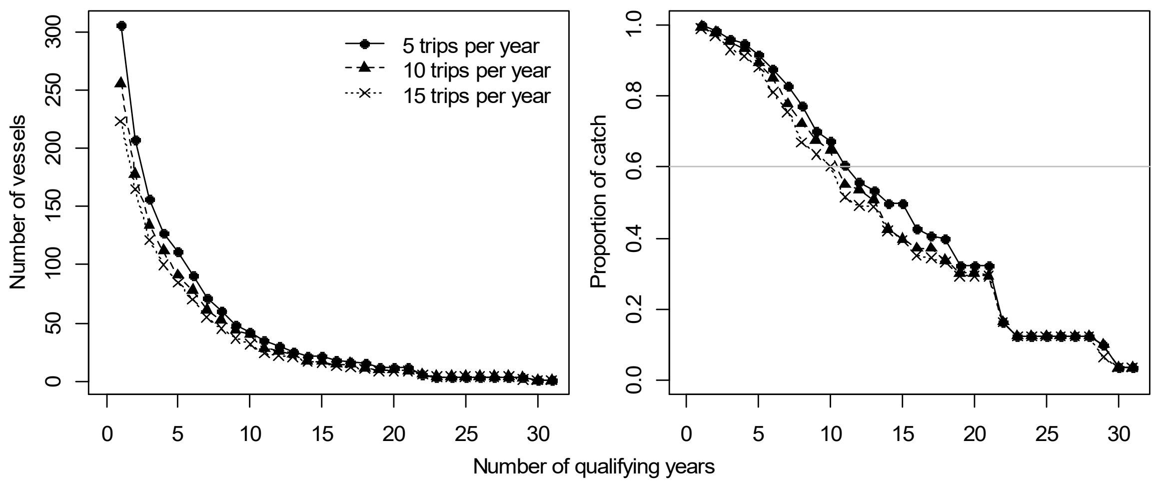
Table Appendix 7: Covariate terms offered to GLM longline CPUE standardisation models.

Variable	Type	Description
Fishing year	Categorical	Fishing year (Oct–Sept)
Vessel	Categorical	Unique vessel identifier
Statistical area	Categorical	Regional Fisheries New Zealand statistical reporting areas
Month	Categorical	Beginning with month 1 = October
Season	Categorical	SPR[Sep – Nov];SUM[Dec–Feb];AUT[Mar–May];WIN[Jun–Aug]
Target (BPLE model only)	Categorical	Target species (SNA, GUR)
log(number of hooks)	Cubic spline	Total number of hooks per day
log(number of sets)	Cubic spline	Number of sets per day
Vessel experience	Cubic spline	Number of years in fishery

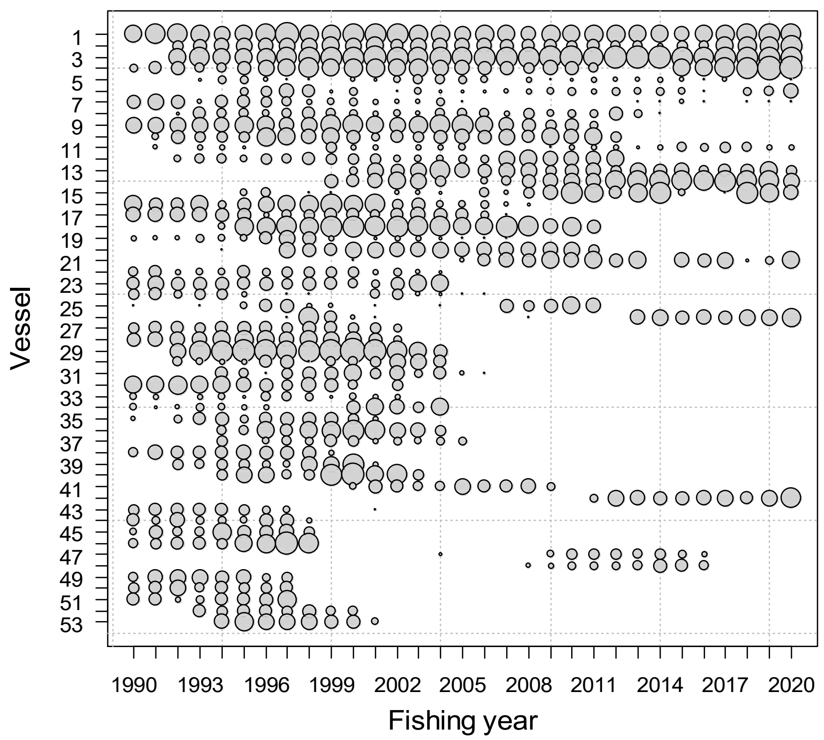
Trip landed snapper catch totals were pro-rated across reported effort based on the event catch estimates. Missing value records were excluded from the analyses, as were records where the linked reported catch and/or any of the continuous covariate values fell outside the 99% quartile range.

East Northland

Core vessels were selected based on all selected vessels having to account for 60% of the total landed longline catch over all years; the optimum selection criteria to achieve this corresponded to a minimum catch history of ten years of at least eight trips per year (Appendix Figure 10). There was a high proportion of long catch-history vessels included in the east Northland GLM standardisations (Appendix Figure 11).



Appendix Figure 10: East Northland longline CPUE vessel selection criteria plots.

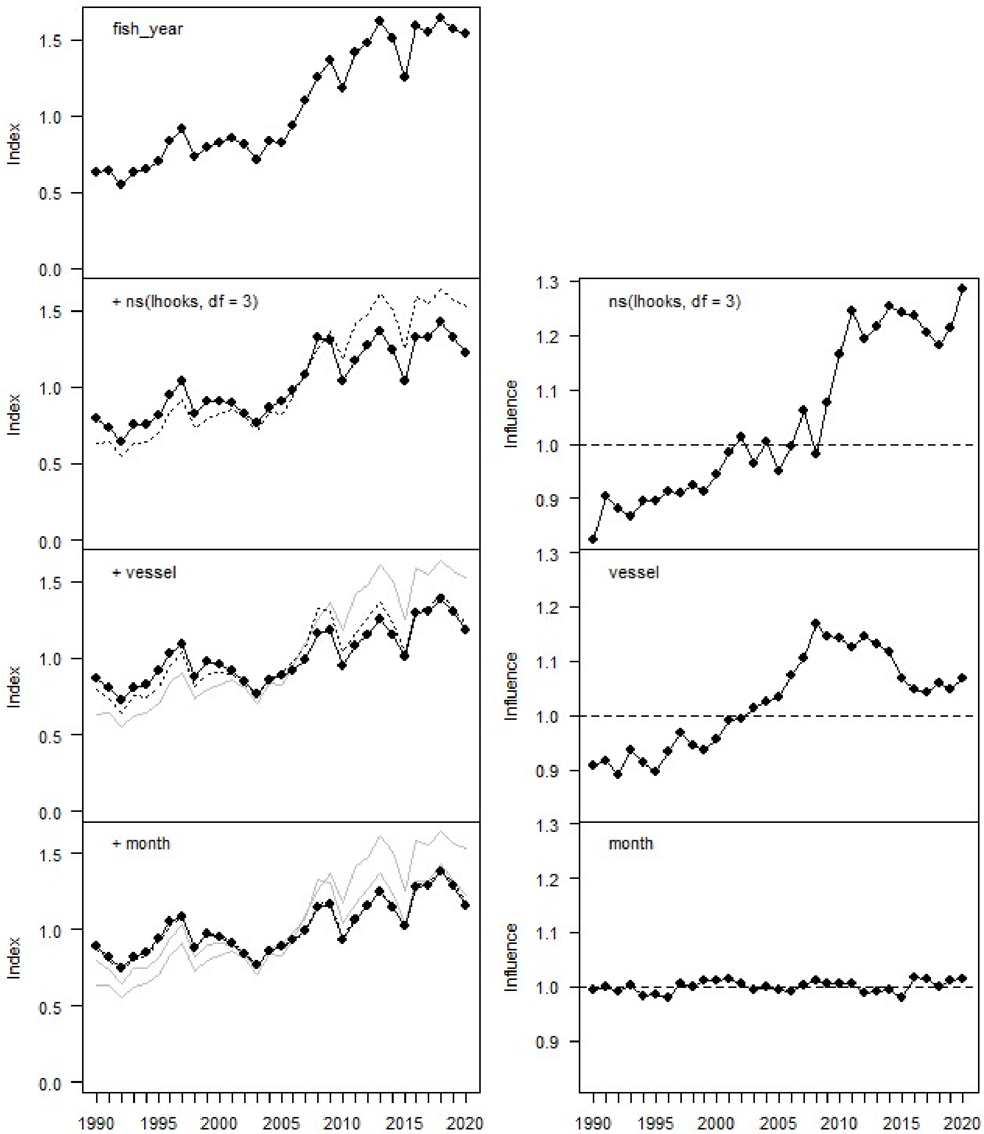


Appendix Figure 11: East Northland longline core vessel catch histories, bubble areas proportional to annual vessel catch totals.

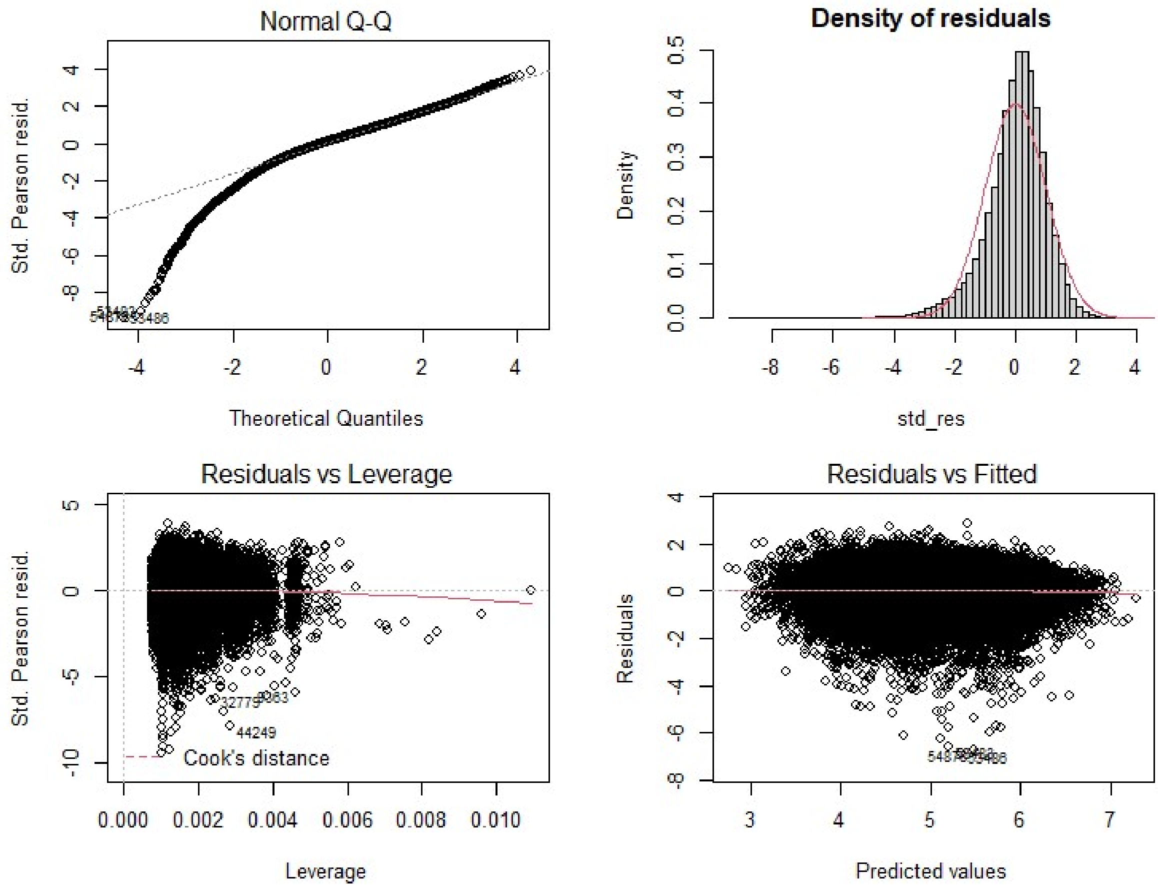
The final fitted east Northland GLM explained 43% of the longline daily log catch (Table Appendix 8), “log-hooks” accounting for most of the standardisation effect (Appendix Figure 12). The pattern in the residuals in the final GLM show departures from normality in the lower 25% quartile in predicting small catches but most of the observed catch range appeared well described by the model (Appendix Figure 13).

Table Appendix 8: East Northland GLM fitted parameterisation for response variable log daily catch.

Predictors	Deg. freedom	Cumulative R^2
fish_year	30	0.11
ns(lhooks, df = 3)	3	0.34
vessel	52	0.40
month	11	0.43



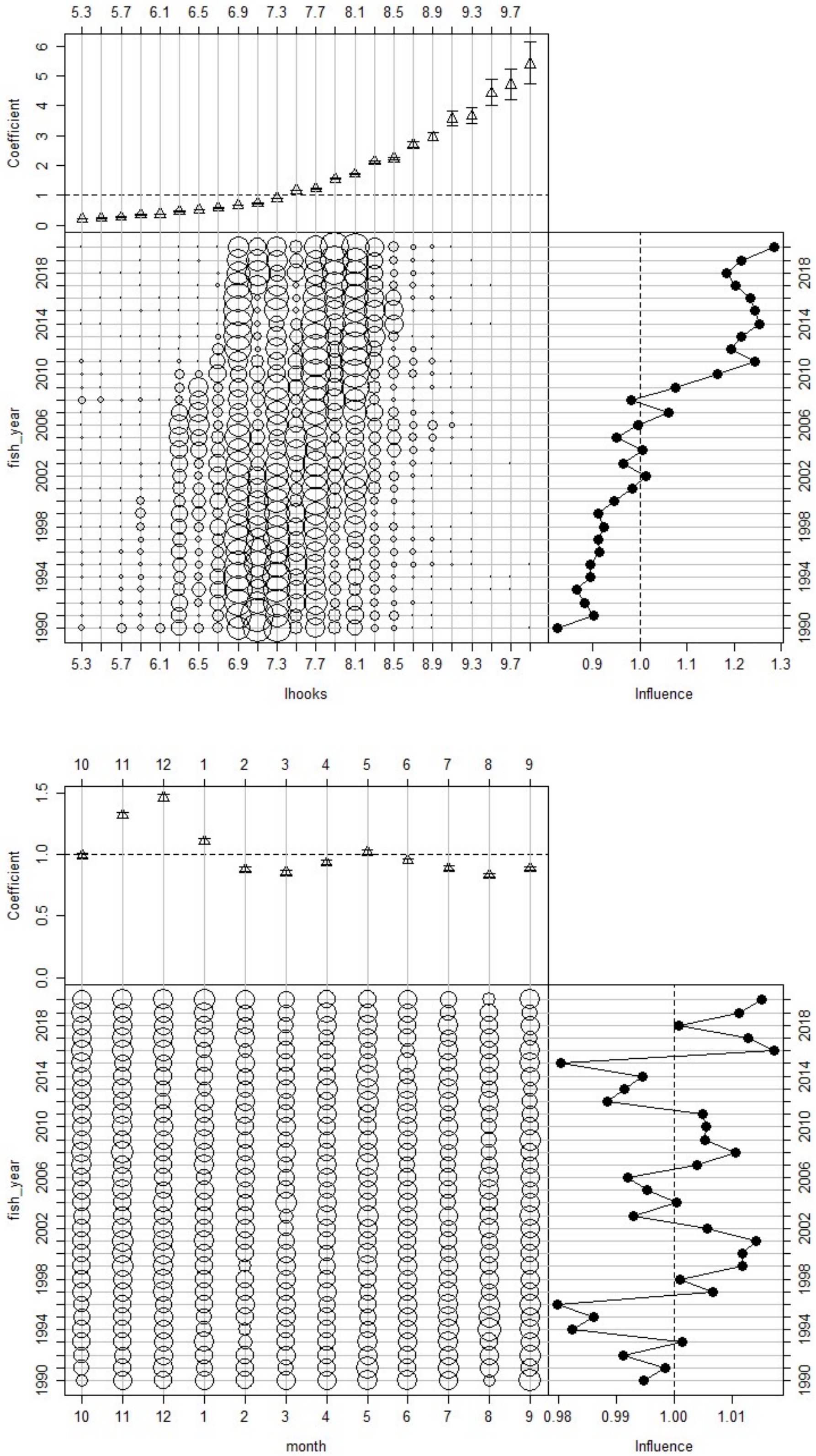
Appendix Figure 12: Degree of standardisation in final GLM East Northland index relative to each added covariate term.



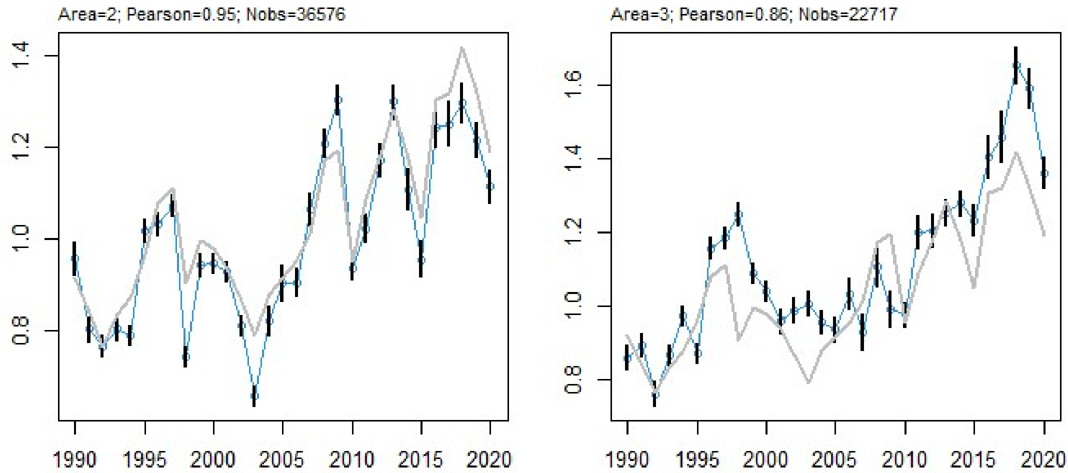
Appendix Figure 13: Normality tests on the final East Northland GLM residuals.

The standardisation influence of "log-hooks" in the final east Northland GLM shows a strong increasing trend (Appendix Figure 14). The standardisation influence of "month" is consistent with expected higher catch rates over summer months (11, 12, 1) (Appendix Figure 14).

Implied residual plots in the East Northland GLM predicted "fishing year" indices aggregated by statistical area were both highly correlated with the overall index (Appendix Figure 15) suggesting a reasonable level of snapper abundance homogeneity across the whole east Northland region.



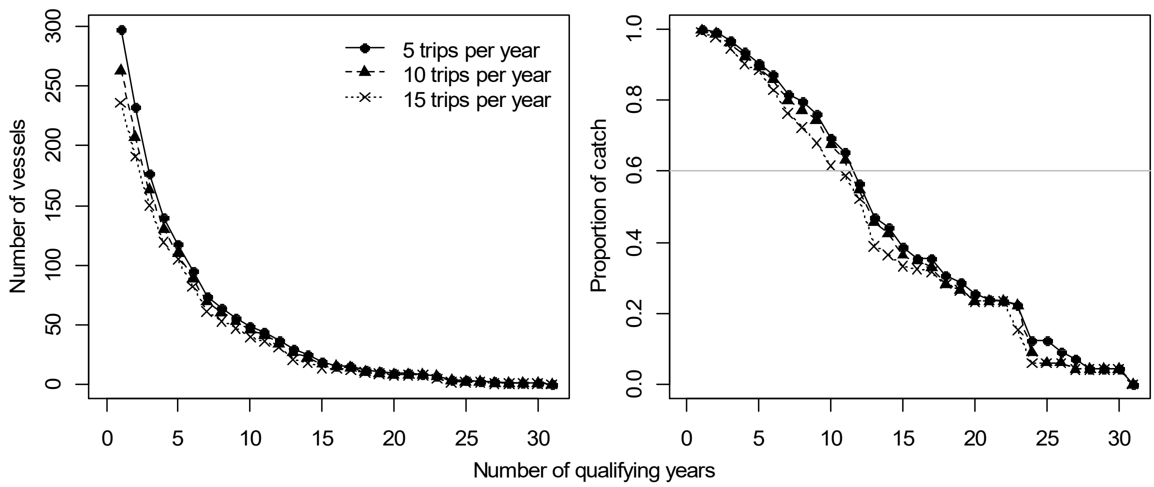
Appendix Figure 14: East Northland GLM influence plots for log-hooks (top) and month (bottom) parameters.



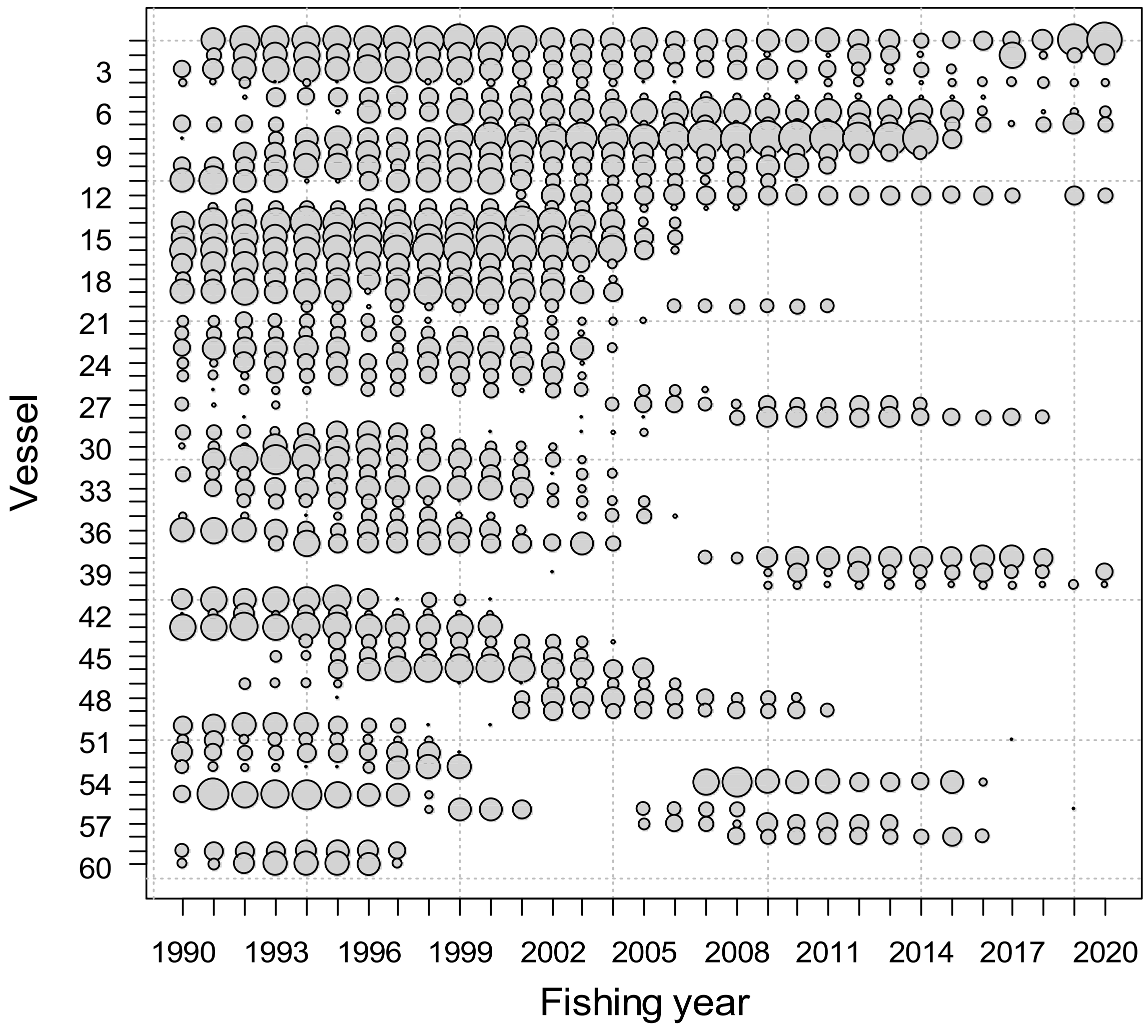
Appendix Figure 15: East Northland GLM implied residual plots by "statistical area".

Hauraki Gulf

Core vessels were selected based all selected vessels having to account for 60% of the total landed longline catch over all years; the optimum selection criteria to achieve this corresponded to a minimum catch history of ten years of at least eight trips per year (Appendix Figure 16). There were a high proportion of long catch-history vessels included in the Hauraki Gulf GLM standardisations (Appendix Figure 17).



Appendix Figure 16: Hauraki Gulf longline CPUE vessel selection criteria plots.

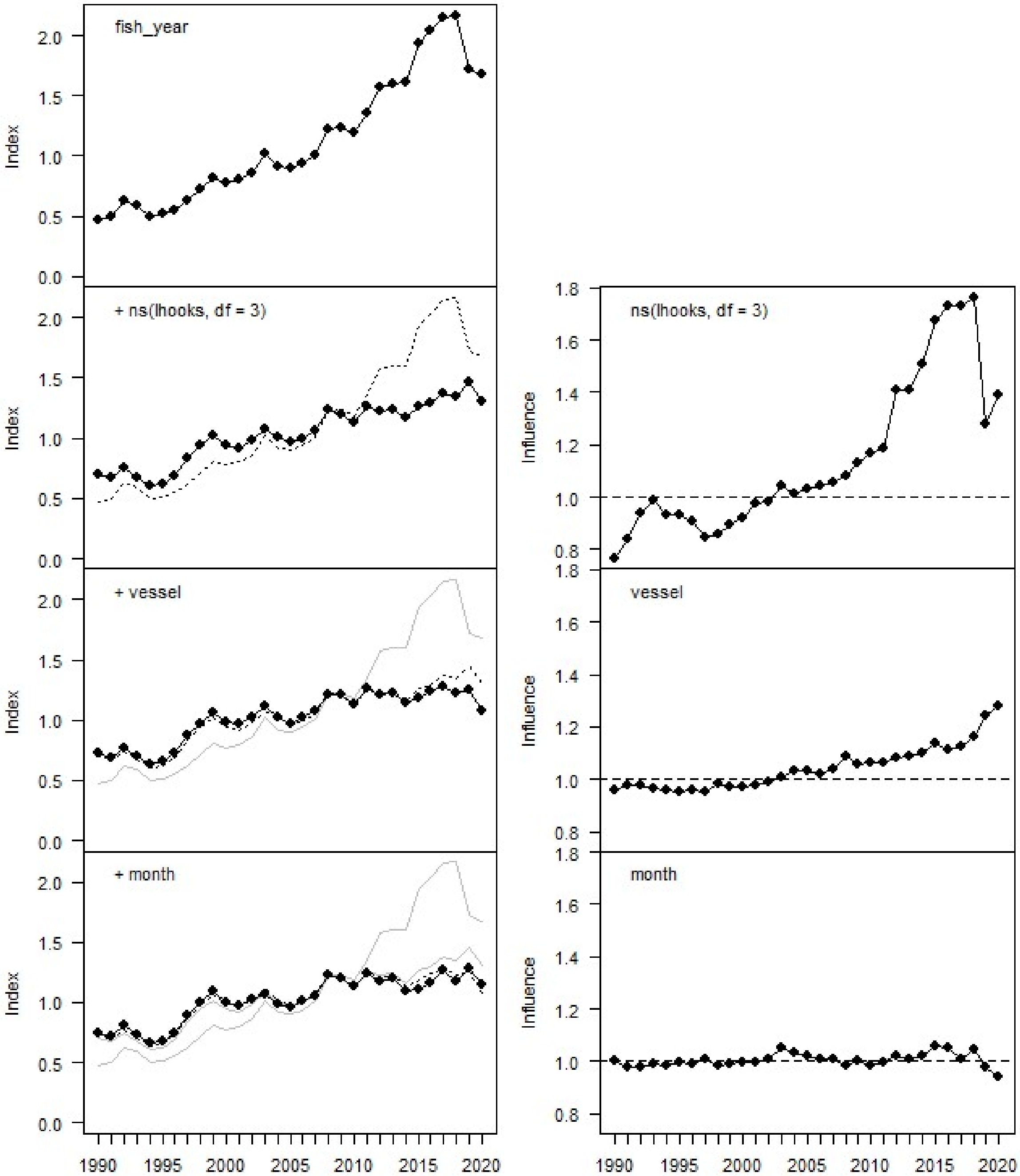


Appendix Figure 17: Hauraki Gulf longline core vessel catch histories, bubble areas proportional to annual vessel catch totals.

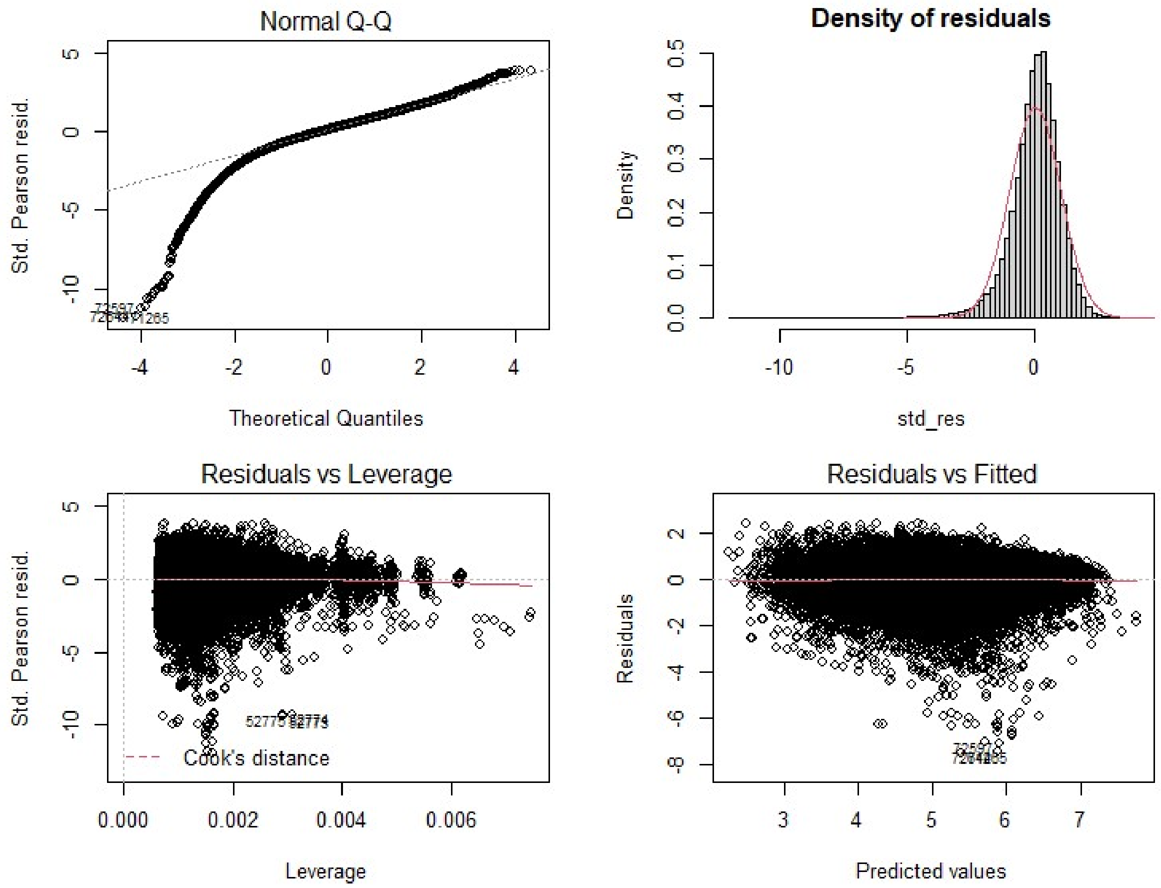
The final fitted Hauraki Gulf GLM explained 57% of the longline daily log catch (Table Appendix 9), "log-hooks" accounting for most of the standardisation effect (Appendix Figure 18). The pattern in the residuals in the final GLM shows departures from normality in the lower 25% quartile in predicting small catches but most of the observed catch range appears well described by the model (Appendix Figure 19).

Table Appendix 9: Hauraki Gulf GLM fitted parameterisation for response variable log daily catch.

Predictors	Deg. freedom	Cumulative R^2
fish_year	30	0.16
ns(lhooks, df = 3)	3	0.46
vessel	52	0.52
month	11	0.57



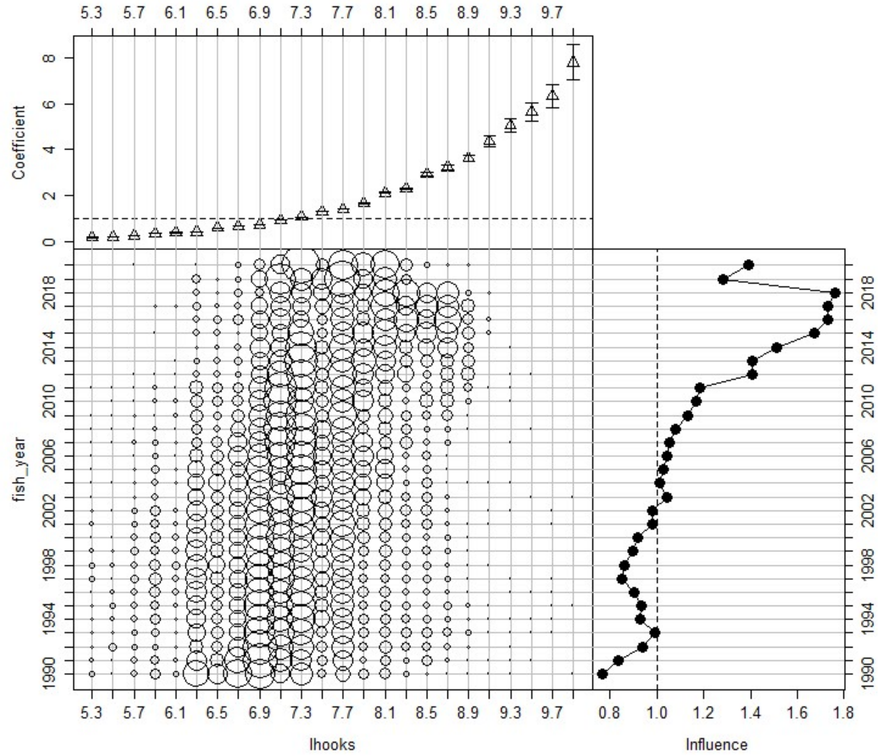
Appendix Figure 18: Degree of standardisation in final GLM Hauraki Gulf index relative to each added covariate term.

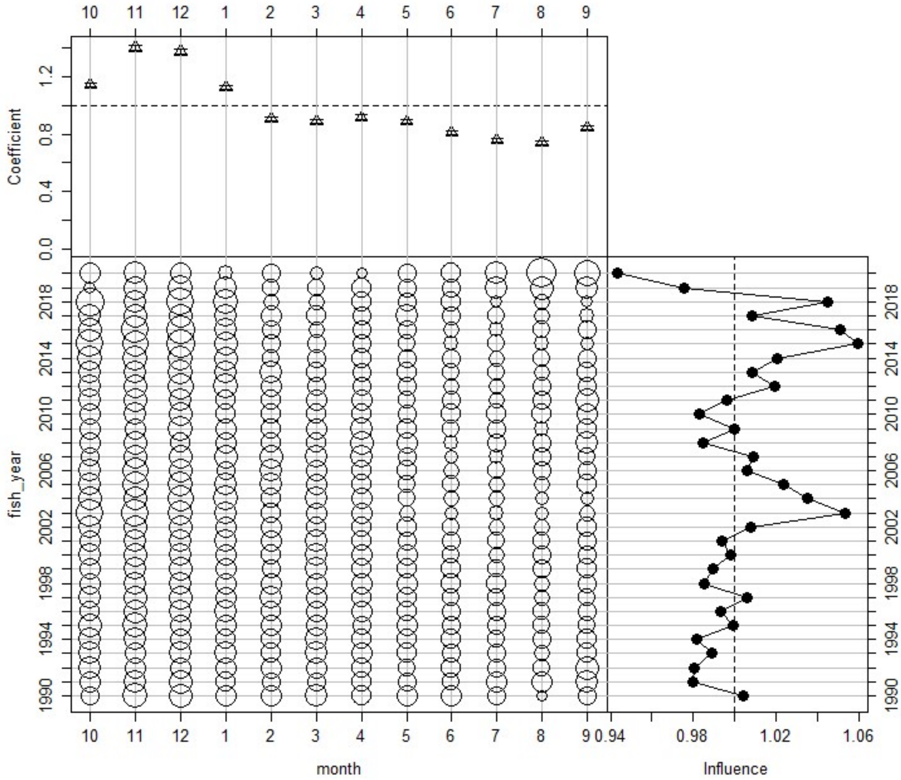


Appendix Figure 19: **Normality tests on the final Hauraki Gulf GLM residuals.**

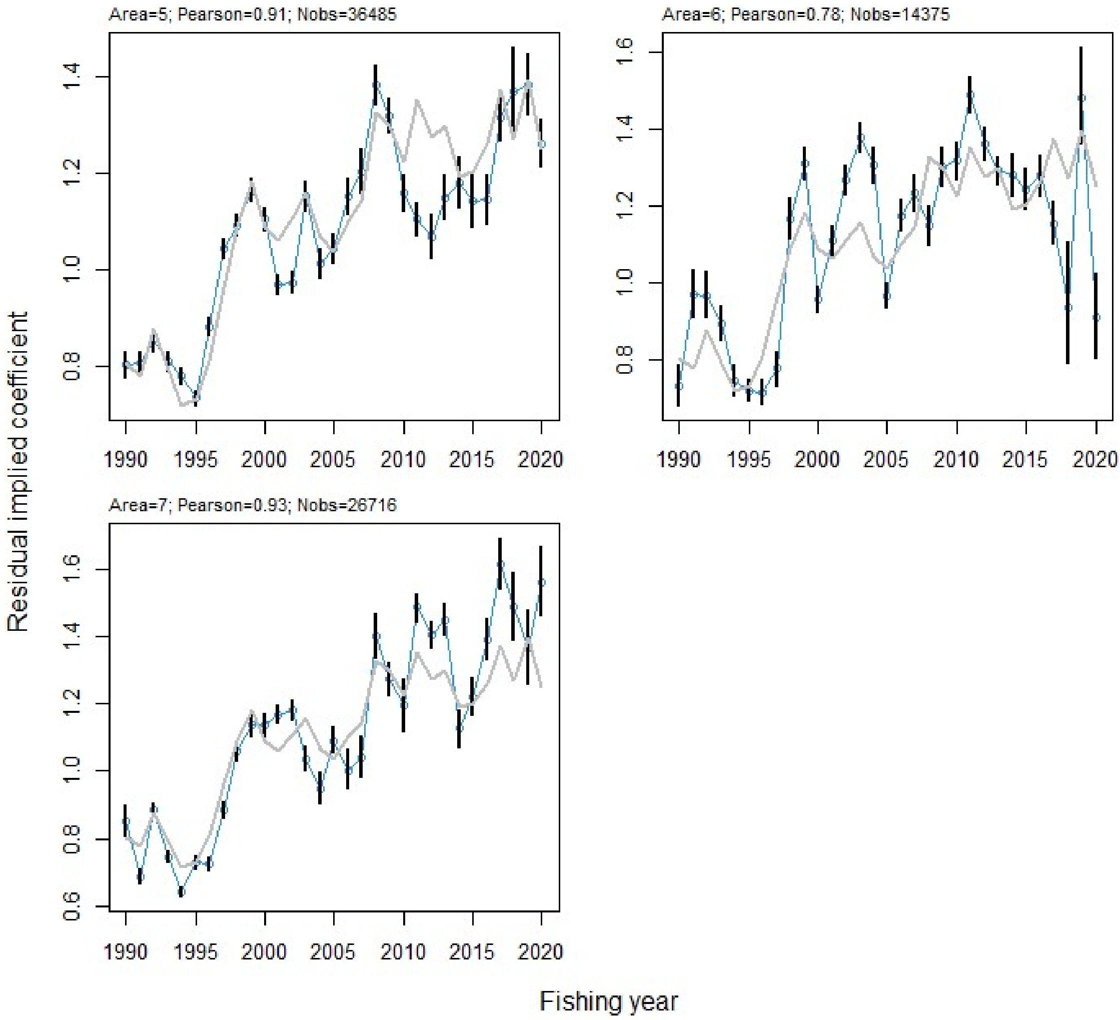
The standardisation influence of “log-hooks” in the Hauraki Gulf GLM shows a strong increasing trend (Appendix Figure 20). The standardisation influence of “month” is consistent with expected higher catch rates over spring-summer months (10, 11, 12, 1) (Appendix Figure 20).

Implied residual plots by statistical area in the Hauraki Gulf GLM predicted “fishing year” were each highly correlated with the overall index (Appendix Figure 21) suggesting a reasonable level of snapper abundance homogeneity across the whole Hauraki Gulf region.





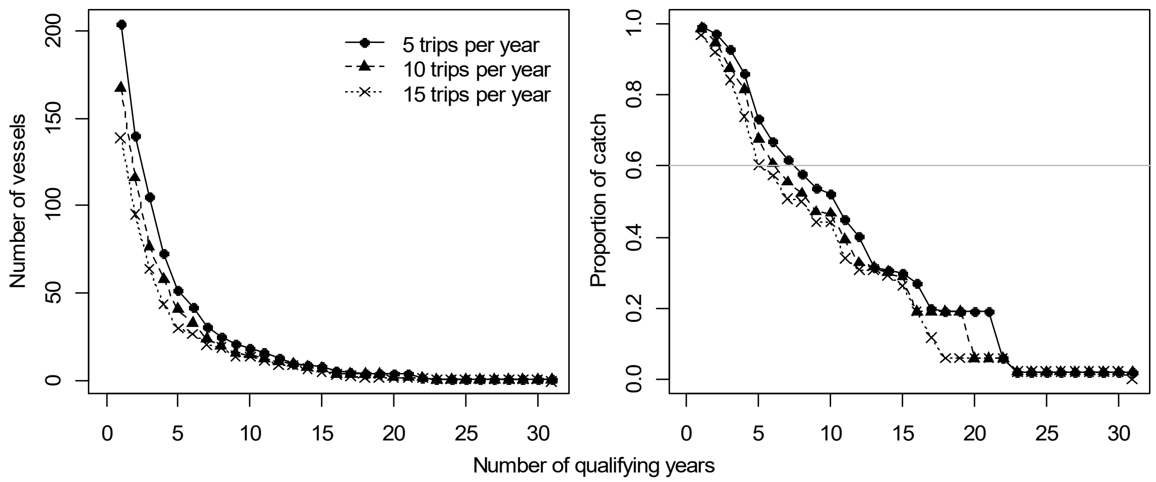
Appendix Figure 20: Hauraki Gulf GLM influence plots for log-hooks (top) and month (bottom) parameters.



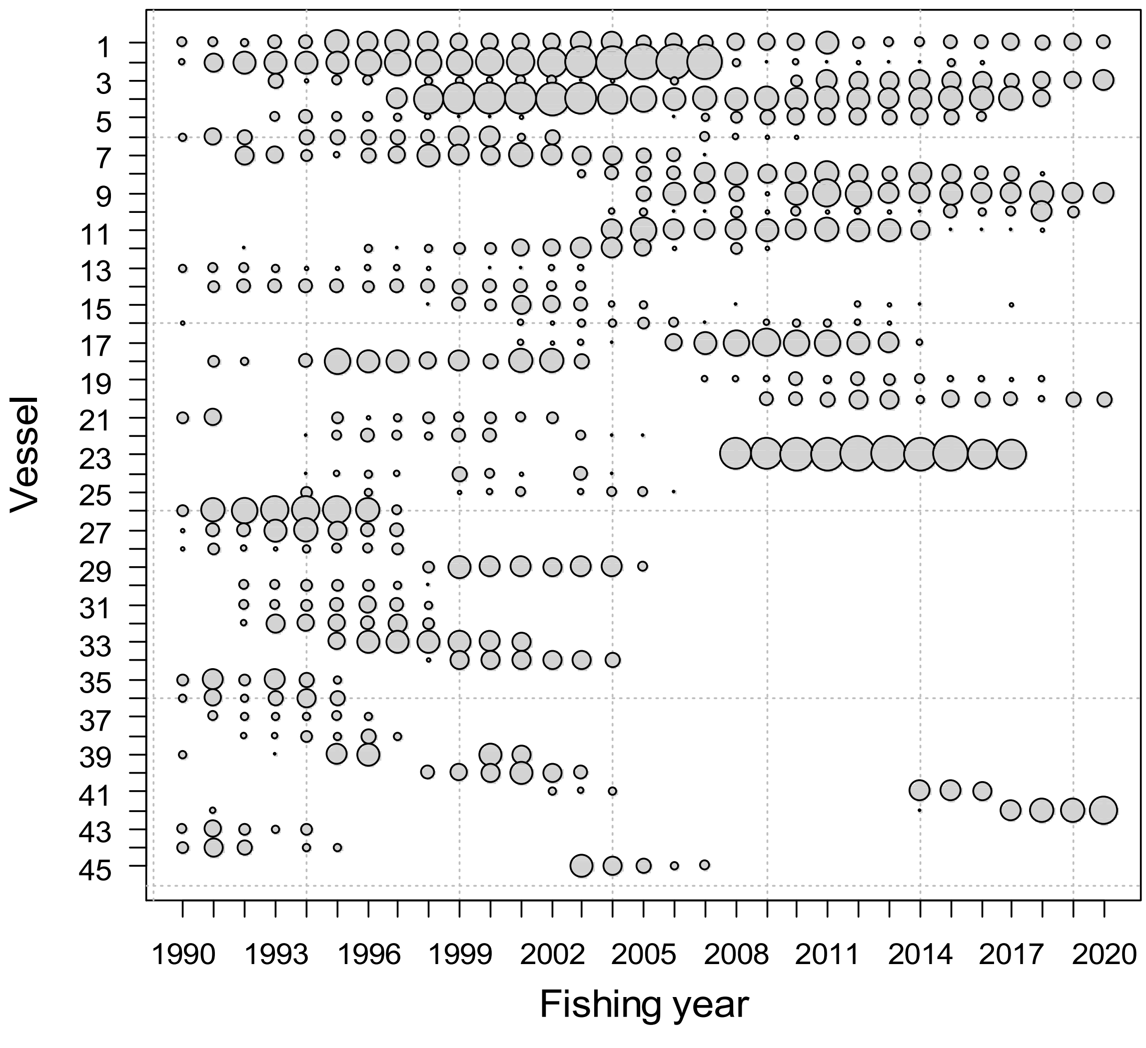
Appendix Figure 21: Hauraki Gulf GLM implied residual plots by "statistical area".

Bay of Plenty

Core vessels were selected having to account for 60% of the total landed longline catch over all years; the optimum selection criteria to achieve this corresponded to a minimum catch history of five years of at least eight trips per year (Appendix Figure 22). There were fewer long catch-history vessels included in the Bay of Plenty GLM standardisations than in the other two areas (Appendix Figure 23).



Appendix Figure 22: Bay of Plenty longline CPUE vessel selection criteria plots.

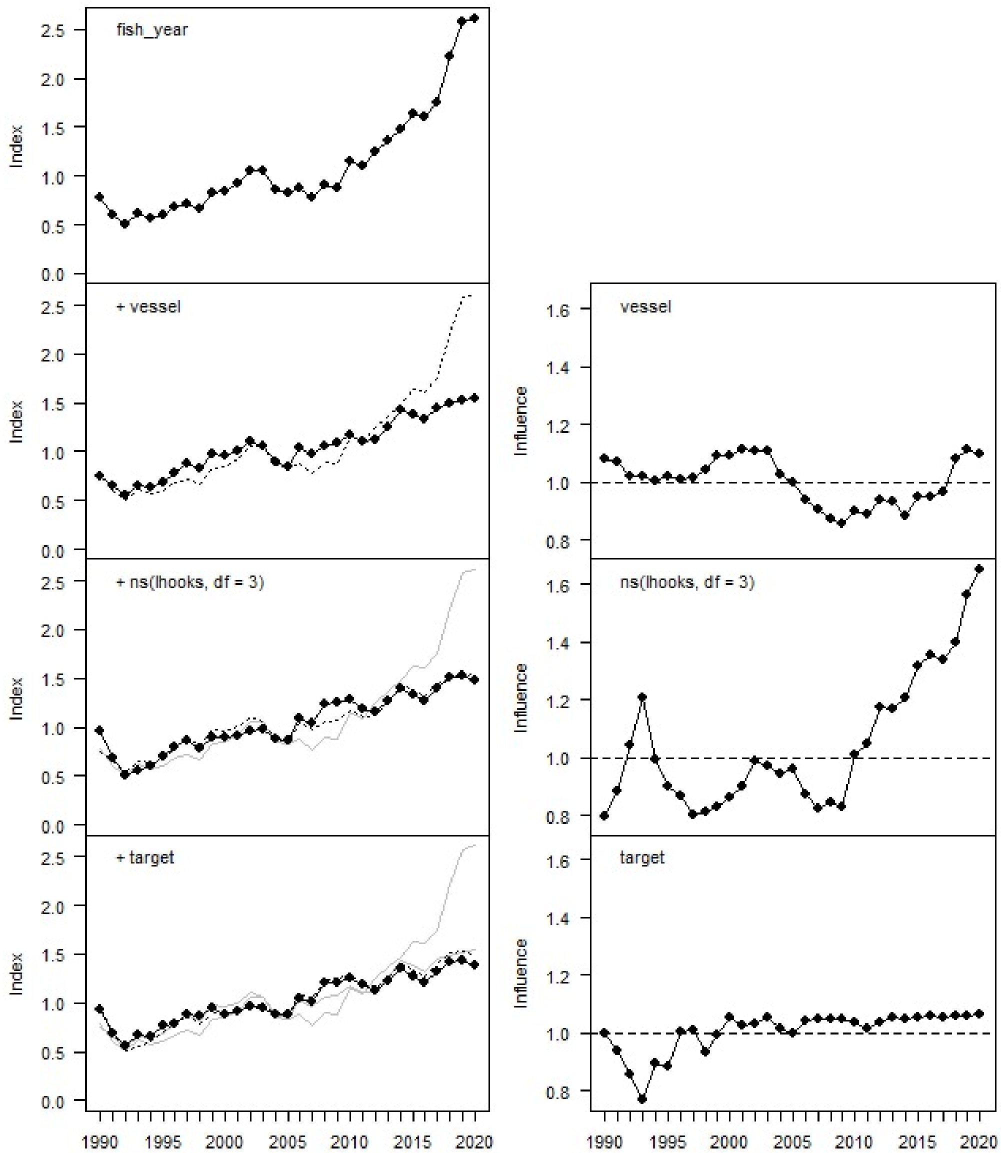


Appendix Figure 23: Bay of Plenty longline core vessel catch histories, bubble areas proportional to annual vessel catch totals.

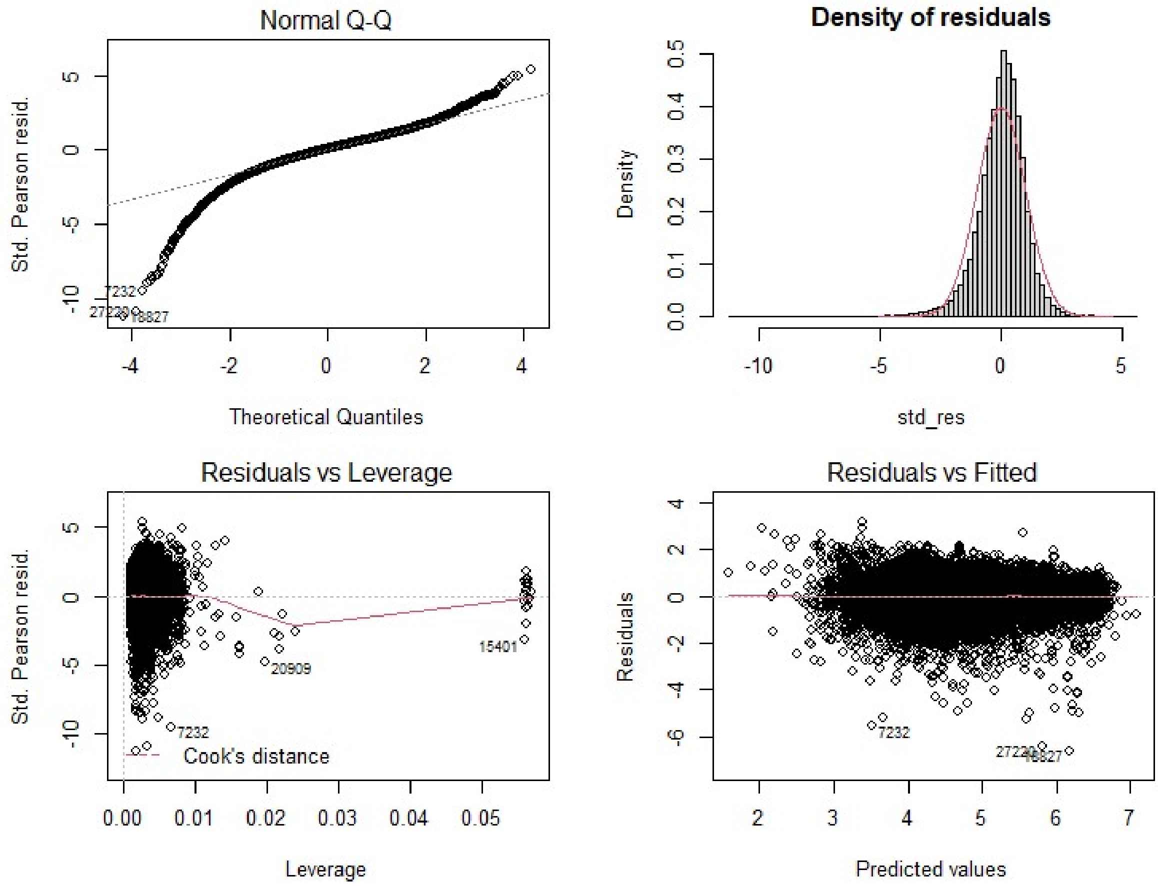
The final fitted Bay of Plenty GLM explained 60% of the longline daily log catch (Table Appendix 10), with "vessel" accounting for most of the standardisation effect after 2015 (Appendix Figure 24). The pattern in the residuals in the final GLM show departures from normality in the lower 25% quartile in predicting small catches but most of the observed catch range appears well described by the model (Appendix Figure 25).

Table Appendix 10: Bay of Plenty GLM fitted parameterisation for response variable log daily catch.

Predictors	Deg. freedom	Cumulative R^2
fish_year	30	0.17
vessel	43	0.48
ns(lhooks)	3	0.57
target	1	0.60



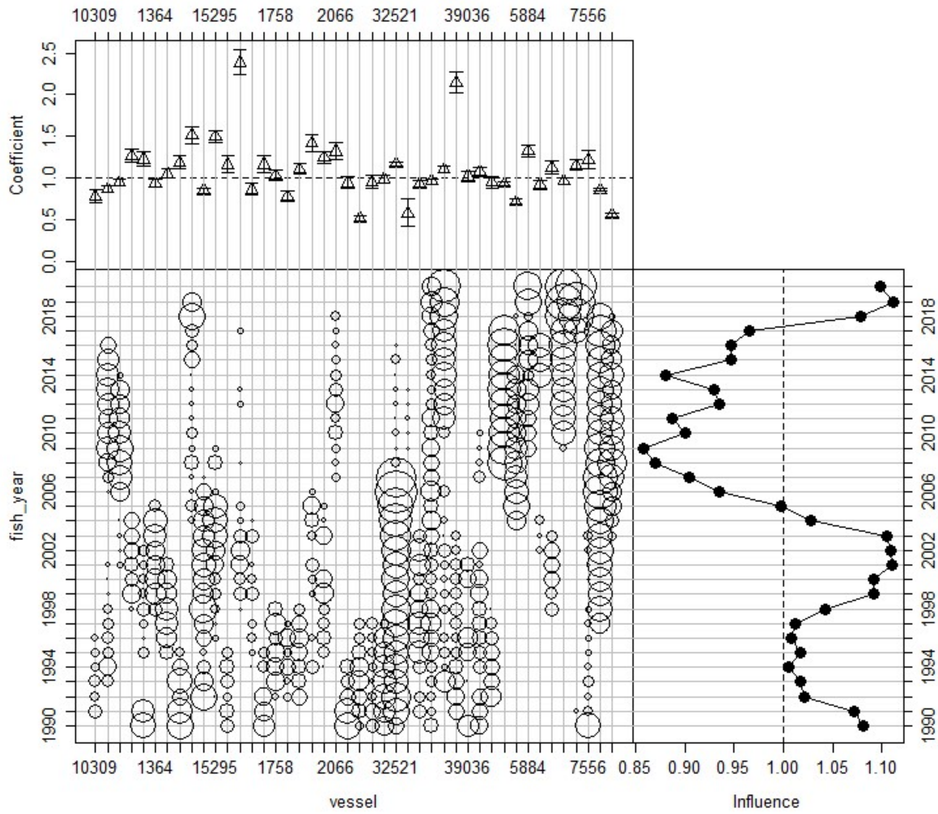
Appendix Figure 24: Degree of standardisation in final GLM Bay of Plenty index relative to each added covariate term.

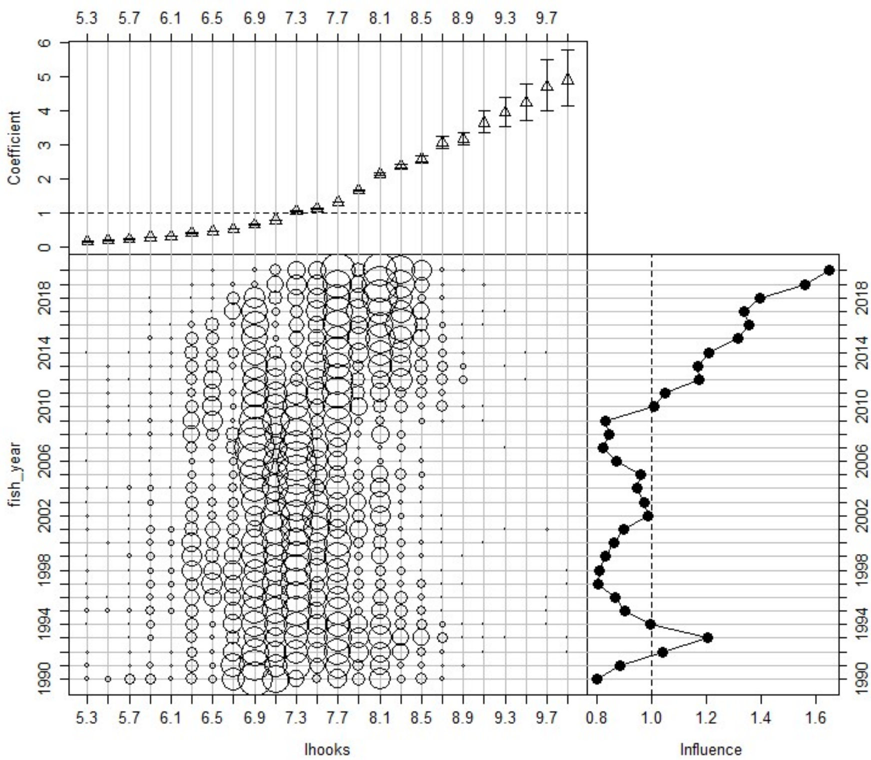


Appendix Figure 25: **Normality tests on the final Bay of Plenty GLM residuals.**

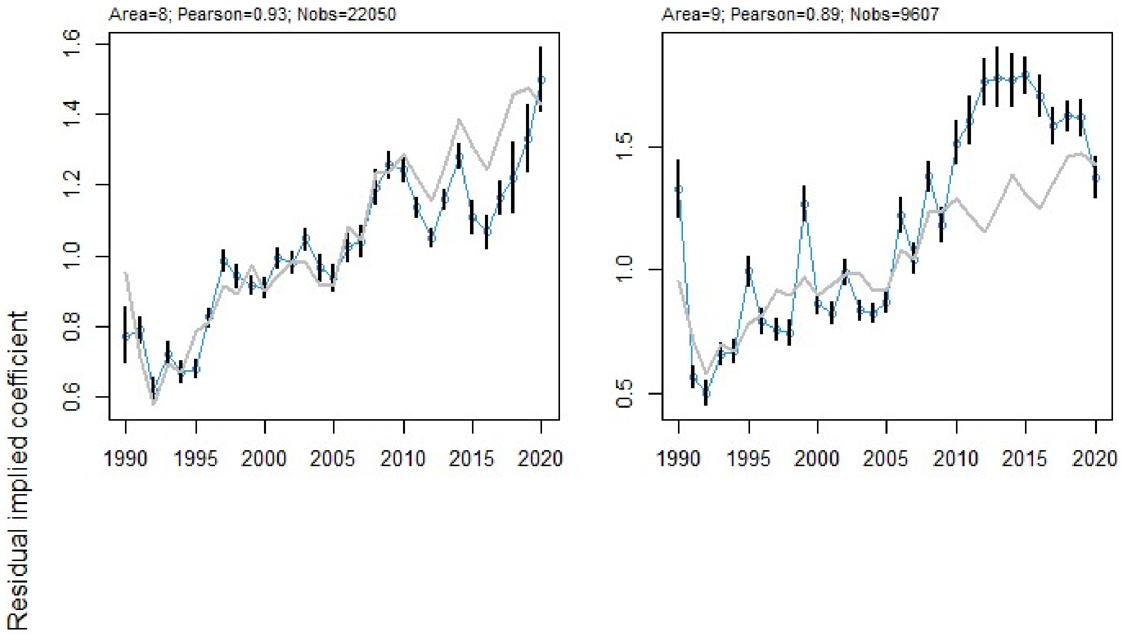
The standardisation influence of "log-hooks" in the Bay of Plenty GLM again shows an increasing trend (Appendix Figure 26).

Implied residual plots in the Bay of Plenty GLM predicted "fishing year" indices aggregated by statistical area both show a similar pattern of increasing trend over the series; however, the Statistical Area 009 residual pattern suggests that abundance stabilised and then declined after 2010–11 (Appendix Figure 27).





Appendix Figure 26: Bay of Plenty GLM influence plots for vessel (top) and log-hooks (bottom) parameters.



Appendix Figure 27: Bay of Plenty GLM implied residual plots by "statistical area".

Bay of Plenty bottom trawl CPUE series

Standardisation of the SNA 1 Bay of Plenty bottom trawl CPUE series was undertaken using generalised linear modelling of event-based (tow-level) data as done for the 2013 assessment (Francis & McKenzie 2015b). Bottom trawl tow-level effort reporting data are available for the Bay of Plenty sub-stock area back to 1995–96. This series was updated through to 2019–20 for the 2022 SNA 1 assessment.

Before standardisation the bottom trawl CPUE data needed to be adjusted to account for an increase in the maximum number of species fishers are required to report catch against per fishing event after 2007–08 (from five to eight). The maximum reported species adjustment required discarding data for species ranking below the top five daily aggregated catches after 2007–08.

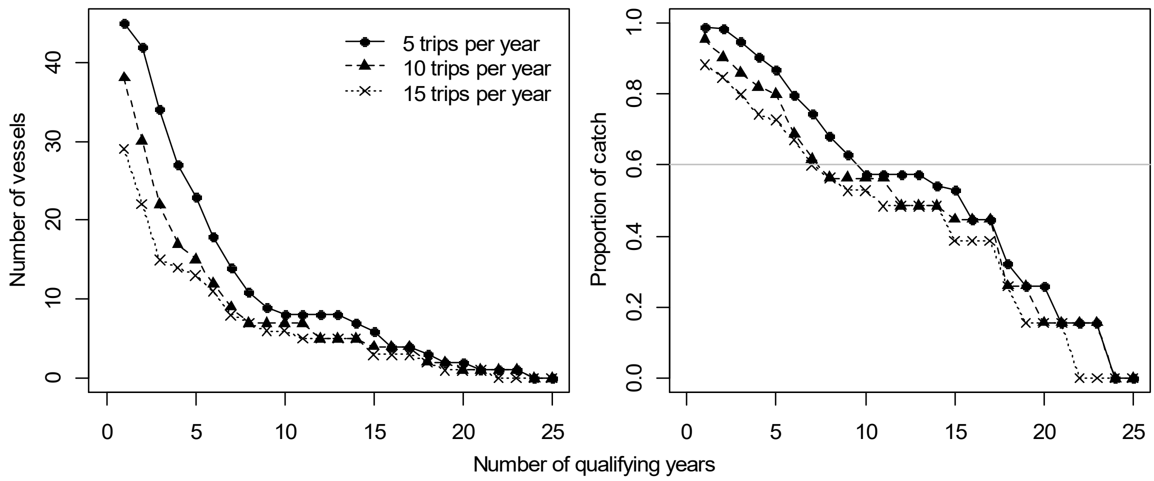
Due to the presence of a significant number of zero events in the bottom trawl series, a delta-lognormal standardisation approach was used for the derivation of the final Bay of Plenty bottom trawl index. The response variable in the positive GLM standardisation was log-catch. The response variable in the binomial GLM was zero/non-zero catch. Fishing-year was always included in the models as a categorical variable. The other covariate terms offered to the models are given in Table Appendix 11. Covariates were added stepwise to log and binomial GLMs, the stopping rule being when the addition of another model term resulted in a less than 1% improvement in residual sums-of-squares (R^2).

Trip landed snapper catch totals were pro-rated across reported effort based on the event catch estimates. Missing value records were excluded from the analyses, as were records where the linked reported catch and/or any of the continuous covariate values fell outside the 99% quartile range.

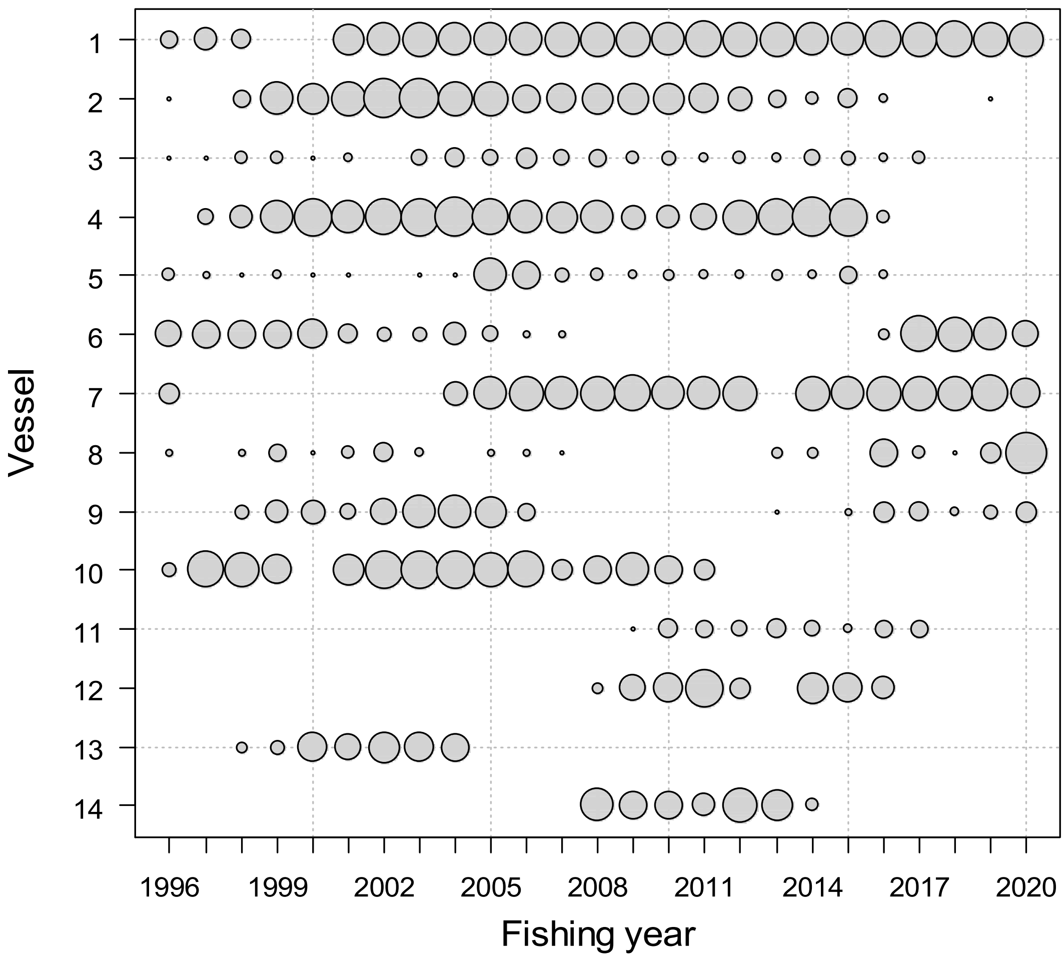
Table Appendix 11: Covariate terms offered to log and binomial GLM bottom trawl CPUE standardisations.

Variable	Type	Description
Fishing year	Categorical	Fishing year (Oct–Sept)
Vessel	Categorical	Unique vessel identifier
Target	Categorical	Target species (SNA, TRE, TAR, JDO, GUR)
Stat area	Categorical	Regional Fisheries New Zealand statistical reporting areas
Month	Categorical	Beginning with month 1 = October
Season	Categorical	SPR[Sep – Nov];SUM[Dec–Feb];AUT[Mar–May];WIN[Jun–Aug]
Log (Duration)	4knt spline	Duration hours per day
Log (Headline height)	Cubic spline	Height of net (m)
Log (Tow speed)	Cubic spline	Tow speed in knots
Botton Depth	Cubic spline	Bottom Depth (m)
Vessel experience	Cubic spline	Number of years in fishery
Vessel dimension	Cubic spline	Length × draught × beam

Core vessels were selected having to account for 60% of the total landed longline catch over all years; the optimum selection criteria to achieve this corresponded to a minimum catch history of seven years of at least five trips per year (Appendix Figure 28). There were a high proportion of long catch-history vessels included in the Bay of Plenty bottom trawl GLM standardisations (Appendix Figure 29).



Appendix Figure 28: Bottom trawl CPUE vessel selection criteria plots.



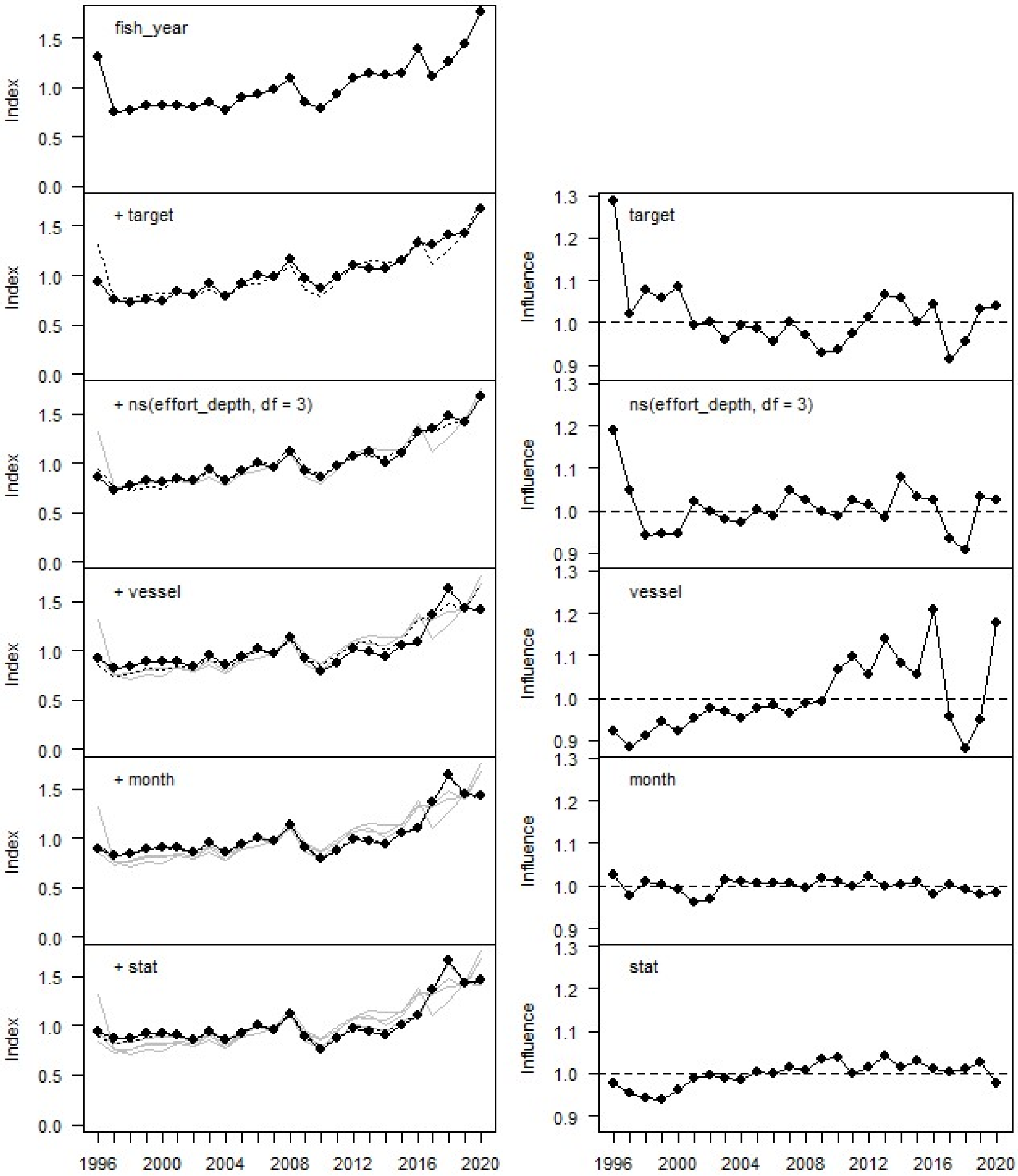
Appendix Figure 29: Bay of Plenty bottom trawl core vessel catch histories, bubble areas proportional to annual vessel catch totals.

Logistic (log(tow-catch)) GLM

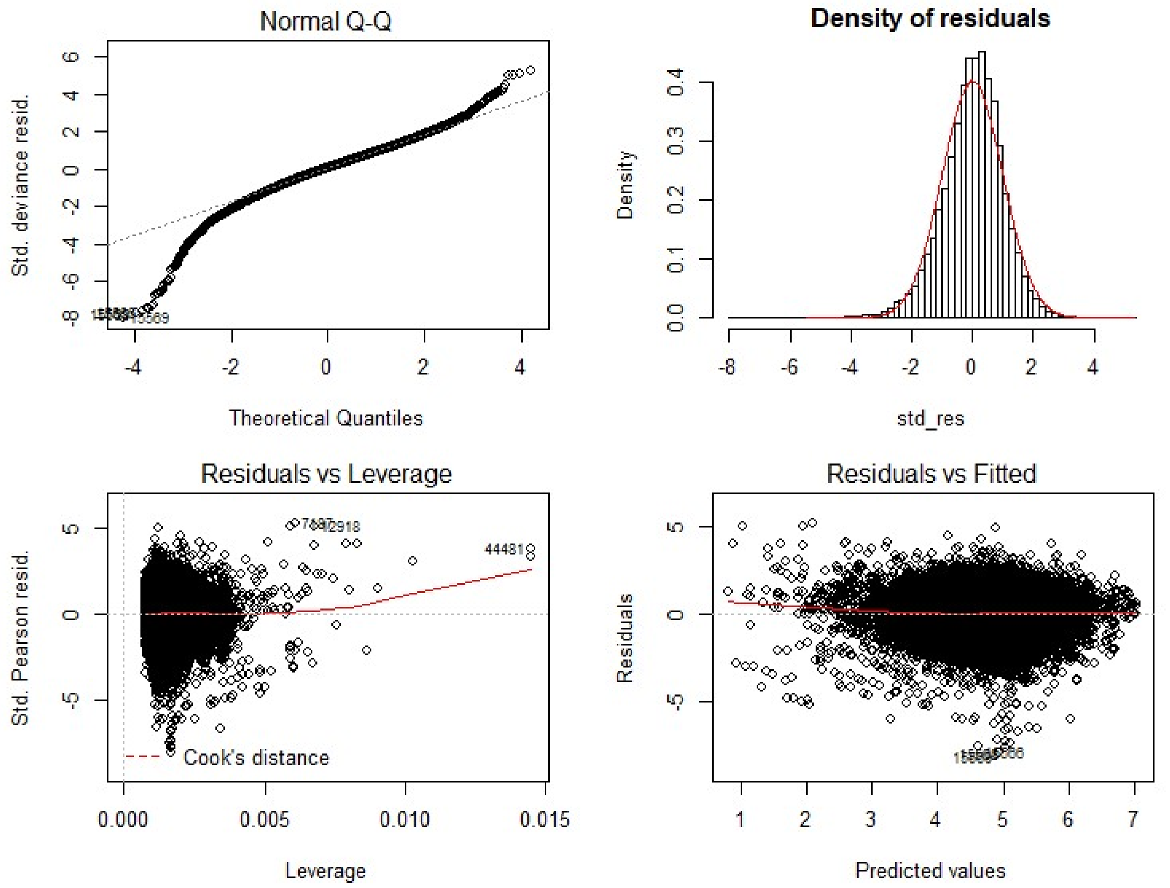
The Bay of Plenty bottom trawl positive GLM explained 27% of the variation in the log positive-catch data (Table Appendix 12). Although "target" was the most explanatory variable, its influence on the final positive index was minor as was the influence of the other explanatory variables selected by the positive model (Appendix Figure 30). The pattern in the residuals in the final logistic GLM show departures from normality in the lower 25% quartile in predicting small catches but most of the observed catch range appears well described by the model (Appendix Figure 31).

Table Appendix 12: Bay of Plenty bottom trawl fitted logistic GLM parameterisation for response variable log tow-catch.

Predictors	Deg. freedom	Cumulative R^2
Fishing year	24	0.03
target	4	0.16
ns(depth)	3	0.2
vessel	13	0.25
month	11	0.26
stat	2	0.27



Appendix Figure 30: Degree of standardisation in final Bay of Plenty bottom trawl log-normal index relative to each added covariate term.

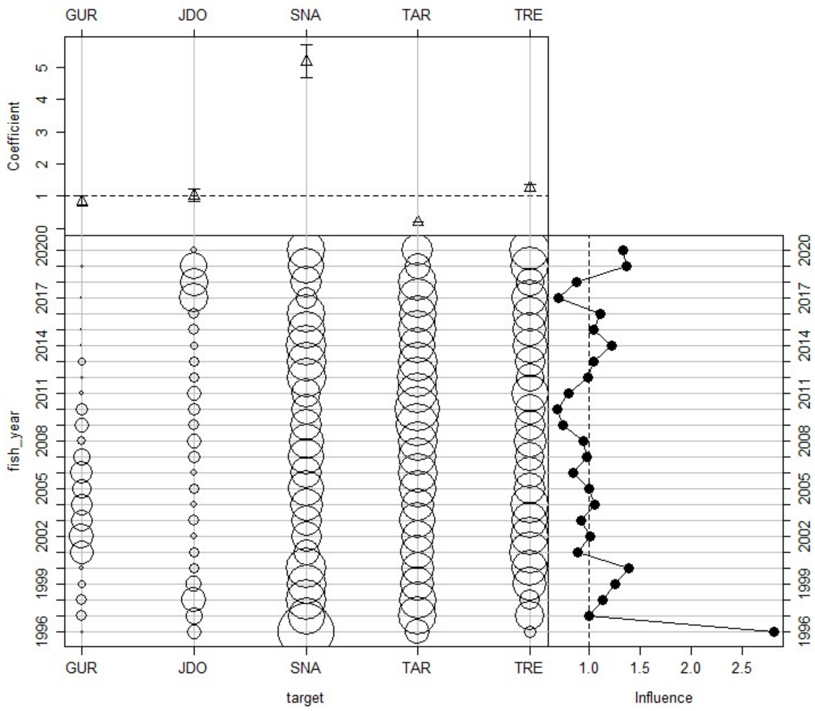


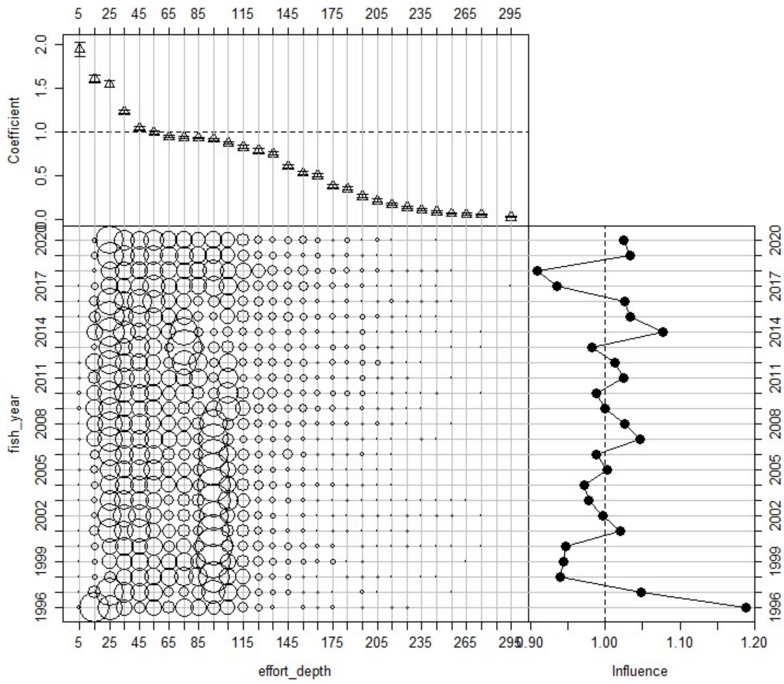
Appendix Figure 31: Normality tests on the final Bay of Plenty logistic model residuals.

The influence plot for "target" shows the high relative effect targeting snapper has on the expected catch rate (Appendix Figure 32). The expected snapper catch rate also shows a strong negative trend with "depth" (Appendix Figure 32).

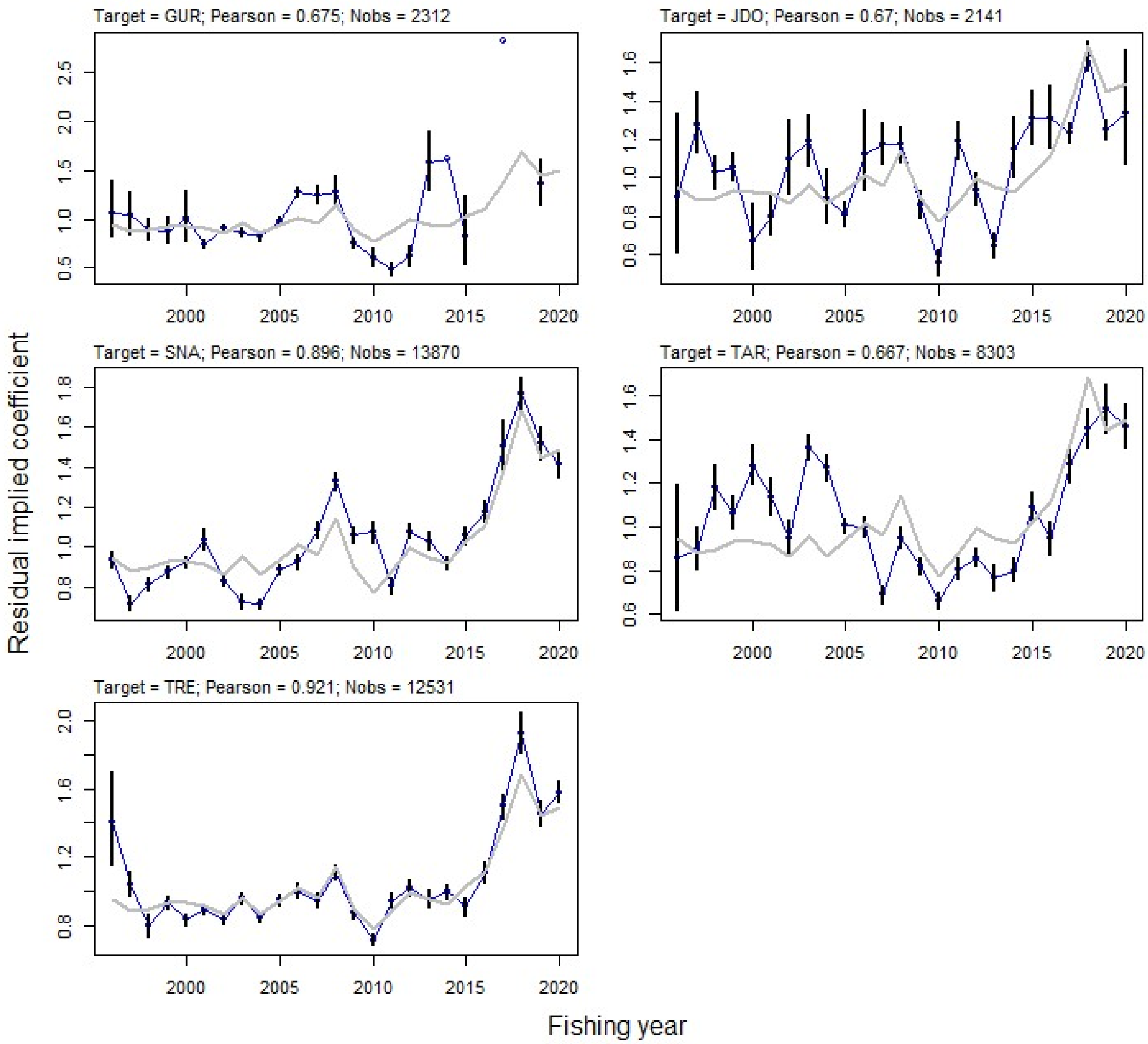
Implied residual plots in the Bay of Plenty bottom "fishing year" indices aggregated by "target" were "reasonably" correlated with the overall index (Appendix Figure 33).

Implied residual plots in the Bay of Plenty bottom trawl positive "fishing year" indices aggregated by "statistical area" were strongly correlated with the overall index (Appendix Figure 34), suggesting a reasonable level of snapper abundance homogeneity across the whole Bay of Plenty sub-stock area where bottom trawl operated.

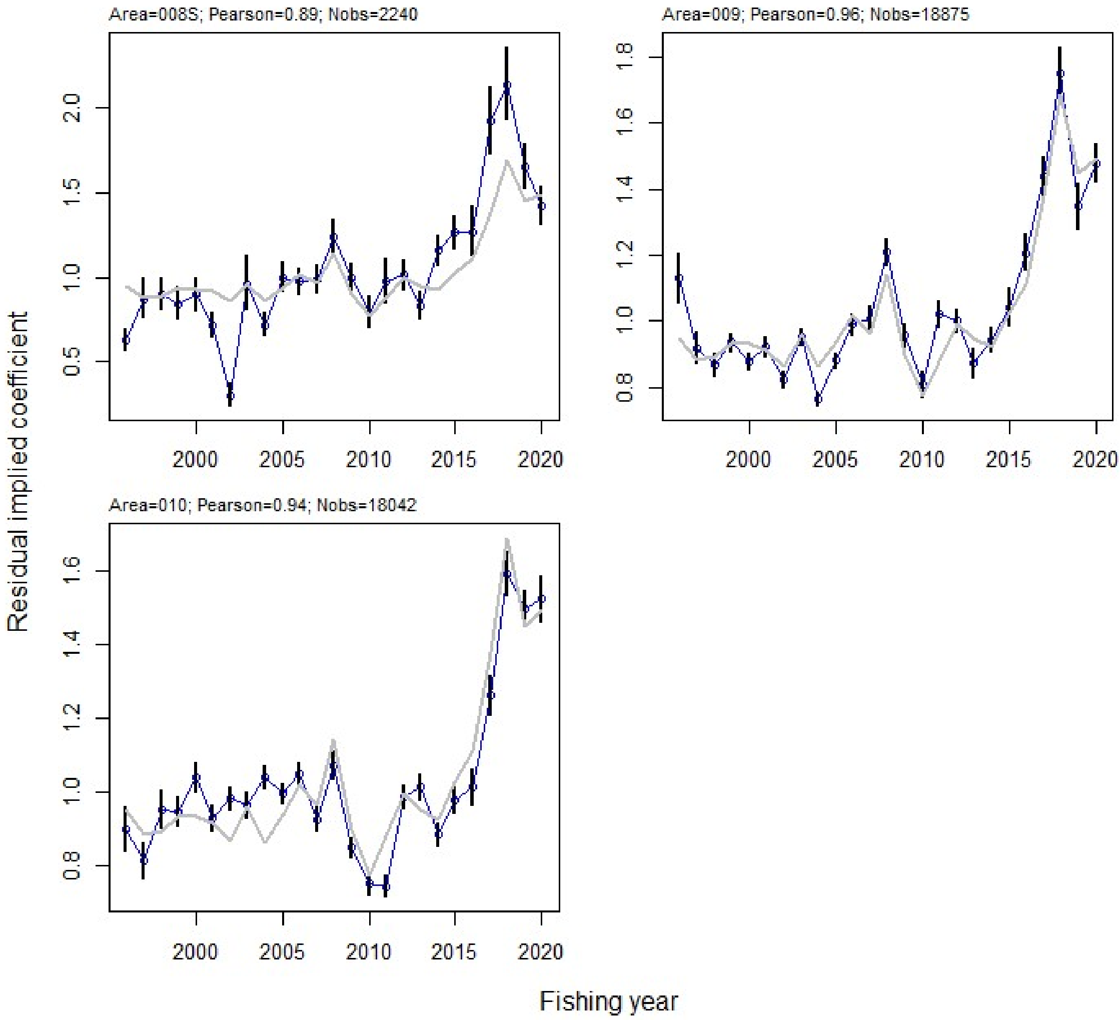




Appendix Figure 32: Bay of Plenty bottom trawl logistic GLM influence plots for target (top) and depth (bottom) parameters.

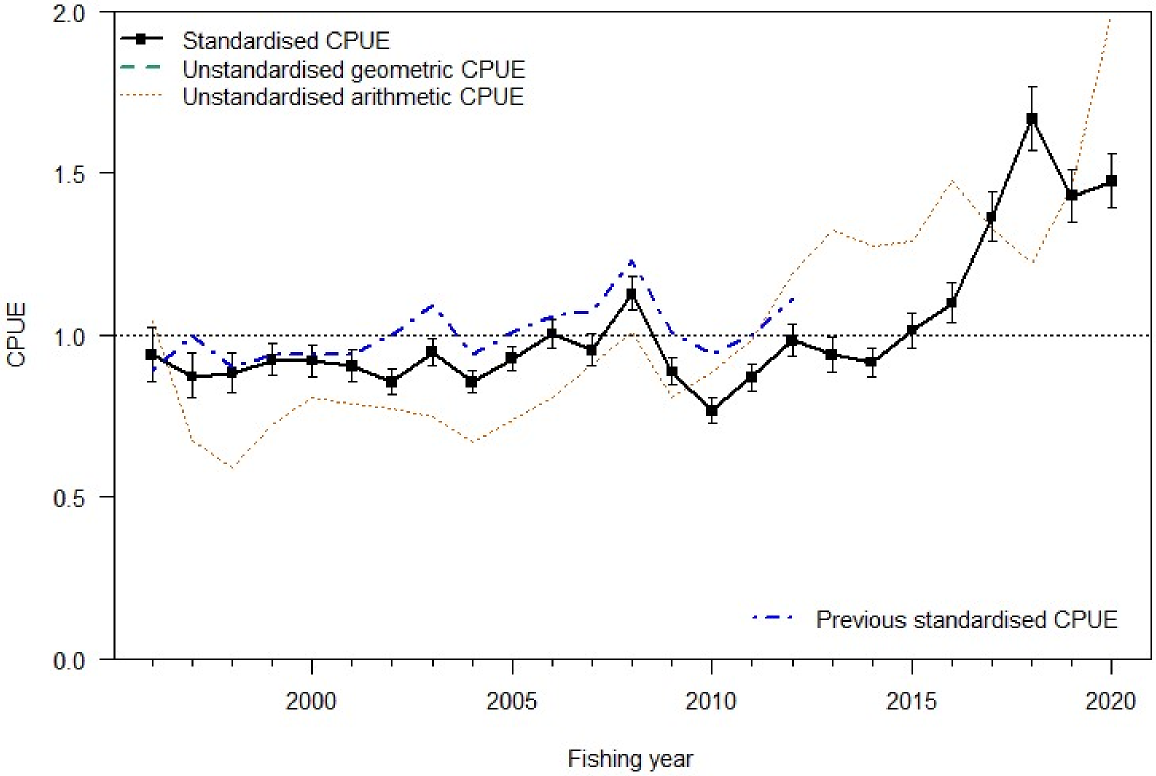


Appendix Figure 33: **Bay of Plenty bottom trawl logistic GLM implied residual plots by "target".**



Appendix Figure 34: Bay of Plenty bottom trawl logistic GLM implied residual plots by "statistical area".

The Bay of Plenty bottom trawl positive GLM index shows a pronounced increase after 2015–16, being relatively flat prior to this (Appendix Figure 35). The general pattern in 2013 index and the updated index again matched reasonably well over the common years (Appendix Figure 35).



Appendix Figure 35: Bay of Plenty bottom trawl snapper CPUE standardised and unstandardised positive catch indices. Index from 2013 assessment shown for comparison.

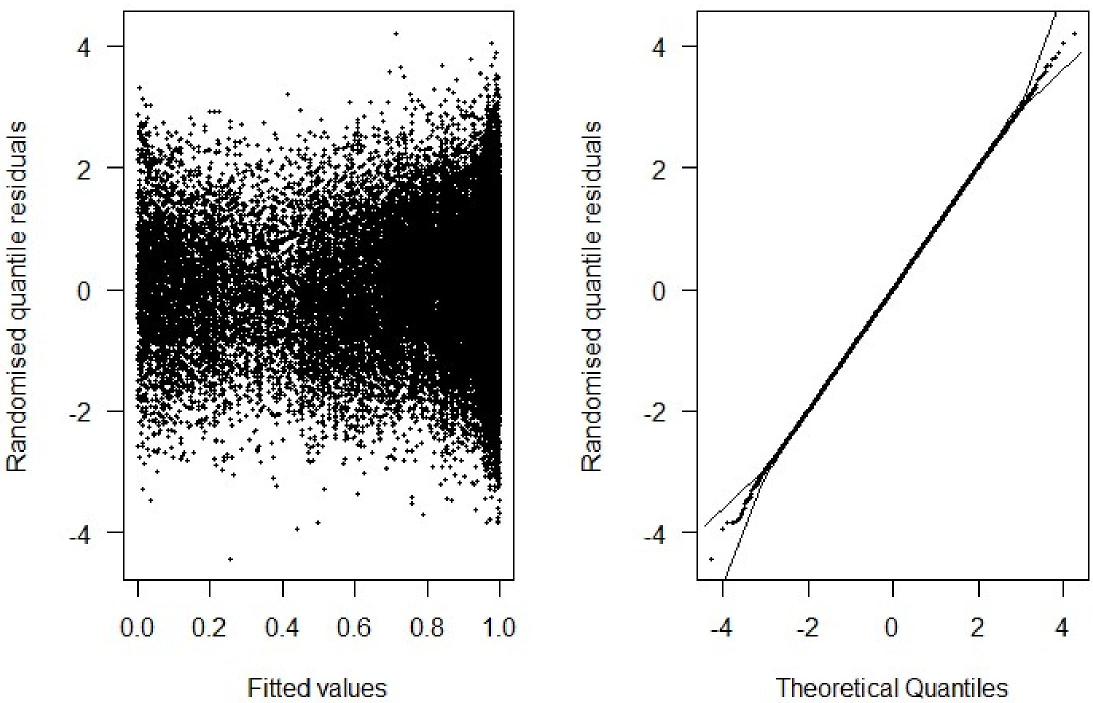
Binomial (positive catch probability) GLM

The Bay of Plenty bottom trawl binomial GLM explained 43% of the variation in the catch probability data (Table Appendix 13). As with the positive model, “depth”, “target”, and “vessel” were the most explanatory variables in the final model (Table Appendix 13).

The binomial GLM fitted residuals were consistent with normality over most of the catch probability space (Appendix Figure 36).

Table Appendix 13: Bay of Plenty bottom trawl fitted binomial GLM parameterisation for response variable positive catch probability.

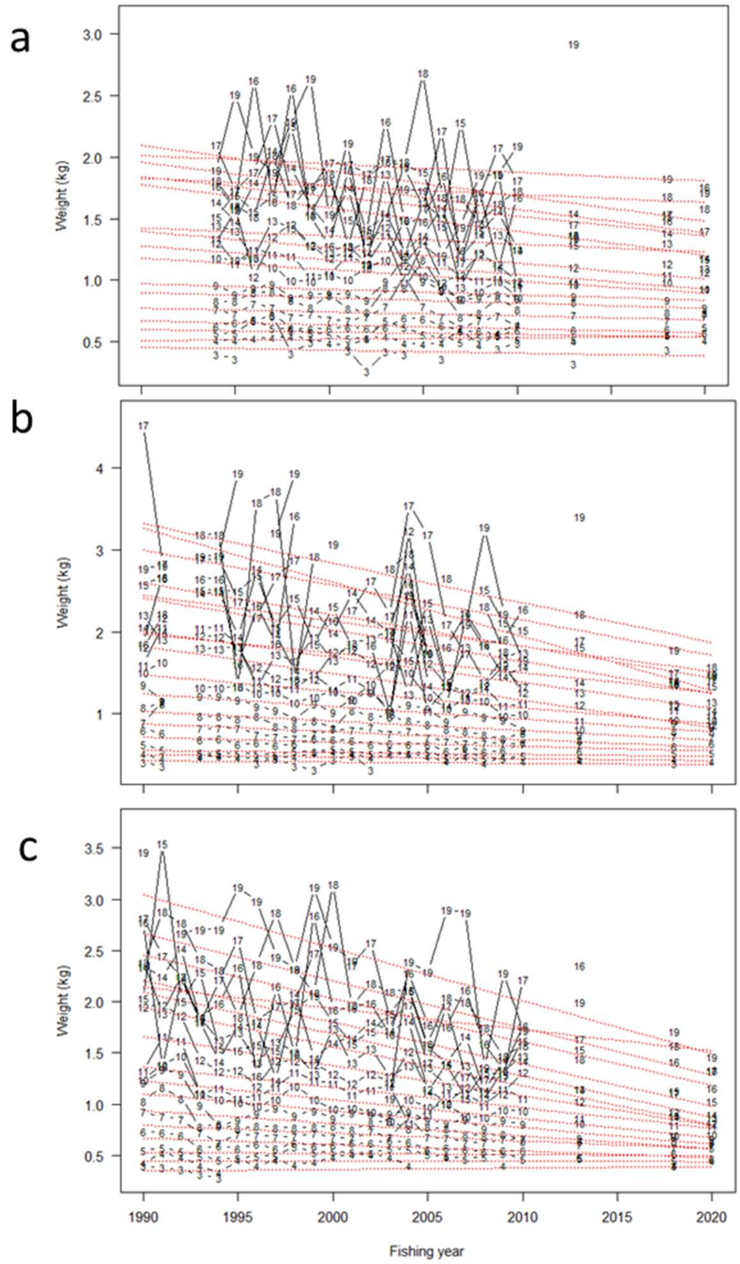
Predictors	Degrees of Freedom	R.squared
Fishing year	24	0.02
ns(effort_depth, df = 3)	3	0.34
target	4	0.4
vessel	15	0.43



Appendix Figure 36: Normality tests on the final Bay of Plenty binomial model residuals.

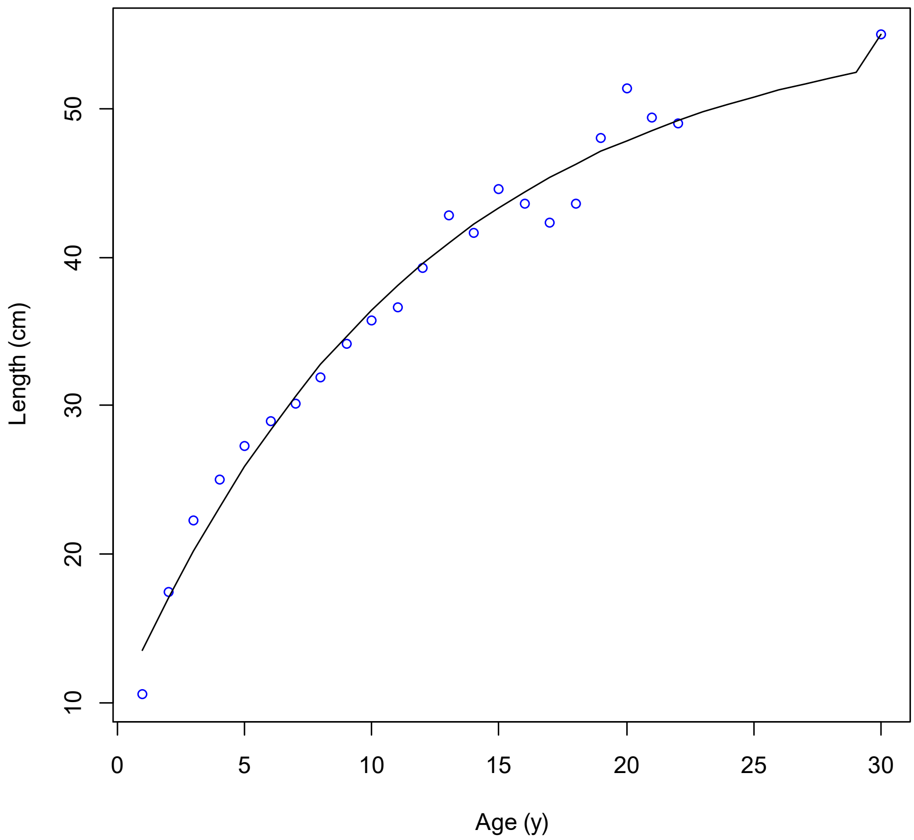
Appendix 5: Derivation of the 2022 and 2023 model sub-stock mean-length at-age growth matrices

The progressive decline in SNA 1 growth rates since 1990 is evident in the regional longline catch at-age time series (Appendix Figure 37). Dynamic growth was incorporated into the 2012 and 2013 SNA 1 assessment models as three mean length at-age matrices (Francis & McKenzie 2015b).



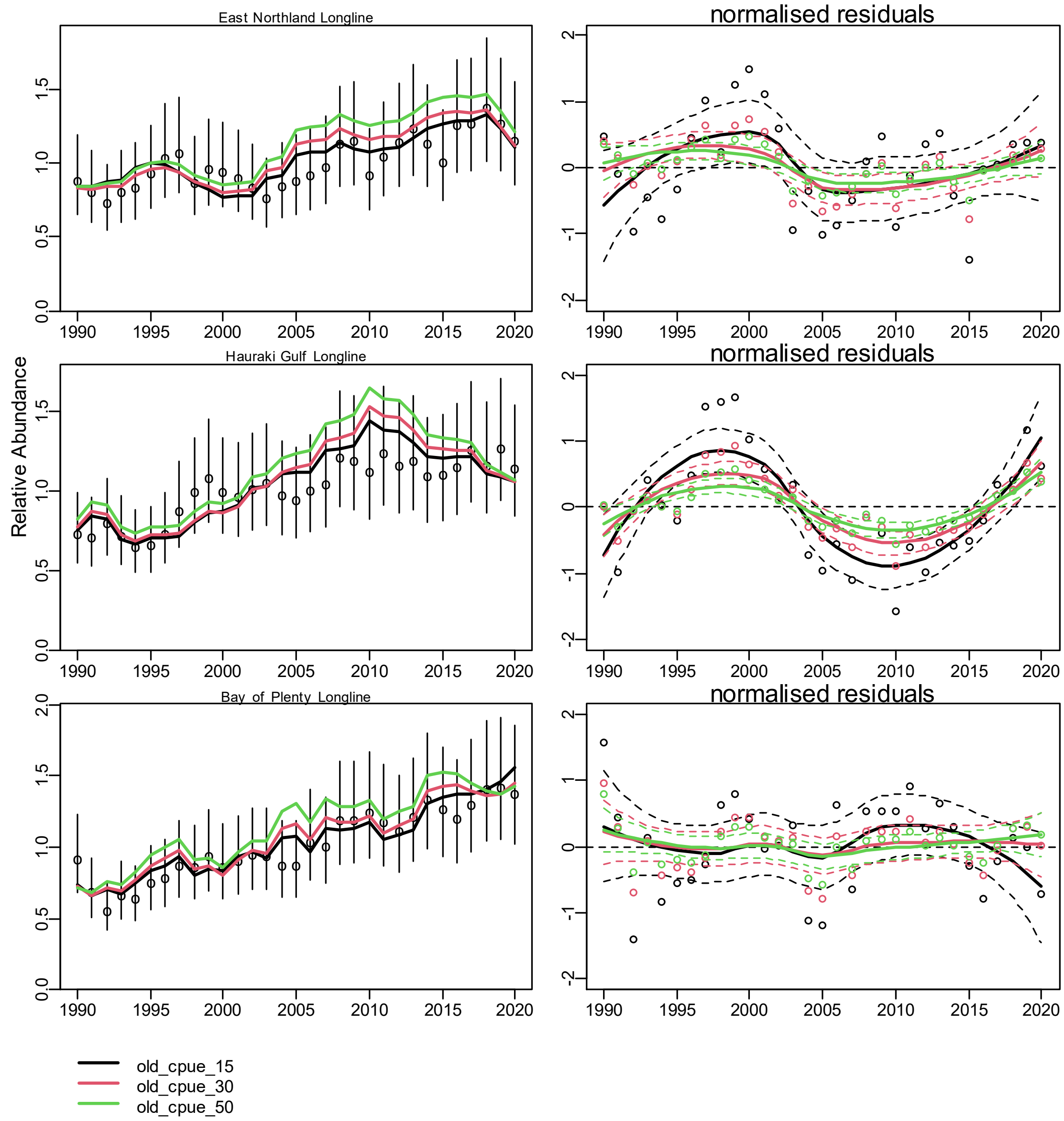
Appendix Figure 37: Mean weight-at-age estimates for 3- to 19-year-old snapper sampled from the SNA 1 bottom longline fisheries (during spring-summer) between 1989–90 and 2019–20 with fitted trend lines (dotted) for each age class depicting long-term changes in growth rates over the 31 year period, a. east Northland, b. Hauraki Gulf, c. Bay of Plenty. (reproduced from Walsh et al. 2022).

Reanalysis of the SNA 1 commercial longline catch sampling data series also provided new estimates of mean-length at-age out to 30+ years. The reanalysis of the Hauraki Gulf and Bay of Plenty trawl survey series provided new estimates of mean-length at-age for ages 1 to 12 years (Parsons & Bian 2022). East Northland mean-length at-age estimates for ages 1 to 12 years in the 1989–90 fishing-year had previously been derived for the 2013 SNA 1 assessment. Past SNA 1 assessments suggested that snapper are uniformly fully selected by longline method in all three sub-stock areas after age six (Francis & McKenzie 2015b), meaning that mean-length at-age estimates derived from longline for ages six and above are likely to be unbiased. The SNA 1 research trawl surveys are optimised to capture pre-recruit snapper and are believed to track the abundance of snapper aged one to six, although they are possibly not uniformly selective of snapper less than two years (Parsons & Bian 2022). The sub-stock area mean-length at-age growth matrices were derived by combining longline and trawl survey age-length data (i.e. ages 1–5 from trawl surveys; ages 6+ from longline). For years where only longline length-age data were available, age 1–5 mean-length estimates were derived from the regional trawl survey closest in time to the longline sample year. Mean length at-age estimates were "smoothed" by fitting Von Bertalanffy (vb) growth curves to the estimated values for ages 1 to 29 (e.g., Appendix Figure 38). The 30+ mean-length at-age estimates in the model growth matrices were the originally derived values (example: Appendix Figure 38).



Appendix Figure 38: Derived 2008–09 Bay of Plenty model mean-length at-age growth matrix values (black line) from a Von Bertalanffy growth model fit to estimated values (blue dots). Age estimates 1 – 6: 2019–20 Bay of Plenty trawl survey; ages 6 – 30+: 2008–09 commercial longline sampling.

Appendix 6: 2022 SNA 1 assessment model fits to commercial CPUE abundance indices at alternative levels of precision



Appendix Figure 39: 2022 SNA 1 assessment model fits to commercial CPUE abundance indices relative to alternative CV's (0.15, 0.30, and 0.50).

Appendix 7: Reweighting of tag-recapture data (reproduced for Francis & McKenzie 2015b)

In the *i*th length bin of the *j*th tag-recapture observation (in which both recaptures and numbers scanned are by length), let

N_i^j be the number of fish scanned
n_i^j be the actual number of tags recovered
m_i^j be the expected number of tags recovered

The likelihoods used in CASAL assume that the n_i^j are independent (between length bins and between observations) and $n_i^j \sim \text{RobustBinomial}(N_i^j, p_i^j)$, where $p_i^j = m_i^j/N_i^j$.

Since the N_i^j are large, this is very similar to assuming that $n_i^j \sim \text{Poisson}(m_i^j)$, and we can use the additive property of independent Poisson distributions to infer that that $n^j \sim \text{Poisson}(m^j)$, where $n^j = \Sigma_i n_i^j$ and $m^j = \Sigma_i m_i^j$.

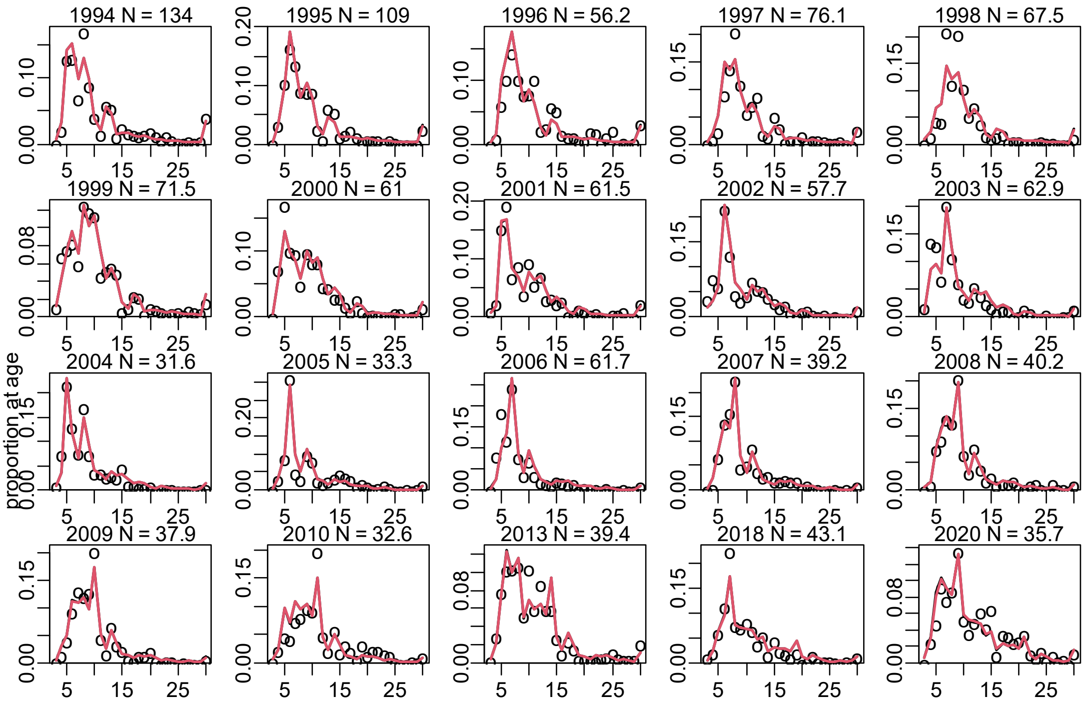
If we define $r^j = (n^j - m^j)/(m^j)^{0.5}$, then the r^j act as standardised residuals (in that they have mean 0 and variance 1). That means we can expect that $\text{Var}_j(r^j)$ to be about 1 if the above assumptions are correct.

The assumption of independence between length bins for the same observation will often be wrong. In particular, for a given *j* the n_i^j are likely to be positively correlated (i.e., if in a particular year we observe more tags than expected in a given length bin, we are likely to observe more tags than expected in other length bins). The effect of this correlation will be to reduce the amount of information in the tag-recapture observations and to increase the expected value of $\text{Var}_j(r^j)$. Because of the way the tag-recapture dispersion parameter is used in the likelihood this means that, to avoid over- or under-weighting the tag-recapture observations, we should aim to use a dispersion that is approximately equal to $\text{Var}_j(r^j)$.

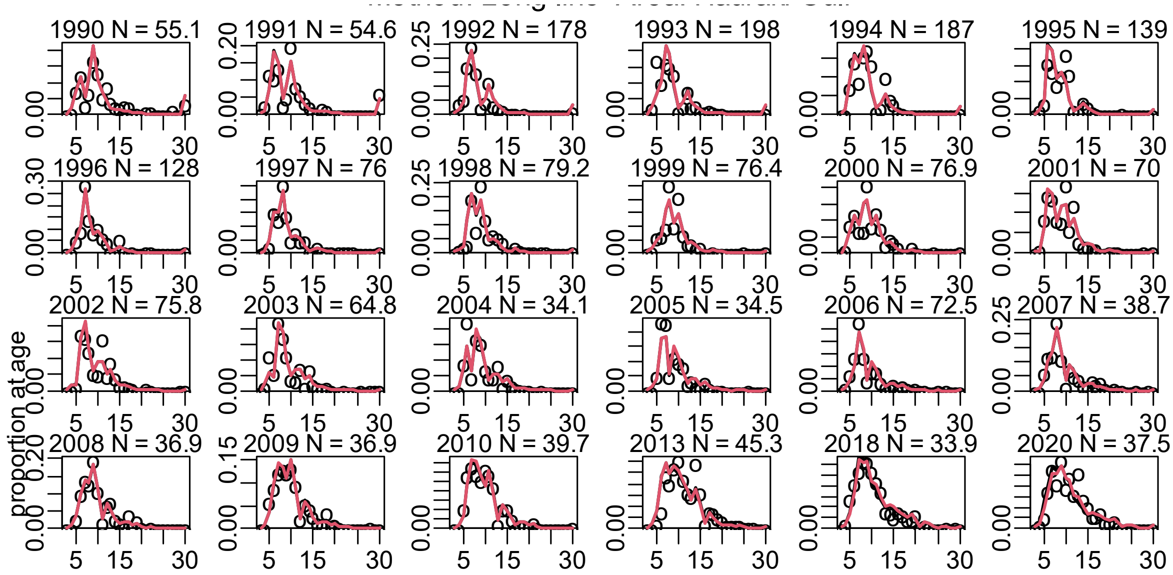
We can use this idea to do a 2-stage weighting of the tag-recapture observations in a CASAL model. The stage-one weight is given by the dispersion parameter that is initially assumed for these observations. The stage-two weighting is to set the dispersion parameter equal to the value of $\text{Var}_j(r^j)$ we calculate from a model fit using the stage-one weight.

If we have lots of tag-recapture observations then we may want to split them into several groups, and have separate stage-one and stage-two weights for each group (in this case we would calculate a separate $\text{Var}_j(r^j)$ for each group).

Appendix 8: All-Likelihood and Reduced-LL-CPUE 2022 SNA 1 assessment model compositional data fits.

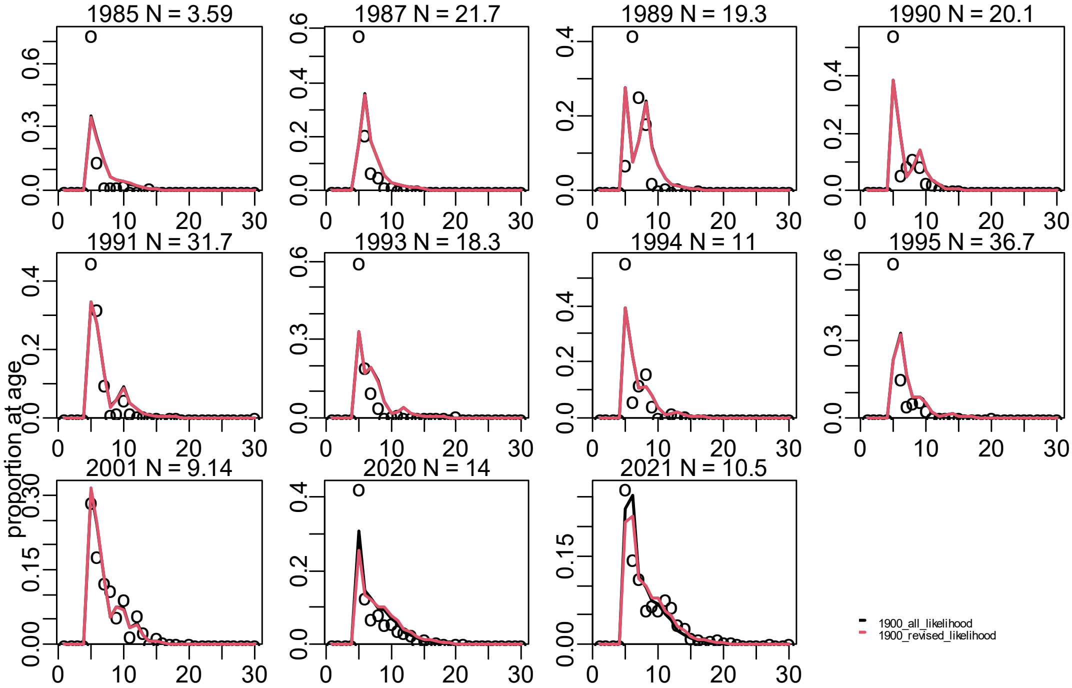


Appendix Figure 40: All-likelihood (red) and reduced-LL-CPUE (black) 1900 model east Northland longline compositional fits. N = effective multinomial error after likelihood reweighting.

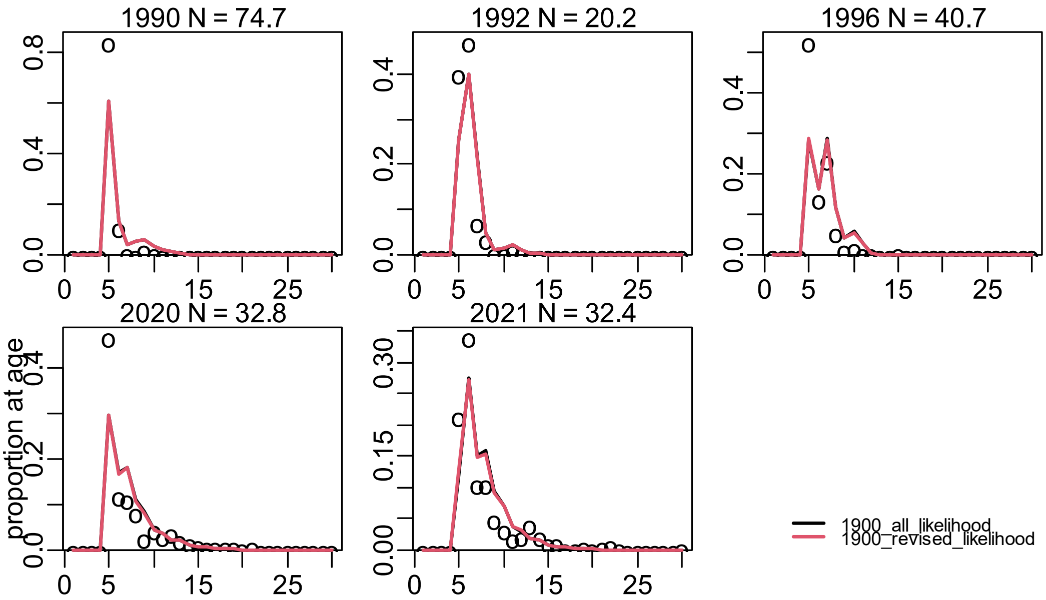


Appendix Figure 41: All-likelihood (red) and reduced-LL-CPUE (black) 1900 model Hauraki Gulf longline compositional fits. N = effective multinomial error after likelihood reweighting.

a.

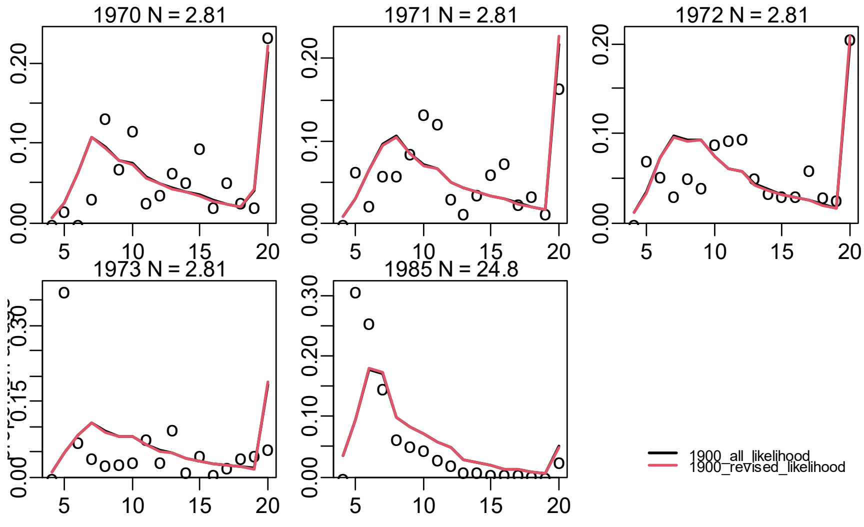


b.

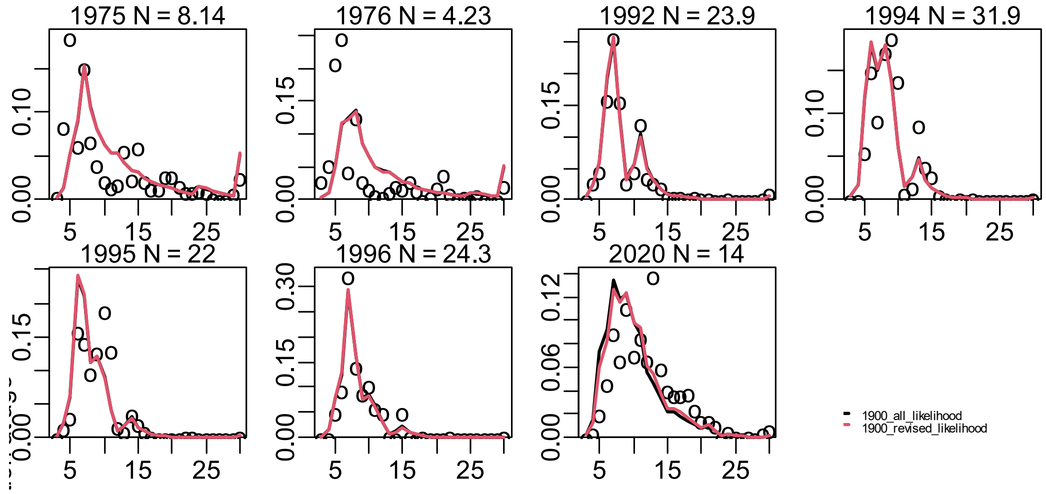


Appendix Figure 42: All-likelihood (red) and reduced-LL-CPUE (black) 1900 model fits to trawl survey 5+ compositional at-age observations, a. Hauraki Gulf survey series, b. Bay of Plenty survey series. N = effective multinomial error after likelihood reweighting.

a.

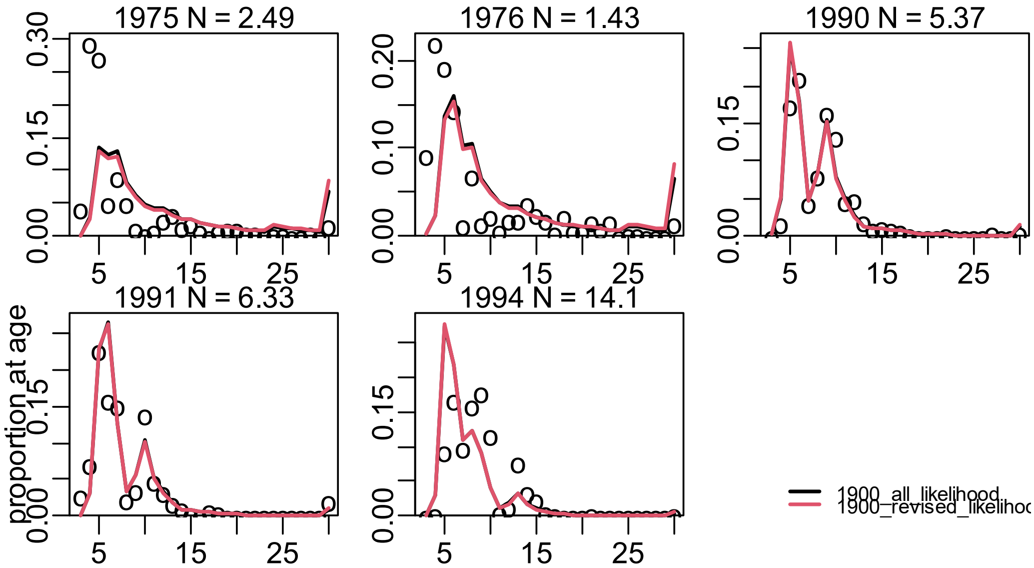


b.

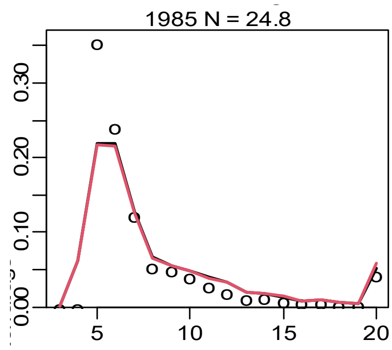


Appendix Figure 43: All-likelihood (red) and reduced-LL-CPUE (black) 1900 model Hauraki Gulf Danish seine catch at-age fits, a. plus group 20+, b. plus group 30+. N = effective multinomial error after likelihood reweighting.

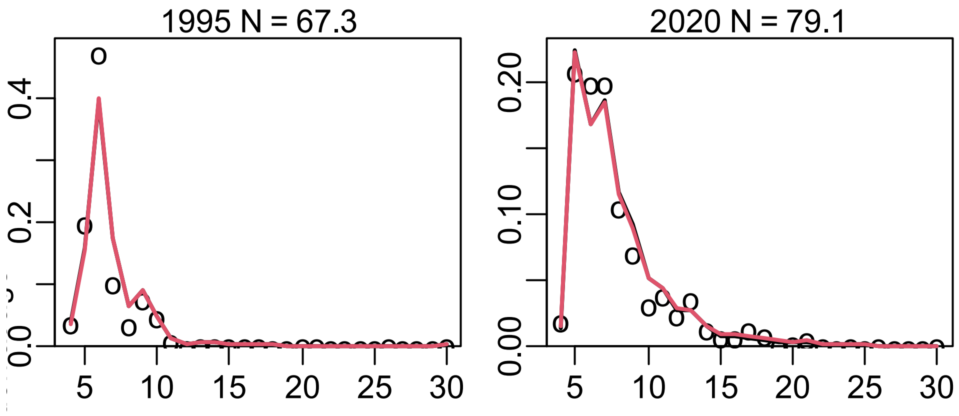
a.



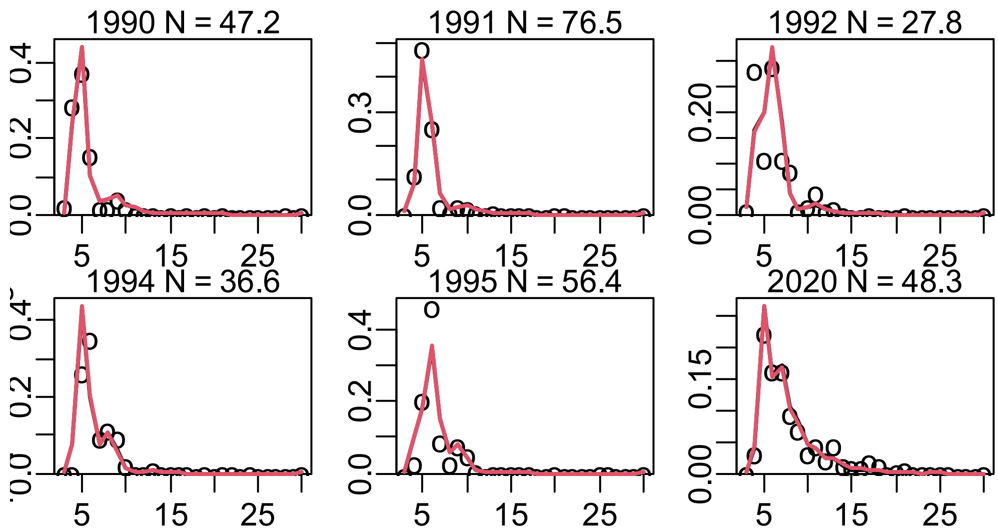
b.



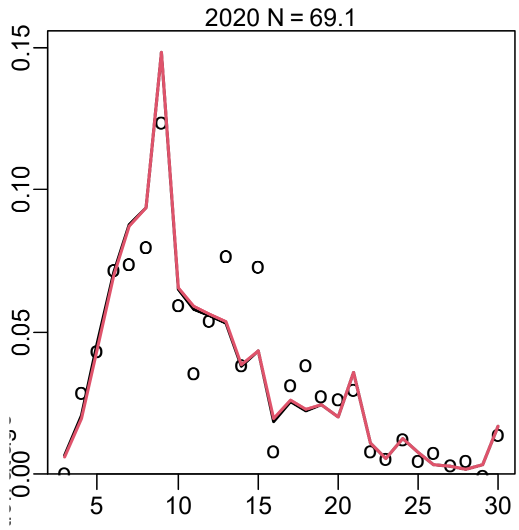
Appendix Figure 44: All-likelihood (red) and reduced-LL-CPUE (black) 1900 model Hauraki Gulf bottom trawl catch at-age fits; a. plus group 30+, b. plus group 20+. N = effective multinomial error after likelihood reweighting.



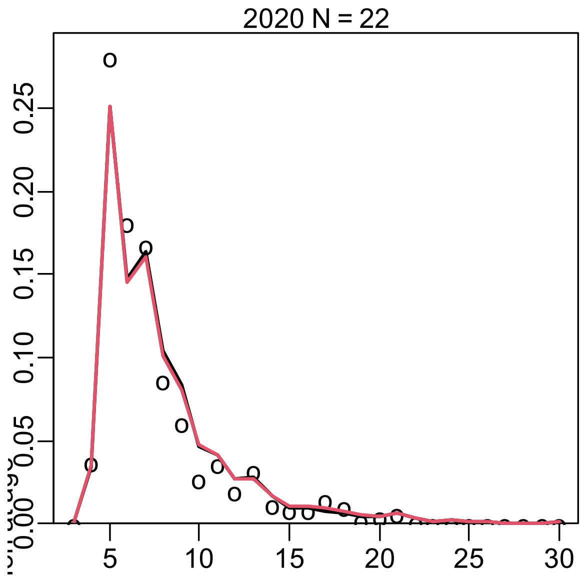
Appendix Figure 45: **All-likelihood (red) and reduced-LL-CPUE (black) 1900 model Bay of Plenty Danish seine catch at-age fits. N = effective multinomial error after likelihood reweighting.**



Appendix Figure 46: **All-likelihood (red) and reduced-LL-CPUE (black) 1900 model Bay of Plenty bottom trawl catch at-age fits. N = effective multinomial error after likelihood reweighting.**

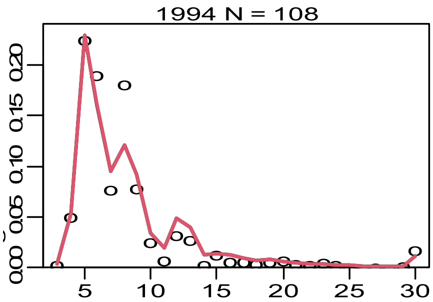


Appendix Figure 47: All-likelihood (red) and reduced-LL-CPUE (black) 1900 model east Northland MHS catch at-age fits. N = effective multinomial error after likelihood reweighting.

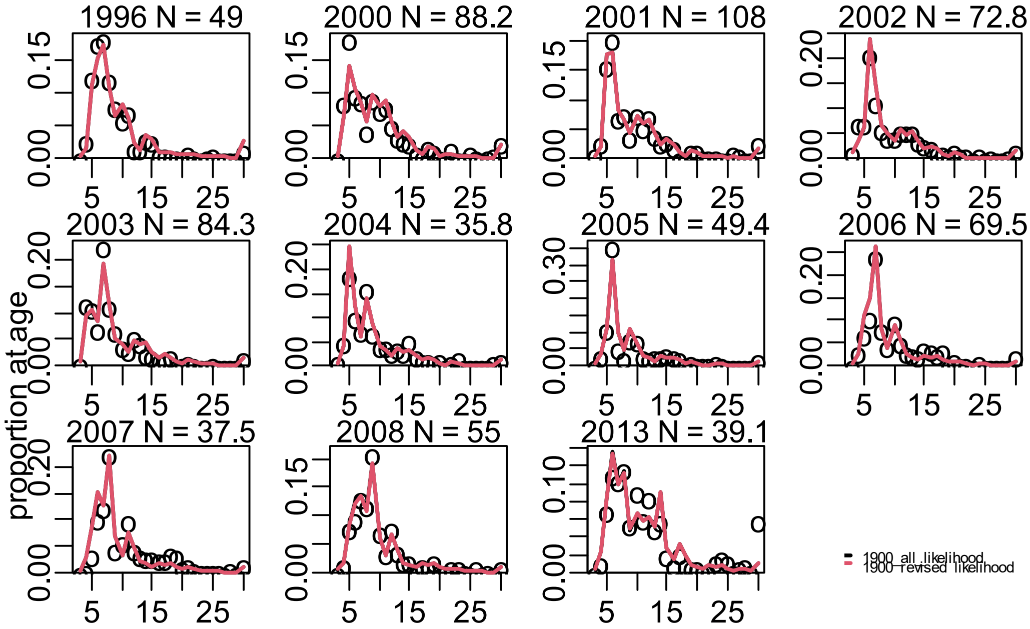


Appendix Figure 48: All-likelihood (red) and reduced-LL-CPUE (black) 1900 model Bay of Plenty MHS catch at-age fits. N = effective multinomial error after likelihood reweighting.

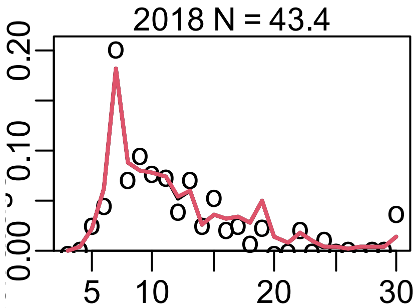
a.



b.

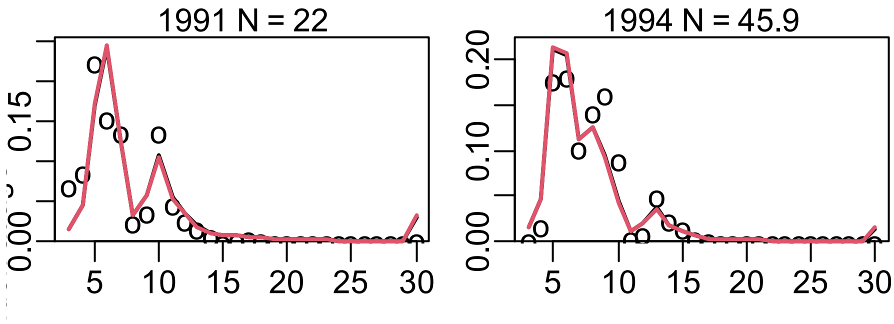


c.

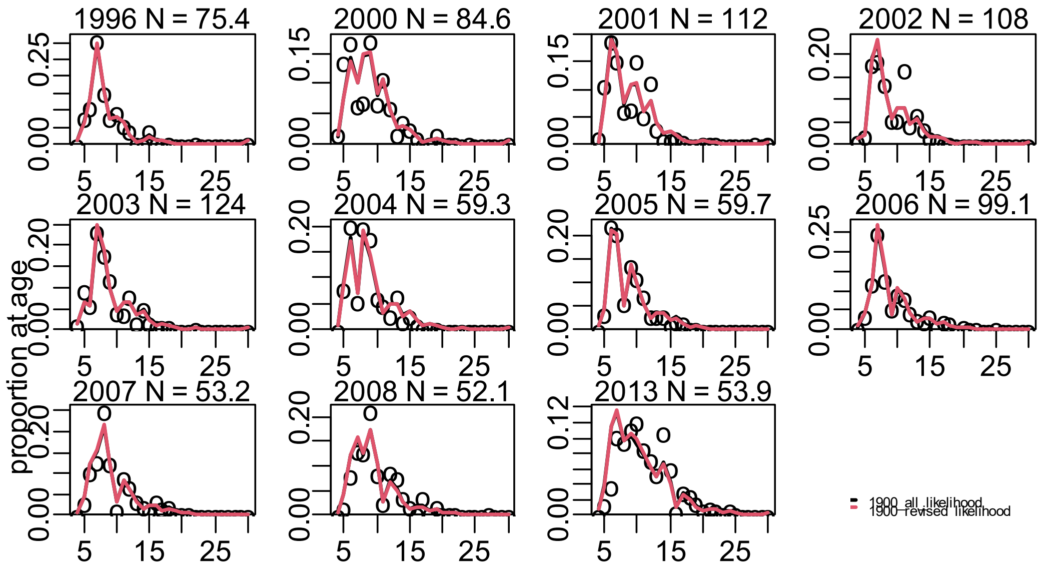


Appendix Figure 49: All-likelihood (red) and reduced-LL-CPUE (black) 1900 model east Northland recreational line catch at-age fits, a. pre-1995 selectivity b. post-1995 selectivity c. post-2015 selectivity. N= effective multinomial error after likelihood reweighting.

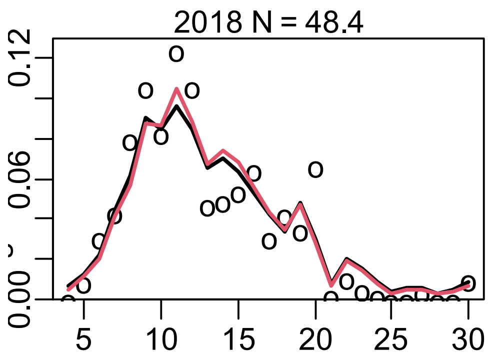
a.



b.

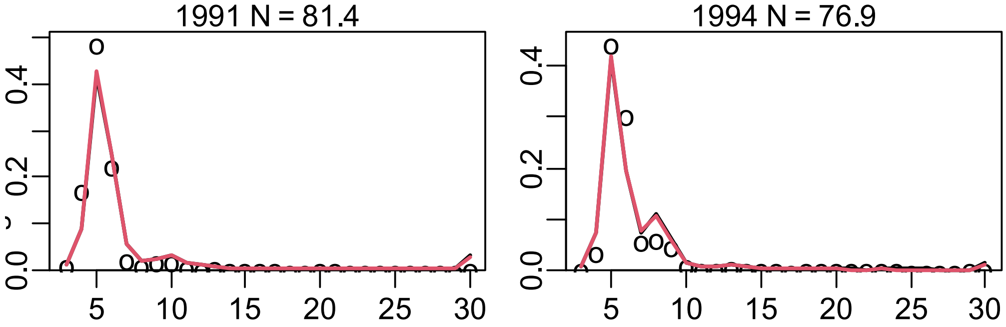


c.

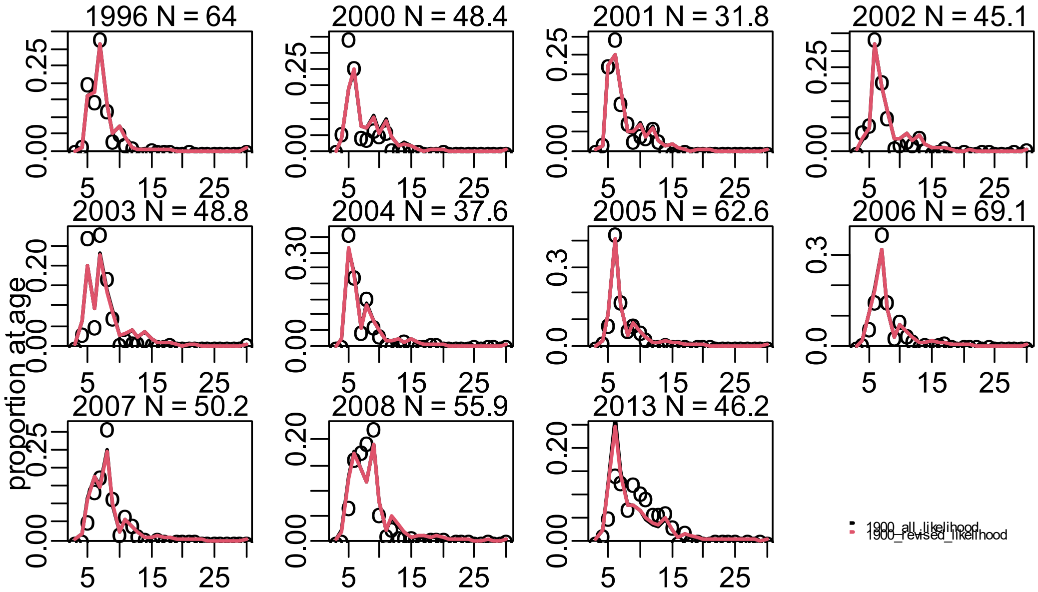


Appendix Figure 50: All-likelihood (red) and reduced-LL-CPUE (black) 1900 model Hauraki Gulf recreational line catch at-age fits, a. pre-1995 selectivity b. post-1995 selectivity c. post-2015 selectivity. N= effective multinomial error after likelihood reweighting.

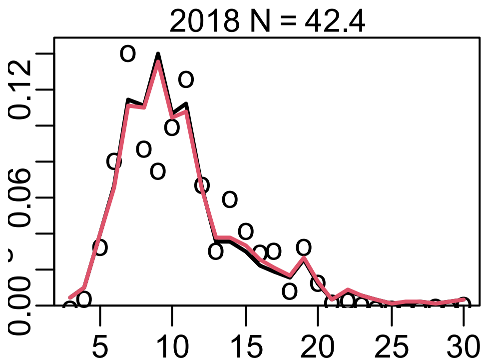
a.



b.

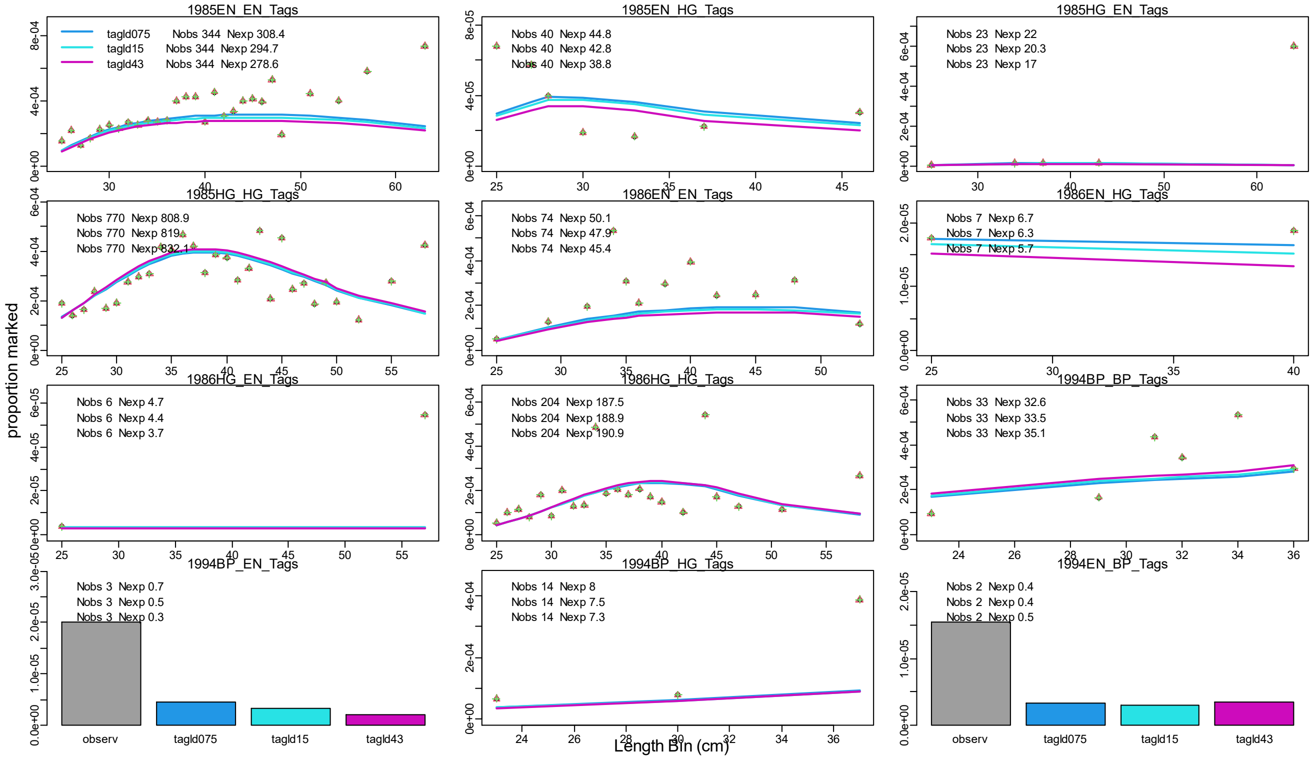


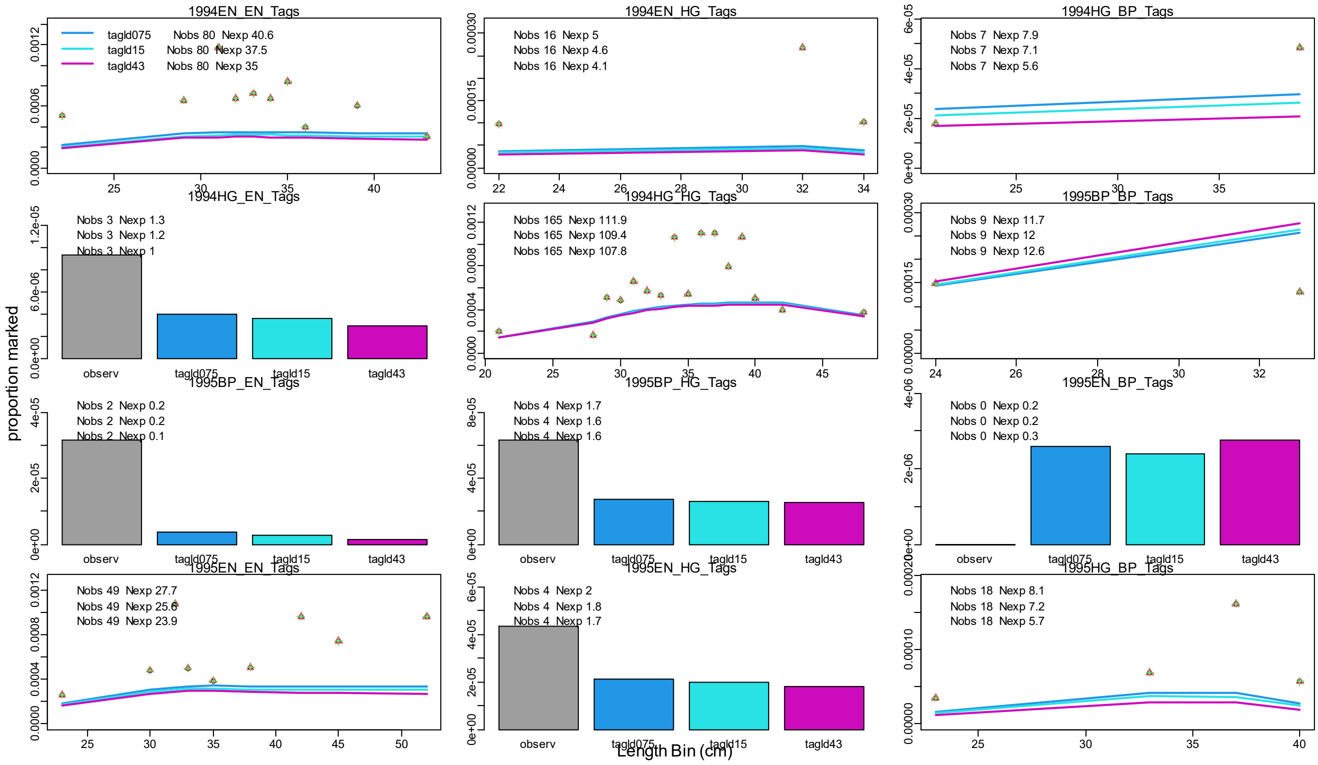
c.



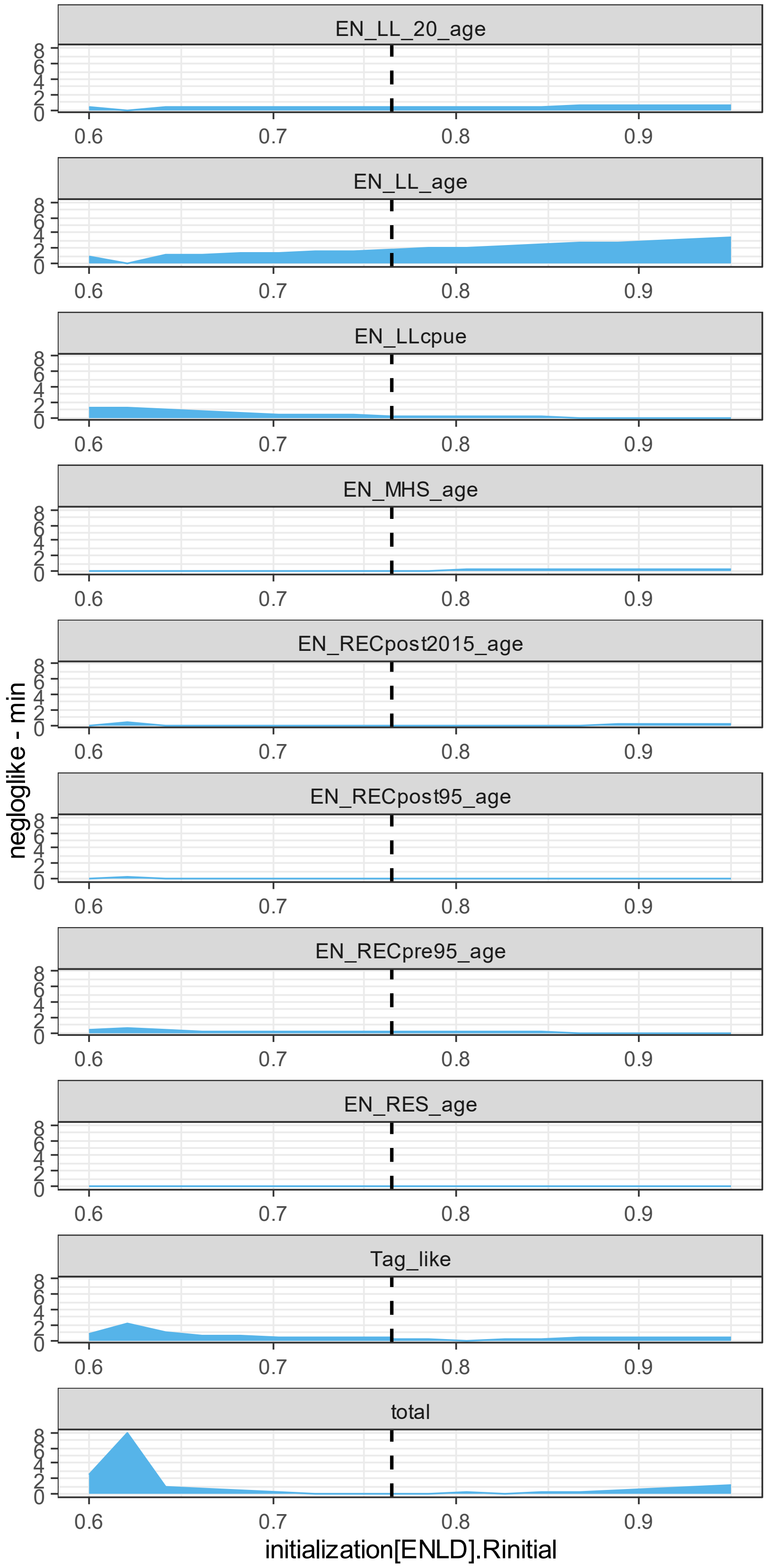
Appendix Figure 51: All-likelihood (red) and reduced-LL-CPUE (black) 1900 model Bay of Plenty recreational line catch at-age fits, a. pre-1995 selectivity b. post-1995 selectivity c. post-2015 selectivity. N= effective multinomial error after likelihood reweighting.

Appendix 9: Changes in base 2022 SNA 1 model fits to the tag recovery observational data relative to increases in tag likelihood weighting.

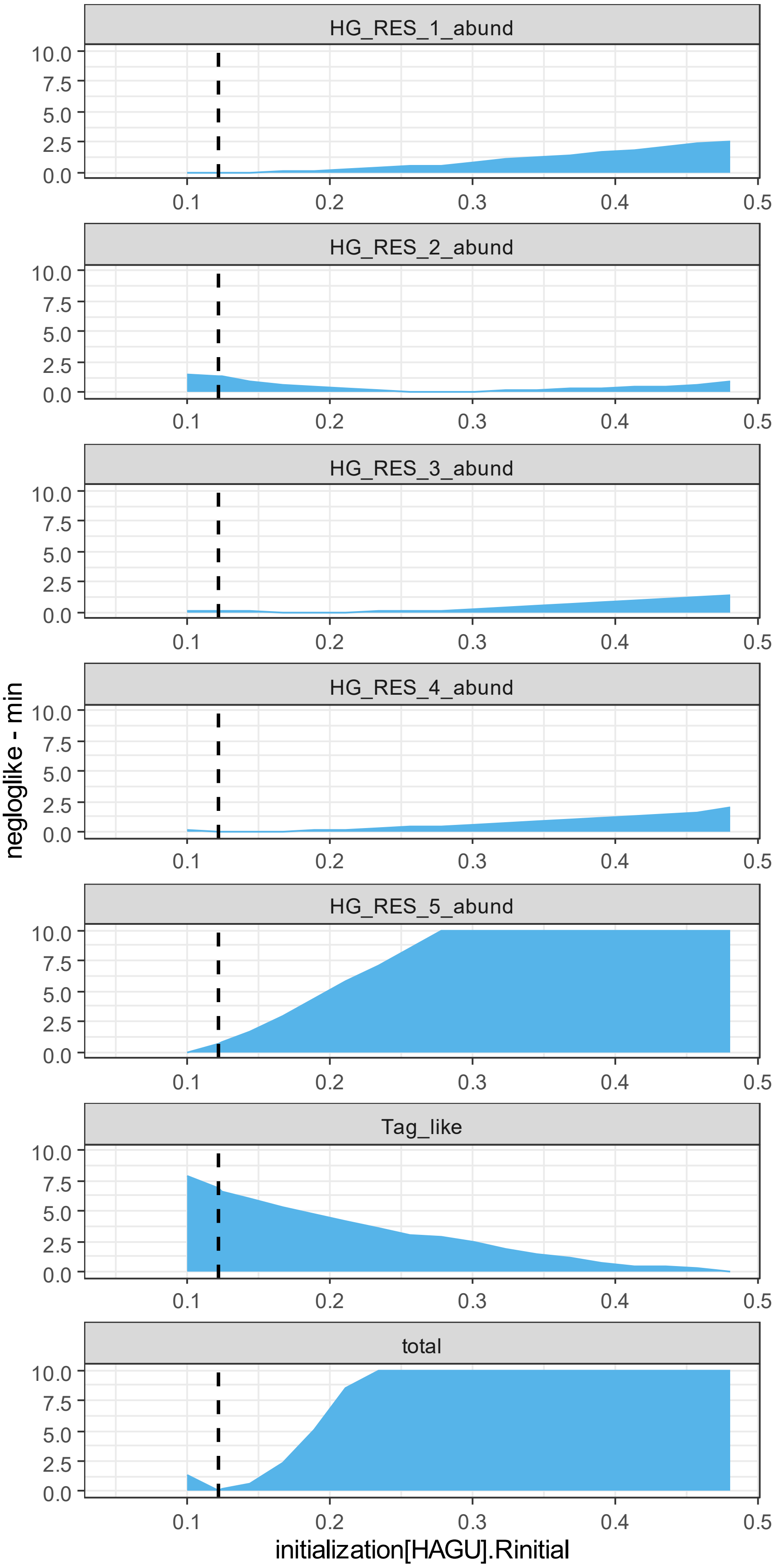




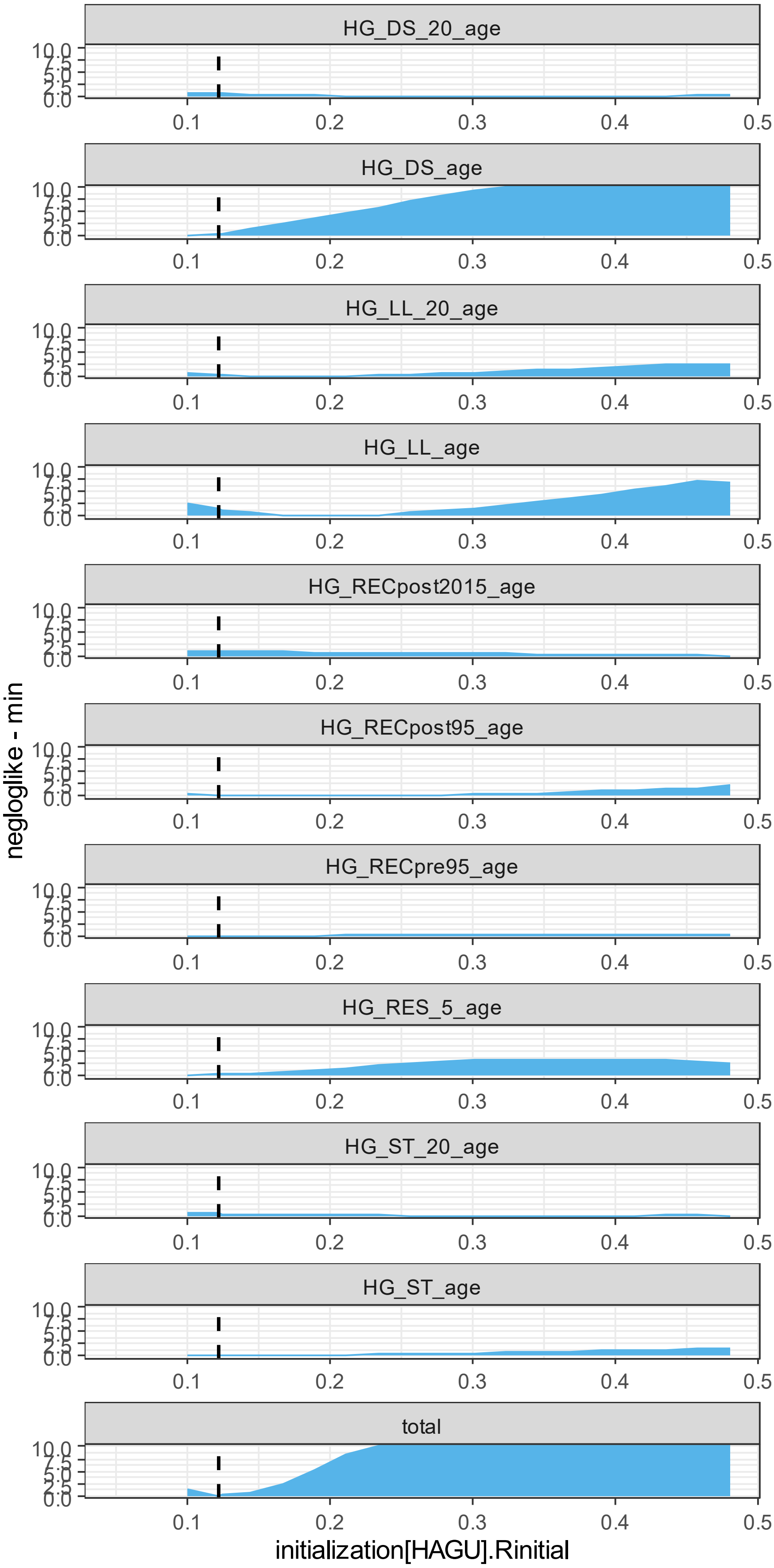
Appendix 10: 1970-base-likelihood model $R_{initial}$ likelihood profiles



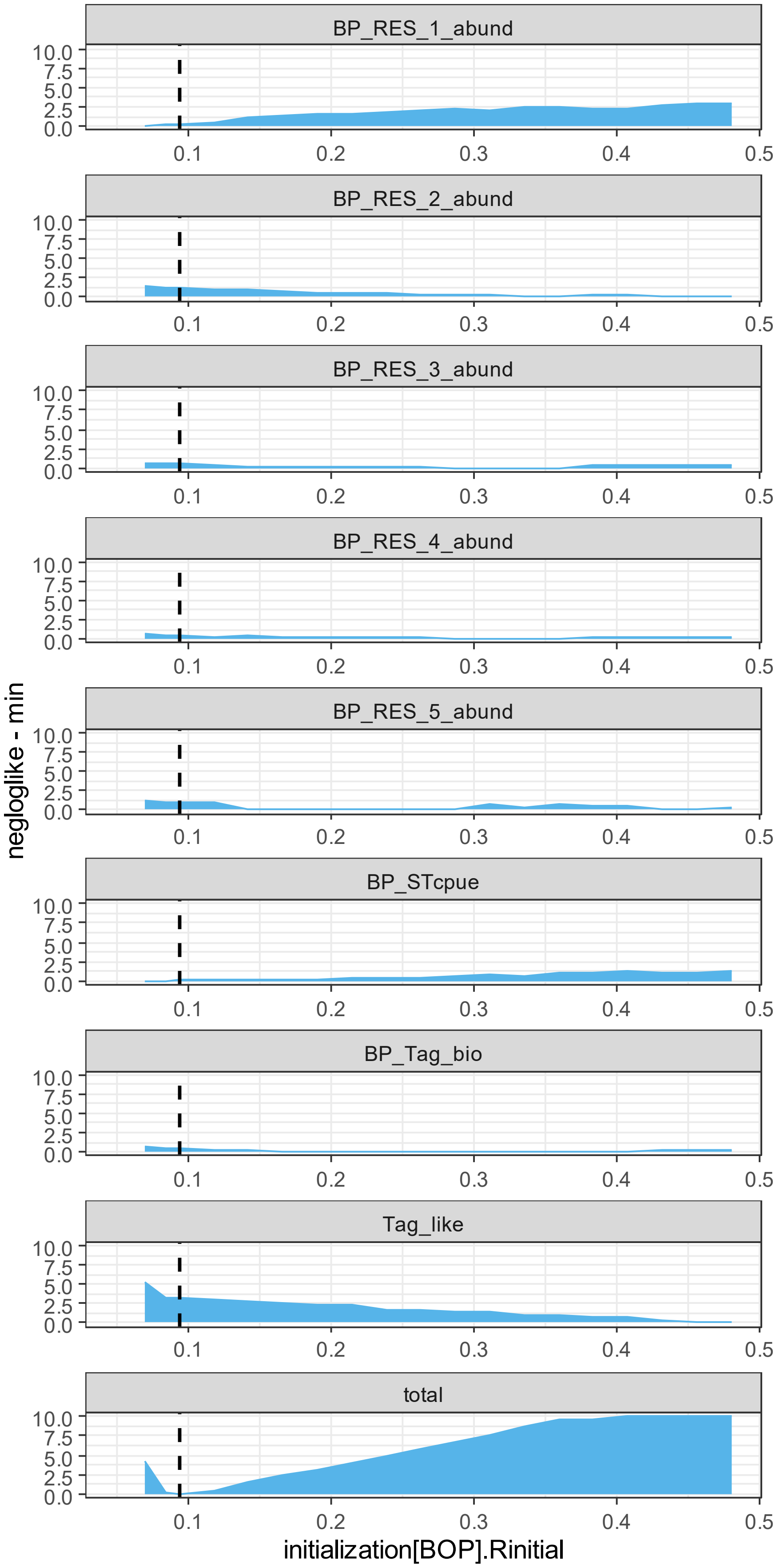
Appendix Figure 52: East Northland $R_{initial}$ all likelihood profiles.



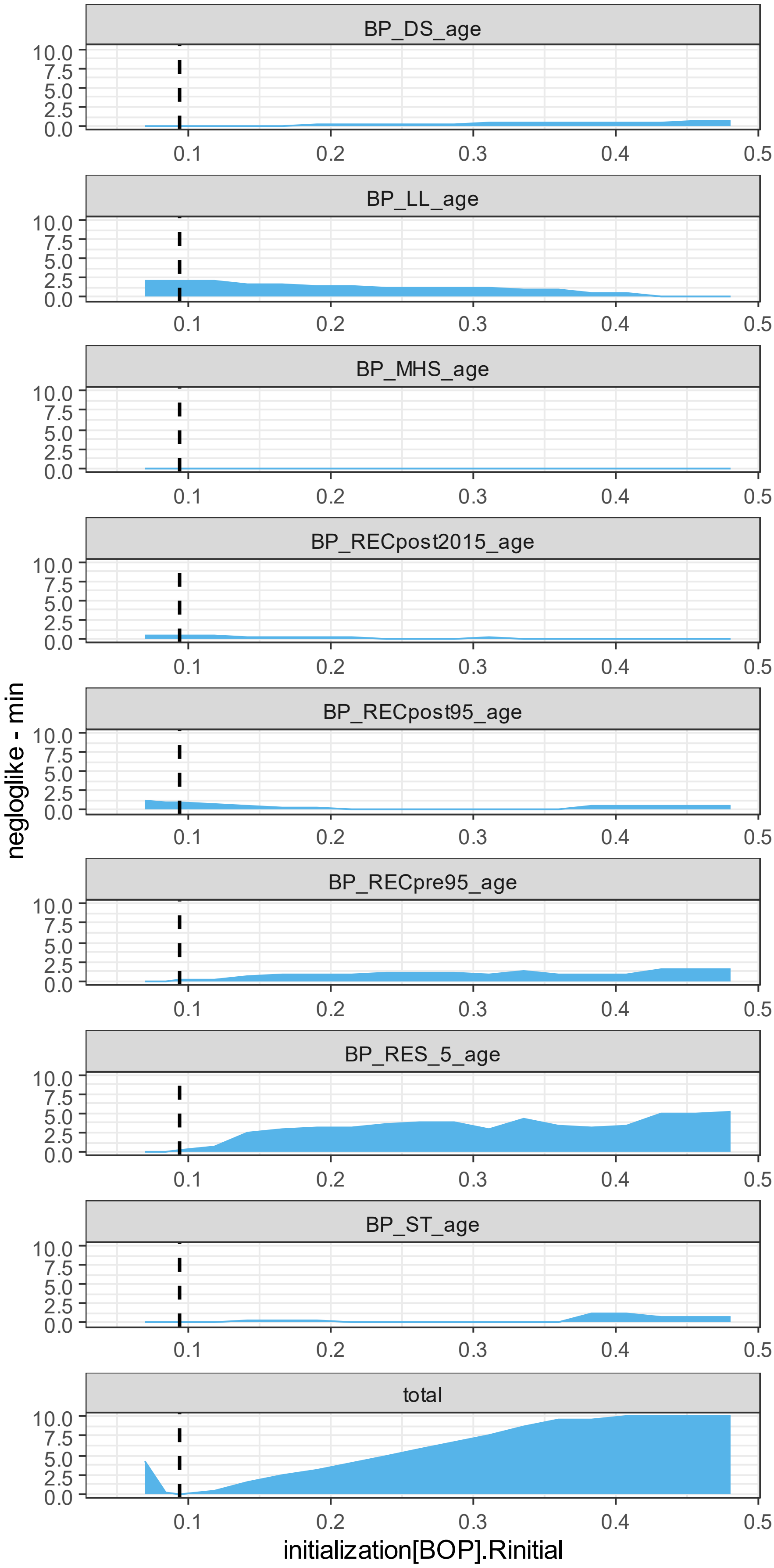
Appendix Figure 53: Hauraki Gulf $R_{initial}$ abundance likelihood profiles.



Appendix Figure 54: Hauraki Gulf $R_{initial}$ compositional likelihood profiles.

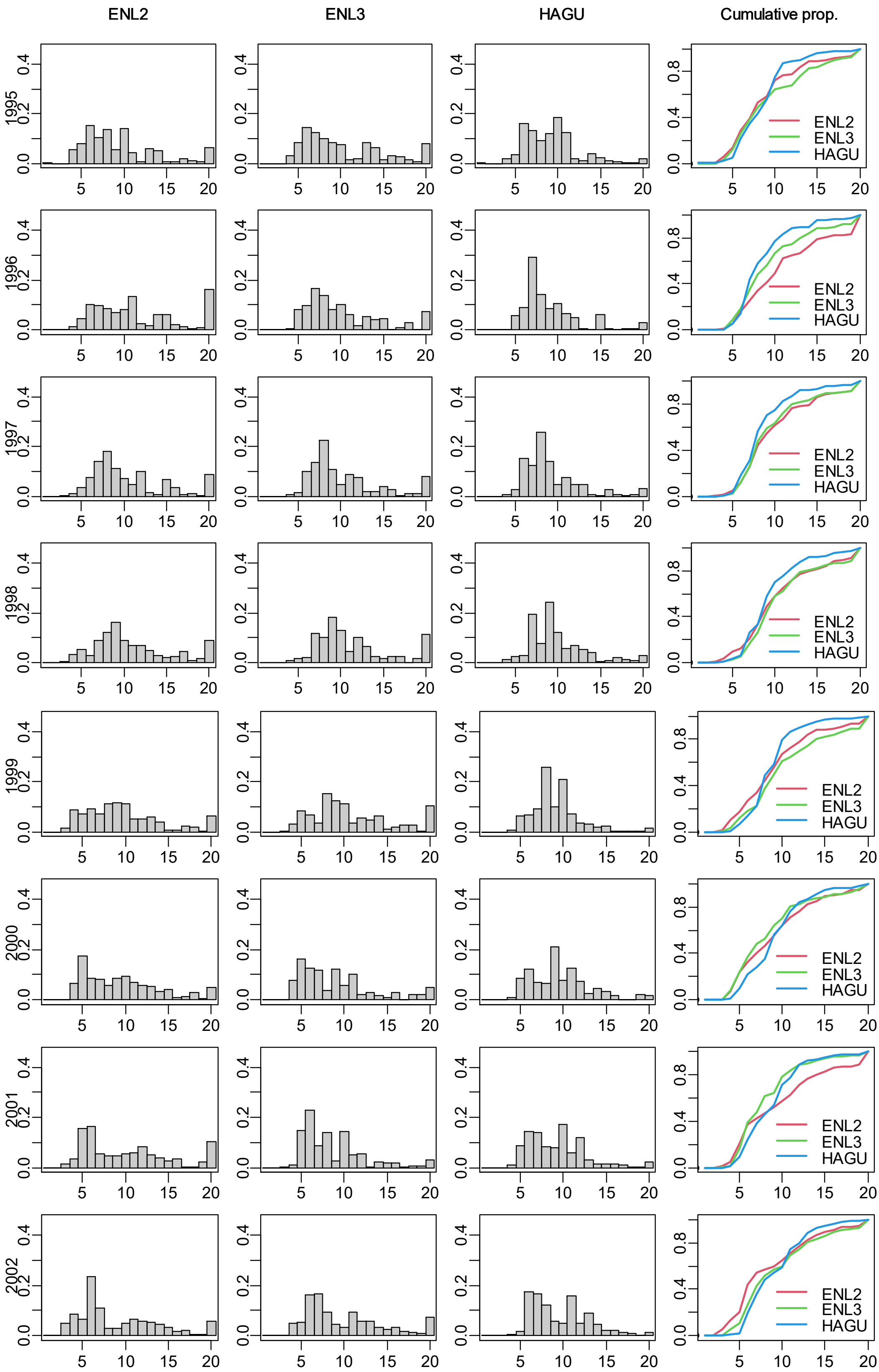


Appendix Figure 55: Bay of Plenty $R_{initial}$ abundance likelihood profiles.

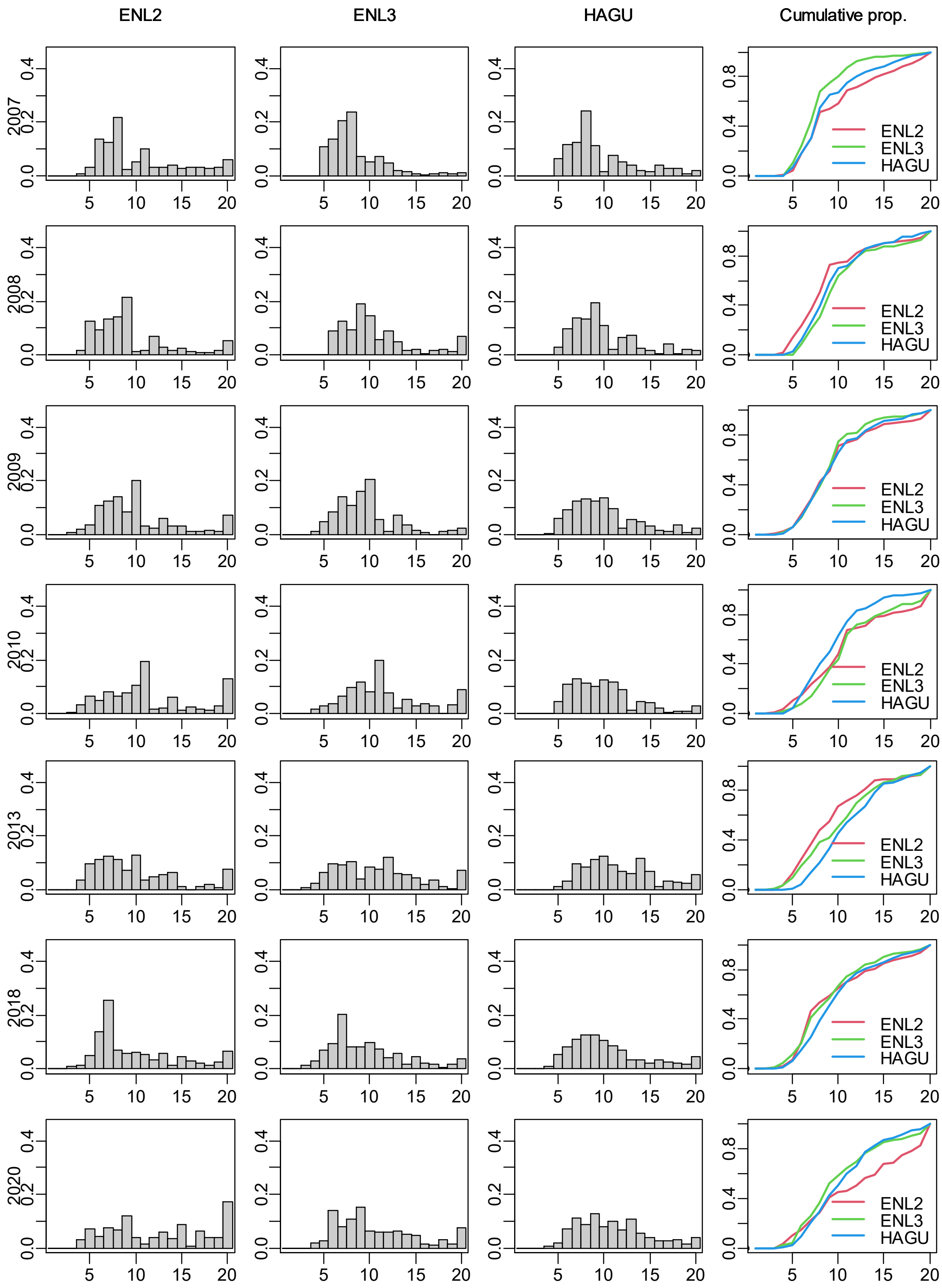


Appendix Figure 56: Bay of Plenty $R_{initial}$ compositional likelihood profiles.

Appendix 11: East Northland 002, East Northland 003, and Hauraki Gulf longline catch at-age comparisons

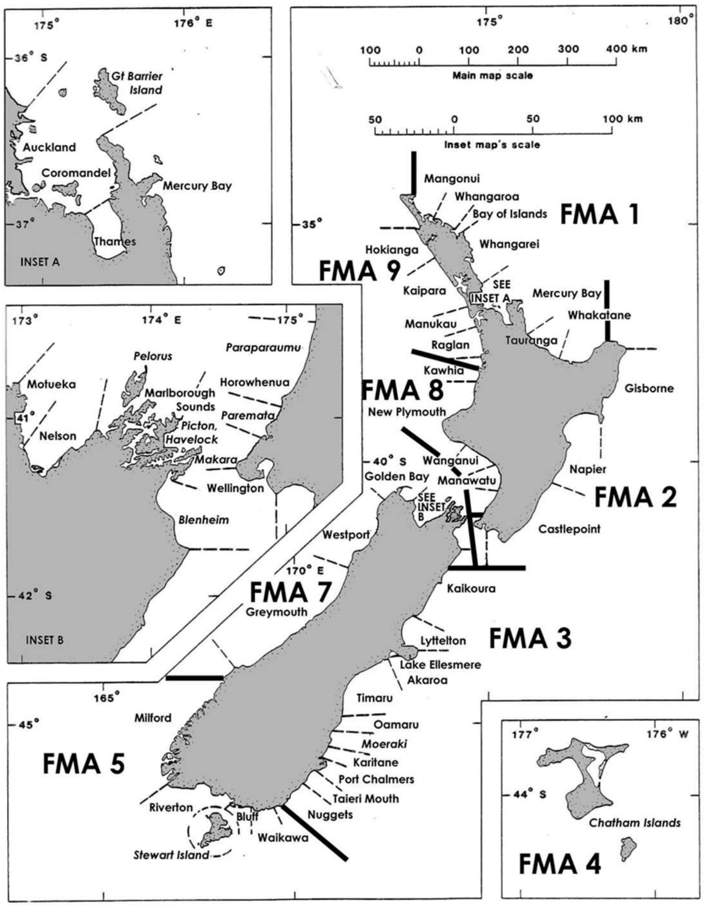


Appendix 11 cont: East Northland 002, East Northland 003, and Hauraki Gulf longline catch at-age comparisons



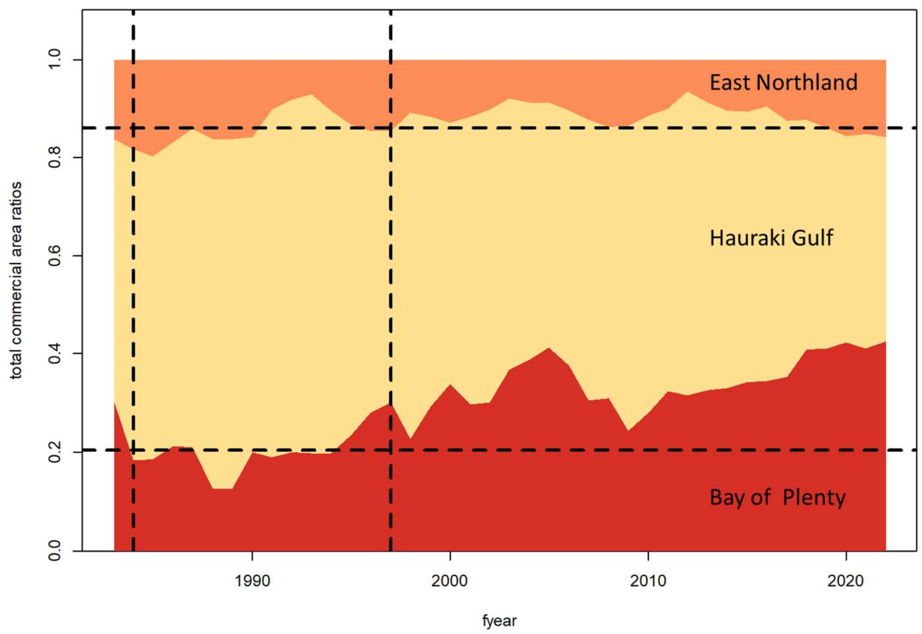
Appendix 12: 2023 SNA 1 Assessment revised east Northland/Hauraki Gulf boundaries

The process for deriving the revised east Northland/Hauraki Gulf boundary catch histories largely followed the methods described under Appendix 1. However, a different approach was needed to apportion the east Northland/Hauraki Gulf annual catches prior to 1982–83 with the revised stock boundaries. As described in Appendix 1, SNA 1 catches were reported spatially between 1960 and 1973, the spatial report areas largely matching the original SNA 1 sub-stock area definitions. These catch data were compiled spatially in 1996 (Gilbert et al. 1996) and had been used in all SNA 1 assessments up to and including the 2022 assessment. Annual sub-stock catches from 1900 to 1972 were derived by application of 1960–1973 sub-stock catch-split ratio averages. The change in the east Northland/Hauraki Gulf boundary meant that this approach for deriving pre-1973 east Northland/Hauraki Gulf catches was no longer feasible. An alternative apportionment approach using the port-of-landing catch records available from 1931 to 1982 (Appendix Figure 57; Ritchie et al. 1975) was considered. However, a comparison of the 1960–73 SNA 1 sub-stock port-of-landing and area reporting totals from Gilbert et al. (1996) indicated that the sub-stock port-of-landing totals were likely to be erroneous due to vessels fishing outside the port-of-landing sub-stock region.



Appendix Figure 57: New Zealand Port-of-landing catch reporting locations in relation to Fisheries Management Area in use from 1931 to 1982 (from King 1985).

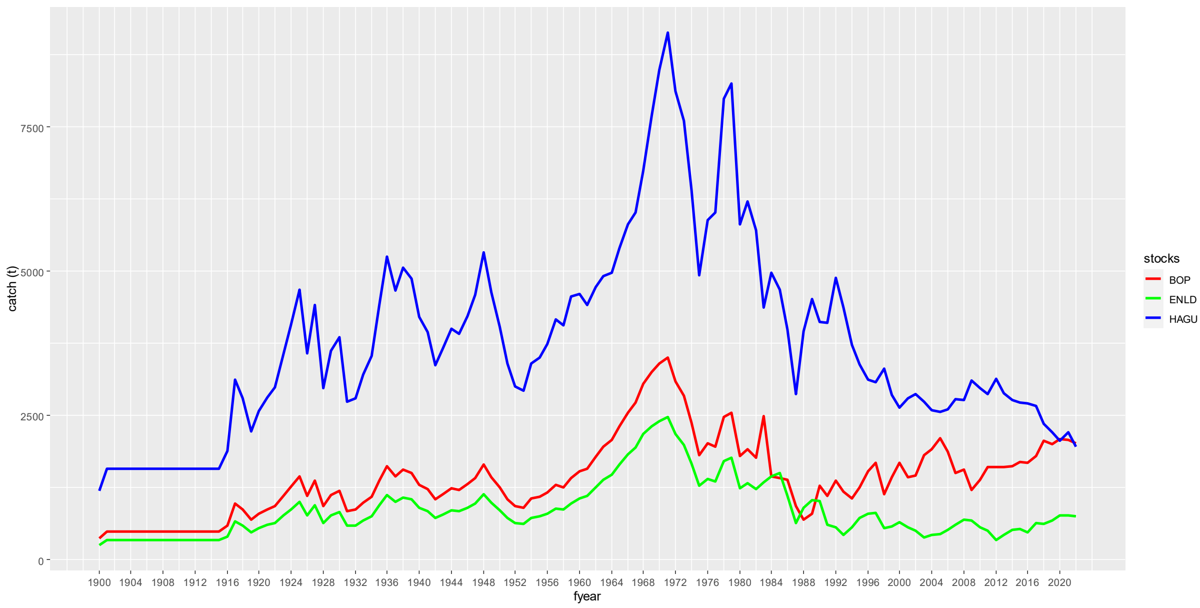
The SNA 1 spatial data prior to 1982–83 meant that east Northland/Hauraki Gulf could only be inferred from post 1982 spatial catch data, i.e. the time at which catch reporting against the modern statistical area definitions commenced. A plot of the SNA 1 annual sub-stock catches post 1982 showed that sub-stock catch ratios were relatively stable between 1984 and 1997 (Appendix Figure 58). Average East Northland/Hauraki Gulf area-method catch ratios from this period were applied back to 1900. Note that the SNA 1 total annual catches over this period remained the same as those derived for the 2022 SNA 1 assessment (Appendix 1).



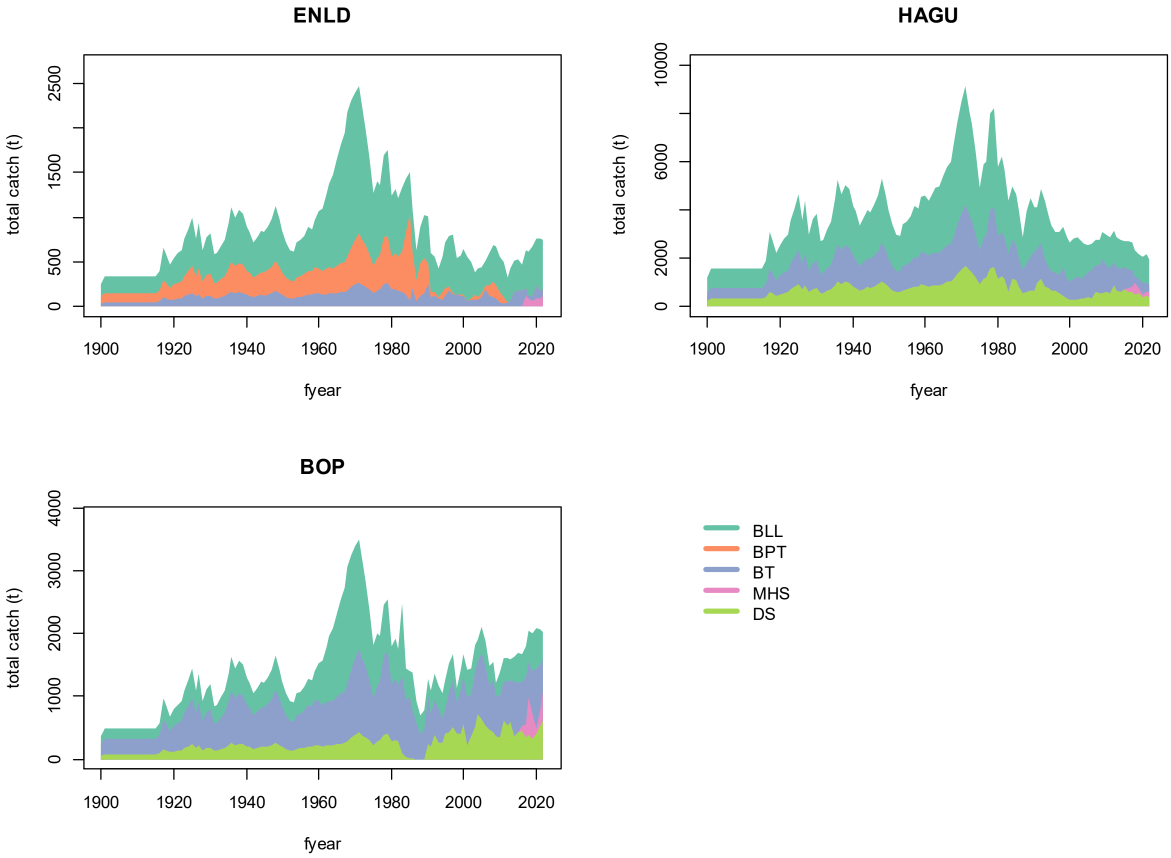
Appendix Figure 58: SNA 1 new boundary sub-stock catch ratios 1983 – 2021. Vertical lines show 1984 – 1997 ratio averaging period. Horizontal lines show sub-stock ratio averages.

The 1960 to 1977 30 000 t Japanese longline catch was added to the longline method commercial catch history as described in Appendix 1, the revised apportionment ratios among the three sub-stocks being 30% East Northland, 30% Hauraki Gulf and 40% Bay of Plenty.

Recent SNA 1 method-area catch histories were also updated to include the 2021–22 fishing year (Appendix Figure 59; Appendix Figure 60; Table Appendix 14; Table Appendix 15; Table Appendix 16).



Appendix Figure 59: Commercial catch histories by area (adjusted for under-reporting) plus foreign catch.



Appendix Figure 60: Commercial catch histories split by method and area.

Table Appendix 14: East Northland 2023 assessment model catch history (tonnes)

Fish Year	LL	MHS	PT	ST	REC	Fish Year	LL	MHS	PT	ST	REC	Fish Year	LL	MHS	PT	ST	REC
1900	138	0	76	38	50	1941	459	0	254	127	111	1982	664	0	368	184	173
1901	183	0	102	51	51	1942	392	0	217	109	113	1983	720	0	447	170	174
1902	183	0	102	51	53	1943	426	0	236	118	114	1984	607	0	694	135	176
1903	183	0	102	51	54	1944	465	0	257	129	116	1985	468	0	981	57	177
1904	183	0	102	51	56	1945	456	0	252	126	117	1986	486	0	397	213	179
1905	183	0	102	51	57	1946	491	0	272	136	119	1987	334	0	227	66	180
1906	183	0	102	51	59	1947	533	0	295	148	120	1988	414	0	355	128	182
1907	183	0	102	51	60	1948	618	0	342	172	122	1989	473	0	405	146	183
1908	183	0	102	51	62	1949	538	0	298	149	123	1990	526	0	242	247	185
1909	183	0	102	51	63	1950	468	0	259	130	125	1991	438	0	45	113	186
1910	183	0	102	51	65	1951	394	0	218	109	126	1992	392	0	45	121	188
1911	183	0	102	51	66	1952	348	0	193	97	128	1993	321	0	10	90	189
1912	183	0	102	51	68	1953	340	0	188	94	129	1994	394	0	78	83	191
1913	183	0	102	51	69	1954	396	0	219	110	131	1995	502	0	93	119	192
1914	183	0	102	51	71	1955	407	0	225	113	132	1996	569	0	50	173	194
1915	183	0	102	51	72	1956	435	0	241	121	134	1997	653	0	19	133	195
1916	219	0	121	61	74	1957	485	0	268	134	135	1998	402	0	1	136	197
1917	363	0	201	101	75	1958	473	0	262	131	137	1999	442	0	16	114	198
1918	324	0	180	90	77	1959	530	0	293	147	138	2000	504	0	22	120	200
1919	258	0	143	71	78	1960	628	0	289	145	140	2001	499	0	5	58	264
1920	299	0	166	83	80	1961	698	0	270	135	141	2002	412	0	12	73	155
1921	326	0	181	90	81	1962	828	0	283	142	143	2003	247	0	58	83	180
1922	347	0	192	96	83	1963	944	0	290	145	144	2004	322	0	31	75	314
1923	414	0	229	115	84	1964	1044	0	286	144	146	2005	292	0	54	101	256
1924	474	0	263	132	86	1965	1185	0	307	154	147	2006	277	0	54	189	272
1925	544	0	301	151	87	1966	1326	0	326	163	149	2007	365	0	112	127	273
1926	415	0	230	115	89	1967	1443	0	333	167	150	2008	406	0	181	101	440
1927	513	0	284	142	90	1968	1620	0	372	186	152	2009	439	0	153	87	441
1928	346	0	192	96	92	1969	1648	0	440	221	153	2010	392	0	120	50	443
1929	421	0	233	117	93	1970	1656	0	497	249	155	2011	396	0	72	27	444
1930	448	0	248	124	95	1971	1648	0	545	273	156	2012	280	0	0	51	420
1931	318	0	176	88	96	1972	1446	0	486	243	158	2013	366	0	0	63	691
1932	325	0	180	90	98	1973	1302	0	459	230	159	2014	344	0	0	169	407
1933	372	0	206	103	99	1974	1079	0	388	194	161	2015	339	0	0	184	611
1934	411	0	228	114	101	1975	825	0	299	150	162	2016	294	5	0	171	468
1935	514	0	284	143	102	1976	852	0	367	184	164	2017	429	121	0	87	404
1936	610	0	338	169	104	1977	784	0	381	191	165	2018	501	96	0	23	469
1937	542	0	300	150	105	1978	929	0	514	258	167	2019	557	68	0	53	432
1938	588	0	326	163	107	1979	959	0	531	266	168	2020	531	95	0	137	395
1939	566	0	313	157	108	1980	676	0	374	187	170	2021	589	87	0	92	686
1940	488	0	270	135	110	1981	722	0	400	200	171	2022	561	114	0	73	477

Table Appendix 15: Hauraki Gulf 2023 assessment model catch history (tonnes)

Fish Year	LL	MHS	BT	DS	REC	Fish Year	LL	MHS	BT	DS	REC	Fish Year	LL	MHS	BT	DS	REC
1900	592	0	354	238	175	1941	1972	0	1181	792	845	1982	2854	0	1710	1146	1515
1901	788	0	472	317	191	1942	1686	0	1010	677	862	1983	2173	0	1584	604	1532
1902	788	0	472	317	208	1943	1830	0	1096	735	878	1984	2215	0	1584	1175	1548
1903	788	0	472	317	224	1944	1998	0	1197	803	894	1985	2110	0	1463	1104	1564
1904	788	0	472	317	240	1945	1958	0	1173	787	911	1986	1998	0	1157	835	1581
1905	788	0	472	317	257	1946	2108	0	1263	847	927	1987	1340	0	989	532	1597
1906	788	0	472	317	273	1947	2292	0	1373	920	943	1988	2149	0	1219	587	1613
1907	788	0	472	317	289	1948	2658	0	1592	1068	960	1989	2455	0	1392	670	1630
1908	788	0	472	317	306	1949	2312	0	1385	928	976	1990	1821	0	1631	665	1646
1909	788	0	472	317	322	1950	2013	0	1206	808	992	1991	1692	0	1414	1001	1662
1910	788	0	472	317	338	1951	1695	0	1015	681	1009	1992	2210	0	1520	1146	1679
1911	788	0	472	317	355	1952	1495	0	896	601	1025	1993	2402	0	1120	844	1695
1912	788	0	472	317	371	1953	1459	0	874	586	1041	1994	2098	0	880	748	1711
1913	788	0	472	317	387	1954	1701	0	1019	683	1058	1995	1903	0	800	675	1728
1914	788	0	472	317	404	1955	1750	0	1049	703	1074	1996	1710	0	739	661	1744
1915	788	0	472	317	420	1956	1869	0	1120	751	1090	1997	1749	0	777	544	1761
1916	940	0	563	378	437	1957	2083	0	1248	837	1107	1998	1676	0	1173	457	1777
1917	1558	0	933	626	453	1958	2031	0	1217	816	1123	1999	1727	0	793	335	1793
1918	1394	0	835	560	469	1959	2277	0	1364	915	1139	2000	1576	0	782	279	1810
1919	1107	0	663	445	486	1960	2350	0	1345	902	1156	2001	1669	0	816	311	1386
1920	1285	0	770	516	502	1961	2306	0	1256	842	1172	2002	1599	0	952	312	2022
1921	1402	0	840	563	518	1962	2516	0	1318	884	1188	2003	1602	0	789	342	2021
1922	1490	0	892	598	535	1963	2668	0	1346	903	1205	2004	1305	0	941	335	1993
1923	1780	0	1066	715	551	1964	2750	0	1332	893	1221	2005	1108	0	1043	400	1632
1924	2038	0	1221	819	567	1965	3011	0	1426	956	1237	2006	1095	0	1167	336	2255
1925	2336	0	1399	938	584	1966	3270	0	1518	1018	1254	2007	1035	0	1158	583	1786
1926	1783	0	1068	716	600	1967	3426	0	1548	1038	1270	2008	1091	0	1122	549	2558
1927	2205	0	1321	886	616	1968	3837	0	1731	1161	1286	2009	1168	0	1372	567	2638
1928	1488	0	891	598	633	1969	4271	0	2048	1373	1303	2010	1239	0	1136	598	2717
1929	1809	0	1084	727	649	1970	4617	0	2312	1550	1319	2011	1273	0	1050	542	2797
1930	1923	0	1152	772	665	1971	4894	0	2535	1699	1336	2012	1284	0	965	887	2666
1931	1365	0	818	548	682	1972	4341	0	2260	1515	1352	2013	1217	0	980	681	2246
1932	1396	0	836	561	698	1973	4035	0	2133	1430	1368	2014	1198	0	947	626	1193
1933	1600	0	959	643	714	1974	3388	0	1802	1209	1385	2015	1066	0	932	722	981
1934	1767	0	1058	710	731	1975	2607	0	1391	933	1401	2016	1172	123	783	628	1471
1935	2208	0	1323	887	747	1976	3035	0	1704	1143	1417	2017	1154	225	681	595	1581
1936	2622	0	1571	1053	763	1977	3056	0	1774	1189	1434	2018	1070	490	271	520	2391
1937	2329	0	1395	935	780	1978	3991	0	2391	1603	1450	2019	1038	237	382	544	2549
1938	2527	0	1514	1015	796	1979	4122	0	2469	1656	1466	2020	1083	70	490	419	2708
1939	2431	0	1456	976	812	1980	2904	0	1740	1166	1483	2021	1200	127	410	461	2433
1940	2098	0	1257	843	829	1981	3102	0	1858	1246	1499	2022	1036	206	334	386	2332

Table Appendix 16: Bay of Plenty 2023 assessment model catch history (tonnes)

Fish Year	LL	MHS	BT	DS	REC	Fish Year	LL	MHS	BT	DS	REC	Fish Year	LL	MHS	BT	DS	REC
1900	120	0	187	59	75	1941	400	0	622	197	254	1982	579	0	900	285	433
1901	160	0	249	79	79	1942	342	0	532	169	258	1983	1160	0	1227	93	437
1902	160	0	249	79	84	1943	371	0	577	183	263	1984	483	0	913	42	442
1903	160	0	249	79	88	1944	406	0	630	200	267	1985	409	0	982	14	446
1904	160	0	249	79	92	1945	397	0	618	196	271	1986	599	0	773	6	451
1905	160	0	249	79	97	1946	428	0	665	211	276	1987	347	0	579	3	455
1906	160	0	249	79	101	1947	465	0	723	229	280	1988	278	0	412	0	459
1907	160	0	249	79	106	1948	539	0	838	266	285	1989	318	0	471	0	464
1908	160	0	249	79	110	1949	469	0	729	231	289	1990	269	0	765	242	468
1909	160	0	249	79	114	1950	408	0	635	201	293	1991	377	0	528	193	472
1910	160	0	249	79	119	1951	344	0	534	169	298	1992	405	0	571	384	477
1911	160	0	249	79	123	1952	304	0	472	150	302	1993	375	0	546	261	481
1912	160	0	249	79	127	1953	296	0	460	146	306	1994	395	0	400	256	485
1913	160	0	249	79	132	1954	345	0	536	170	311	1995	479	0	360	413	490
1914	160	0	249	79	136	1955	355	0	552	175	315	1996	453	0	644	433	494
1915	160	0	249	79	140	1956	379	0	589	187	320	1997	411	0	754	511	499
1916	191	0	296	94	145	1957	423	0	657	208	324	1998	218	0	502	414	503
1917	316	0	491	156	149	1958	412	0	640	203	328	1999	312	0	698	416	507
1918	283	0	440	139	154	1959	462	0	718	228	333	2000	349	0	768	559	512
1919	225	0	349	111	158	1960	596	0	708	224	337	2001	444	0	748	232	139
1920	261	0	405	128	162	1961	706	0	661	210	341	2002	417	0	667	367	416
1921	284	0	442	140	167	1962	868	0	694	220	346	2003	410	0	882	522	316
1922	302	0	470	149	171	1963	1018	0	709	225	350	2004	352	0	837	717	438
1923	361	0	561	178	175	1964	1153	0	701	222	354	2005	416	0	1047	643	525
1924	414	0	643	204	180	1965	1325	0	750	238	359	2006	395	0	943	535	750
1925	474	0	737	234	184	1966	1497	0	799	253	363	2007	312	0	709	471	629
1926	362	0	562	178	189	1967	1647	0	815	258	368	2008	299	0	817	436	648
1927	448	0	695	221	193	1968	1850	0	911	289	372	2009	202	0	639	371	672
1928	302	0	469	149	197	1969	1831	0	1078	342	376	2010	368	0	663	347	697
1929	367	0	570	181	202	1970	1794	0	1217	386	381	2011	364	0	632	612	721
1930	390	0	606	192	206	1971	1743	0	1334	423	385	2012	368	0	711	529	429
1931	277	0	431	137	210	1972	1524	0	1190	377	389	2013	345	0	645	606	389
1932	283	0	440	140	215	1973	1354	0	1123	356	394	2014	387	0	875	359	349
1933	325	0	505	160	219	1974	1116	0	949	301	398	2015	475	0	781	428	309
1934	359	0	557	177	223	1975	850	0	732	232	402	2016	441	75	699	459	268
1935	448	0	696	221	228	1976	830	0	897	284	407	2017	481	214	757	338	300
1936	532	0	827	262	232	1977	727	0	934	296	411	2018	500	593	565	397	832
1937	473	0	734	233	237	1978	810	0	1259	399	416	2019	600	393	681	328	705
1938	513	0	797	253	241	1979	837	0	1300	412	420	2020	627	83	967	403	579
1939	493	0	766	243	245	1980	589	0	916	290	424	2021	556	260	724	532	537
1940	426	0	662	210	250	1981	630	0	978	310	429	2022	427	445	524	618	590

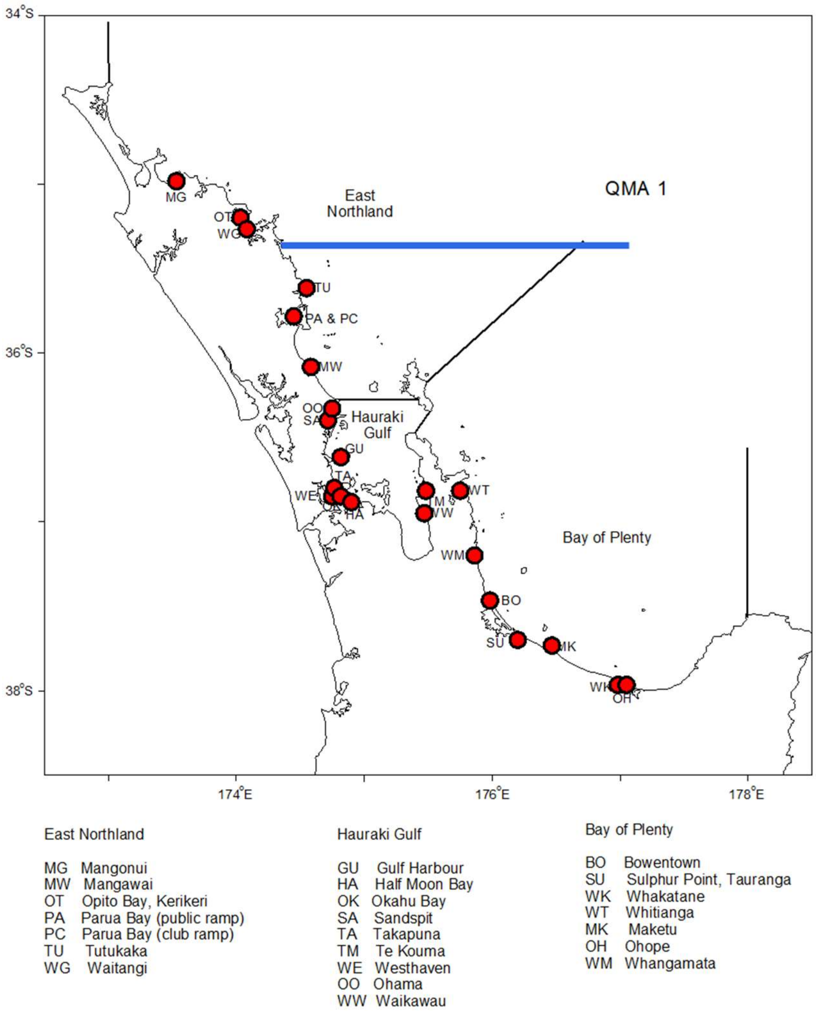
Appendix 13: 2023 SNA 1 assessment revised boundary recreational catch history derivation

Revised historical SNA 1 annual aerial-access recreational catch estimates are given in Table Appendix 17, note: revised National panel survey estimates are unavailable for new east Northland and Hauraki Gulf boundaries (Appendix Figure 61).

Table Appendix 17: Aerial-access (A-A) and National panel survey (NPS) estimates of the recreational harvest tonnage taken from the SNA 1 stock, by revised region, by fishing year. Coefficients of variation are given for each estimate in brackets.

Region	2004–05		2011–12		2017–18	
	A-A	NPS	A-A	NPS	A-A	NPS
East Northland	339 (0.13)	–	705 (0.14)	–	720 (0.10)	–
Hauraki Gulf	1 563 (0.10)	–	2 465 (0.08)	–	2 068 (0.07)	–
Bay of Plenty	516 (0.10)	–	534 (0.12)	691 (0.12)	680 (0.10)	627 (0.12)
SNA 1	2 418 (0.06)	–	3 704 (0.06)	–	3 468(0.05)	–

Recreation catch analysis methods were as given in Appendix 3.



Appendix Figure 61: Analysis survey boat ramp area definitions relative to revised east Northland and Hauraki Gulf revised boundary (blue line).

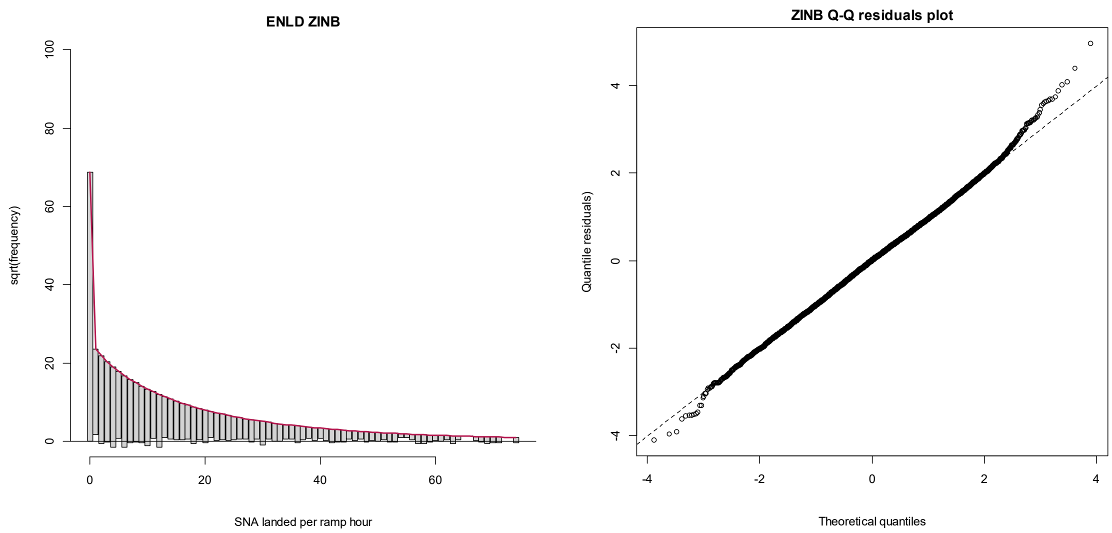
East Northland and Hauraki Gulf revised ZINB Results

East Northland

The final East Northland fitted ZINB model parameterisation was:

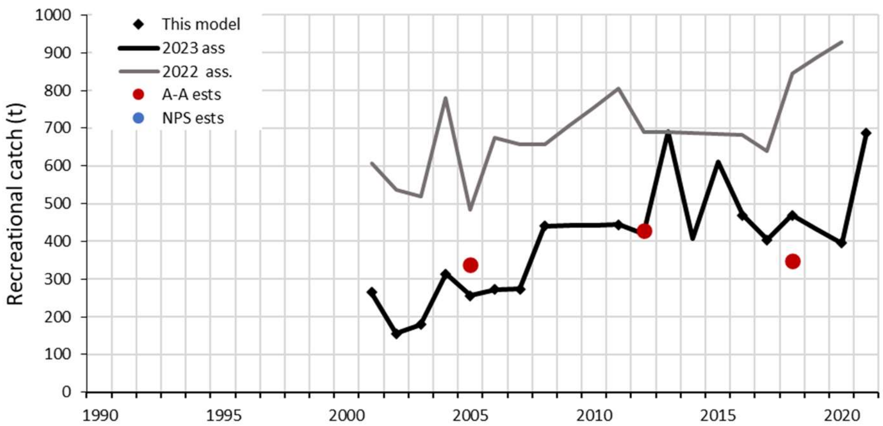
Numbers/hr^{-1} ~ month + hour + ramp + wind-speed + fyear + day-type | hour + ramp.

Rootogram and QQ diagnostics suggest the model fit to the data was "acceptable" (Appendix Figure 62).



Appendix Figure 62: East Northland ZINB model fit diagnostic plots. Right: rootogram (Kleiber & Zeileis 2016) of predicted and observed snapper catch per hour. Left: ZINB model QQ normality residuals.

The final predicted East Northland recreational snapper catches post 2000–01 derived by fitting the ZINB model predicted catch index to the geometric mean of the aerial-access estimate years is given in Appendix Figure 63.



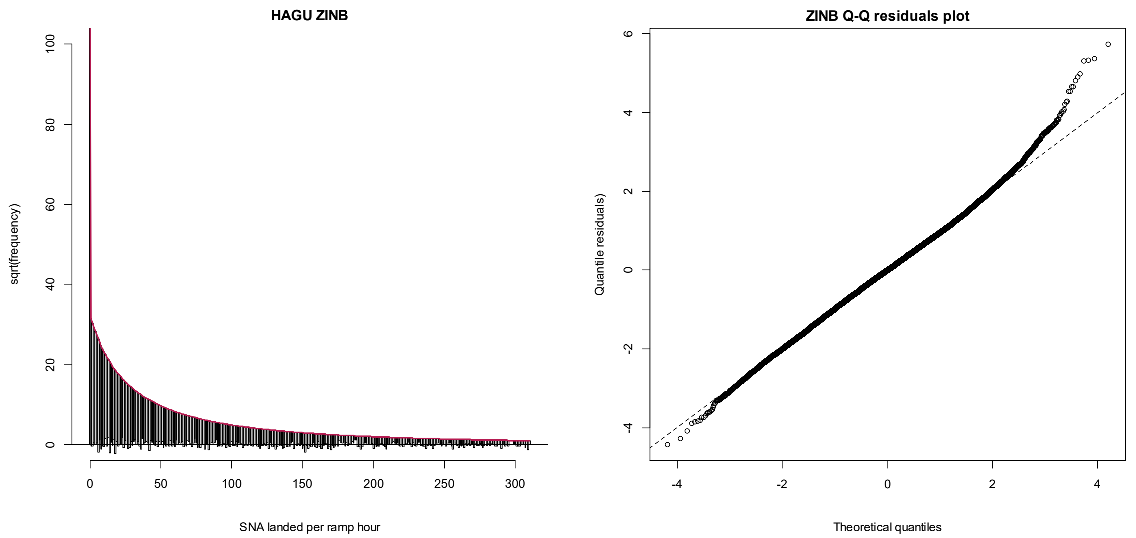
Appendix Figure 63: East Northland post 2000-01 ZINB model predicted recreational snapper harvest estimates. Note: catches for years with no survey data are interpolated. Grey line shows recreational catch estimates used in the 2022 SNA 1 assessment.

Hauraki Gulf

The final Hauraki Gulf fitted ZINB model parameterisation was:

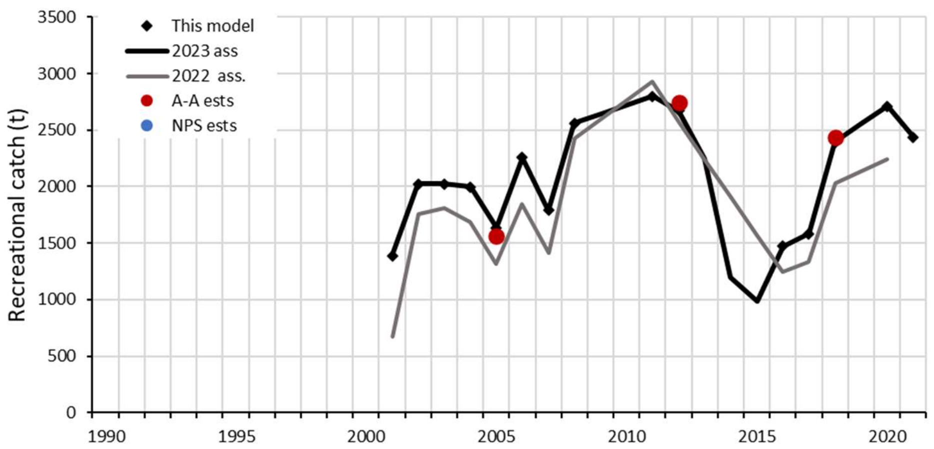
Numbers/hr^{-1} ~ month + hour + ramp + wind-speed + fyear + day-type | hour + ramp.

Rootogram and QQ diagnostics suggest the model fit to the data was "acceptable" (Appendix Figure 64).



Appendix Figure 64: Hauraki Gulf ZINB model fit diagnostic plots. Right: rootogram (Kleiber & Zeileis 2016) of predicted and observed snapper catch per hour. Left: ZINB model QQ normality residuals.

The final predicted Hauraki Gulf recreational snapper catches post 2000–01 derived by fitting the ZINB model predicted catch index to the geometric mean of the aerial-access estimate years is given in Appendix Figure 65.



Appendix Figure 65: Hauraki Gulf post 2000–01 ZINB model predicted recreational snapper harvest estimates. Note: catches for years with no survey data are interpolated. Grey line shows recreational catch estimates used in the 2022 SNA 1 assessment (note: inclusion of more ramps allowed wider temporal predictive coverage between 2010 and 2016).

Appendix 14: Petersen tag estimator model validation

The SNA 1 agent-based operating model (ABM) developed by McKenzie et al. (2018) was used to generate mark-recapture data from a simulated tag release event. The operating model generated tag recovery observations from five recovery events occurring 1, 13, 25, 37, and 49 months after tagging. The tagged and untagged components of the simulated SNA 1 sub-stock populations were subject to movement and growth. Tag-loss, under-detection and initial-mortality, and trap avoidance were not simulated. The simulated tag release events were set to achieve uniform mark-rates across all length classes. To minimise observational error the simulation was configured to achieve a high number of tag recoveries (Table Appendix 18).

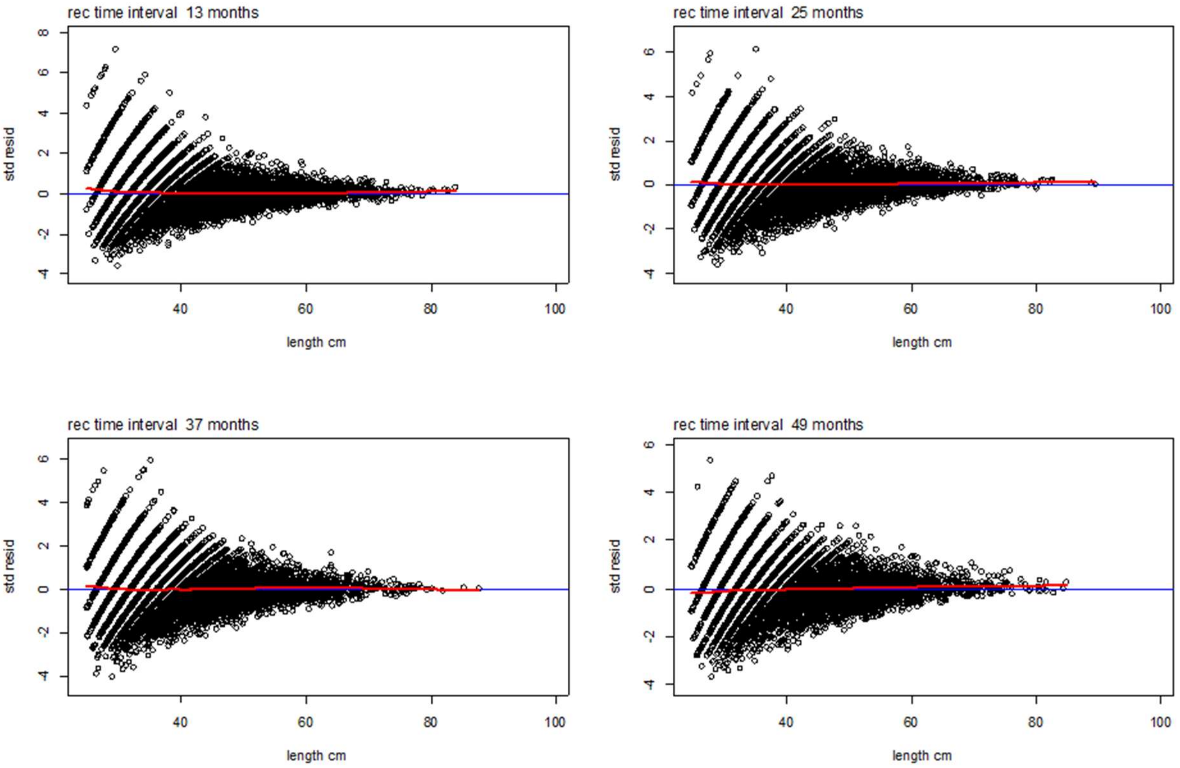
The Petersen estimator model could be stratified into one or more length-bin categories, the number of length-bins dependant on there being sufficient tag recoveries to derive a population estimate for each specific length-bin. Given the high number of ABM recoveries simulated, the Petersen estimator was able to support up to 20 length bin categories in the analysis. The Petersen estimator thus derived separate population estimates for each length-bin sub-stock stratum, as specific estimable parameters, by fitting to the observed number of tag recoveries in each recovery month. Fitting made use of the R non-linear solver "nlimb" (R Core Development Team 2022) with a binomial likelihood function.

The total sub-stock population estimates were the summation of the sub-stock length bin estimates. The Petersen estimator also estimated annual proportional movement between the three SNA 1 sub-stocks by fitting to the tag movement observations (i.e. nine movement parameters as derived from six estimable parameters). Note: movement in the ABM was specified independent of length.

Table Appendix 18: SNA 1 ABM simulated tagging data totals.

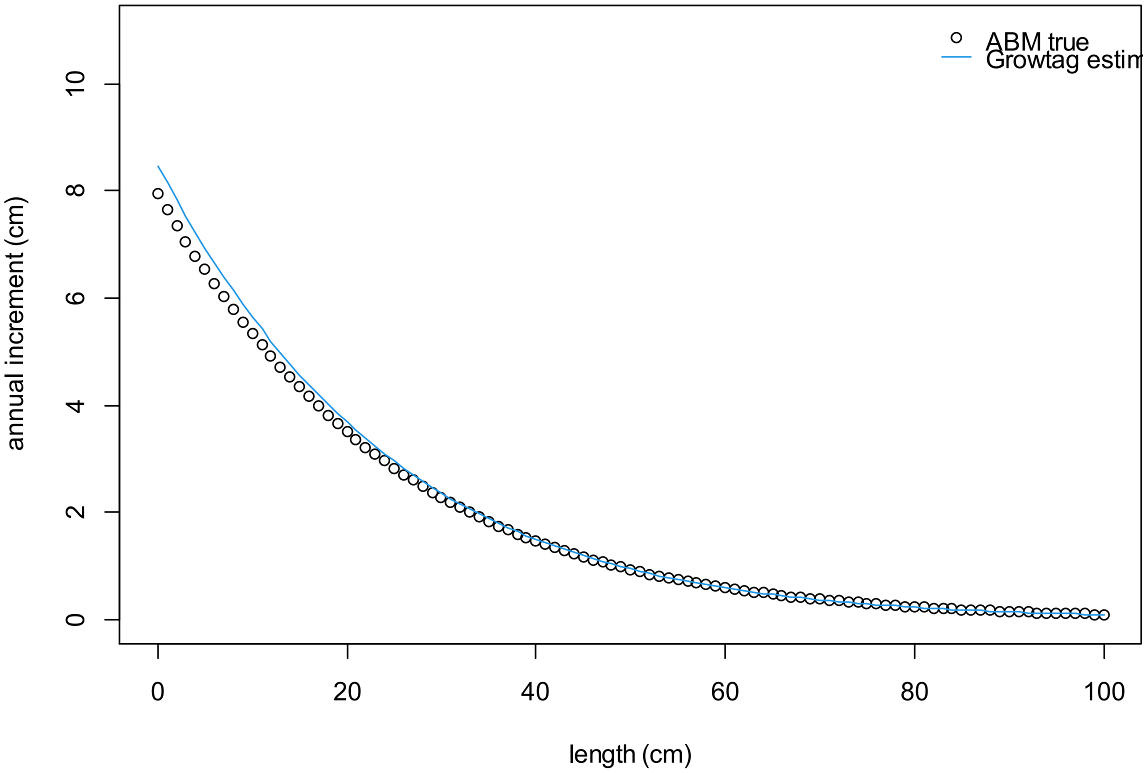
Sub-stock	Number tagged	Number scanned	Recovered tags
East Northland	300 000	785 604	11 722
Hauraki Gulf	300 000	1 873 043	25 408
Bay of Plenty	300 000	1 030 017	26 090
Total	900 000	3 688 664	63 220

The Petersen estimator achieved “acceptable” fits to the ABM simulated tag growth-increment data as seen in the standardised residuals (Appendix Figure 66).

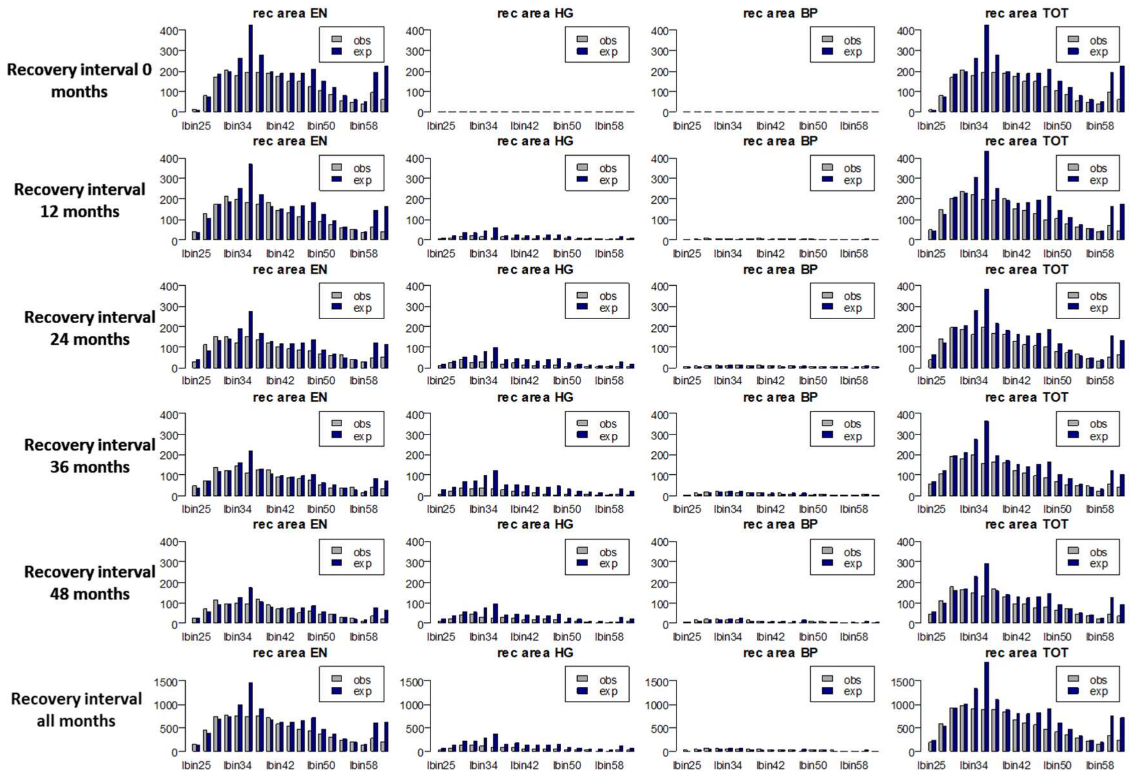


Appendix Figure 66: Petersen estimator model standardised residual predicted growth fits to the ABM tag growth-increment data. Red lines are loess smoother trends.

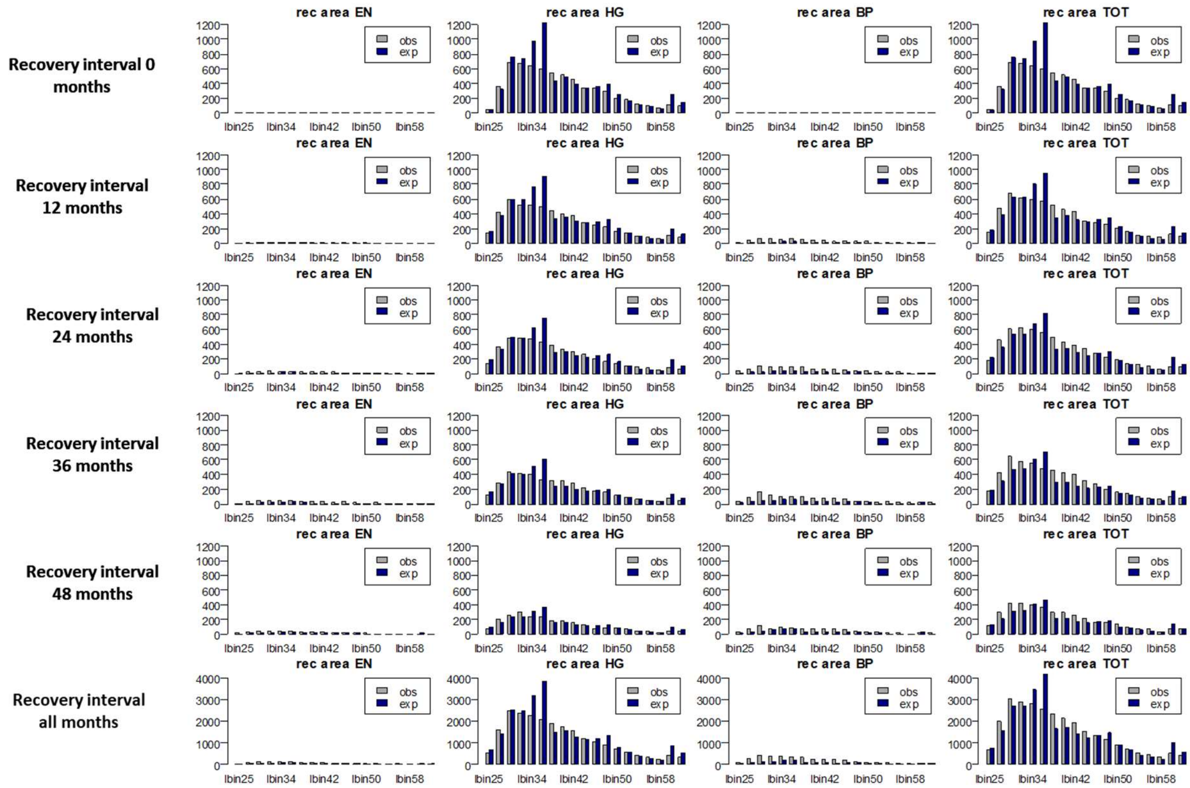
The Petersen estimator tag growth-increment growth prediction from the ABM simulated tagging data closely matched the average growth rates from the “true” operating model (Appendix Figure 67).



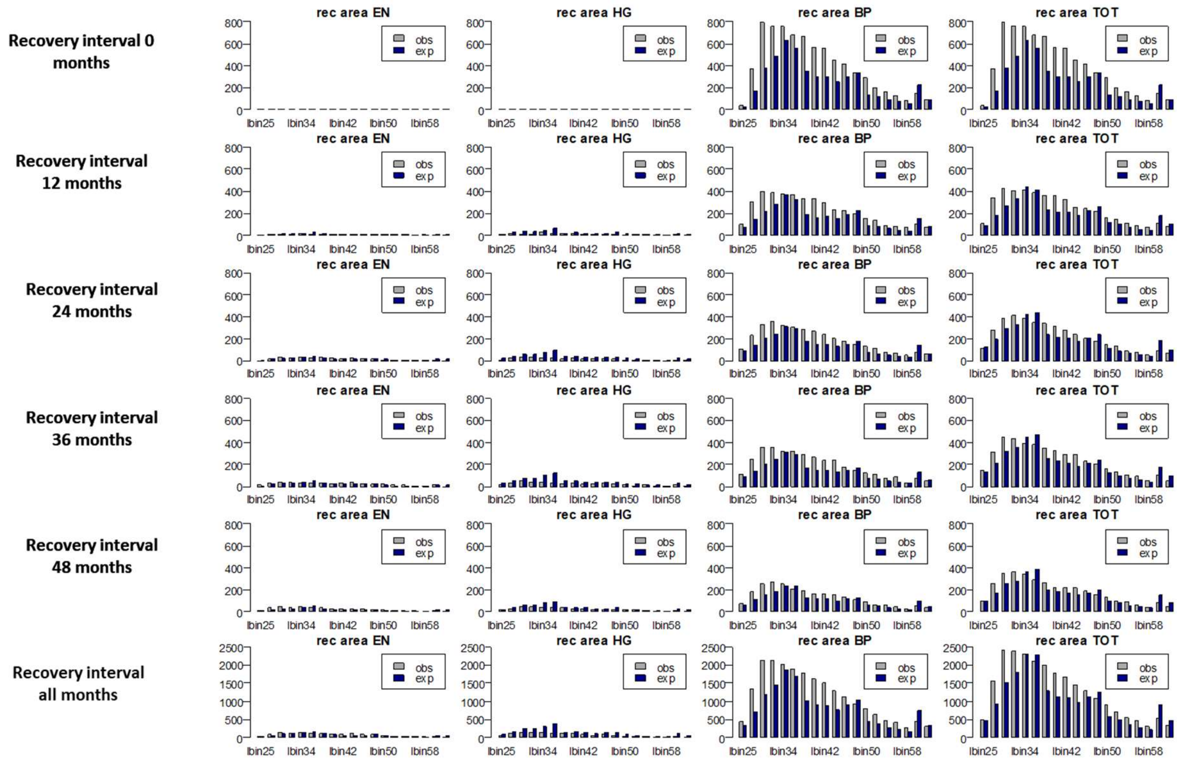
Appendix Figure 67: Petersen model growth increment model prediction compared to “true” ABM mean growth.



Appendix Figure 68: Petersen model fits to ABM observed east Northland tag snapper recoveries stratified by length.



Appendix Figure 69: Petersen model fits to ABM observed Hauraki Gulf tag snapper recoveries stratified by length.



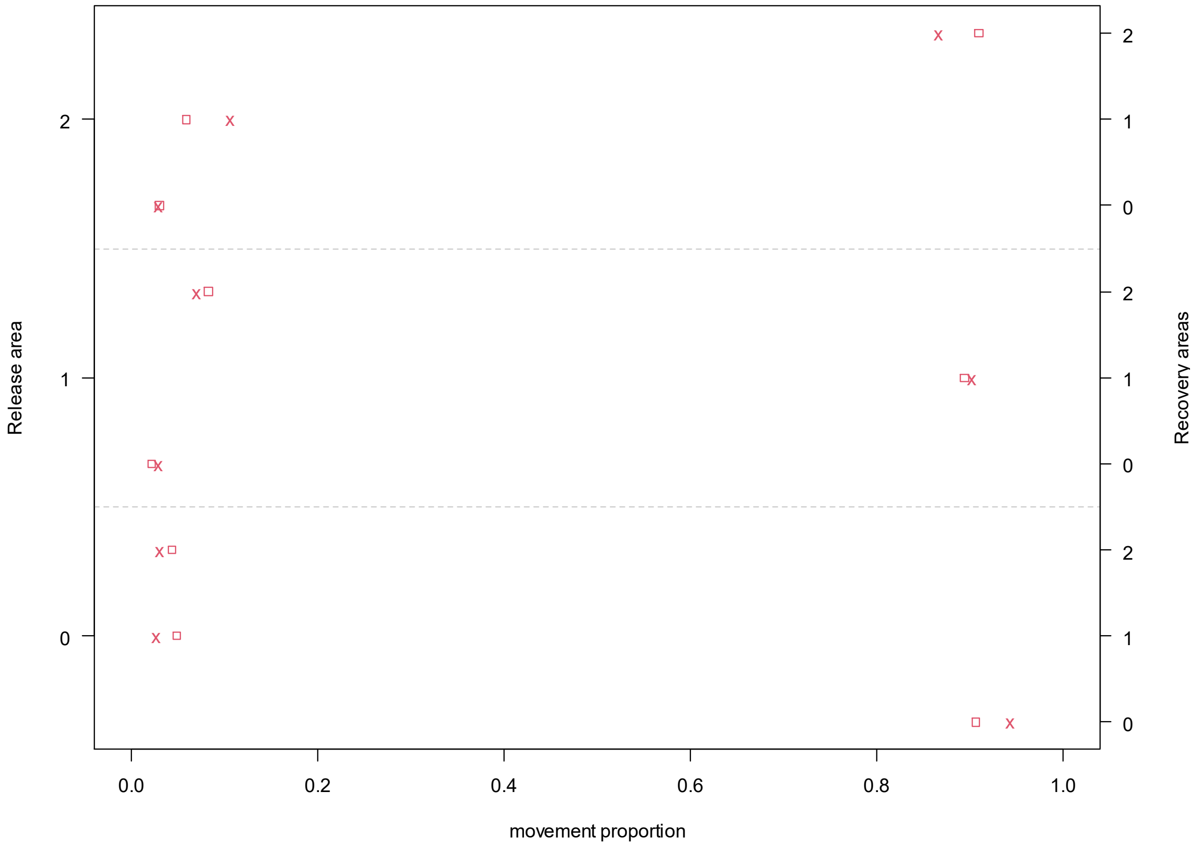
Appendix Figure 70: Petersen model fits to ABM observed Bay of Plenty tag snapper recoveries stratified by length.

The Petersen estimator was able to achieve relatively unbiased estimates of the ABM true sub-stock population numbers at time of release (Table Appendix 19).

Table Appendix 19: Petersen 25 cm + population estimates at time of release compared to the true ABM population numbers.

Region	True ABM pop. Number	Petersen pop. Estimate	% estimation bias
East Northland	22 986 834	23 463 288	2.10%
Hauraki Gulf	20 588 695	20 724 720	0.70%
Bay of Plenty	11 313 328	11 069 414	-2.20%
Total	54 888 857	55 257 422	0.70%

The Petersen estimator estimation of the true ABM sub-stock annual proportional movements were also “reasonably close” (Appendix Figure 71).



Appendix Figure 71: Petersen estimated sub-stock annual proportional movement (□) compared to ABM operating model "true" population movement (x). 0 = Bay of Plenty; 1 = Hauraki Gulf; 2 = East Northland.

It was concluded from the simulation test that the Petersen estimator is likely to produce relatively "unbiased" population and movement estimates when applied to unbiased "rich" and spatially representative datasets, the level of imprecision seen in the above ABM simulation results is largely within the bounds of the random observational error in the simulated dataset.

Potential for growth bias in tagging data.

The Petersen population estimates when growth is not accounted for in the analysis were markedly biased which shows the importance of correcting for growth in tag recovery data collected more than one year after release (Table Appendix 20).

Table Appendix 20: Petersen 25 cm + population estimates at time of release compared to the true ABM population numbers when growth was not corrected for in the analysis.

Region	True ABM pop. Number	Petersen pop. estimate	% estimation bias
East Northland	22 986 834	27 403 842	-19.22%
Hauraki Gulf	20 588 695	22 155 018	-7.61%
Bay of Plenty	11 313 328	10 242 596	9.46%
Total	54 888 857	59 801 456	-8.95%

Appendix 15: 2023 SNA 1 assessment commercial bottom trawl updated CPUE analyses

Standardisation of the SNA 1 bottom trawl CPUE series was undertaken using generalised linear modelling of event-based (tow-level) data as done for the 2013 assessment (Francis & McKenzie 2015b). Bottom trawl tow-level effort reporting data are available for the SNA 1 sub-stock areas back to 1995–96, and data compiled through to 2020–21 for the 2023 SNA 1 assessment.

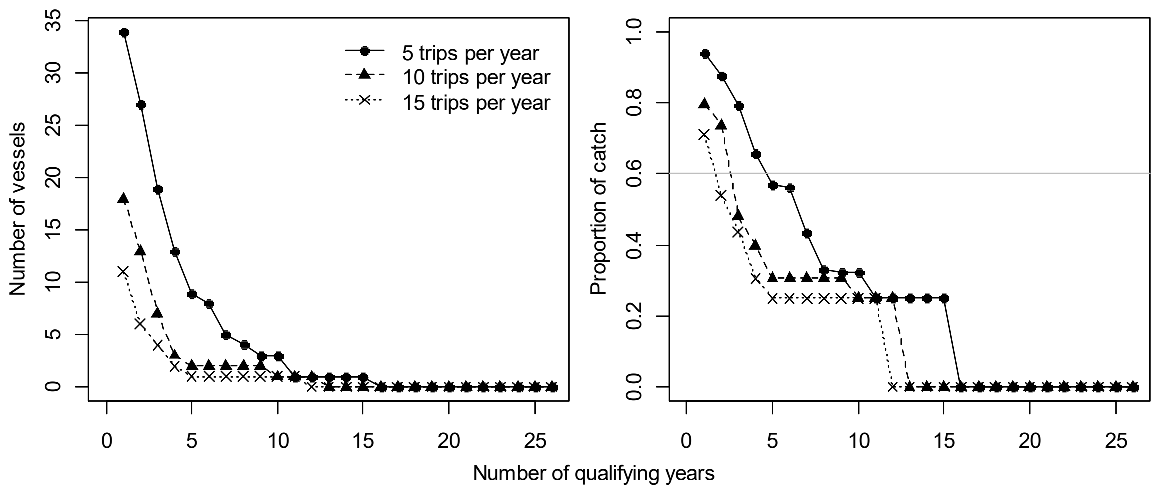
Before standardisation the bottom trawl CPUE data needed to be adjusted to account for an increase from the maximum number of species fishers are required to report catch against per fishing event after 2007–08 (from five to eight). The maximum reported species adjustment required discarding data for species ranking below the top five daily aggregated catches after 2007–08.

Due to the presence of a significant number of zero events in the bottom trawl series, a delta-lognormal standardisation approach was used for the derivation of the final sub-stock bottom trawl indices. The response variable in the positive GLM standardisation was log-catch. The response variable in the binomial GLM was zero/non-zero catch. Fishing-year was always included in the models as a categorical variable. The other covariate terms offered to the models are given in Table Appendix 11. Covariates were added stepwise to log and binomial GLMs, the stopping rule being when the addition of another model term resulted in a less than 1% improvement in residual sums-of-squares (R^2).

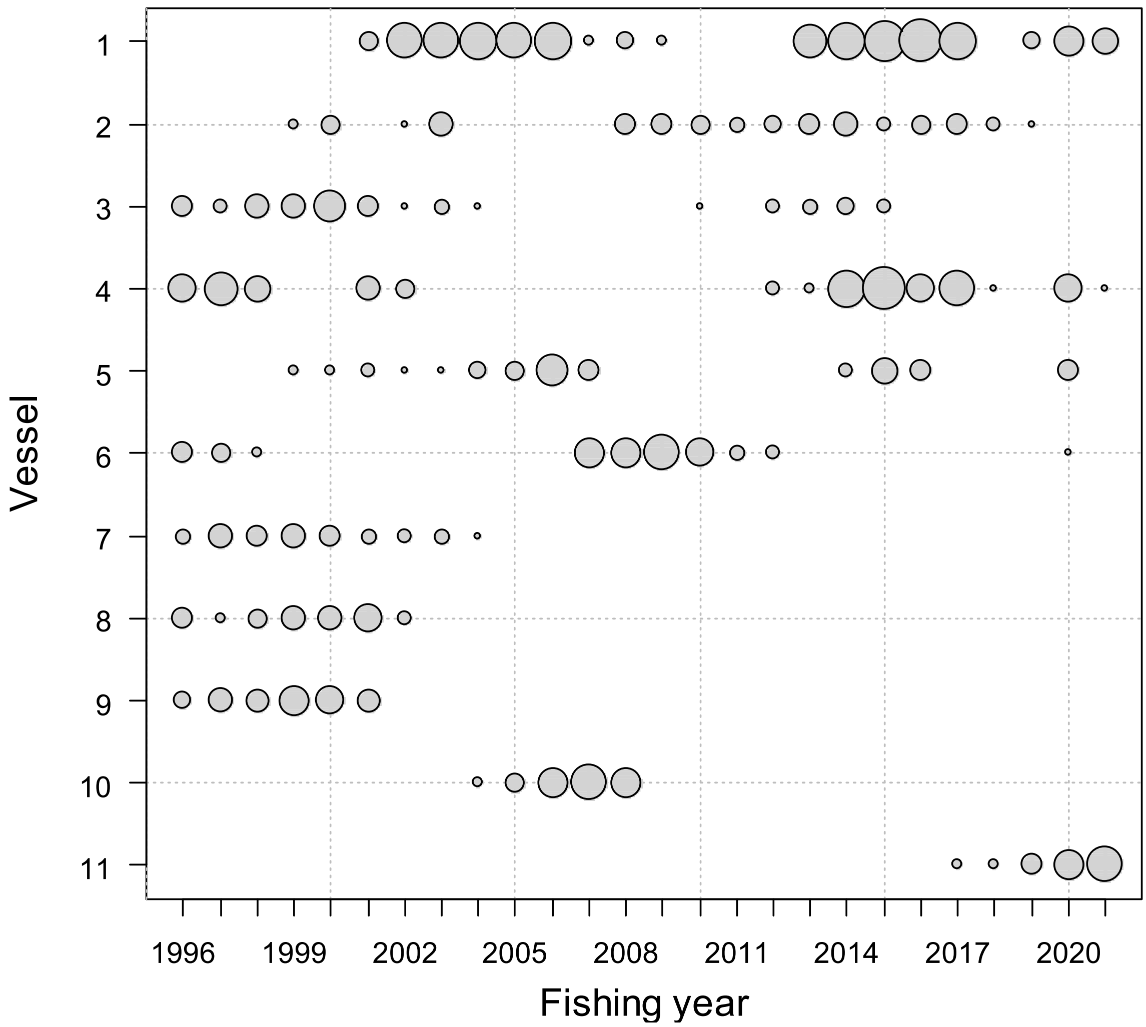
Trip landed snapper catch totals were pro-rated across reported effort based on the event catch estimates. Missing value records were excluded from the analyses, as were records where the linked reported catch and/or any of the continuous covariate values fell outside the 99% quartile range.

East Northland

Core vessels were selected having to account for 60% of the total landed longline catch over all years; the optimum selection criteria to achieve this corresponded to a minimum catch history of five years of at least five trips per year (Appendix Figure 72). There were few long catch-history vessels included in the east Northland bottom trawl GLM standardisations (Appendix Figure 73).



Appendix Figure 72: East Northland (002) Bottom trawl CPUE vessel selection criteria plots.



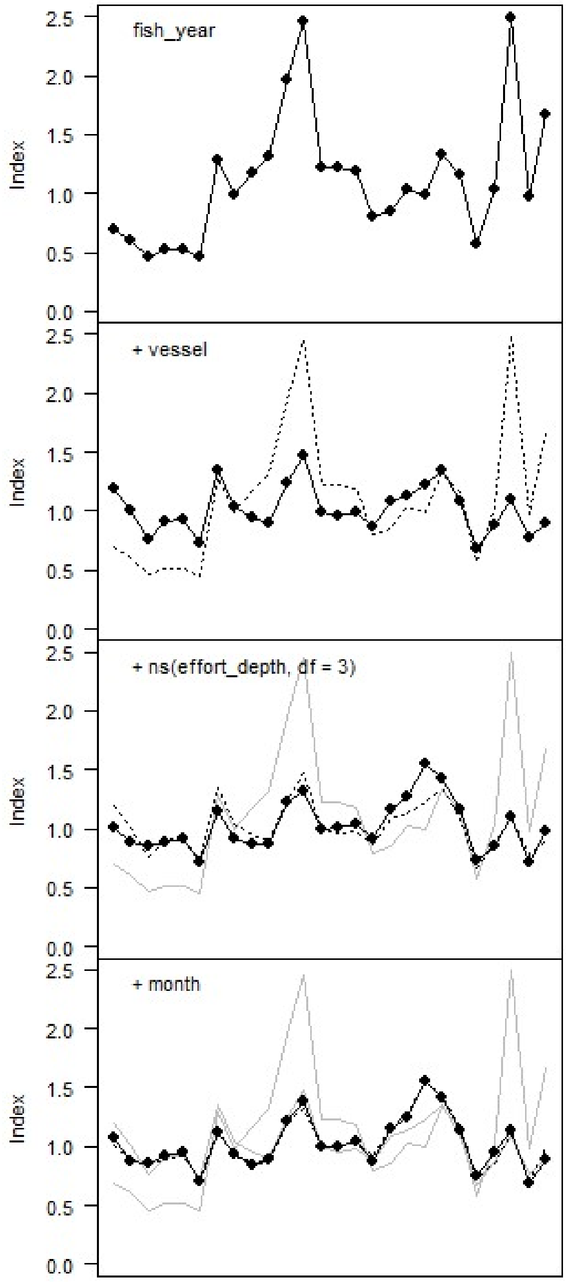
Appendix Figure 73: East Northland (002) bottom trawl core vessel catch histories, bubble areas proportional to annual vessel catch totals.

Logistic (log(tow-catch)) GLM

The east Northland bottom trawl GLM explained 32% of the variation in the log positive-catch data (Table Appendix 21). The "vessel" had the most standardisation effect on the final positive index, the degree of standardisation by the other variables being comparatively minor (Appendix Figure 74). The pattern in the residuals in the final logistic GLM show departures from normality in the lower 25% quartile in predicting small catches but most of the observed catch range appeared well described by the model (Appendix Figure 75).

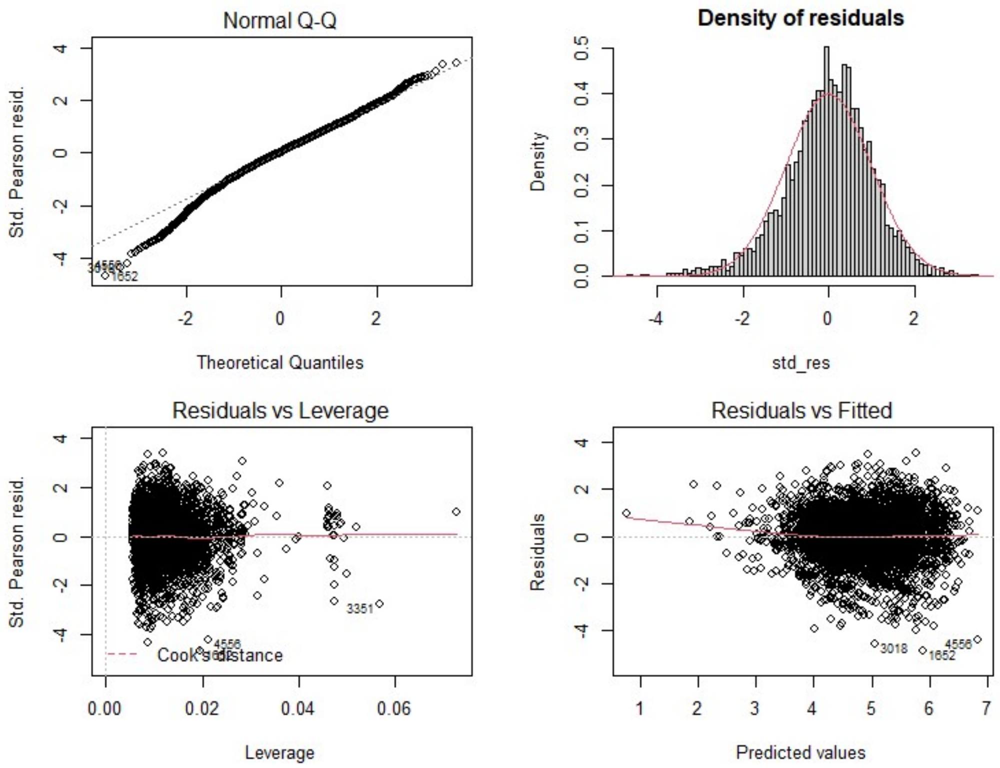
Table Appendix 21: East Northland bottom trawl fitted logistic GLM parameterisation for response variable log tow-catch.

Predictors	Deg. freedom	Cumulative R^2
Fishing year	25	0.13
Vessel	10	0.25
ns(depth)	3	0.31
month	13	0.32

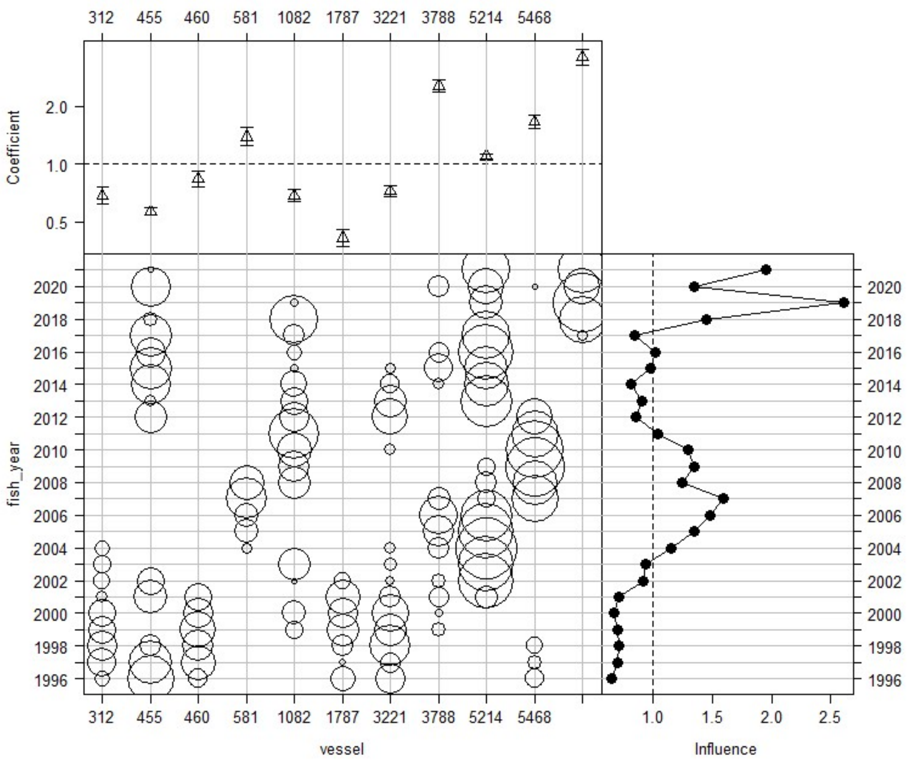


Appendix Figure 74: Degree of standardisation in final east Northland bottom trawl log-normal index relative to each added covariate term.

The influence plot for "vessel" shows the high relative effect on the expected snapper catch rate (Appendix Figure 76).

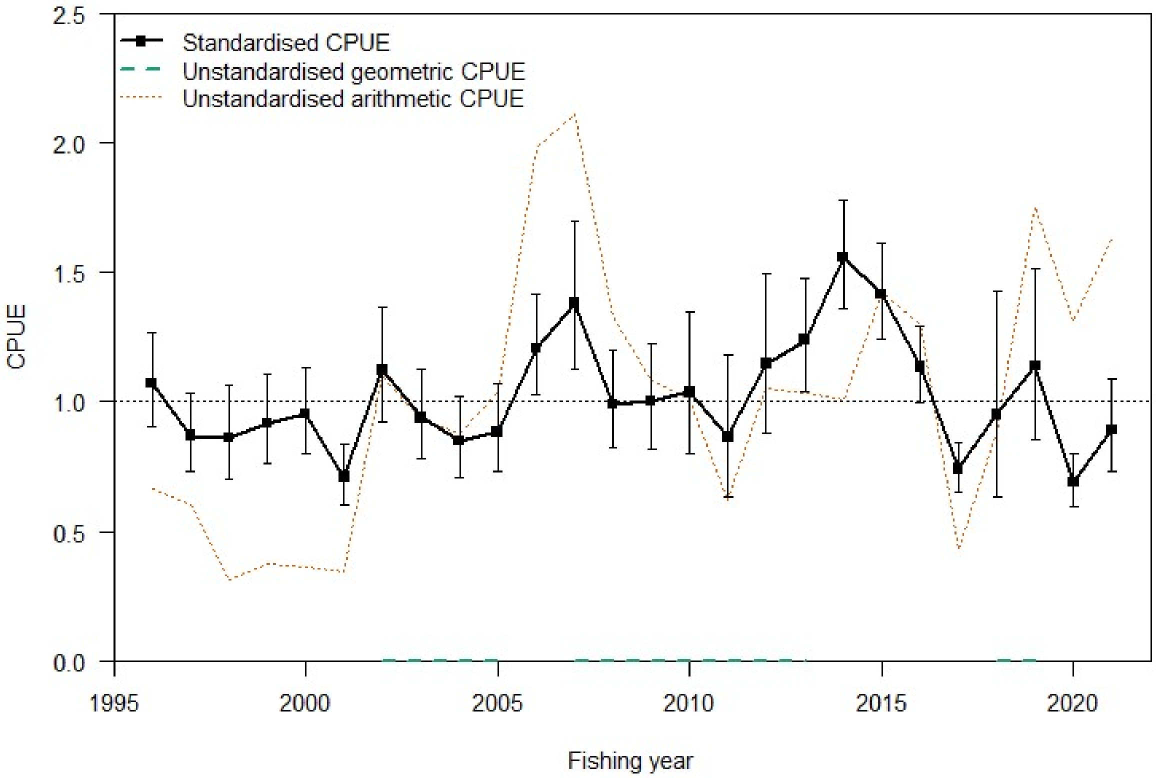


Appendix Figure 75: Normality tests on the final east Northland logistic model residuals.



Appendix Figure 76: East Northland bottom trawl logistic GLM influence plots for vessel parameters.

The east Northland bottom trawl positive GLM index, although fluctuating, was relatively flat (Appendix Figure 77).



Appendix Figure 77: East Northland bottom trawl snapper CPUE standardised and unstandardised positive catch indices.

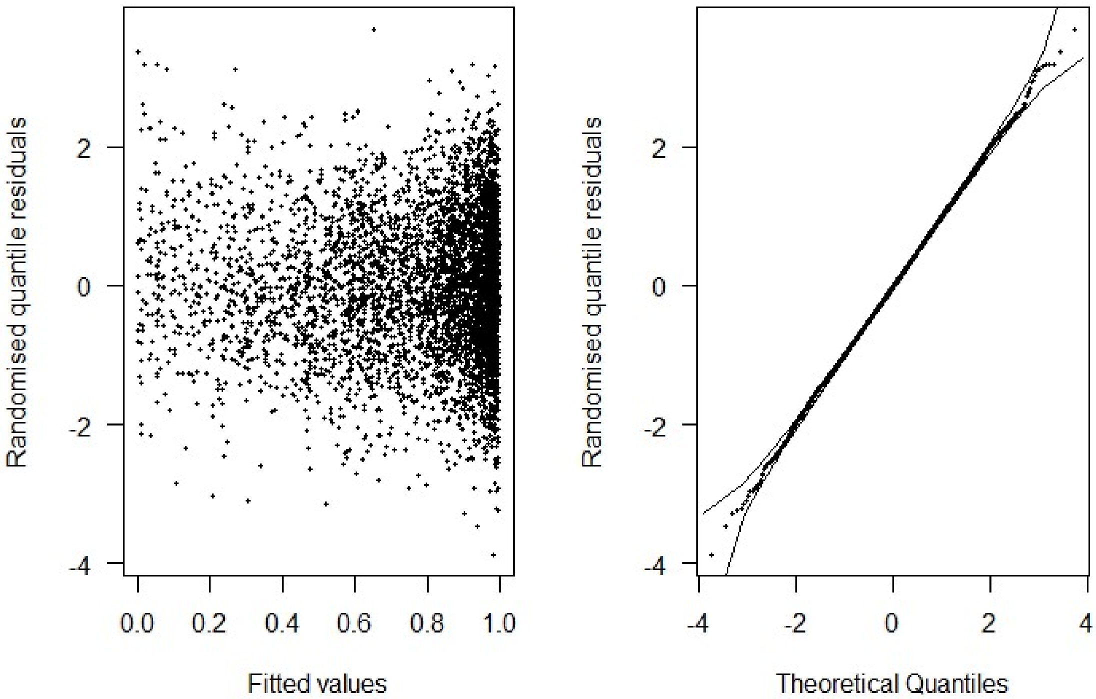
Binomial (positive catch probability) GLM

The east Northland bottom trawl binomial GLM explained 32% of the variation in the catch probability data (Table Appendix 22). As with the positive model, "depth", "target", and "vessel" were the most explanatory variables in the final model (Table Appendix 22).

The binomial GLM fitted residuals were consistent with normality over most of the catch probability space (Appendix Figure 78).

Table Appendix 22: Bay of Plenty bottom trawl fitted binomial GLM parameterisation for response variable positive catch probability.

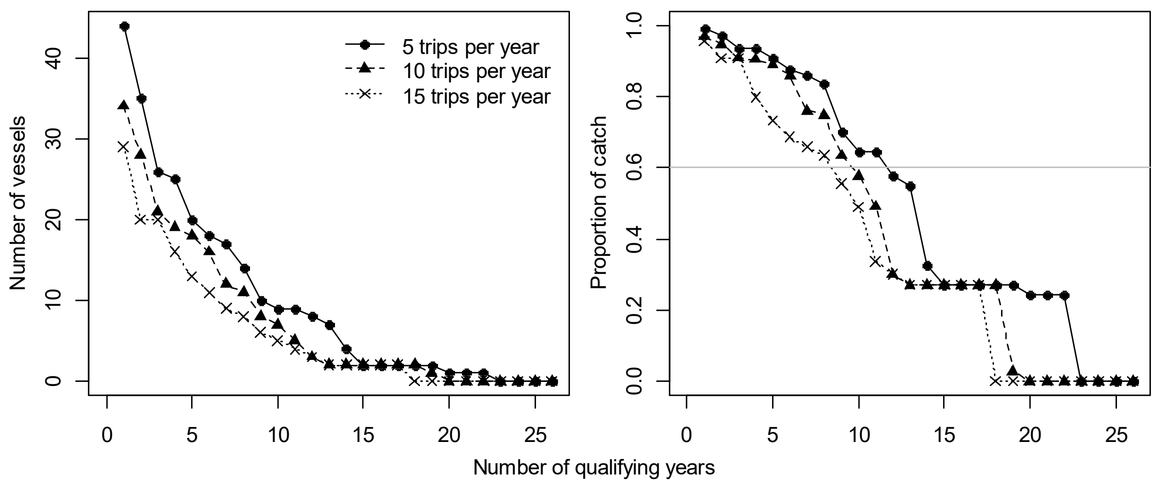
Predictors	Df	R.squared
Fishing year	25	0.06
ns(effort_depth, df = 3)	3	0.23
target	4	0.28
vessel	10	0.31
month	11	0.32



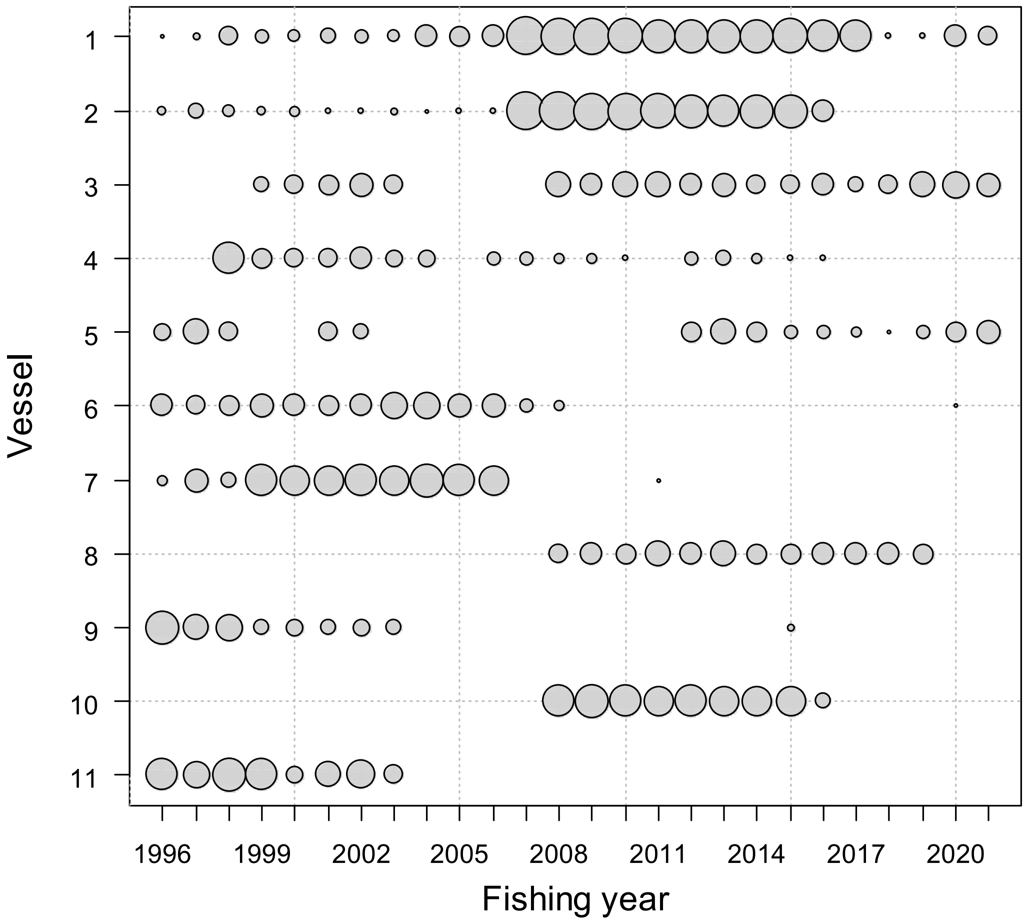
Appendix Figure 78: Normality tests on the final east Northland binomial model residuals.

Hauraki Gulf

Core vessels were selected having to account for 60% of the total landed longline catch over all years; the optimum selection criteria to achieve this corresponded to a minimum catch history of eight years of at least five trips per year (Appendix Figure 79). There were a high proportion of long catch-history vessels included in the Hauraki Gulf bottom trawl GLM standardisations (Appendix Figure 80).



Appendix Figure 79: Hauraki Gulf (005, 006, 007) Bottom trawl CPUE vessel selection criteria plots.



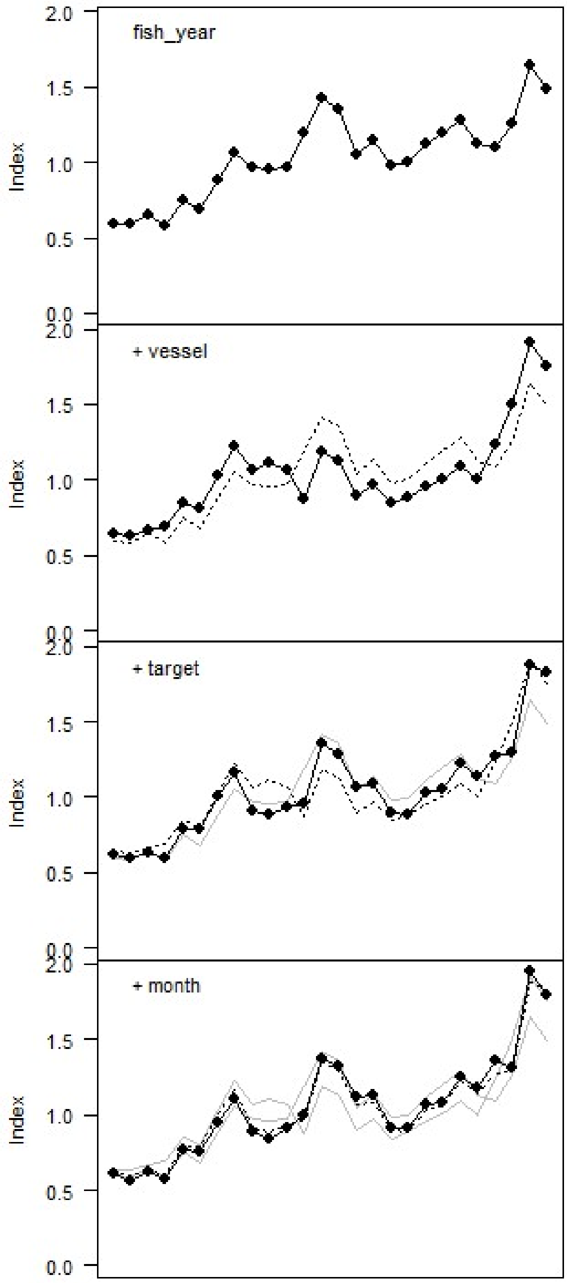
Appendix Figure 80: Hauraki Gulf (005, 006, 007) bottom trawl core vessel catch histories, bubble areas proportional to annual vessel catch totals.

Logistic (log(tow-catch)) GLM

The Hauraki Gulf bottom trawl GLM explained 21% of the variation in the log positive-catch data (Table Appendix 23). The "vessel" had the most standardisation effect on the final positive index but the combined standardisation effect of all significant parameters was relatively minor (Appendix Figure 81). The pattern in the residuals in the final logistic GLM show departures from normality in the lower 25% quartile in predicting small catches but most of the observed catch range appeared well described by the model (Appendix Figure 82).

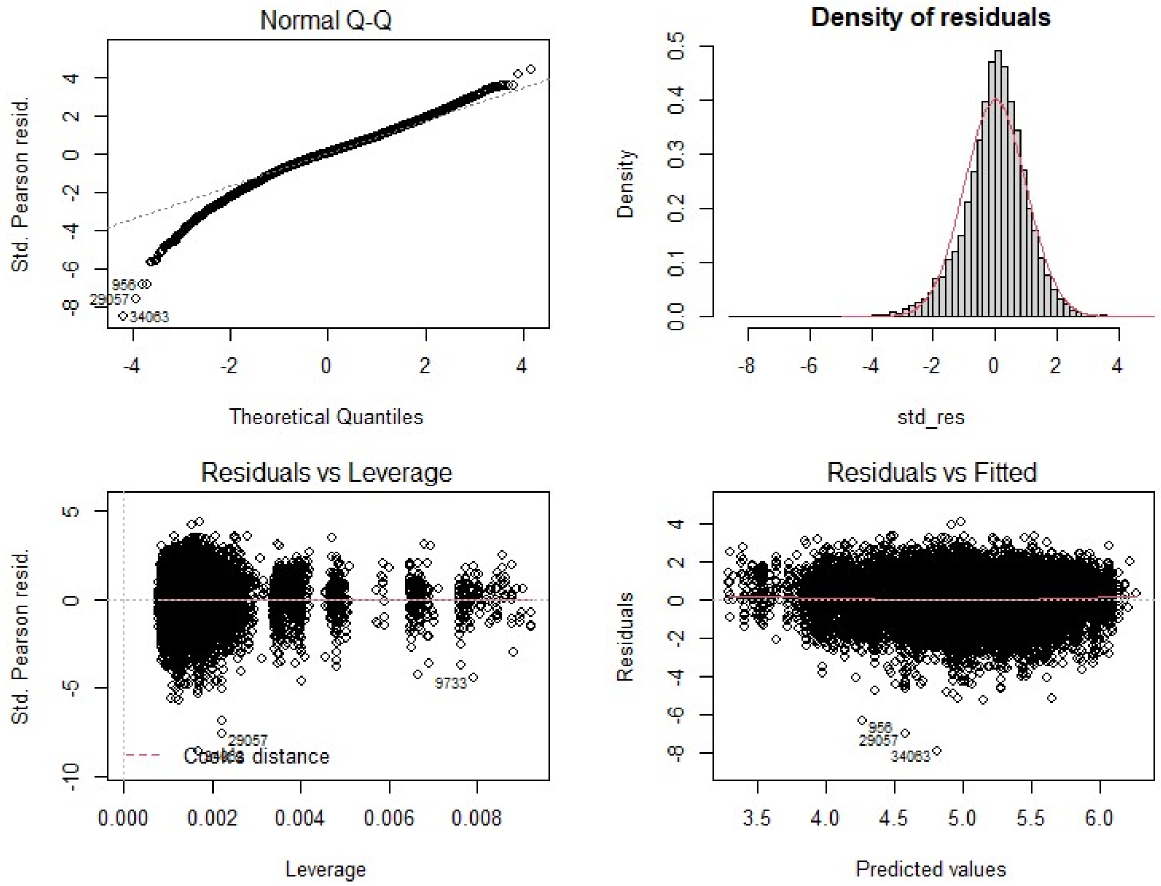
Table Appendix 23: Hauraki Gulf bottom trawl fitted logistic GLM parameterisation for response variable log tow-catch.

Predictors	Deg. freedom	Cumulative R^2
Fishing year	25	0.07
vessel	10	0.14
target	4	0.20
month	11	0.21

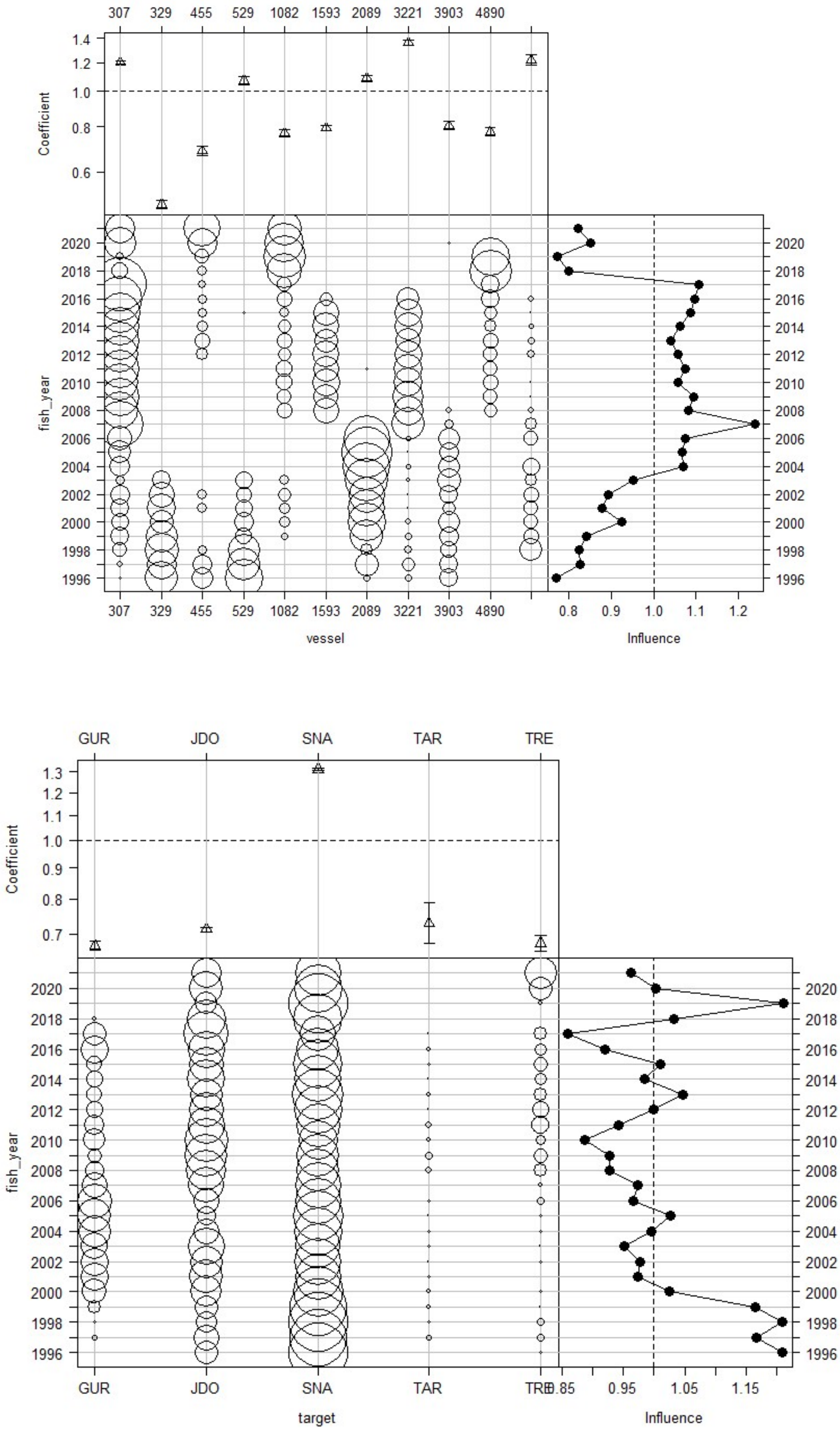


Appendix Figure 81: Degree of standardisation in final Hauraki Gulf bottom trawl log-normal index relative to each added covariate term.

The influence plot for "target" shows the high relative effect targeting snapper has on the expected catch rate (Appendix Figure 83).

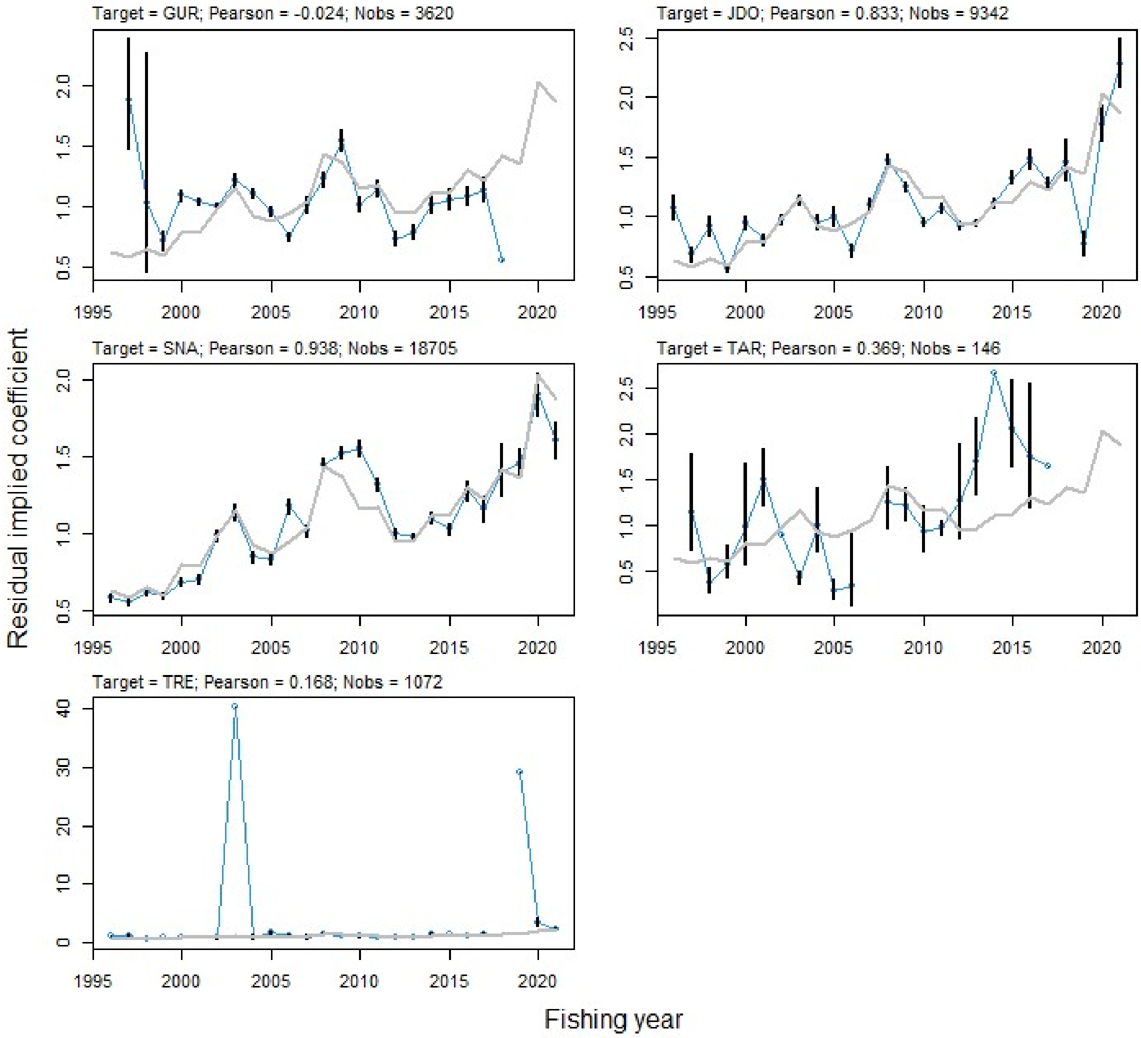


Appendix Figure 82: Normality tests on the final Hauraki Gulf logistic model residuals.

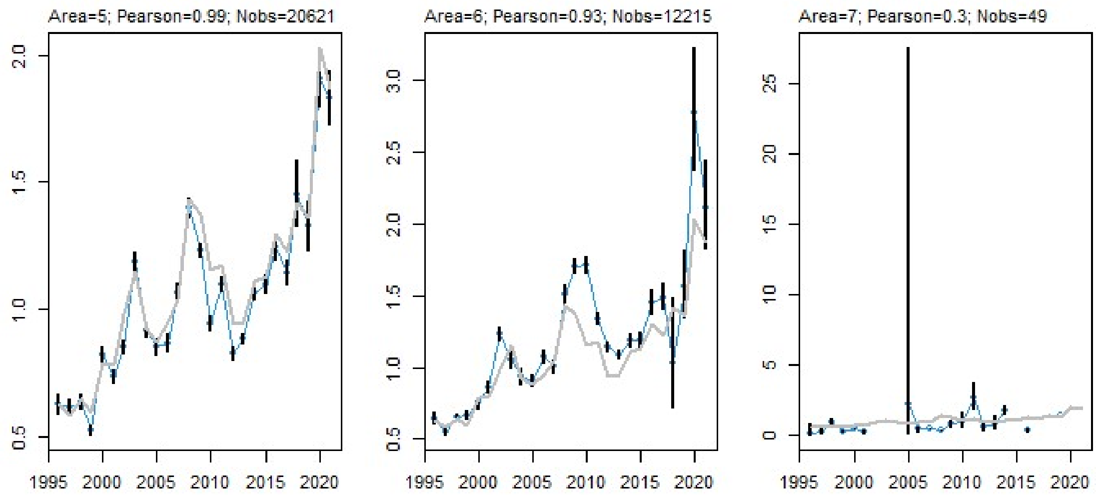


Appendix Figure 83: Hauraki Gulf bottom trawl logistic GLM influence plots for vessel (top) and target (bottom) parameters.

Implied residual plots in the Hauraki Gulf bottom trawl positive “fishing year” indices aggregated by “target” were “reasonably” correlated with the overall index for snapper and John Dory but less so for gurnard (Appendix Figure 84). Implied residual plots in the Bay of Plenty bottom trawl positive “fishing year” indices aggregated by “statistical area” were strongly correlated with the overall index (Appendix Figure 85).

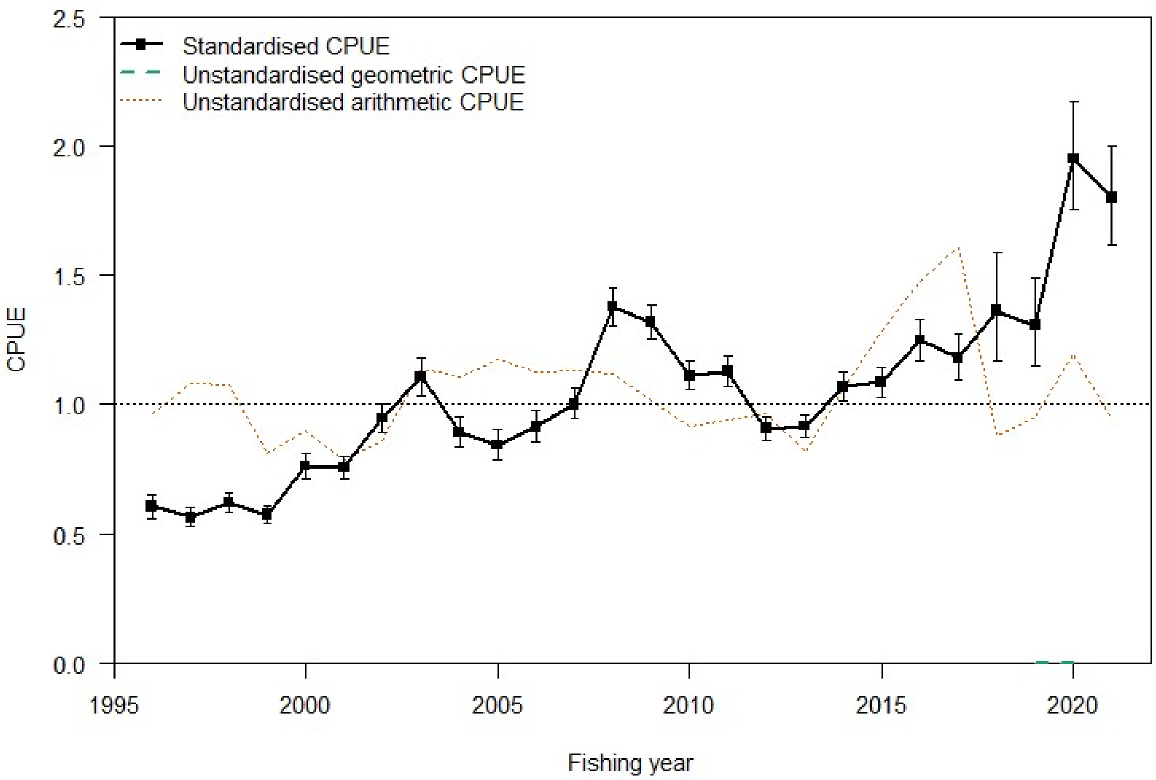


Appendix Figure 84: Hauraki Gulf bottom trawl logistic GLM implied residual plots by “target”.



Appendix Figure 85: Hauraki Gulf bottom trawl logistic GLM implied residual plots by “statistical area”.

The Hauraki Gulf bottom trawl positive GLM index shows an overall increasing positive trend (Appendix Figure 86).



Appendix Figure 86: Hauraki Gulf bottom trawl snapper CPUE standardised and unstandardised positive catch indices.

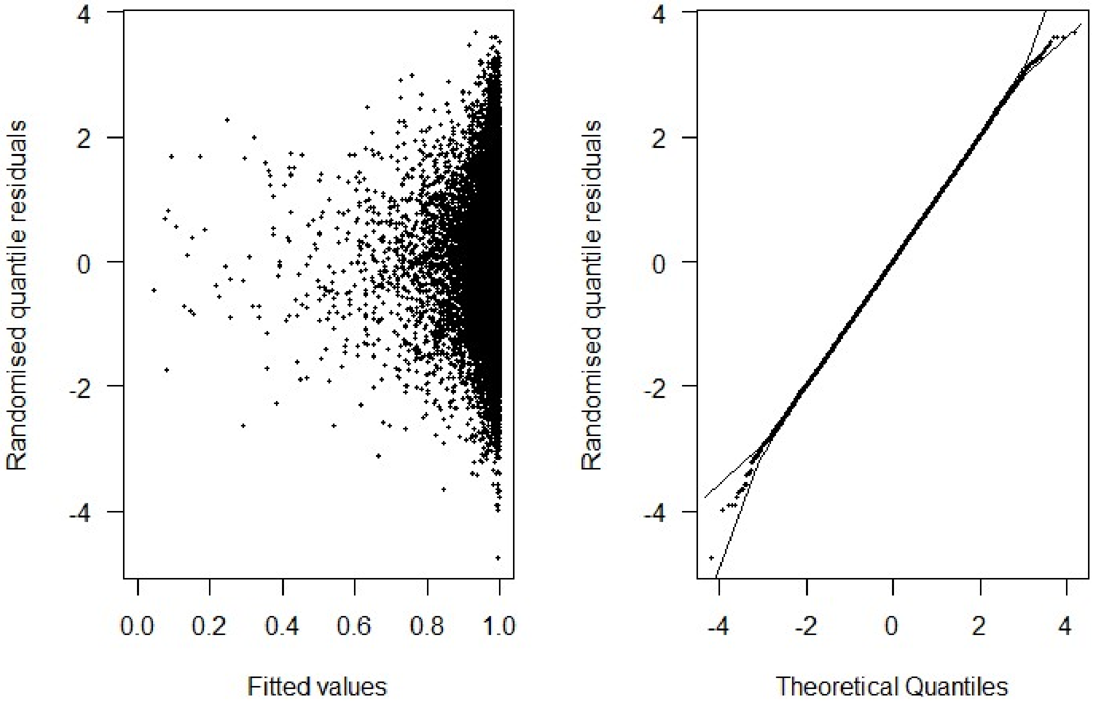
Binomial (positive catch probability) GLM

The Hauraki Gulf bottom trawl binomial GLM explained 19% of the variation in the catch probability data (Table Appendix 24).

The binomial GLM fitted residuals were consistent with normality over most of the catch probability space (Appendix Figure 87).

Table Appendix 24: Hauraki Gulf bottom trawl fitted binomial GLM parameterisation for response variable positive catch probability.

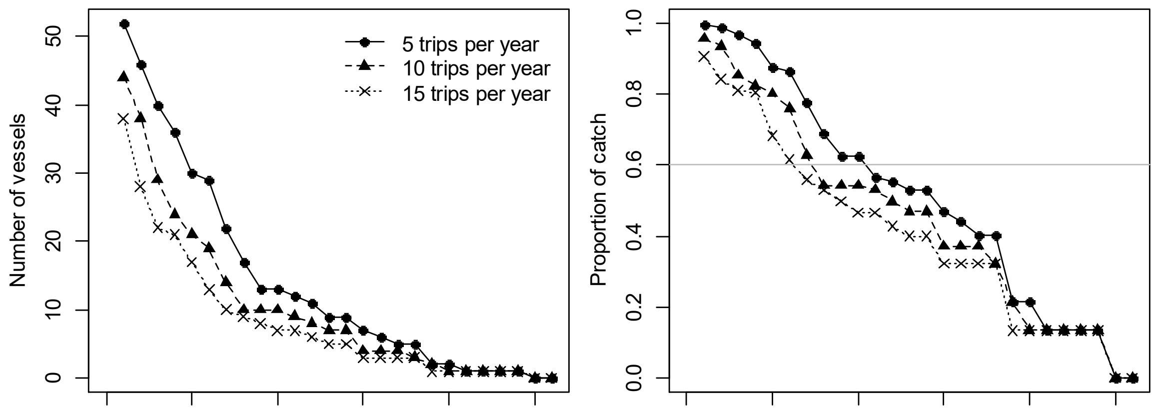
Predictors	Df	R.squared
Fishing year	25	0.05
target	4	0.1
month	11	0.14
vessel	10	0.18
Log-duration	3	0.19



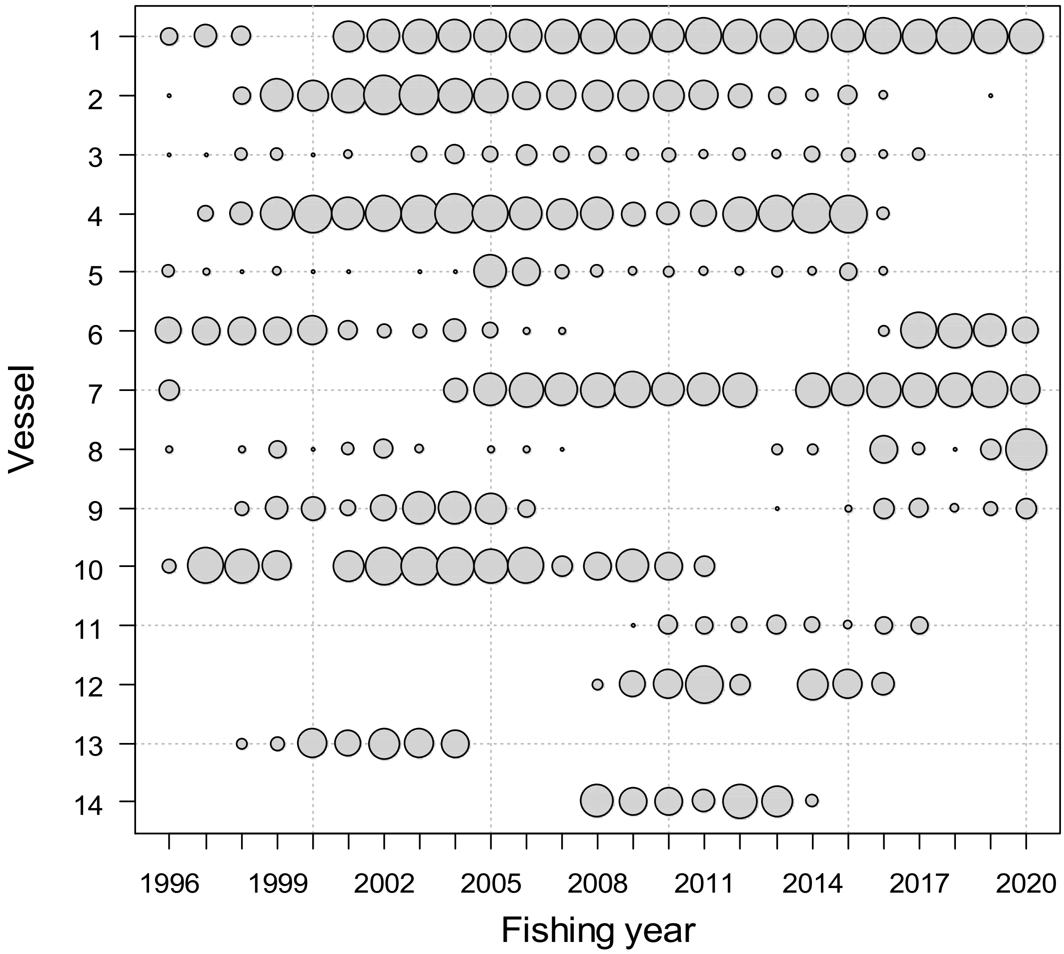
Appendix Figure 87: Normality tests on the final Hauraki Gulf binomial model residuals.

Bay of Plenty

Core vessels were selected having to account for 60% of the total landed longline catch over all years; the optimum selection criteria to achieve this corresponded to a minimum catch history of seven years of at least five trips per year (Appendix Figure 88). There were a high proportion of long catch-history vessels included in the Bay of Plenty bottom trawl GLM standardisations (Appendix Figure 89).



Appendix Figure 88: Bay of Plenty Bottom trawl CPUE vessel selection criteria plots.



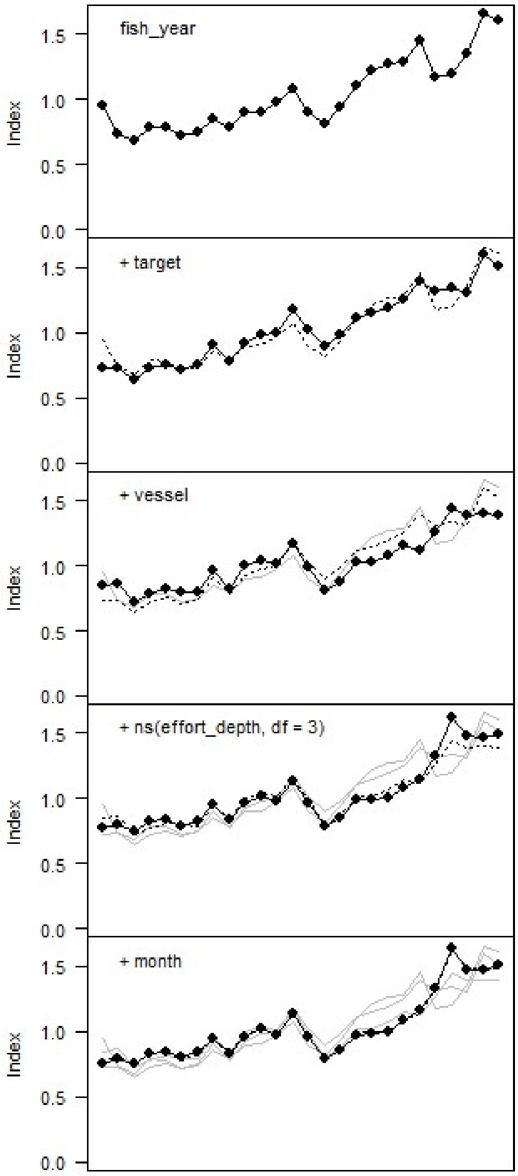
Appendix Figure 89: Bay of Plenty bottom trawl core vessel catch histories, bubble areas proportional to annual vessel catch totals.

Logistic (log(tow-catch)) GLM

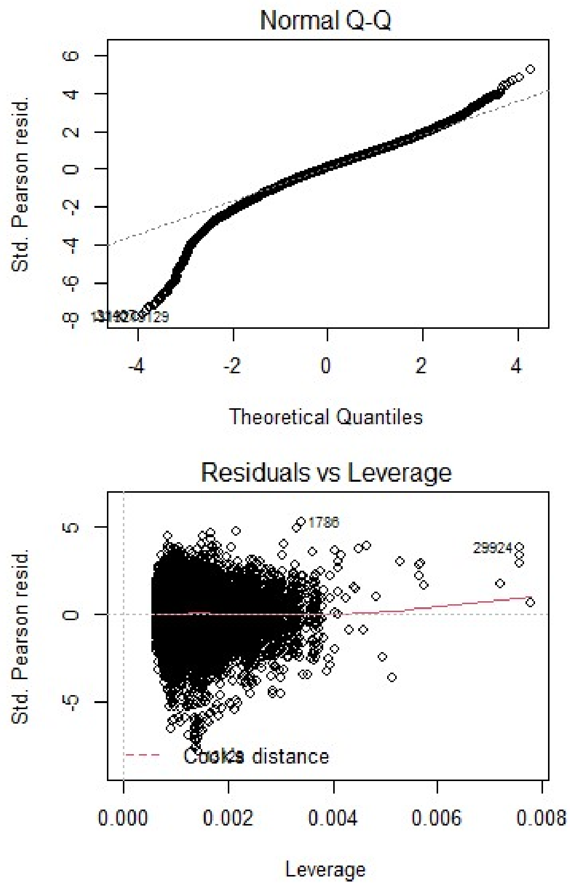
The Bay of Plenty bottom trawl positive GLM explained 26% of the variation in the log positive-catch data (Table Appendix 25). Although "target" was the most explanatory variable, its influence on the final positive index was minor as was the influence of the other explanatory variables selected by the positive model (Appendix Figure 90). The pattern in the residuals in the final logistic GLM show departures from normality in the lower 25% quartile in predicting small catches but most of the observed catch range appeared well described by the model (Appendix Figure 91).

Table Appendix 25: Bay of Plenty bottom trawl fitted logistic GLM parameterisation for response variable log tow-catch.

Predictors	Deg. freedom	Cumulative R^2
Fishing year	24	0.04
target	4	0.16
vessel	13	0.21
ns(depth)	3	0.25
month	11	0.26



Appendix Figure 90: Degree of standardisation in final Bay of Plenty bottom trawl log-normal index relative to each added covariate term.

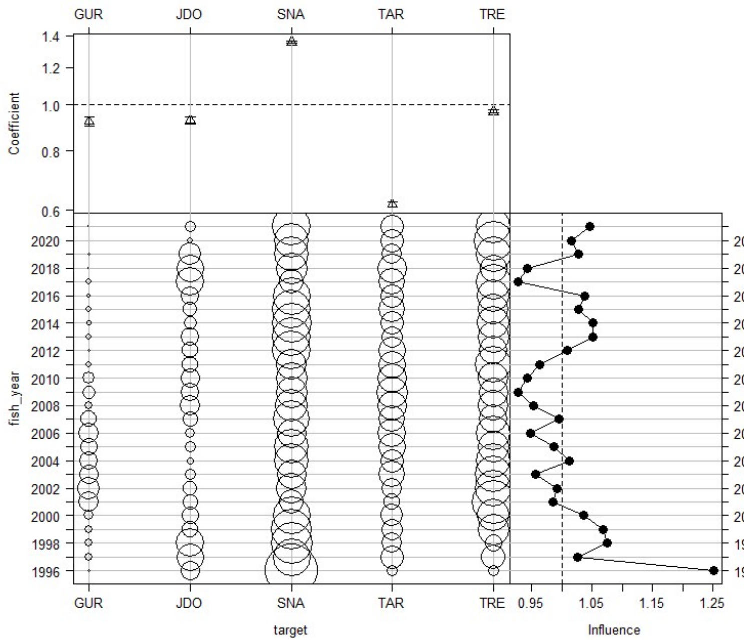


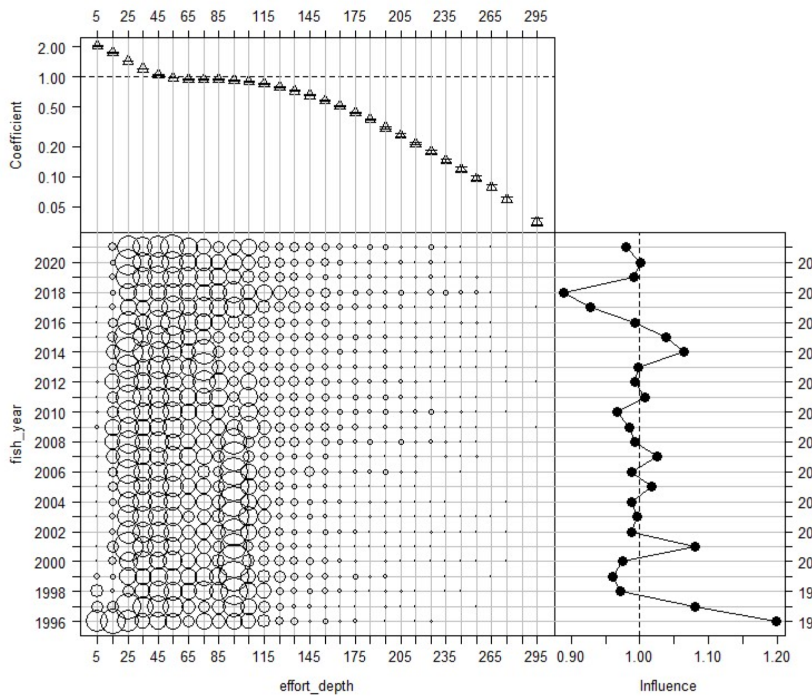
Appendix Figure 91: Normality tests on the final Bay of Plenty logistic model residuals.

The influence plot for "target" shows the high relative effect targeting snapper has on the expected catch rate (Appendix Figure 92). The expected snapper catch rate also shows a strong negative trend with "depth" (Appendix Figure 92).

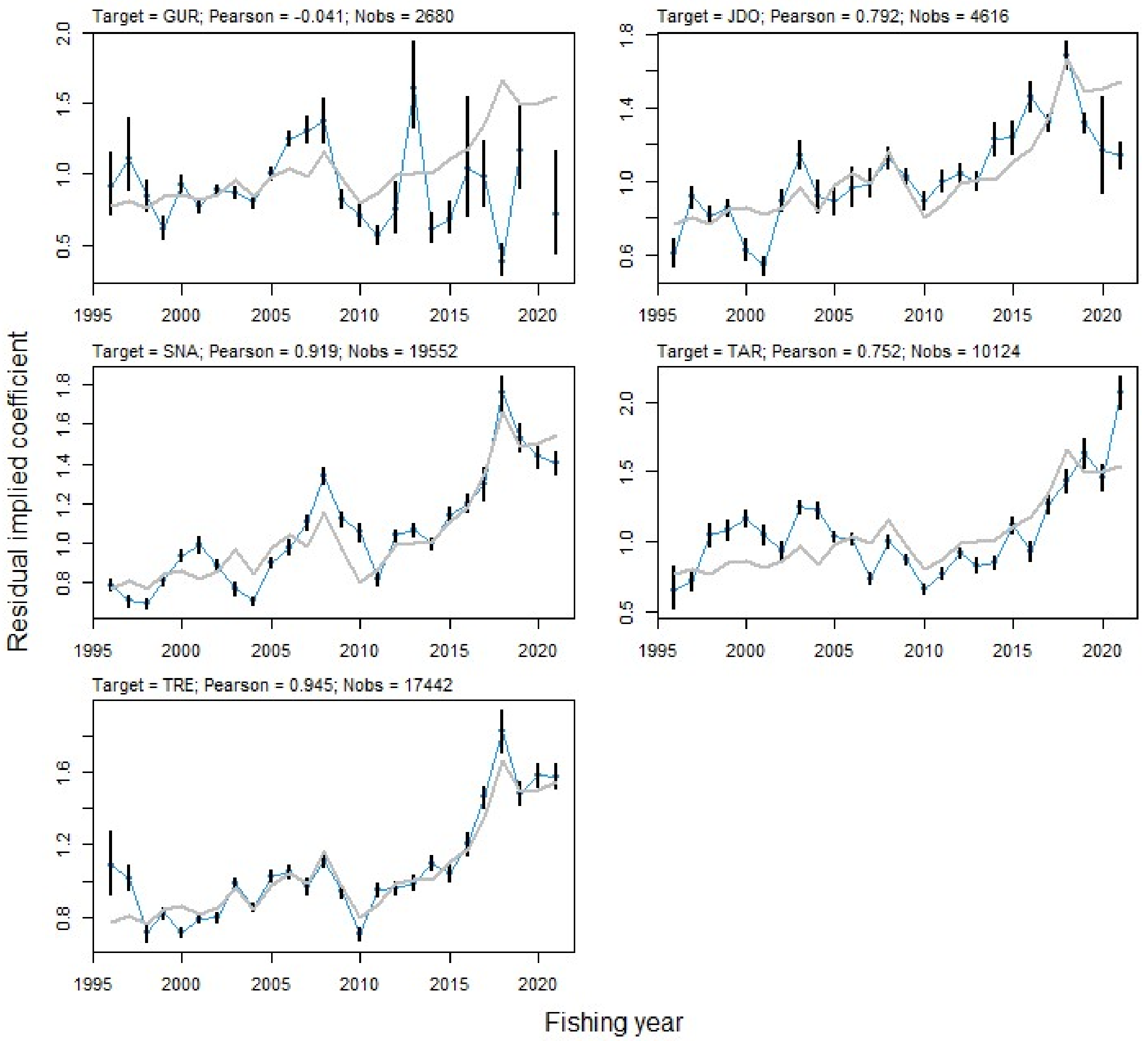
Implied residual plots of the Bay of Plenty bottom trawl positive "target" indices aggregated by "statistical area" were "reasonably" correlated with the overall index (Appendix Figure 93).

Implied residual plots in the Bay of Plenty bottom trawl positive "fishing year" indices aggregated by "statistical area" were strongly correlated with the overall index (Appendix Figure 94), suggesting a reasonable level of snapper abundance homogeneity across the whole Bay of Plenty sub-stock area where bottom trawl operated.

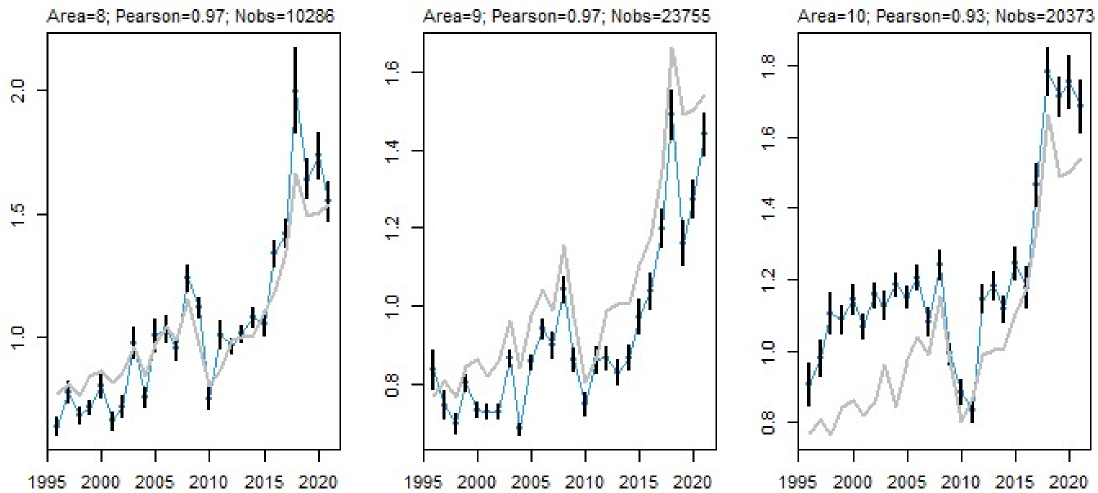




Appendix Figure 92: Bay of Plenty bottom trawl logistic GLM influence plots for target (top) and depth (bottom) parameters.

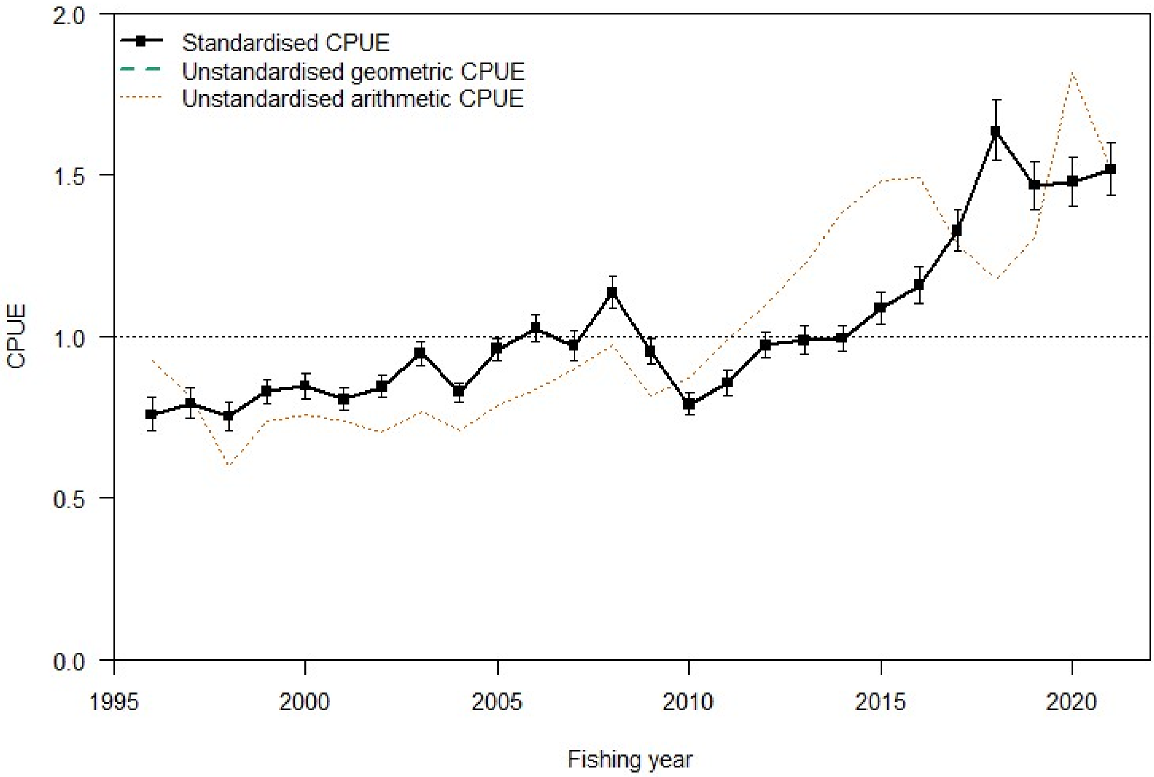


Appendix Figure 93: Bay of Plenty bottom trawl logistic GLM implied residual plots by "target".



Appendix Figure 94: Bay of Plenty bottom trawl logistic GLM implied residual plots by "statistical area".

The Bay of Plenty bottom trawl positive GLM index shows a pronounced increase after 2015–16, being relatively flat prior to this (Appendix Figure 95). The general pattern in 2013 index and the updated index again matched reasonably well over the common years (Appendix Figure 95).



Appendix Figure 95: Bay of Plenty bottom trawl snapper CPUE standardised and unstandardised positive catch indices.

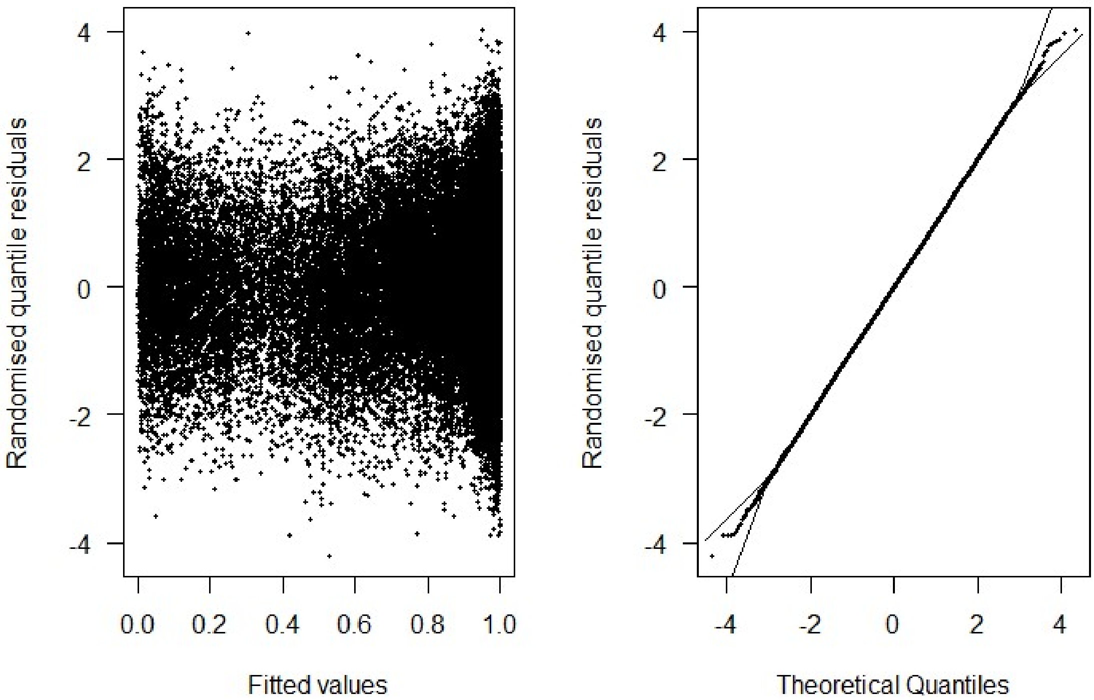
Binomial (positive catch probability) GLM

The Bay of Plenty bottom trawl binomial GLM explained 45% of the variation in the catch probability data (Table Appendix 26). As with the positive model, “depth”, “target”, and “vessel” were the most explanatory variables in the final model (Table Appendix 26).

The binomial GLM fitted residuals were consistent with normality over most of the catch probability space (Appendix Figure 96).

Table Appendix 26: Bay of Plenty bottom trawl fitted binomial GLM parameterisation for response variable positive catch probability.

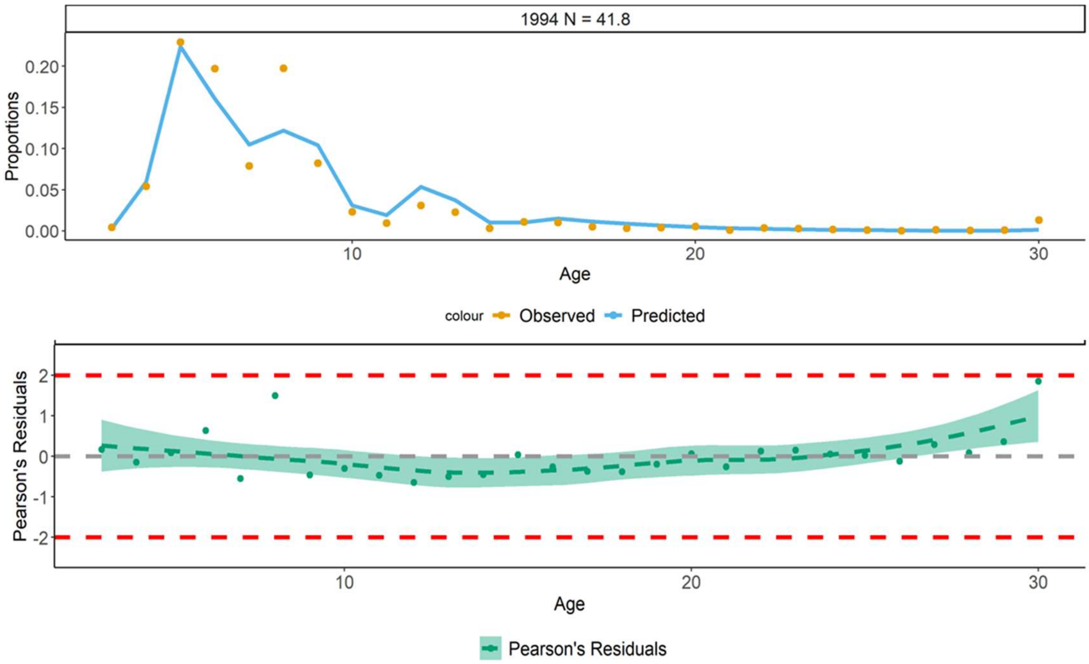
Predictors	Df	R.squared
Fishing year	25	0.01
ns(effort_depth)	3	0.37
target	4	0.42
vessel	13	0.45



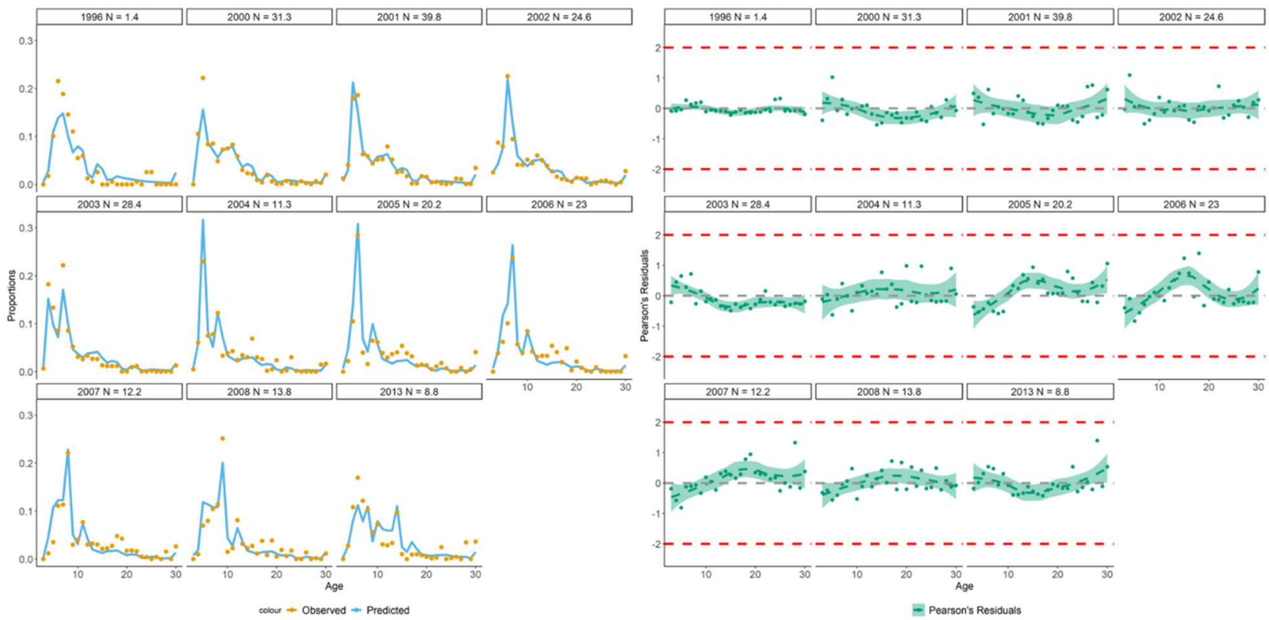
Appendix Figure 96: Normality tests on the final Bay of Plenty binomial model residuals.

Appendix 16: East Northland 1968 base model compositional data fits.

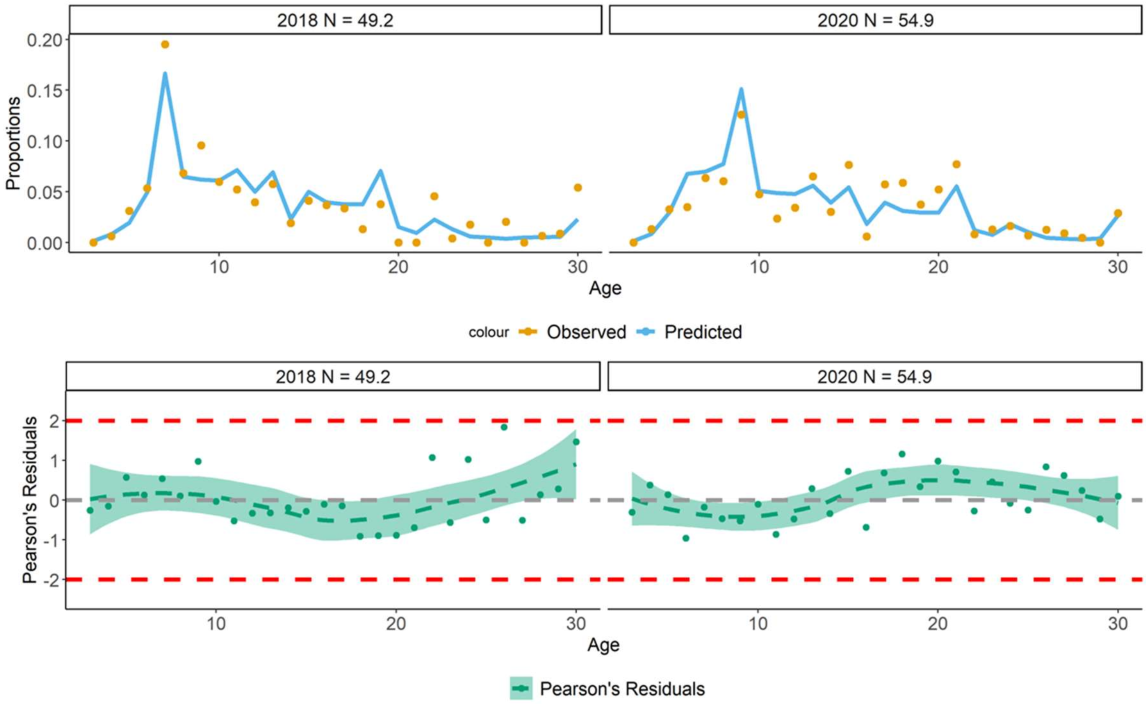
Appendix Figure 97: **East Northland 1968 base model longline compositional fits. N = effective multinomial error after likelihood reweighting.**



Appendix Figure 98: East Northland 1968 base model pre-1995 recreational line compositional fits. N = effective multinomial error after likelihood reweighting.

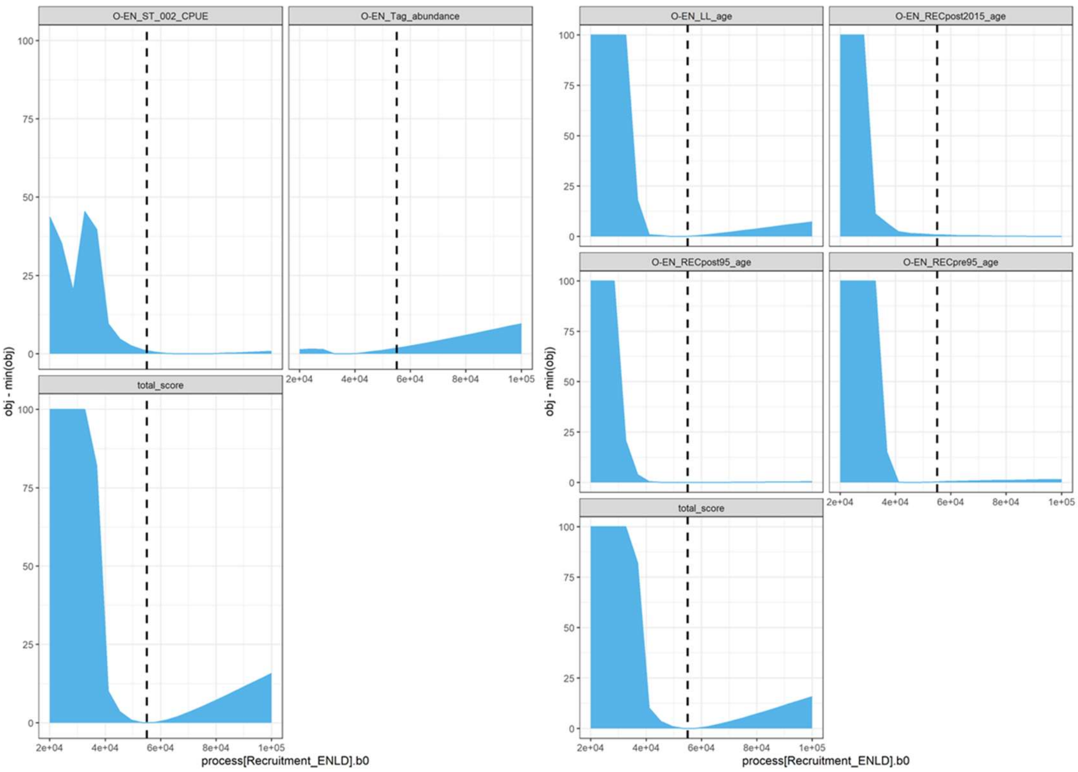


Appendix Figure 99: East Northland 1968 base model post-1995 recreational line compositional fits. N = effective multinomial error after likelihood reweighting.

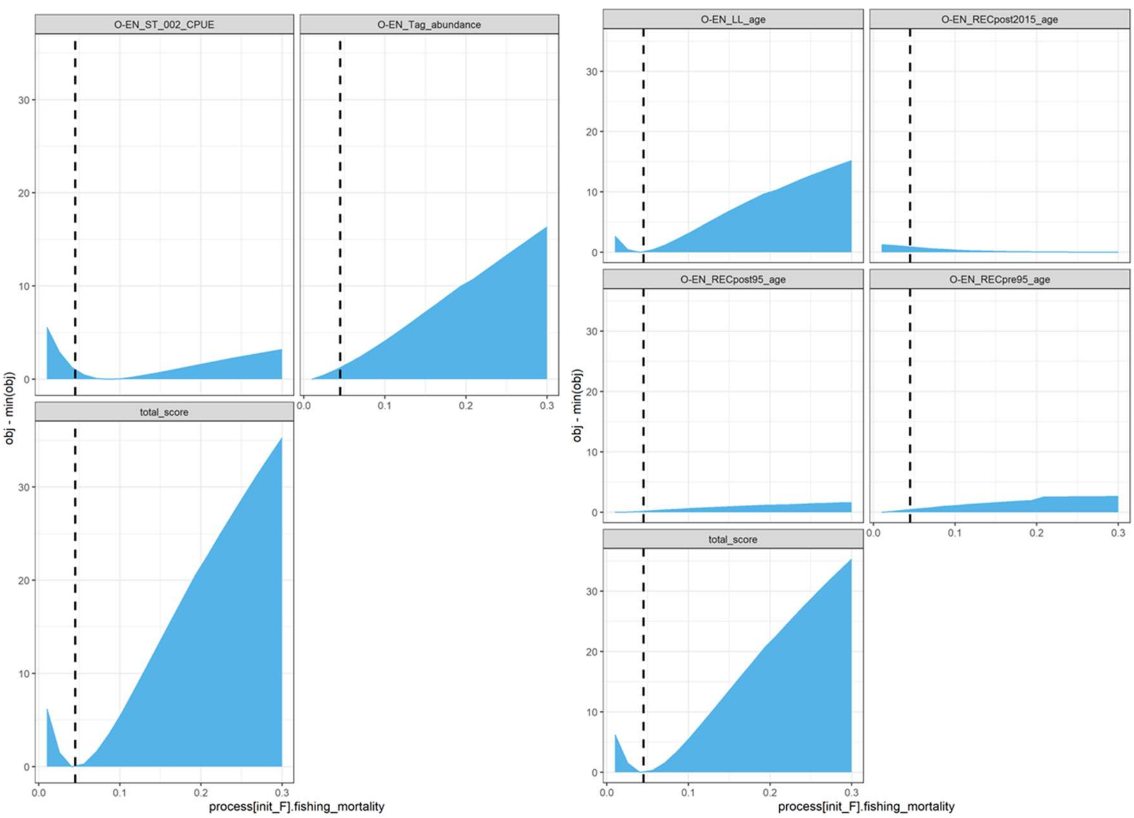


Appendix Figure 100: East Northland 1968 base model post-2018 recreational line compositional fits. N = effective multinomial error after likelihood reweighting.

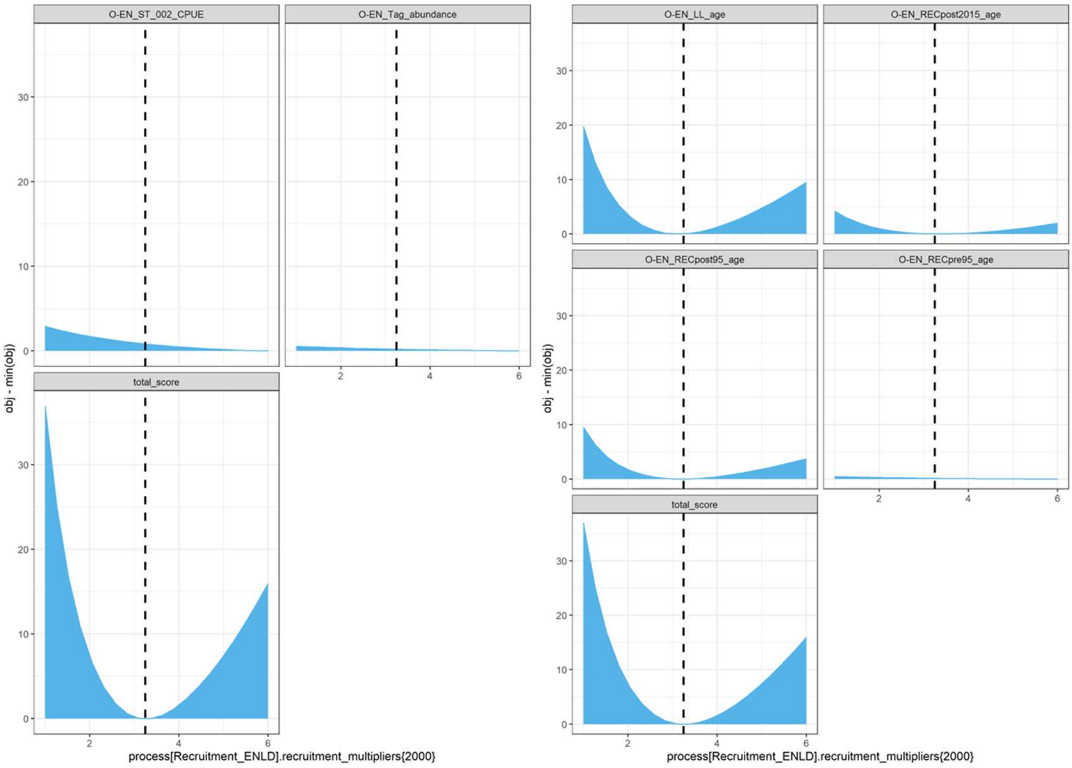
Appendix 17: East Northland 1968 base model likelihood profiles



Appendix Figure 101: B0 likelihood profiles, abundance data left plots, compositional data right plots.



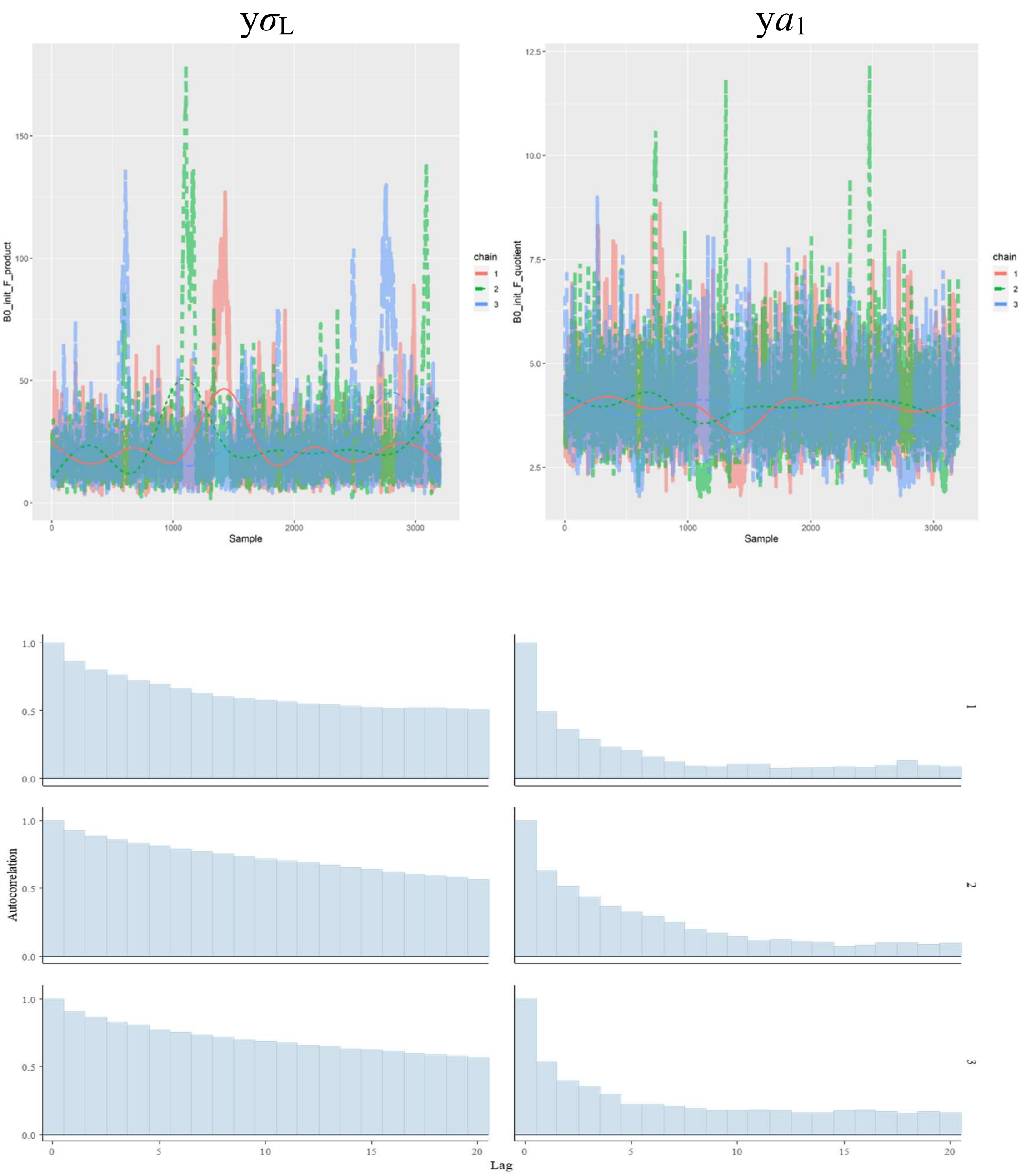
Appendix Figure 102: $F_{initial}$ likelihood profiles, abundance data left plots, compositional data right plots.



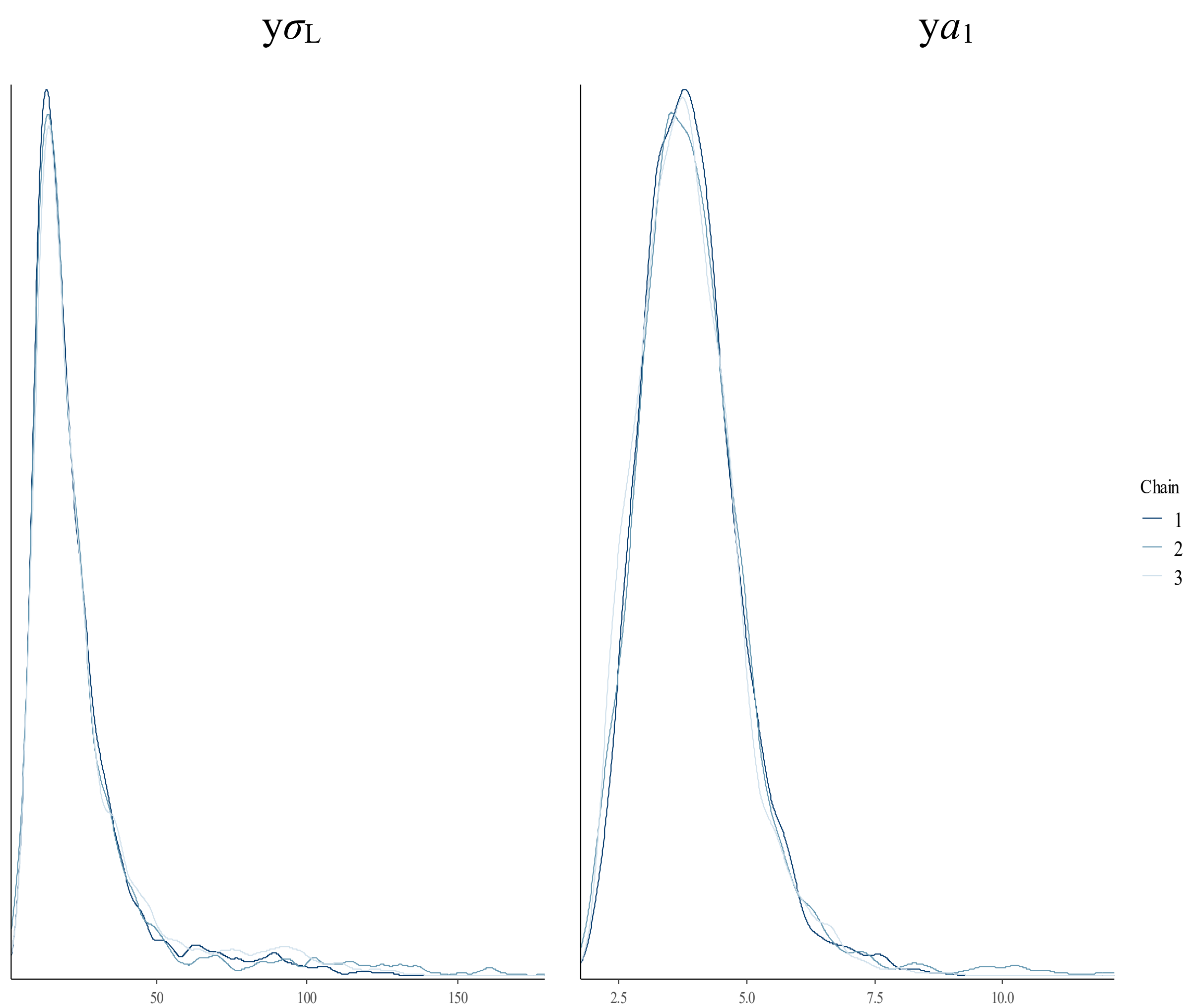
Appendix Figure 103: Model 1999 year-class likelihood profiles, abundance data left plots, compositional data right plots.

Appendix 18: East Northland 1968 base model MCMC diagnostics

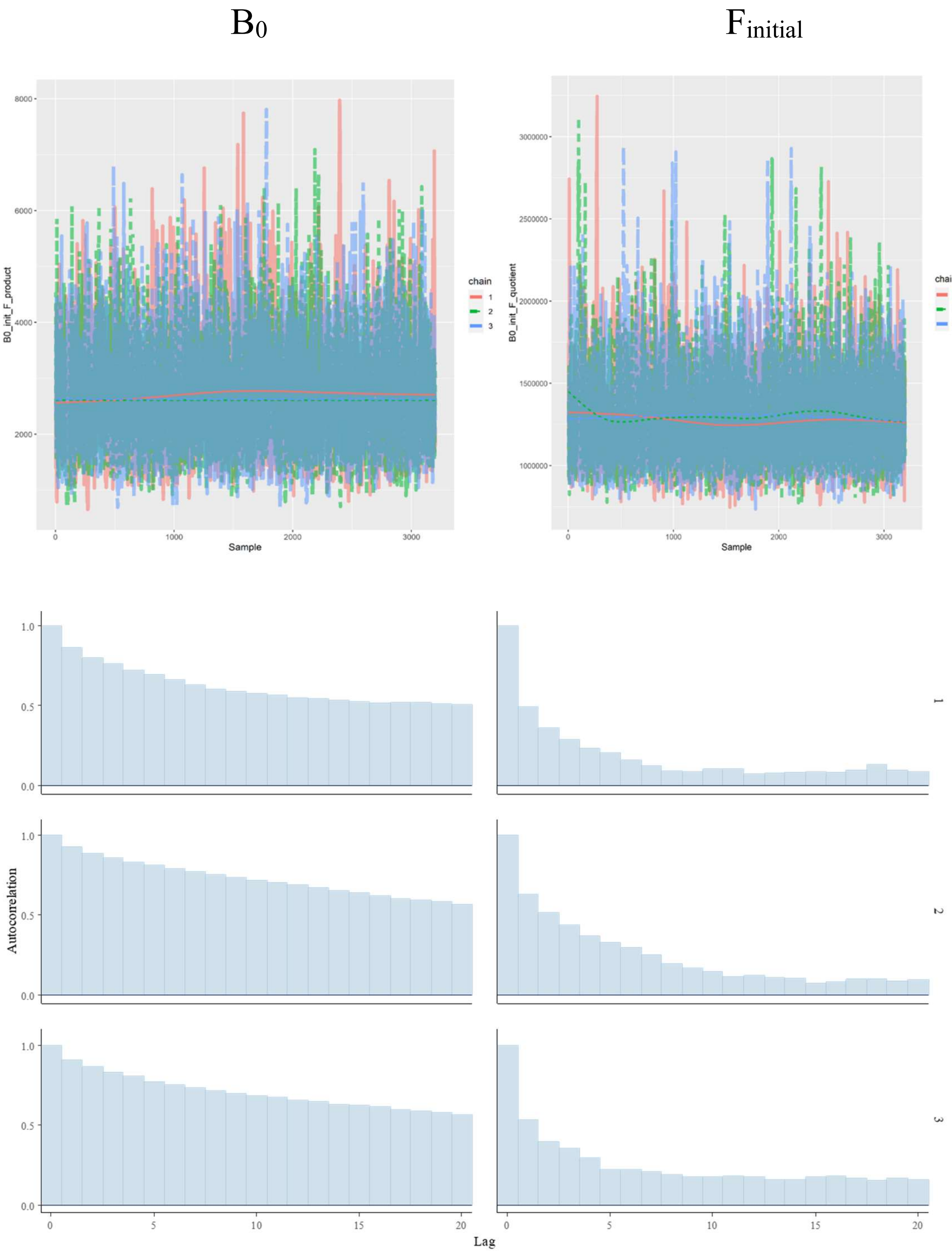
Appendix Figure 104: $\hat{R}$ MCMC between- and within-chain convergence on all 1968 base model free parameters. Values less than 1.05 denote "acceptable" convergence (Vehtari, et al. 2021).



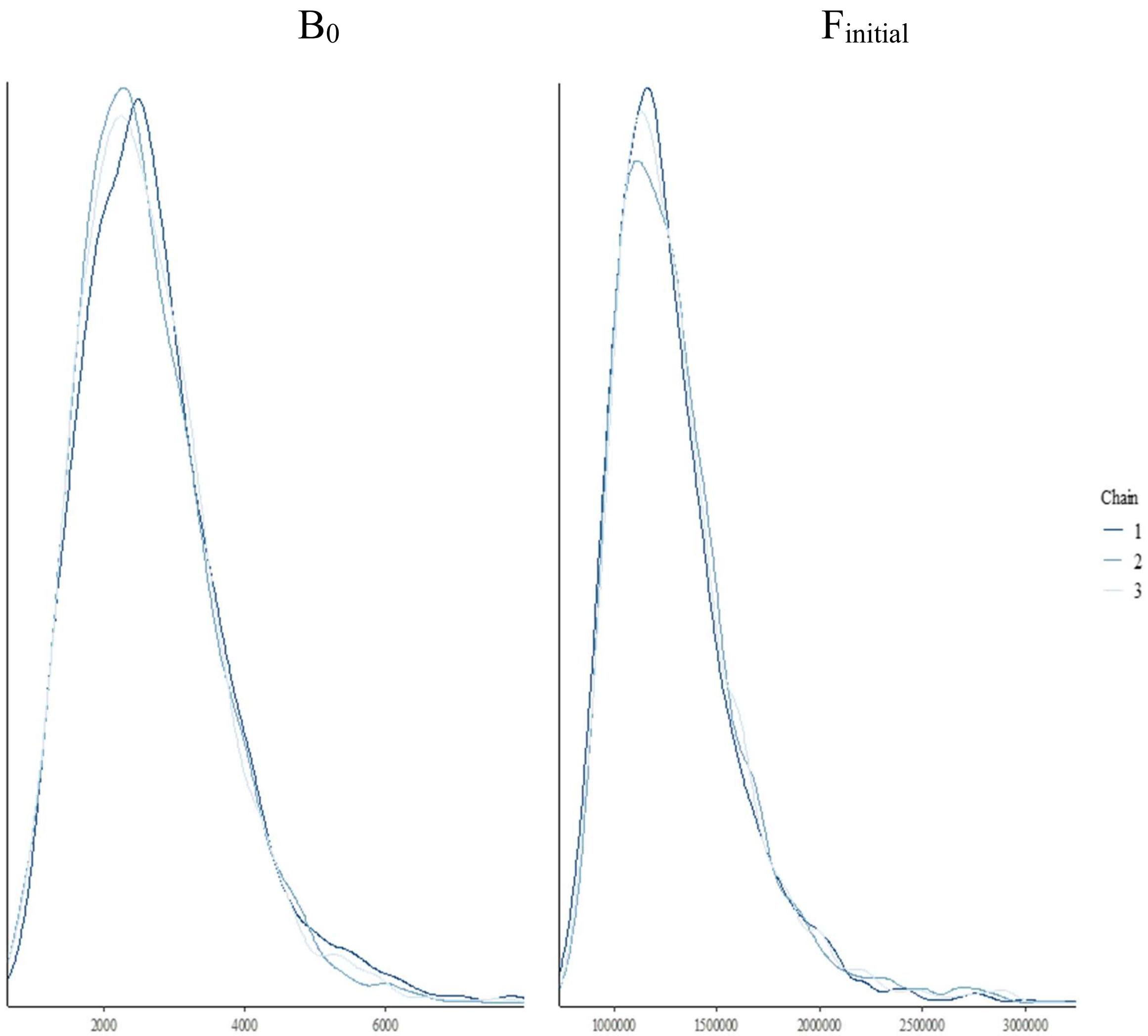
Appendix Figure 105: MCMC chain convergence diagnostics for post-2015 recreational line selectivity parameters $y\sigma_L$ and ya_1 (orthogonally-transformed). Overlaid MCMC chains (top). Level of autocorrelation reduction after 20 samples (bottom).



Appendix Figure 106: MCMC chain convergence diagnostics for post-2015 recreational line selectivity parameters $y\sigma_L$ and ya_1 (orthogonally-transformed) MCMC chain posterior densities overlaid.



Appendix Figure 107: MCMC chain convergence diagnostics for post-2015 recreational line selectivity parameters B_0 and $F_{initial}$ (orthogonally-transformed). Overlaid MCMC chains (top). Level of autocorrelation reduction after 20 samples (bottom).

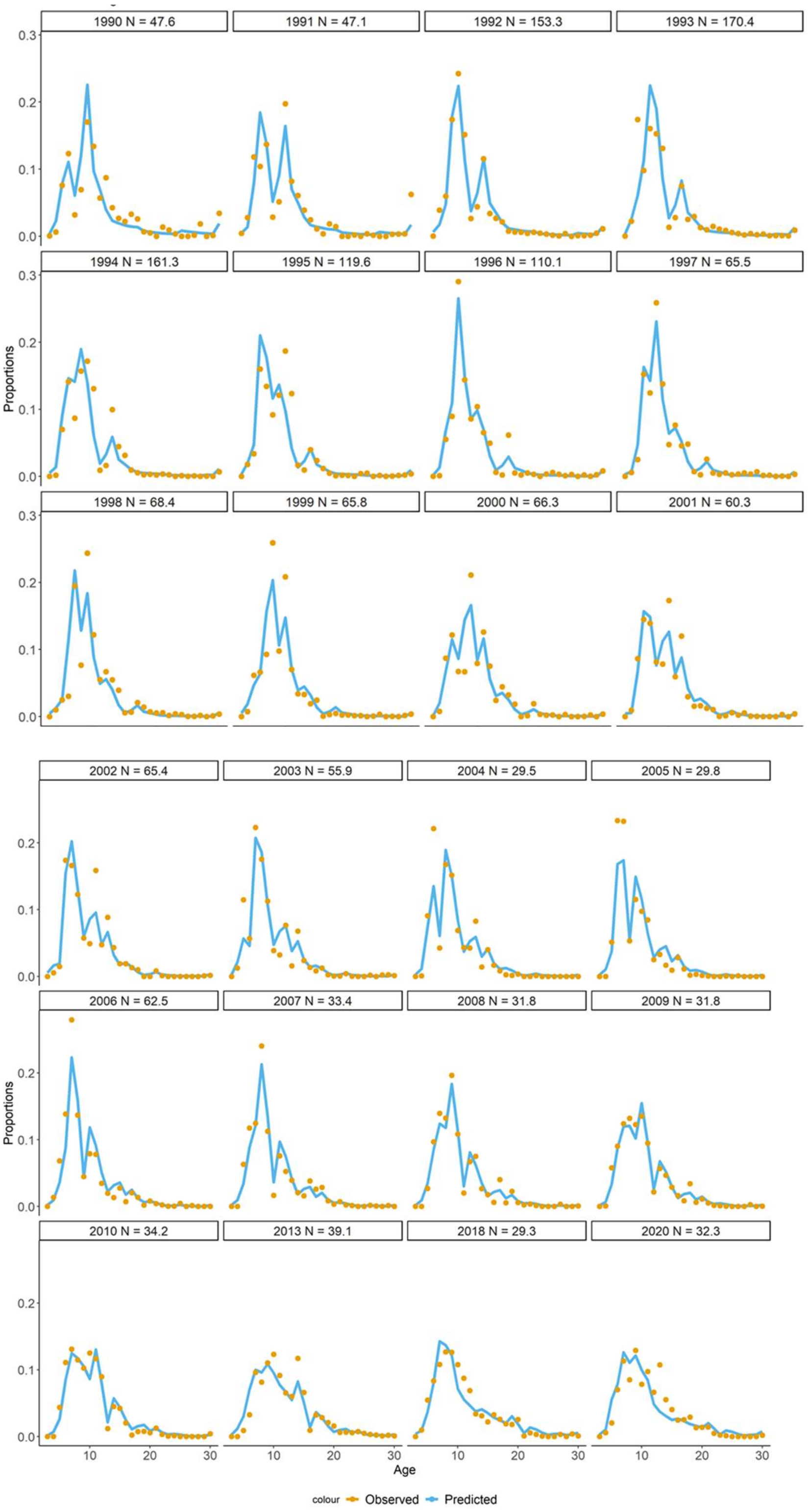


Appendix Figure 108: MCMC chain convergence diagnostics for post-2015 recreational line selectivity parameters B_0 and $F_{initial}$ (orthogonally-transformed) MCMC chain posterior densities overlaid.

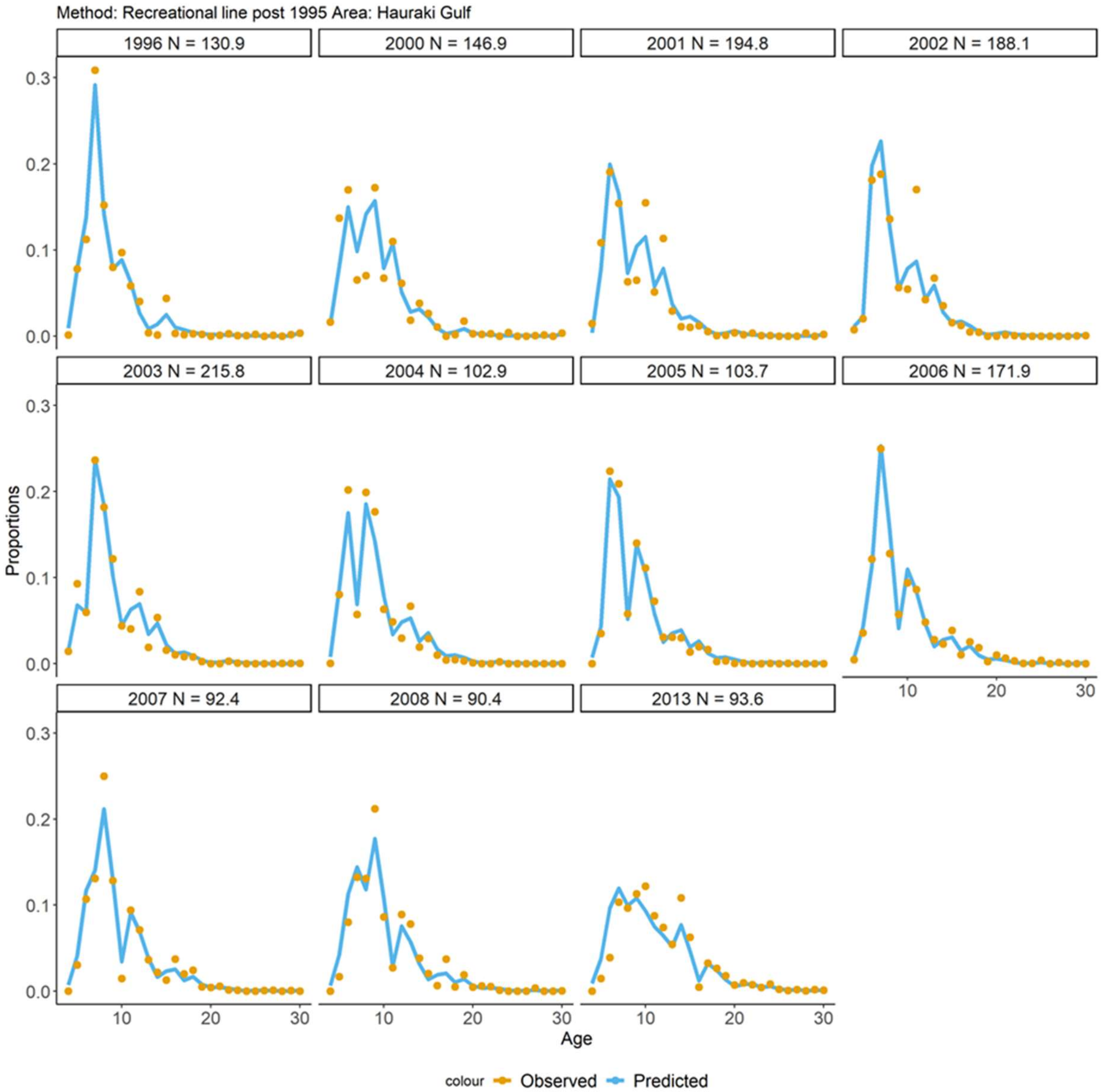
Appendix 19: Fishing-pressure exploitation (U), as used in this report, definition and derivation

Fishing-pressure (U), as used in this report, is simply the ratio of total annual catch to mid-year spawning stock biomass. The U ratio corresponding to 40% B_0 sustainability target ($U_{B40\%}$) was derived through a series of deterministic projections of MPD base model to find the U ratio that corresponded to a projection equilibrium at 40% B_0. U search projections were undertaken with the model fishing method catch ratios and selectivities as per the final fishing year (e.g. 2022).

Appendix 20: Hauraki Gulf 1968 model compositional data fits.

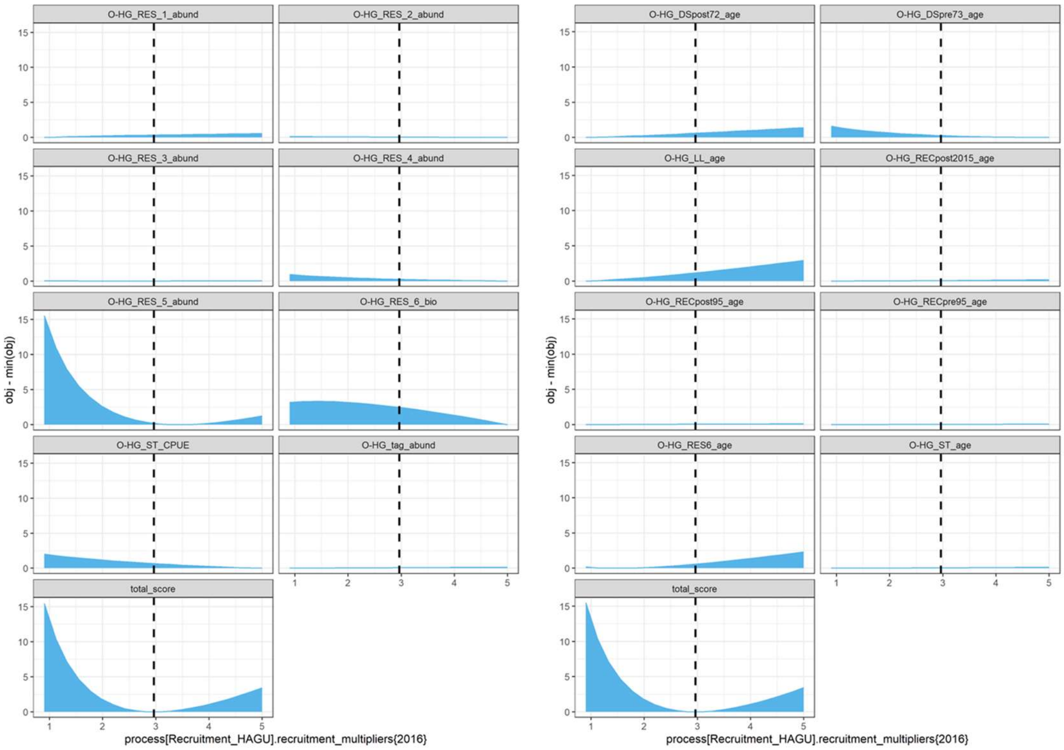


Appendix Figure 109: **1968 model fit to Hauraki Gulf longline at-age data. N= effective multinomial error after likelihood reweighting.**

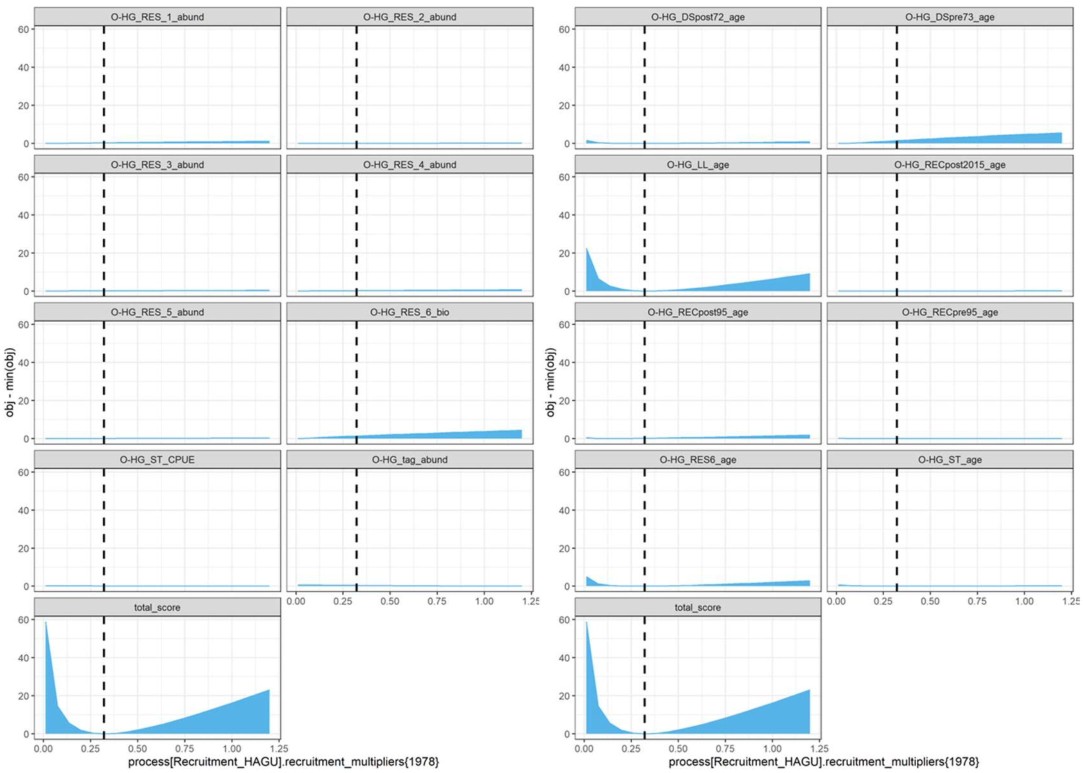


Appendix Figure 110: 1968 model fit to Hauraki Gulf post-1995 recreational line at-age data. N= effective multinomial error after likelihood reweighting.

Appendix 21: Hauraki Gulf 1968 base model likelihood profiles

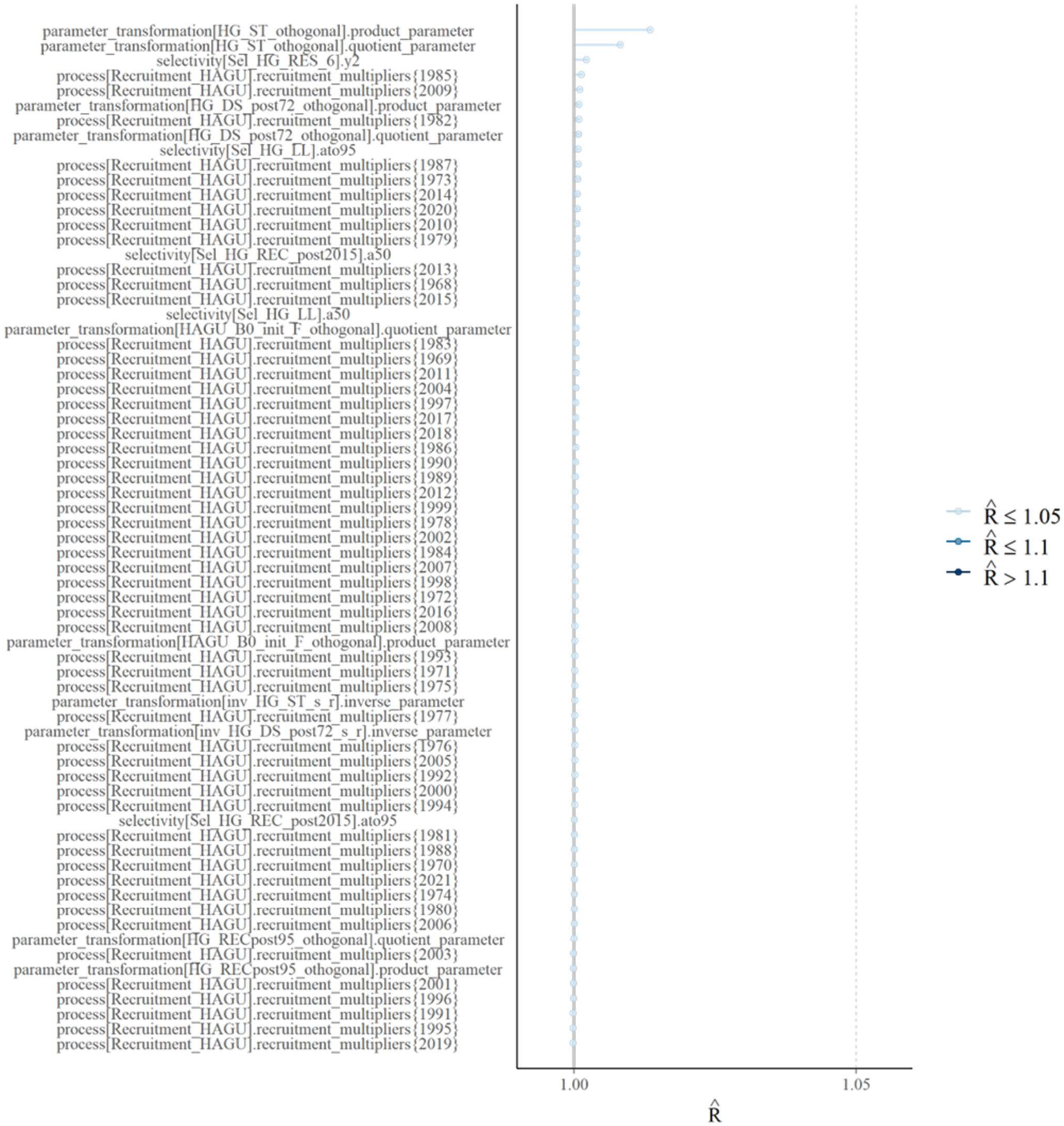


Appendix Figure 111: **Strong 2015 year-class likelihood profiles, abundance data left plots, compositional data right plots.**

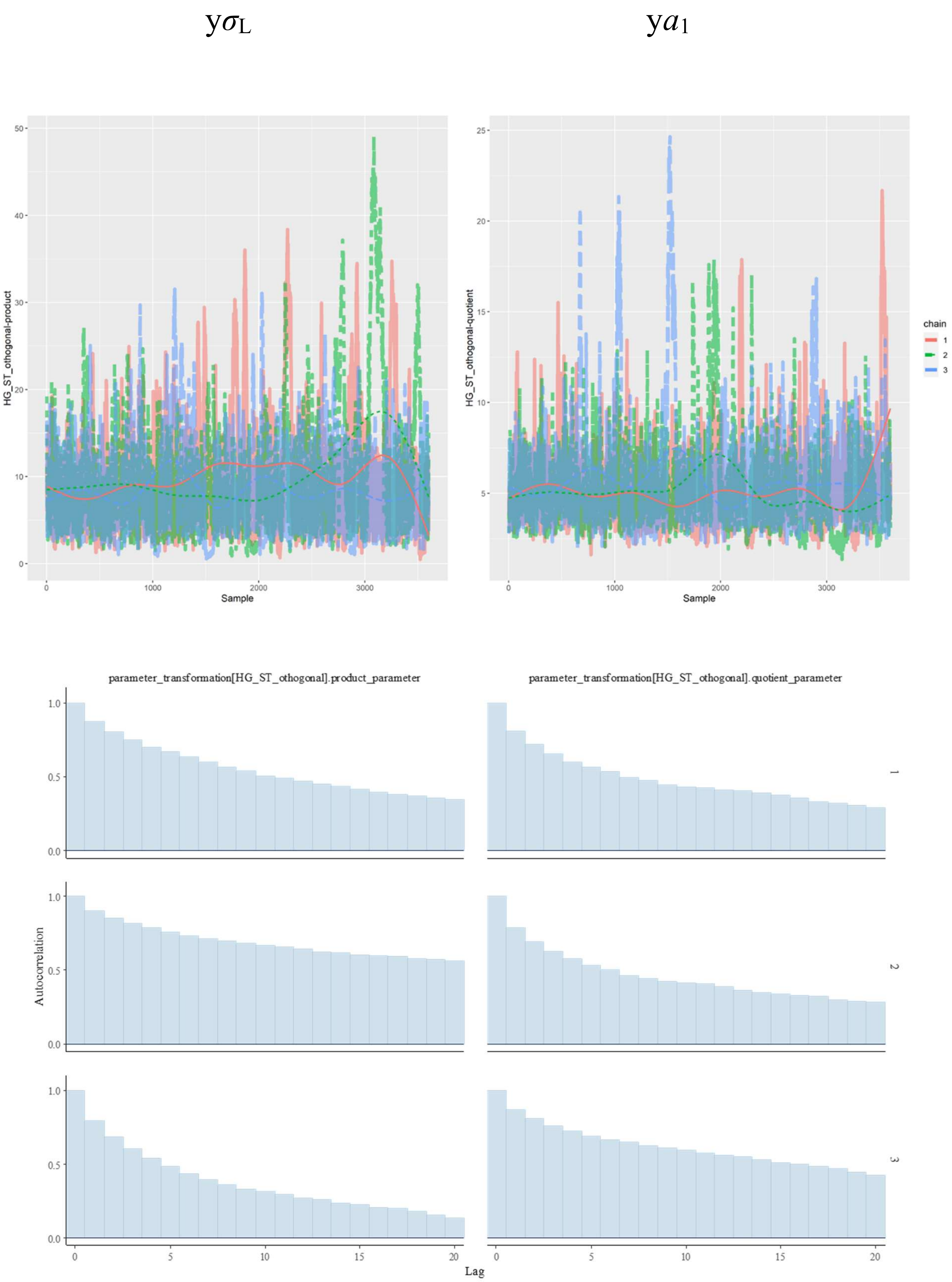


Appendix Figure 112: **Weak 1977 year-class likelihood profiles, abundance data left plots, compositional data right plots.**

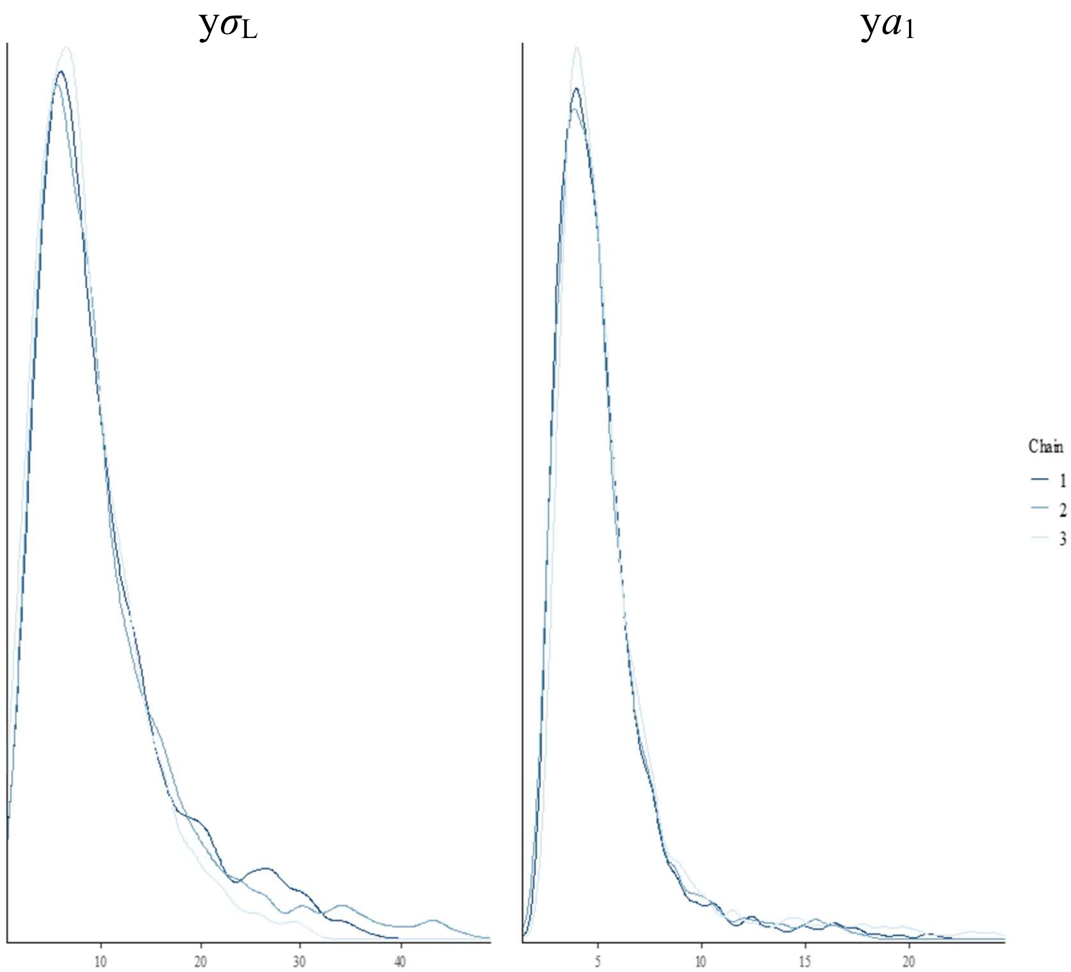
Appendix 22: Hauraki Gulf 1968 base model MCMC diagnostics



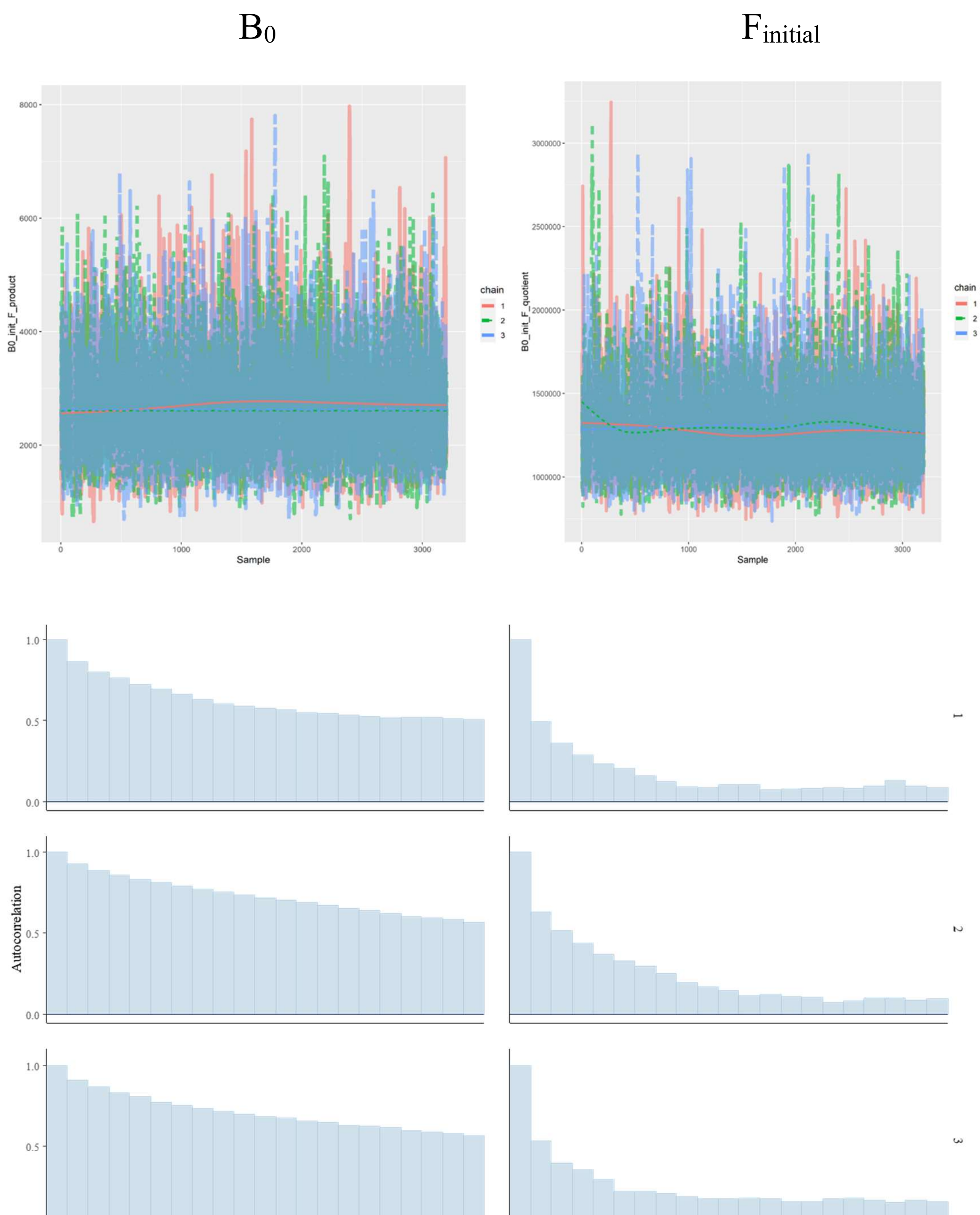
Appendix Figure 113: $\hat{R}$ MCMC between- and within-chain convergence on all 1968 base model free parameters. Values less than 1.05 denote "acceptable" convergence (Vehtari, et al. 2021).



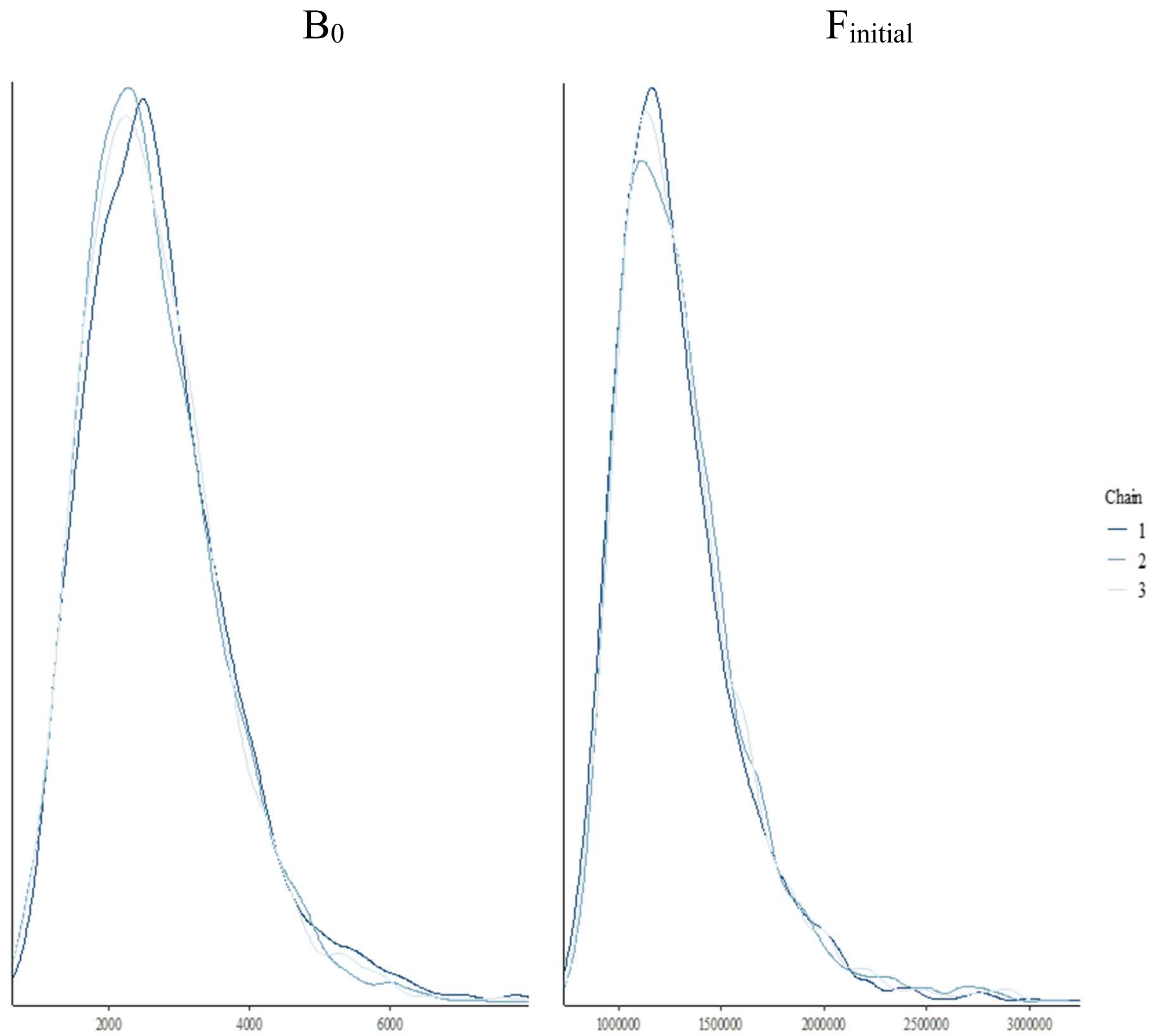
Appendix Figure 114: MCMC chain convergence diagnostics for Hauraki Gulf Bottom trawl selectivity parameters $y\sigma_L$ and ya_1 (orthogonally-transformed). Overlaid MCMC chains (top). Level of autocorrelation reduction after 20 samples (bottom).



Appendix Figure 115: MCMC chain convergence diagnostics for Hauraki Gulf Bottom trawl selectivity parameters $y\sigma_L$ and ya_1 (orthogonally-transformed) MCMC chain posterior densities overlaid.

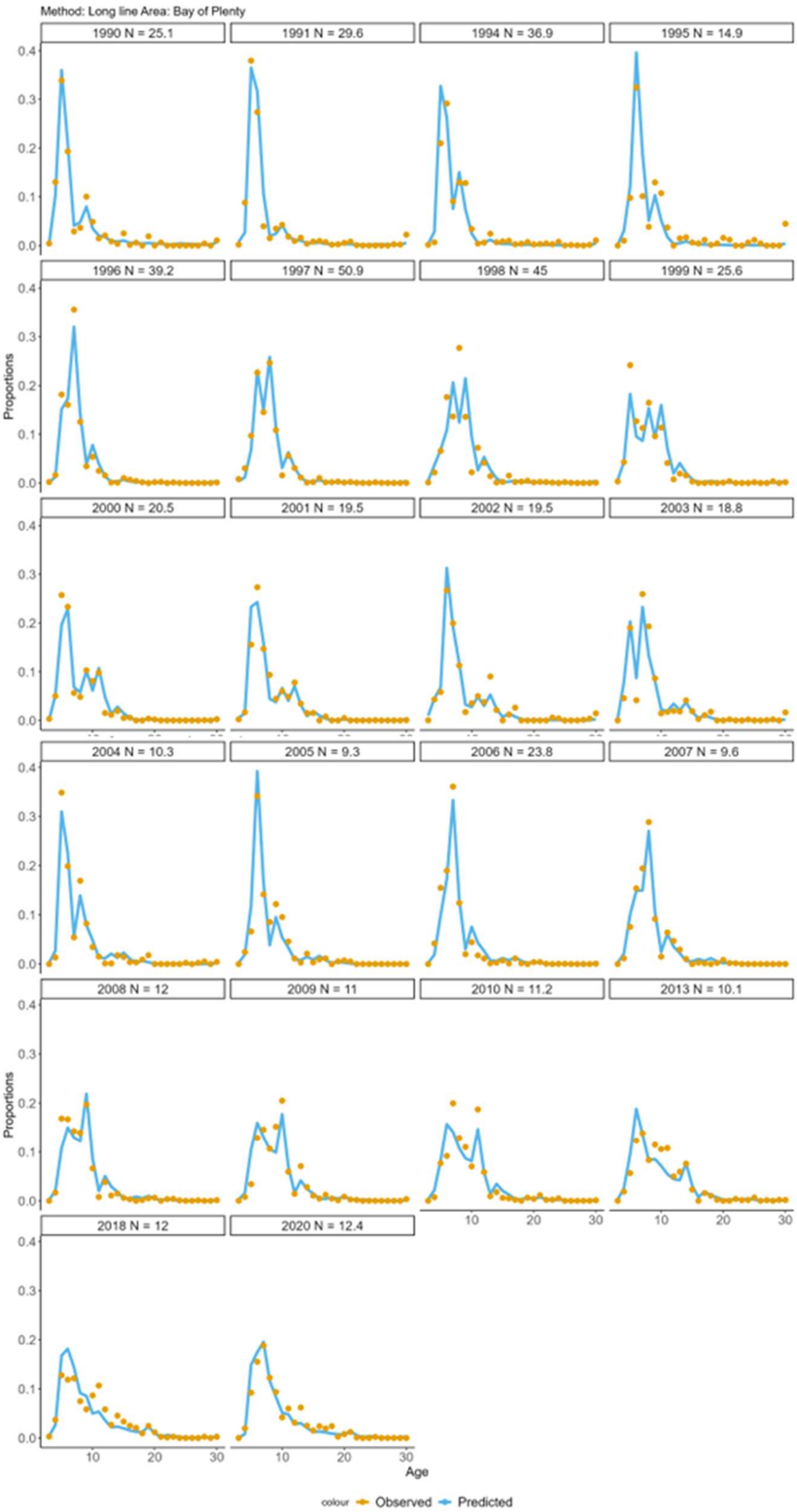


Appendix Figure 116: MCMC chain convergence diagnostics for B_0 and $F_{initial}$ parameters (orthogonally-transformed). Overlaid MCMC chains (top). Level of autocorrelation reduction after 20 samples (bottom).

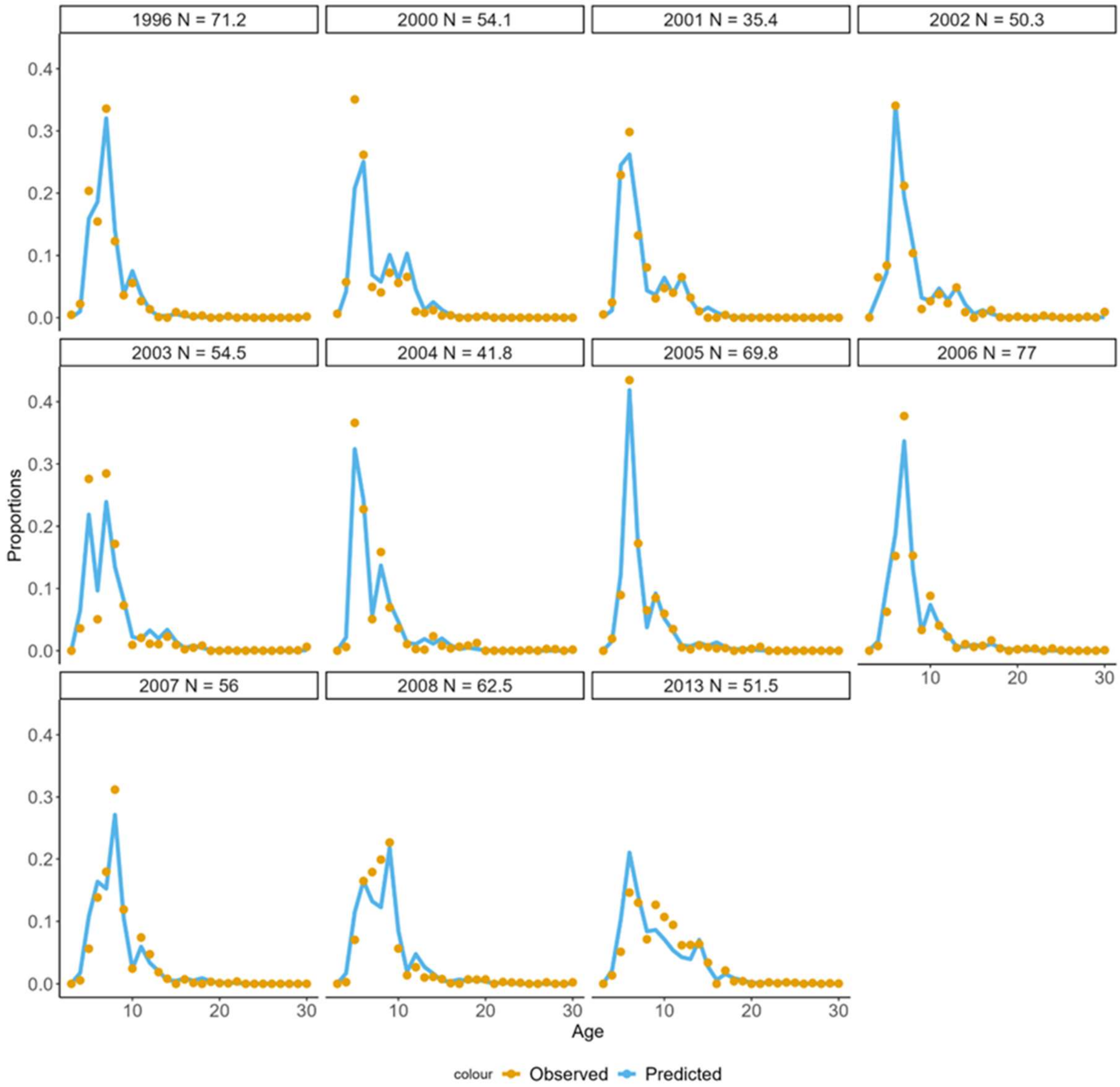


Appendix Figure 117: MCMC chain convergence diagnostics for B0 and Finitial parameters (orthogonally-transformed). (orthogonally-transformed) MCMC chain posterior densities overlaid.

Appendix 23: Bay of Plenty 1968 base model compositional data fits



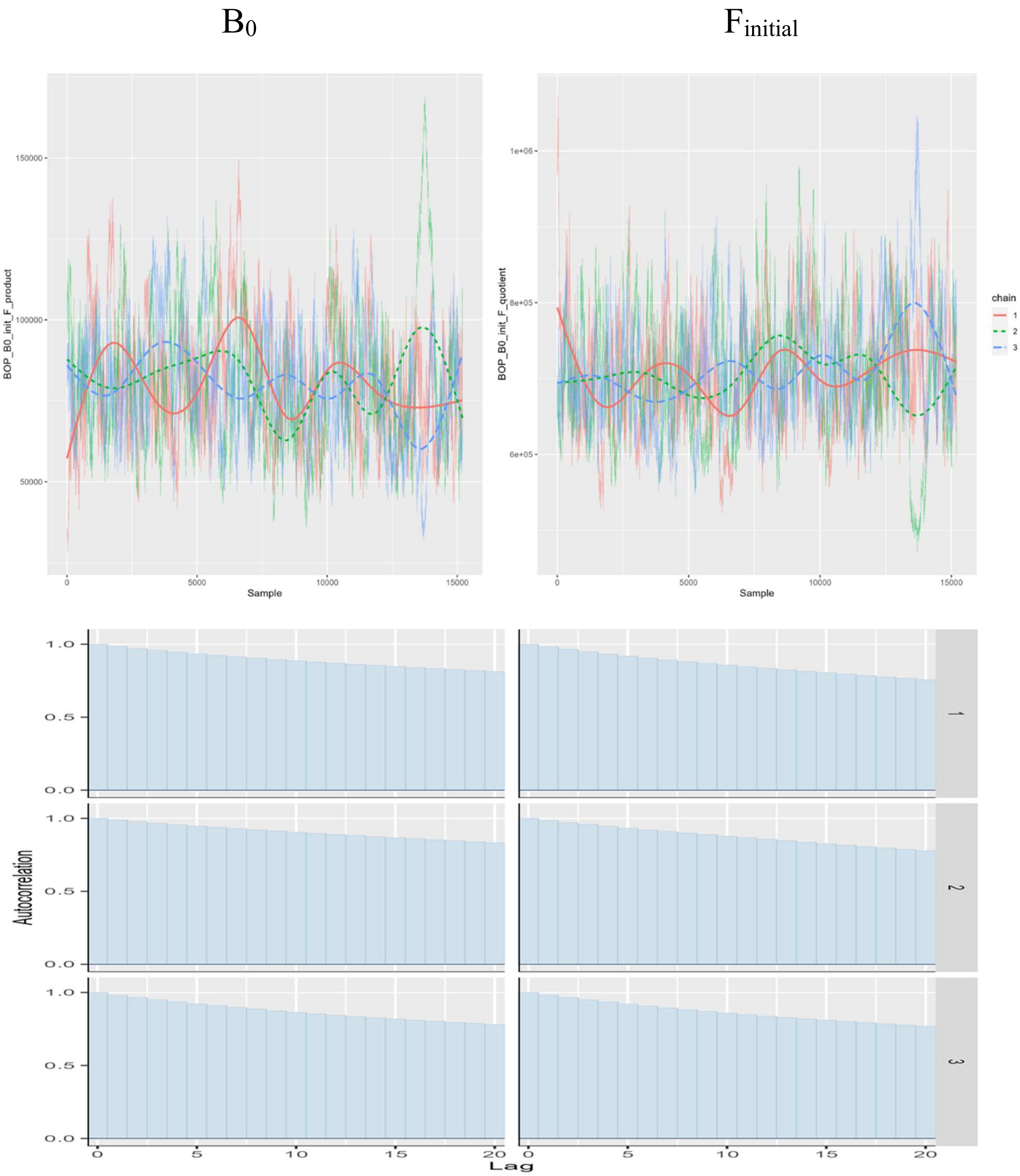
Appendix Figure 118: **Bay of Plenty 1968 base model fit to Bay of Plenty longline at-age data. N= effective multinomial error after likelihood reweighting.**



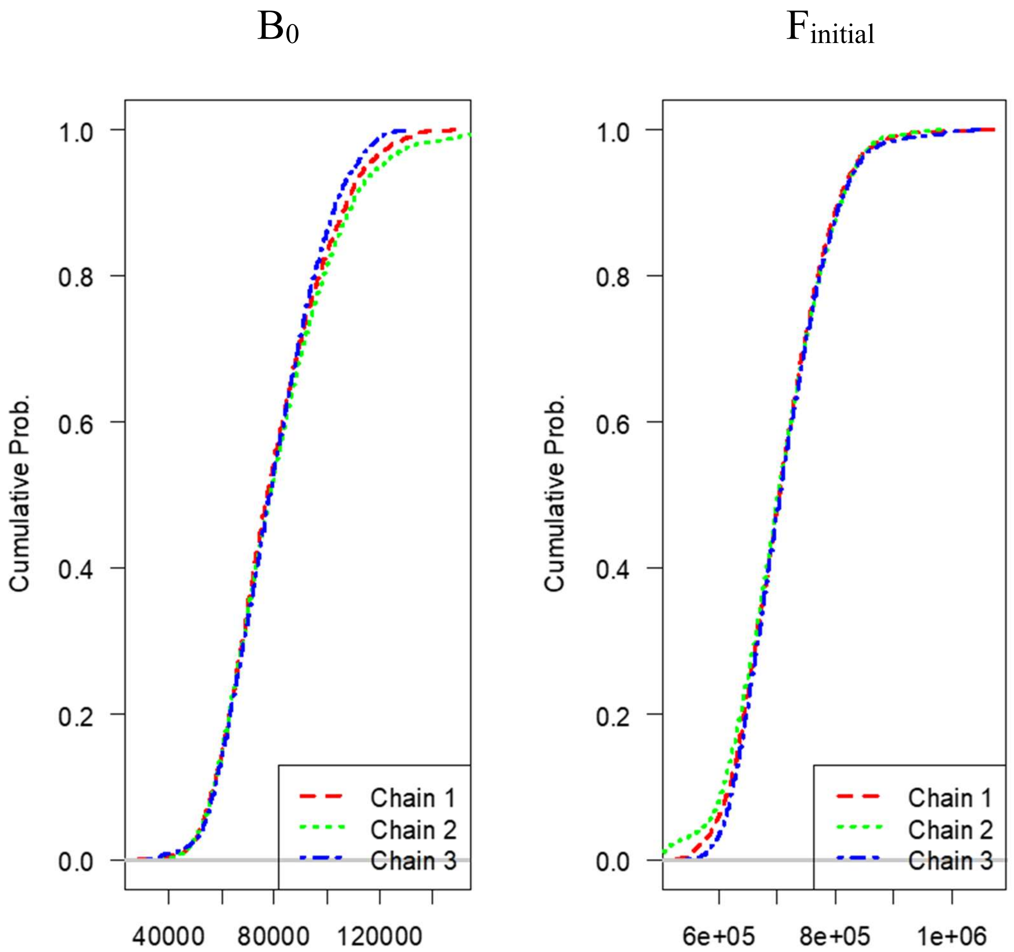
Appendix Figure 119: Bay of Plenty 1968 base model fit to Bay of Plenty post-1995 recreational line at-age data. N= effective multinomial error after likelihood reweighting.

Appendix 24: Bay of Plenty 1968 base model MCMC diagnostics

Appendix Figure 120: $\widehat{R}$ MCMC between- and within-chain convergence on all Bay of Plenty 1968 base model free parameters. Values less than 1.05 denote "acceptable" convergence (Vehtari, et al. 2021).



Appendix Figure 121: MCMC chain convergence diagnostics for B_0 and $F_{initial}$ parameters (orthogonally-transformed). Overlaid MCMC chains (top). Level of autocorrelation reduction after 20 samples (bottom).



Appendix Figure 122: MCMC chain convergence diagnostics for B_0 and $F_{initial}$ parameters (orthogonally-transformed) MCMC chain posterior densities overlaid.