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Stock assessment of kahawai (*Arripis trutta*) in 2021 for KAH 1, 1930–31 to 2019–20

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EXECUTIVE SUMMARY

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***New Zealand Fisheries Assessment Report 2022/54*. 66 p.**

This report describes the 2021 assessment of the kahawai (*Arripis trutta*) stock off the northeast of the North Island (KAH 1). The assessment was based on an update of the previous 2015 CASAL stock assessment model. Model inputs that were revised as part of this assessment included: the addition of regional recreational catch-at-age composition data collected during the first four months of 2016, 2017, and 2018; recreational and commercial catch histories that were updated to the end of the 2019–20 fishing year; and updated recreational catch-per-unit-effort (CPUE) indices.

A review of the updated recreational catch composition data at an early stage of the research led to the decision to reconfigure the assessment from a single area to a fleets-as-areas model structure. This was done because there was clear evidence of consistent regional differences in the age composition of recreational landings, with further evidence of an episodic influx of older and larger fish migrating from the Bay of Plenty to the Hauraki Gulf around 2010. The methods previously used to combine the recreational catch-at-age data from these three regions into a single catch-at-age time series for the single area model (2015 assessment) were no longer considered appropriate.

The primary abundance indices used to inform this and the previous KAH 1 assessments were derived from recreational CPUE data, which were standardised here for the first time, using negative binomial and zero inflated negative binomial generalised linear modelling methods. A novel zero inflated negative binomial modelling approach was also developed and applied to reconstruct regional recreational catch histories, given the observed rate at which kahawai have been landed at boat ramp surveys conducted intermittently throughout KAH 1 since 1990–91. This assessment model was therefore almost entirely informed by data sourced from surveys of recreational fisheries, but catch-at-age data sampled from the main commercial fisheries over a small number of years were still used to estimate selectivities, to model the removals by age for this sector.

The main source of uncertainty explored during this assessment was the assumed rate of natural mortality (M). Early exploitation age composition data were reviewed during the initial stages of this assessment, and likelihood profiling of M suggested that the plausible range of values for this parameter may have been higher than previously thought. A mid-range value of 0.22 y^{-1} was assumed for the base case MCMC model, alongside sensitivity MCMC model runs where lower and upper natural mortality rates were assumed (0.20 $y^{-1}$and 0.24 y^{-1}, respectively). Regardless of the assumed M, however, all three models indicated a current stock status that was close to or above the target level of 52% B_0, which was set by the Minister of Fisheries in 2010.

[1] National Institute of Water and Atmospheric Research (NIWA), New Zealand.

1. INTRODUCTION

Populations of kahawai (*Arripis trutta*) support valued customary, recreational, and commercial fisheries in New Zealand, with most of the catch taken off the north-eastern coast of the North Island (KAH 1). A related, though far less common, species (*A. xylabion*) is also sometimes caught around the top of the North Island, although landings of this species are thought to be insignificant.

Although customary fisheries for kahawai are among the first described by early European settlers, levels of exploitation are thought to have been relatively light up until the mid-1970s, when the commercial harvest rapidly increased following the development of a multi-species purse seine fishery. Recreational fishers began to express some concern about commercial fishing pressure in the late 1980s, however, which led to the introduction of purse seine kahawai catch limits and commercial kahawai catch sampling during the early 1990s.

The first quantitative kahawai stock assessment was a stock reduction model analysis undertaken by Bradford (1996, 1997), which assumed that the kahawai resource was a single New Zealand wide stock

> "*... because of the difficulty in estimating immigration to and emigration from the kahawai Fishstocks as they are defined*" (Bradford 1997).

A subsequent review of available tagging data by Hartill & Walsh (2005) found only limited evidence of immigration and emigration to and from KAH 1.

The first age structured stock assessment for the KAH 1 stock was implemented in CASAL (Bull et al. 2008, 2012) in 2007 (Hartill 2009). Most of the data used in that assessment were catch-at-age data collected annually from recreational fisheries between 2000–01 and 2005–06. Recreational landings were sampled because amateur fishers interacted with a far greater number of kahawai schools in a more random and representative manner than the commercial sector. The main outcome of that assessment was an exploration of model sensitivity to four key sources of uncertainty: assumed values for natural mortality (M); the steepness of a Beverton-Holt stock recruitment relationship (h); choice of abundance index; and different constant levels of recreational catch.

The 2007 assessment was updated in 2015, to include catch-at-age data collected from recreational and commercial landings between 2006–07 and 2011–12 (Hartill & Bian 2016). The 2007 model was reconfigured from a fleets-as-areas model to a single area / single fleet per method model configuration, and the influence of alternative assumed natural mortality values and the choice of abundance index on the stock size and status estimates were assessed.

The 2015 stock assessment was updated in 2021 for Fisheries New Zealand research project KAH2020-01 (reported here), to include additional regional catch-at-age data sampled from the recreational KAH 1 fishery in 2015–16, 2016–17, and 2017–18, as well as updated catch histories. The structure of the stock assessment model was also revised, along with the methods used to estimate recreational catch histories and generate recreational catch-per-unit-effort (CPUE) indices. A base case and two sensitivity models were used to estimate alternative stock size and status trajectories for the KAH 1 stock, with Markov Chain Monte Carlo (MCMC) estimates of parameter uncertainty.

Objectives

1. To collate and update catch histories through to 2019–20 and all observational data series required for the KAH 1 stock assessment.

2. To conduct a stock assessment, including estimating biomass and sustainable yields for kahawai in KAH 1.

2. DEFINITION OF THE KAH 1 STOCK

The population of kahawai in KAH 1 is assumed to be a single stock (Figure 1). Tagging programmes conducted in 1981–84 (Wood et al. 1990) and in 1991 (Griggs et al. 1998) showed that although individual kahawai can undergo migrations over hundreds of miles, most recaptured fish were within 100 nautical miles of their release location. Only a small percentage of the kahawai tagged in KAH 1 were recaptured outside this area. The insights into stock structure provided by these tagging programmes are limited, however, because most of the tagged fish were released in the Bay of Plenty, and because almost no tagging occurred in the Hauraki Gulf. Another limitation with these data is that the location of recaptures was influenced by the spatial distribution and intensity of fishing effort likely to capture kahawai, which mainly occurred in the Bay of Plenty.

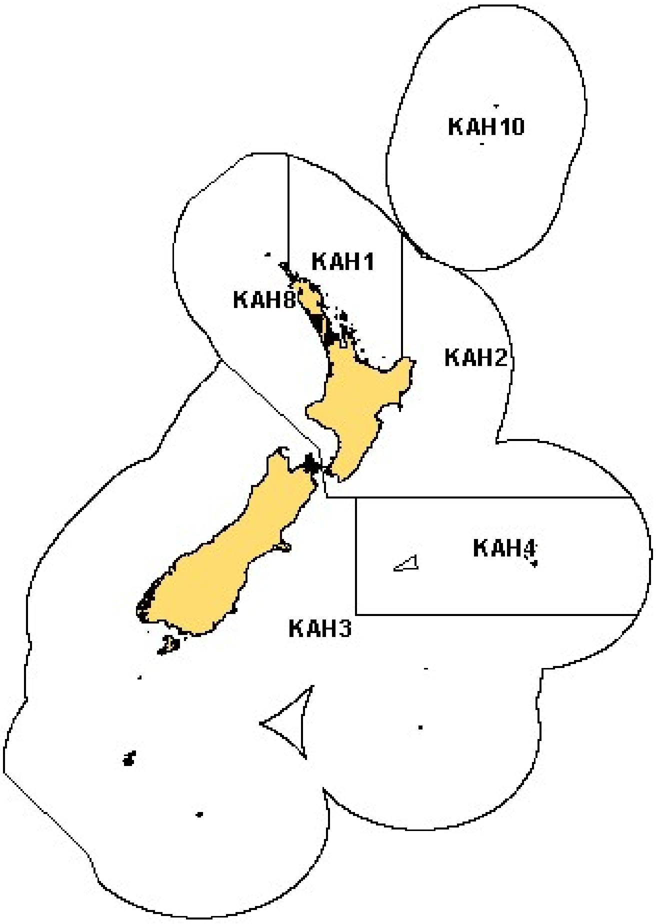


Figure 1: Quota Management Areas for kahawai Fisheries New Zealand (2022).

The potential use of otolith microchemistry and meristics to define kahawai stock boundaries was explored (Smith et al. 2008), but the results were inconclusive. Genetic marker methods also found no evidence for population structuring around New Zealand. As part of an MSc study, Hodgson (2011) analysed tissue sampled from 182 kahawai collected from throughout New Zealand, and from a further three fish from Australia, and concluded that:

> *"There is very little evidence of population genetic structure in the samples of A. trutta collected in New Zealand or Australia."*

and that

> *"It was found that a single, highly connected population of A. trutta inhabit New Zealand waters, and approximately 15 migrants per generation make the journey between New Zealand and Australia, genetically linking these populations."*

The stock structure of kahawai around New Zealand is therefore still considered uncertain. Hence, we assume that the population of kahawai in KAH 1 represents a distinct stock, and that migrations to and from this area have a negligible effect on the age composition, biomass, and productivity of the KAH 1 stock. The possibility remains that all kahawai in New Zealand belong to a single interconnected stock, but there is insufficient information currently available to accept this hypothesis.

Although the KAH 1 stock was regarded as a single population in the 2007 and 2015 assessments, consistent regional differences were evident in recently observed recreational catch-at-age distributions (Armiger et al. 2019). The age distributions of recreational landings from the Bay of Plenty, and to a lesser extent in East Northland, were broad, whereas recreational landings from the Hauraki Gulf between 2001 and 2008 were dominated by immature 3 year old fish. There has since been a sudden influx of much larger fish into the Gulf (in around 2009), but distinct regional differences in the age distributions of kahawai landed by recreational fishers are still evident (Armiger et al. 2019). Separate selectivities are therefore estimated for the recreational fisheries in each region, to account for their differing impact on the KAH 1 stock. The changing selectivity of the recreational fishery in the Hauraki Gulf, as a result of the influx of larger fish in around 2009, was further investigated as part of this assessment.

3. BIOLOGICAL PROCESSES AND PARAMETERS

3.1 Growth rates

Von Bertalanffy growth model parameter estimates for the KAH 1 stock were reviewed by Hartill & Walsh (2005), who found no significant difference between the growth of males and females.

Growth rates can potentially vary over time, however, and annual length-at-age data collected from recreational landings sampled during thirteen summers between 2001 and 2018 were compared (Figure 2). Nonlinear least squared regressions implemented using the *R* package *FSA* were used to estimate von Bertalanffy growth rate parameters for each year.

This comparison suggested that growth had been relatively consistent over the period examined. All length-age data collected since 2000–01 were therefore pooled and used to estimate up-to-date von Bertalanffy parameters. The resulting revised growth parameters used in this assessment were very similar to those reported by Hartill & Walsh (2005) (Figure 3).

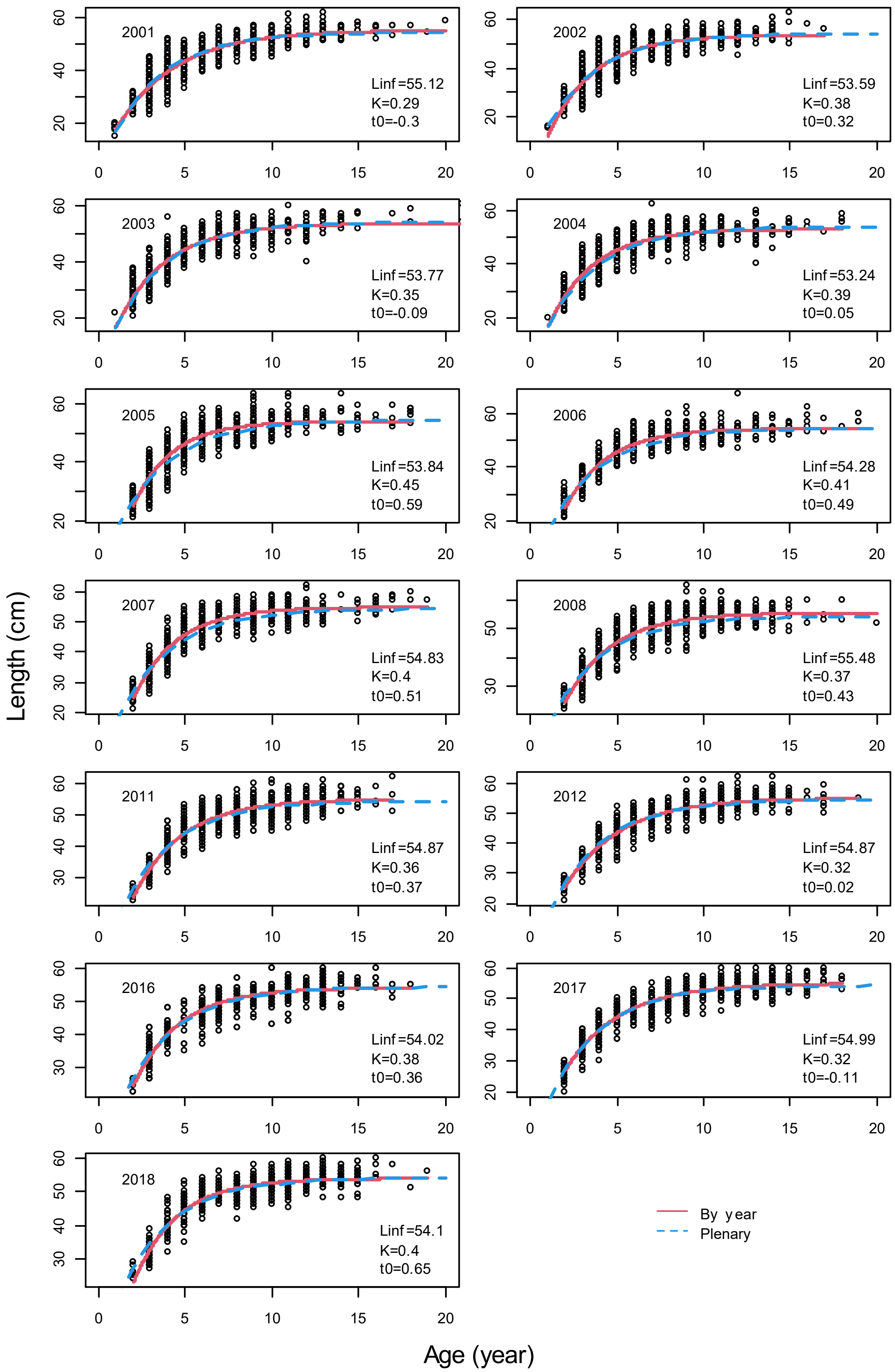


Figure 2: Annual von Bertalanffy growth curves fitted to recreational catch-at-age data collected in KAH 1 since 2001. The solid red lines denote the von Bertalanffy relationship for each year and the dashed blue lines denote the default relationship reported by Hartill & Walsh (2005).

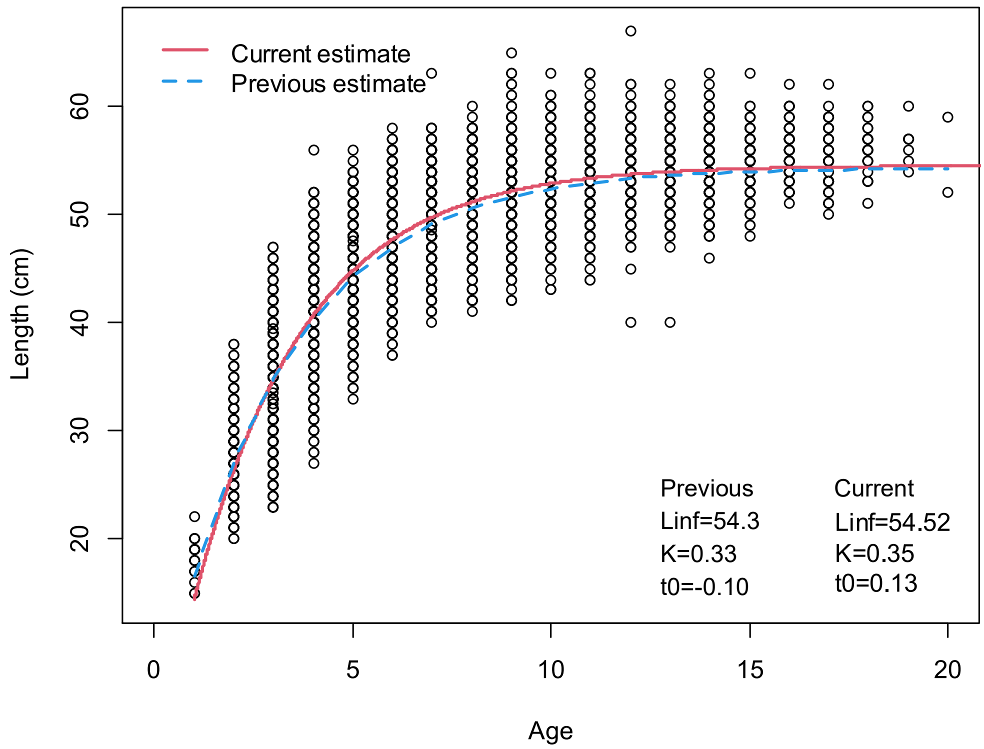


Figure 3: Von Bertalanffy growth rates derived from recreational catch-at-age data pooled across all survey years between 2001 and 2012, compared with the previous relationship reported by Hartill & Walsh (2005) that was based on data collected between 2001 and 2003 only.

3.2 Natural mortality

The only substantive change to the biological parameter values used in the 2007 and 2015 assessments was the assumed value for natural mortality (*M*), which was a previously recognised source of uncertainty (assumed values for sensitivity model runs were 0.12, 0.18, and 0.24 y^{-1} in 2007 and 0.18, 0.20, and 0.23 y^{-1} in 2015).

The natural mortality rate assumed for the 2007 base case model was 0.18 y^{-1} (Jones et al. 1992), which was estimated using the maximum observed age approach of Hoenig (1983). Eggleston (1975) sampled purse seine landings from KAH 2 & 3 for age between 1973 and 1975, and the oldest age estimate he obtained from these landings was a 26 year old fish, which would equate to an *M* of 0.18 y^{-1} (Fisheries New Zealand, unpublished data). Eggleston compared more than one otolith ageing technique and preferred to interpret whole burnt otoliths, as readings by this method resulted in comparable ages to those achieved by the break and burn method (Eggleston 1975). We note, however, that although the commonly used estimate of *M* is based on a single 26 year old fish aged by Eggleston in 1973, he stated in his 1975 paper that the maximum age recorded was 22 years, which would correspond to an *M* of 0.21 y^{-1} given Hoenig's (1983) method.

Regardless, Hoenig's method assumes that the maximum observed age represents the 99th percentile of the age distribution of an unexploited population, which does not necessarily equate to the age of the oldest aged fish. A search of NIWA's archives in 2014 revealed a box file containing Eggleston's original hand-written ageing data for KAH 2 and KAH 3 purse seine landings that he sampled from over a three-year period from 1973 to 1975. Although up to 60 fish were aged from each landing, no catch weight data were available and the age distribution for each landing was therefore weighted together given the number of fish aged from each landing (Figure 4).

The resulting annual age distributions were highly variable, however, because few landings were sampled in each year (9 landings in 1973–74, 4 in 1974–75, and 6 in 1975–76), and because only a small number of kahawai schools are usually targeted during a purse seine trip. Kahawai school together with similar sized fish, so the size composition of a landing will therefore vary considerably depending on which schools are targeted during a trip. Catch-at-age data from all three years were therefore combined to get the best estimate of the age distribution of a relatively unexploited kahawai stock (based on data from KAH 2 and KAH 3), from which estimates of natural mortality could be inferred.

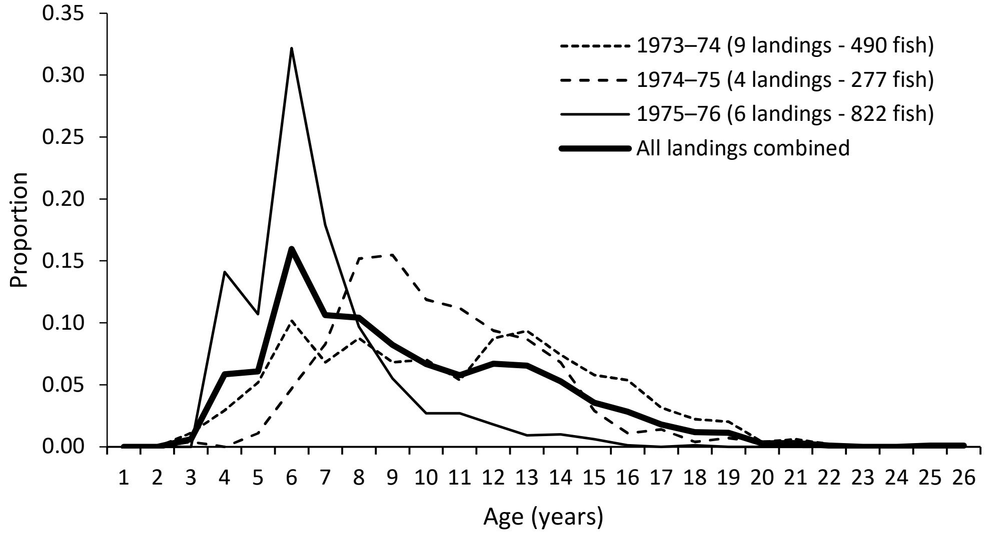


Figure 4: Unweighted catch-at-age distributions for KAH 2 and 3 purse seine landings sampled in 1973–74, 1974–75, 1975–76, and all three years combined.

Two commonly used methods that can be used to generate natural mortality estimates from a relatively unexploited age distribution are the method described by Hoenig (1983) and catch curve analyses, such as Chapman & Robson's (1960) estimator. Using Hoenig's method, the 99th percentile of the 3-year combined age distribution occurred at age 20, which equates to an M of 0.23 y^{-1}. Using the method of Chapman & Robson (1960), an estimate of M of 0.22 y^{-1} was obtained if the age at recruitment was assumed to be 6 or 7 years.

The earliest catch-at-age data available explicitly from KAH 1 were collected by Wood et al. (1990) during a purse seine kahawai tagging programme in 1981–82 (Figure 5). The KAH 1 stock would still have been relatively unexploited at this time, although substantive purse seine catches were taken from 1978 onwards. Otoliths were aged using the break and burn method, and, although the oldest age estimate was 24 years, the 99th percentile of this age distribution occurred at 21 years. This equates to an M of 0.22 y^{-1} if Hoenig's method was used. Chapman Robson estimates of M ranged from 0.22 to 0.27 y^{-1} when the age at recruitment was assumed to be in the range of 8 to 10 years. Note that the age of full selectivity for recreational fisheries is in the 8 to 10 years range, but it is 6 to 7 years for purse seine fisheries.

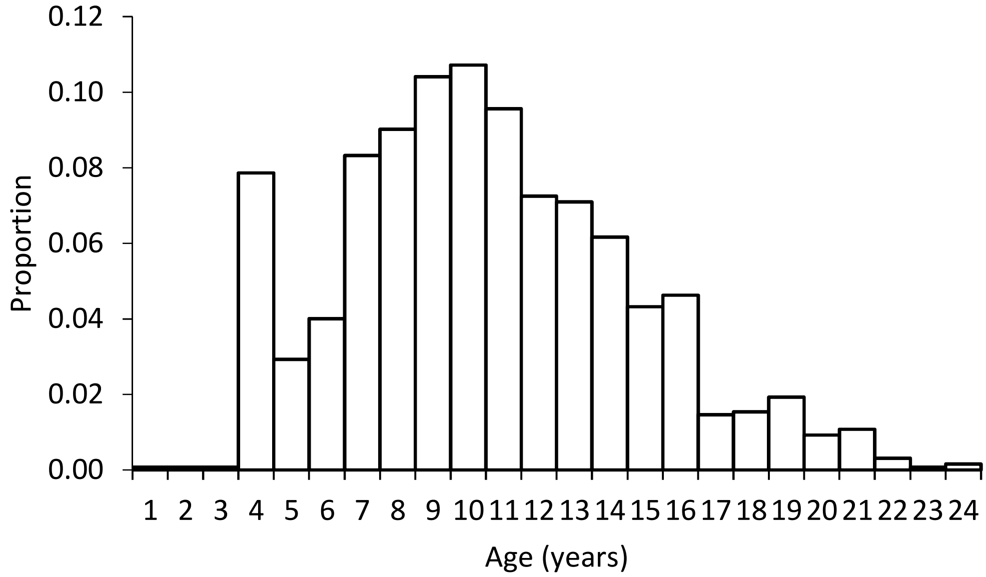


Figure 5: Age distribution of kahawai sampled from purse seine fishing events during a kahawai tagging programme in the Bay of Plenty in 1981–82.

The estimates of *M* derived from these two data sources using two estimation approaches all suggest that the previously assumed value of 0.18 y^{-1} used for the 2007 assessment was probably too low. The reliability of this estimate is also questionable given the fact that it was based on the age of a single fish, which was determined at a time when ageing methods for this species were still being developed.

Some insight into the plausibility of alternative values for *M* can also be gained from recent catch sampling programmes. Almost 13 000 recreational caught kahawai have been aged since 2001, and a tiny proportion of these should still have reached an age that would equate to the 99th percentile of an unexploited population. Only six fish have been aged with estimated ages greater than 20 years (Table 1).

Table 1: Observations of fish sampled from recreational landings in recent years that were thought to be at least 20 years old. Corresponding Hoenig (1983) method-based estimates of *M* are given for each sample.

Year	Region	Fish age(s)	Estimates of *M*	Reference
2001	Bay of Plenty	20	0.22	Hartill et al. (2007a)
2003	Bay of Plenty	21, 21	0.23	Hartill et al. (2007a)
2007	KAH 8 (west coast)	20, 21	0.22, 0.23	Armiger et al. (2009)
2008	East Northland	20	0.22	Armiger et al. (2009)

Likelihood profiles for *M* were also generated as part of this assessment, to determine whether there was any information in the model to inform the estimation of this parameter (see Section 6.4). There was a marked contrast in the total likelihood across the range of potential values explored (0.15 to 0.30 y^{-1}), with the lowest estimated negative log-likelihood occurring when *M* was close to 0.23.

The Inshore Working Group reviewed the available information and recommended an *M* of 0.22 y^{-1} should be assumed for the base case model for this assessment, and that sensitivity runs should be undertaken for alternative values of 0.20 and 0.24 y^{-1}.

3.3 Other biological parameters

No changes have been proposed to the length-weight parameters used in the last assessment (a = 0.0236 and b = 2.89). Reproductive sex stage data for 6107 female kahawai sampled from purse seine and single trawl landings in the early 1990s were examined to verify the age-at-maturity assumed in previous assessments. Females smaller than 38 cm (fork length) were classified as being immature, and all females larger than 40 cm were classified as being either: ripe, running, spent, or resting. Approximately 65% of the 38–40 cm kahawai contributing to the 2011–12 Bay of Plenty age-length key were 4 years old, and a knife-edge age-at-maturity was once again assumed at this age, for this assessment.

Two values of Beverton-Holt stock-recruitment steepness (h) were considered in the 2007 stock assessment: 0.75 and 1.0. A value of 0.75 was used here, as it was considered to be more plausible than deterministic recruitment (a steepness of 1.0).

Year class strengths in this and the previous assessment were estimated using the Haist parameterisation, as described by Bull et al. (2012). The priors on the relative recruitment strengths were log-normally distributed with a mean and coefficient of variation (CV) of 1.0.

4. CATCH HISTORIES

4.1 Commercial catch history

The commercial catch history used for this stock assessment began with the 1930–31 fishing year, when the KAH 1 stock was assumed to be lightly exploited (Table 2). This catch history was based on that used for the 2015 stock assessment, updated to include landings data reported up until the end of the 2019–20 fishing year.

Annual landings for the first part of this catch history (1930–31 to 1981–82) were based on annual port landings statistics compiled by Francis & Paul (2013). There was a gradual increase in the kahawai catch taken during the early part of this catch history, with annual landings reaching a couple of hundred tonnes by the 1970s, before the purse seine fishery was developed to target pelagic schooling species such as kahawai, blue mackerel (*Scomber australasicus*), jack mackerel (*Trachurus* spp), and skipjack tuna (*Katsuwonus pelamis*). The catch history for the period 1981–82 to 1987–88 was based on data from the Fisheries Statistics Unit database and was the same as that used in the last assessment. The catch history from 1989–90 onwards was based on an extract of kahawai catch effort data for landings in all QMAs (defined in Figure 1), including KAH 1. These data were groomed using methods developed by NIWA to identify and correct erroneous catch and effort records and to prorate the landed catch from a fishing trip across fishing events reported for that trip, given the level of effort and/or estimated catch reported for each fishing event.

This process highlighted a small number of trips where the landed catch was substantially higher than the modal catch usually reported by that vessel, and by other vessels reporting the same fishing method. Data for each of these trips were examined in some detail, and for some records there was an obvious reporting or data punching error that was corrected to reconcile the landed catch with estimated catches and fishing effort metrics reported for the same trip. Landings were assigned to Quota Management Areas (QMAs) using the statistical area reported on the catch-and-effort form. This usually corresponded to the QMA recorded on the landings part of the form, but not always. Where there was a discrepancy between the reported statistical area and the QMA, the reported statistical area was assumed to be correct. When fishing occurred in more than one QMA during a trip, the total landed catch weight allocated to each QMA was based on a proration of the estimated catch reported for each statistical area for the same trip.

The resulting commercial catch histories for the key fishing methods for the KAH 1 fishery were very similar to those obtained when more manual line-by-line methods were used to groom the catch-and-effort extracts requested for the previous assessments (Figure 6).

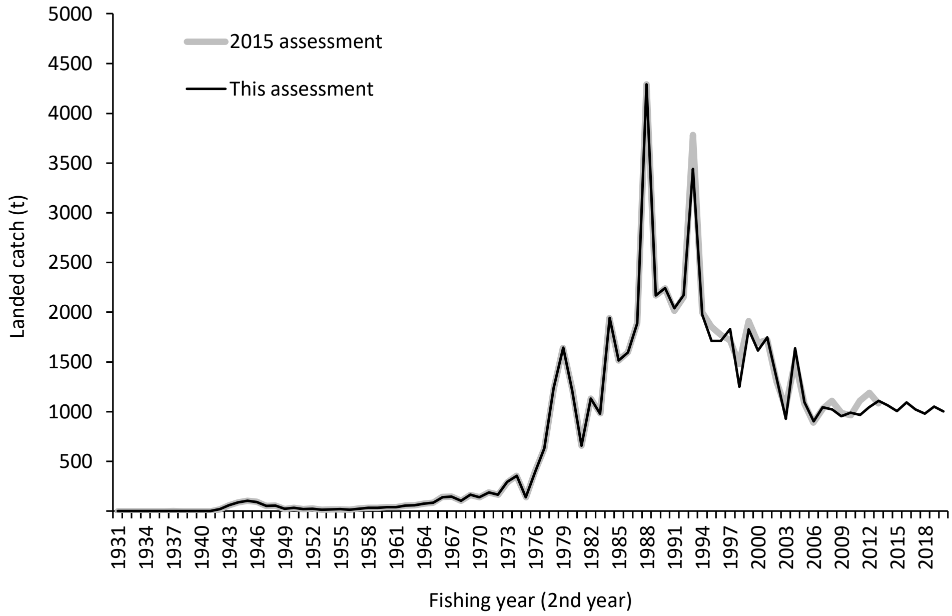


Figure 6: Comparison of commercial catch history totals for KAH 1 used in this and the previous (2015) stock assessment. The fishing year date given refers to the second year of the fishing year (i.e., '2012' refers to the 2011–12 fishing year). Catch statistics for years prior to 1982 were reported for calendar years and these have been assigned to the second year of the fishing year.

Almost 70% commercial catch landed from KAH 1 since 1989 was taken by purse seiners, with landings peaking in the mid 1980s and early 1990s, before purse seine catch limits were imposed. Almost all the purse seine catch was taken from the Bay of Plenty. Set net and ring net fish accounted for about a further 20% of the commercial catch, with almost all of this catch taken from the Firth of Thames and Hauraki Gulf in recent years.

Table 2: Commercial catch (t) history for KAH 1 by method, by fishing year. The method 'Other' mostly refers to landings from bottom longline and Danish seine vessels. The method 'set net' refers to landings from set netters, ring netters, and beach seiners.

Fishing year	Purse seine	Set net	Bottom trawl	Other	KAH 1
1930–31	–	–	–	–	–
1931–32	–	1	–	–	1
1932–33	–	–	–	–	–
1933–34	–	–	–	–	–
1934–35	–	–	–	–	–
1935–36	–	–	–	–	–
1936–37	–	2	–	–	2
1937–38	–	–	–	–	–
1938–39	–	1	–	–	1
1939–40	–	–	–	–	–
1940–41	–	1	–	–	1
1941–42	–	12	4	4	20
1942–43	–	35	12	12	59
1943–44	–	53	18	18	89
1944–45	–	62	21	21	104
1945–46	–	55	19	19	93
1946–47	–	32	11	11	54
1947–48	–	35	11	11	57
1948–49	–	14	4	4	22
1949–50	–	20	7	7	34
1950–51	–	13	4	4	21
1951–52	–	16	5	5	26
1952–53	–	8	3	3	14
1953–54	–	11	4	4	19
1954–55	–	12	4	4	20
1955–56	–	9	3	3	15
1956–57	–	16	5	5	26
1957–58	–	20	7	7	34
1958–59	–	19	7	7	33
1959–60	–	24	8	8	40
1960–61	–	24	8	8	40
1961–62	–	33	12	12	57
1962–63	–	36	12	12	60
1963–64	–	45	15	15	75
1964–65	–	51	17	17	85
1965–66	–	86	28	28	142
1966–67	–	88	29	29	146
1967–68	–	64	21	21	106
1968–69	–	98	33	33	164
1969–70	–	84	28	28	140
1970–71	–	111	38	38	187
1971–72	–	100	33	33	166
1972–73	–	177	58	58	293
1973–74	–	214	71	71	356
1974–75	38	64	19	20	141
1975–76	140	148	65	48	401
1976–77	271	163	123	74	631
1977–78	432	461	200	145	1 238
1978–79	875	228	380	159	1 642
1979–80	561	270	250	132	1 213
1980–81	292	159	131	76	658
1981–82	440	356	202	135	1 133
1982–83	169	527	105	181	982
1983–84	1 445	321	65	111	1 942
1984–85	882	410	82	141	1 515
1985–86	1 191	263	53	91	1 598
1986–87	1 544	224	45	77	1 890
1987–88	3 964	212	43	72	4 291
1988–89	1 644	340	69	117	2 170
1989–90	1 699	351	70	121	2 241
1990–91	1 563	333	82	62	2 040
1991–92	1 726	322	49	75	2 172
1992–93	2 473	628	176	162	3 439
1993–94	1 162	596	80	137	1 975
1994–95	1 053	436	65	157	1 711
1995–96	1 098	350	127	135	1 710
1996–97	921	691	113	105	1 830
1997–98	712	351	116	72	1 251
1998–99	1 374	217	149	85	1 825
1999–00	1 222	243	106	43	1 614
2000–01	1 393	217	79	57	1 746
2001–02	957	292	59	45	1 353
2002–03	608	236	49	37	930
2003–04	1 361	200	51	25	1 637
2004–05	834	178	48	38	1 098
2005–06	535	216	72	82	905
2006–07	696	267	40	43	1 046
2007–08	668	261	57	36	1 022
2008–09	602	274	31	48	955
2009–10	555	329	60	47	991
2010–11	541	306	58	61	966
2011–12	707	185	68	85	1 045
2012–13	707	232	115	54	1 108
2013–14	645	220	132	66	1 063
2014–15	490	212	106	198	1 006
2015–16	717	184	72	121	1 094
2016–17	667	182	87	86	1 022
2017–18	661	161	59	100	981
2018–19	640	200	111	101	1 052
2019–20	682	161	80	81	1 004

4.2 Recreational catch history

The recreational catch history for the KAH 1 stock was essentially unknown, because harvest estimates were only available from a small number of recent aerial-access surveys (Hartill et al. 2007b, 2013a, 2019) and national panel surveys (Wynne-Jones et al. 2014, 2019) (Table 3). Comparisons of harvest estimates produced by these alternative survey methods concurrently in 2011–12 and 2017–18 found a high degree of similarity, and they are therefore considered to be acceptably reliable and accurate.

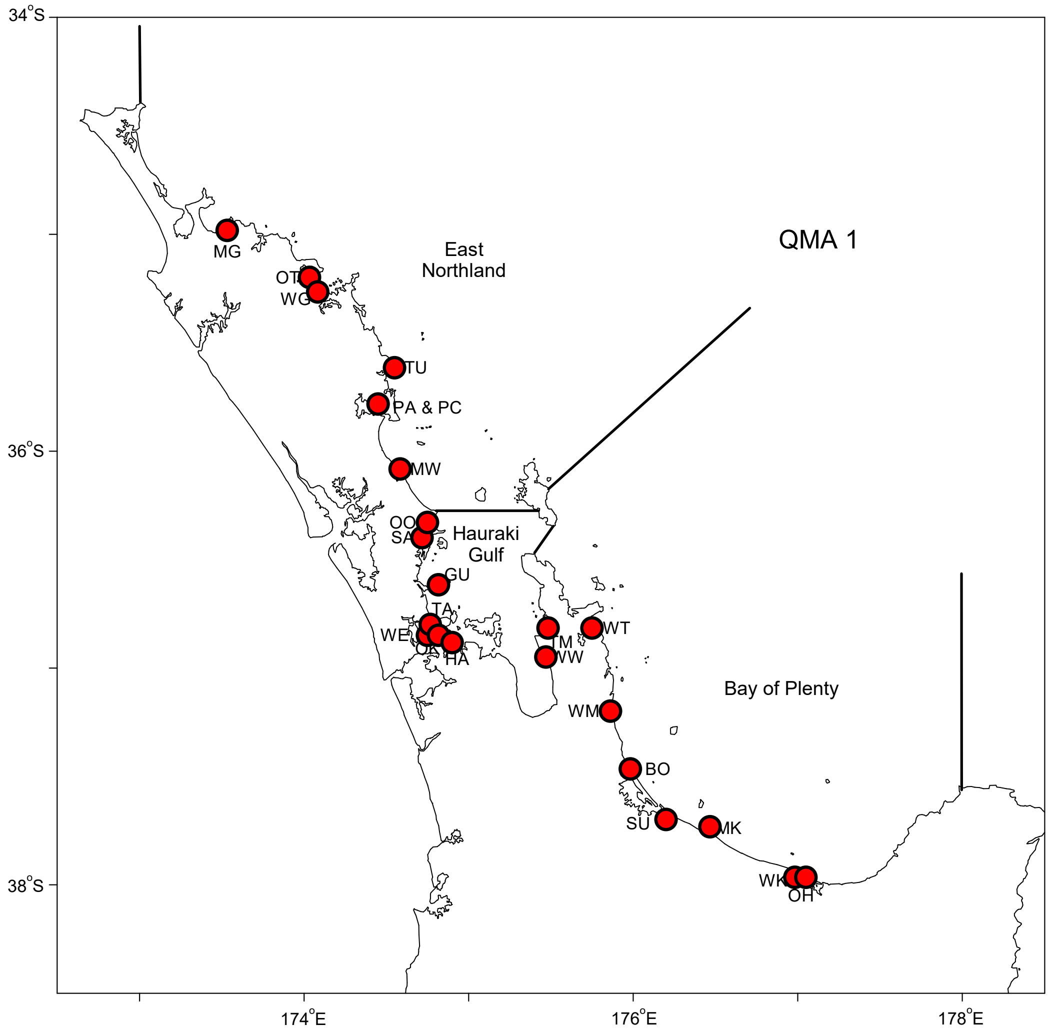
Table 3: Aerial-access (A-A) and national panel survey (NPS) estimates of the recreational harvest tonnage taken from the KAH 1 stock, by region, by fishing year. Coefficients of variation are given for each estimate in brackets.

Region	2003–04	2004–05		2011–12		2017–18	
	A-A	A-A	NPS	A-A	NPS	A-A	NPS
East		129		191	198	312	224
Northland	–	(0.14)	–	(0.16)	(0.14)	(0.13)	(0.14)
Hauraki	56	98		483	377	517	378
Gulf	(0.15)	(0.18)	–	(0.13)	(0.09)	(0.09)	(0.10)
Bay of		303		268	238	390	364
Plenty	–	(0.14)	–	(0.12)	(0.11)	(0.11)	(0.11)
		530		942	958	1 219	966
KAH 1	–	(0.09)	–	(0.08)	(0.07)	(0.06)	(0.07)

In was assumed in the previous 2007 and 2015 KAH 1 stock assessments that there had been little change in levels of recreational harvesting since the mid-1970s, as there was little information available on levels of amateur harvesting over time. Constant catch histories were assumed for both the 2007 and 2015 assessments, because there were concerns that uninformed assumptions about trends in recreational harvesting could have undue influence on estimated biomass trajectories. The harvest estimates given in Table 3, and trends seen in boat ramp interview data collected since the last stock assessment (Hartill et al. 2020), suggest that recreational catches can vary considerably from year to year, and it is therefore not correct to assume a constant catch history for this or any other recreational fishery.

To provide model-based regional catch histories for commonly caught species such as kahawai, we used zero inflated negative binomial (ZINB) generalised linear modelling of the observed number of kahawai landed hourly (the explanatory variable) at a subsample of boat ramps that have been regularly surveyed in each region since 1990–91. The models predicted the number of kahawai landed at each of these ramps throughout each sampled fishing year (Figure 7). Estimates of the number of kahawai landed per hour were available from seven boat ramps in East Northland (21 921 hours surveyed across all ramps cumulatively between 1990–91 to 2019–20), nine ramps in the Hauraki Gulf (25 612 hours), and seven ramps in the Bay of Plenty (16 580 hours). 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 4.

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*. Alternative count data modelling approaches that were also explored were Poisson and negative binomial models, which provided poor fits to the over dispersed data. The primary diagnostic used to assess fits to alternative count data modelling approaches were rootogram plots generated by the R package *countreg*, which provides a visual indication of goodness of fit across the observed frequency range (Kleiber & Zeileis 2016).



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

Figure 7: Location of boat ramps where recreational catch and effort data have been collected and used to provide estimates of the number of kahawai landed per completed surveyed hour, since 1991.

Table 4: Summary of boat ramp interview data used to inform regional models that were used to predict the number of kahawai 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	3 187	6	12	3 655
2018–19	–	–	–	–	–	–	–	–	–
2019–20	3	5	625	5	6	247	5	5	471

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 of 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.

Iterative model selection was explored manually, because automated stepwise variable selection is not possible when fitting ZINB two-component models as the inclusion of a variable in one model component can affect the fit to the second model component. Manual variable selection was also necessary because some model runs failed to converge when some terms were added to the right-hand excess zero model component. The primary diagnostics used to evaluate alternative ZINB model structures were iterative comparisons of AIC statistics and rootograms generated from successive models.

The same response variables were ultimately selected for each regional two component model, and the order in which these terms were fitted, given declining improvements to AIC statistics, was as follows:

$$N\ hr^{-1} \sim \text{hour} + \text{ramp} + \text{fishing year} + \text{day type} + \text{month} + \text{wind speed} \quad | \quad \text{hour} + \text{ramp}$$

There were negligible reductions in AIC when wind direction or tidal state factors were offered to the left-hand negative binomial model component, and models failed to converge or there were negligible reductions in AIC when more than two terms were offered to the right-hand excess zero component for each regional model. Rootogram diagnostic plots are given for final models used for each region of KAH 1 in Figure 8.

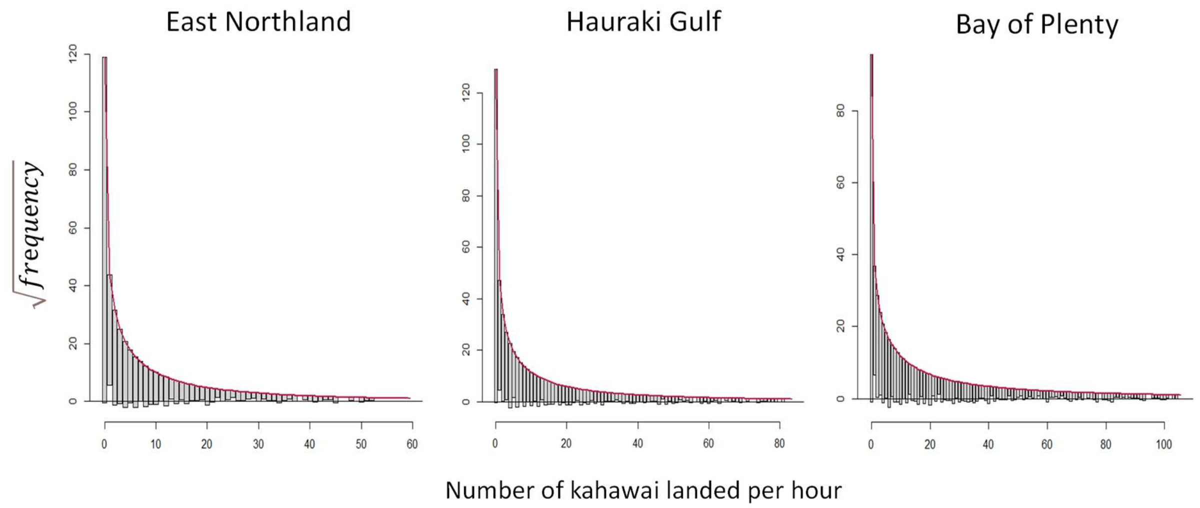


Figure 8: Rootogram diagnostic plots for regional ZINB model predictions of the number of kahawai landed per complete hour of interviewing. The predicted frequency distribution for each region is shown as a curved red line, with observed frequencies shown as vertical bars that are individually 'hung' from their corresponding predicted frequencies. Differences between the base of observed frequency bars and the X -axis indicate how well the ZINB has predicted landing rates, across the observed range. Frequencies are expressed as square roots to condense the range of the Y-axis.

Model-based predictions of the number of kahawai landed hourly at each surveyed ramp were then summed for each region, for each fishing year, and then multiplied by regional annual mean weight estimates. The resulting annual landed weight index was regarded as a relative index, because only a sample of boat ramps were surveyed in each region in each year. These regional relative harvest indices were therefore scaled to the regional aerial-access harvest estimates for 2004–05, 2011–12, and 2017–18 (see Table 3), to provide annual absolute harvest estimates for each region of KAH 1 (Figure 9). Linear interpolation was used to estimate the annual harvest landed by recreational fisheries during years when boat ramp interview surveys had not been conducted, since 1990–91 (see Table 4).

Estimates of recreational harvest were required back to 1930–31, however, and the harvest at that time was assumed to be 10% of that in 1974–75, which was then ramped up to that value over the intervening years.

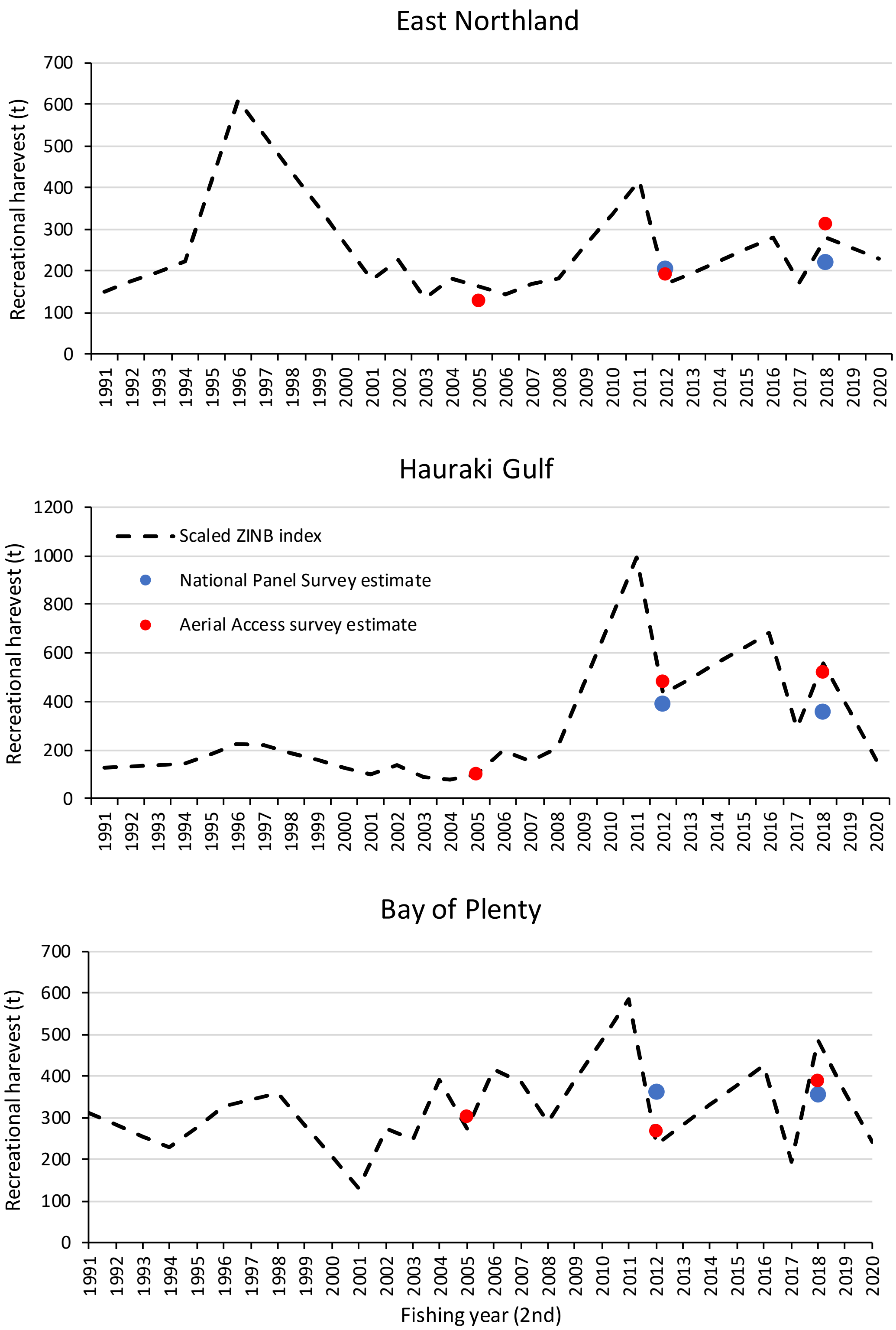


Figure 9: Regional recreational catch histories for KAH 1 based on zero inflated negative binomial modelling of boat ramp interview survey landings data (kahawai landed per complete survey hour). The relative harvest indices generated from regional model predictions were scaled up by regional harvest estimates provided by aerial-access surveys of KAH 1 in 2004–05, 2011–12, and 2017–18, to account for the catch landed by all recreational fishers, at all access points including those which had not been surveyed.

5. OTHER OBSERVATIONAL DATA

5.1 Recreational CPUE abundance indices

The relative abundance indices primarily used to inform this stock assessment were recreational catch per unit effort (CPUE) data collected during boat ramp surveys conducted since 1990–91. Unstandardised regional CPUE indices were used to inform a fleets-as-areas stock assessment for KAH 1 in 2007, and these indices were updated and weighted together for a single area assessment in 2015. The regional recreational CPUE indices used for this assessment have been standardised for the first time.

Baited rod and line catch effort data were extracted from the Fisheries New Zealand Rec_data database, for trailer boat anglers targeting any species in KAH 1 since 1990–91. Fisher-specific kahawai catch data were then linked to these fishing events, including reported catches of unlanded fish that were used for bait and released kahawai that anglers reported to be of ‘legal’ size (there is no minimum legal size limit for kahawai). The majority of kahawai caught by recreational fishers in KAH 1 were landed whole, with 88% of the reported East Northland catch, 87% of the reported Hauraki Gulf catch, and 83% of the reported Bay of Plenty catch, landed in a whole measurable state since 1990–91.

The number of kahawai caught (if any) and effort of all anglers participating in each boat trip were then aggregated at the fishing trip level, for three reasons. Firstly, because aggregating catches at the trip level reduced the degree of zero inflation in catch data. Secondly, aggregating the catch of all members in a fishing party negated the likelihood of fishers ‘sharing’ their reported catch with other members of the same fishing party, as well as removing any correlation in fishing success by anglers fishing alongside each other. Finally, catch aggregation smoothed out peaks in bag frequencies that coincided with daily bag limits (which was rarely the issue here given the 20 fish per day bag limit for this species). Catch aggregation reduced the incidence of zero catch trips from 84% to 73% for fishers and fishing parties, respectively, for East Northland, 87% to 77% for the Hauraki Gulf, and 76% to 62% for the Bay of Plenty.

Recreational fishers interviewed during boat ramp surveys were rarely interviewed more than a few times in any given fishing year, and they were not asked to identify themselves to protect their privacy. Further, anglers may not have fished with the same individuals from trip to trip, so recreational CPUE cannot be standardised by vessel, which is often the most powerful explanatory variable selected when standardising commercial fishery CPUE data. The explanatory variables offered to the standardisation models explored here were: fishing year, the aggregate number of hours fished by all anglers in each boat, target species category (snapper, kahawai, or other), number of anglers in each boat, fishing location polygon ID (12 in the Hauraki Gulf and 22 each in East Northland and the Bay of Plenty), month (categorical), sea surface temperature (recorded daily at Leigh Marine Laboratory), and trip midpoint time of day. Records were dropped from each regional data set when data were available from fewer than 100 boats in any fishing year, or when fewer than 100 fishing parties reported fishing events in a fishing location polygon since 1991.

There were relatively few methods available that could be used to standardise zero inflated discrete count catch rate data and several alternative modelling approaches were explored including: Poisson, zero inflated Poisson (ZIP), negative binomial (NB), and zero inflated negative binomial (ZINB) generalised linear modelling. AIC statistics and rootogram diagnostic plots were compared for a range of exploratory models, for several species including kahawai, which suggested that NB and ZINB modelling were the most appropriate methods that could be used to standardise recreational CPUE data.

Both NB and ZINB GLMs were therefore used to standardise catch per boat trip data for each region, and AIC statistics and rootogram diagnostic plots were compared to determine which of these two standardised CPUE indices should be fitted in the stock assessment model, for each regional fishery (Table 5).

Table 5: Akaike Information Criterion (AIC) statistics for regional negative binomial (NB) and zero inflated negative binomial (ZINB) recreational CPUE standardisations for each region of KAH 1 and the rationale for deciding which of these two indices should be offered to the stock assessment model for each regional fishery.

Region	Model	AIC	Used	Index selection rationale
East Northland	NB	56 360	Y	Higher AIC, better diagnostics available
	ZINB	55 678	N	Lower AIC but many exploration models failed to converge depending on variable choice. Index similar to the NB index
Hauraki Gulf	NB	98 929	Y	Lower AIC
	ZINB	107 934	N	Poor model convergence
Bay of Plenty	NB	85 058	N	Higher AIC and poor fits to some fishing years
	ZINB	83 711	Y	Lower AIC and better fits for most years

The East Northland recreational CPUE indices generated by the NB and ZINB model standardisations were similar to the unstandardised index, with all three indices showing declining but fluctuating abundance in recent years (Figure 10). Rootogram plots for the two models, for both the entire data set (Appendix 1), and for individual fishing years, were also very similar, with little evidence of improved fit when zero inflation was taken into account by the ZINB model. The NB index was preferred because convergence of the ZINB model was sensitive to the choice of variables offered to the right-hand (excess zero) component of the model. Automated stepwise model selection was possible for the NB standardisation only, and the additional informative diagnostic plots available for this type of model indicated reasonable predictions of the incidence of zero landed catches without the need to account for further excess zeros (bottom left-hand plot in Appendix 2). This standardisation had most effect on the earlier index years, with fishing location having the most influence on the final index (Appendix 3).

The only standardised recreational CPUE index available for the Hauraki Gulf fishery was an NB index, because none of the attempted ZINB models converged. The NB index for the Gulf was similar to the unstandardised index, indicating a substantial increase in abundance sometime around 2010, followed by marked fluctuations similar to those see in the East Northland index. The month variable was the only term that had an appreciable influence on this standardisation (Appendix 3). Ultimately, the Hauraki Gulf CPUE index was truncated to cover the 1990–91 to 2007–08 fishing years only, because unstandardised CPUE length class indices shown in Figure 13 suggested the substantial increase in catch rates in 2010 was due to kahawai immigrating into the gulf from elsewhere, rather than being due to an increase in stock abundance.

The standardised Bay of Plenty NB and ZINB indices were substantially different from the standardised index, suggesting more of an increase in abundances since the early 1990s. The AIC statistic for the ZINB model index that was adopted for this assessment was far lower than the NB statistic and ZINB rootogram fits for many of the individual fishing years were noticeably better than their NB counterparts.

The standardised indices generated for all three regions followed similar trends since 2011, indicating declining abundance.

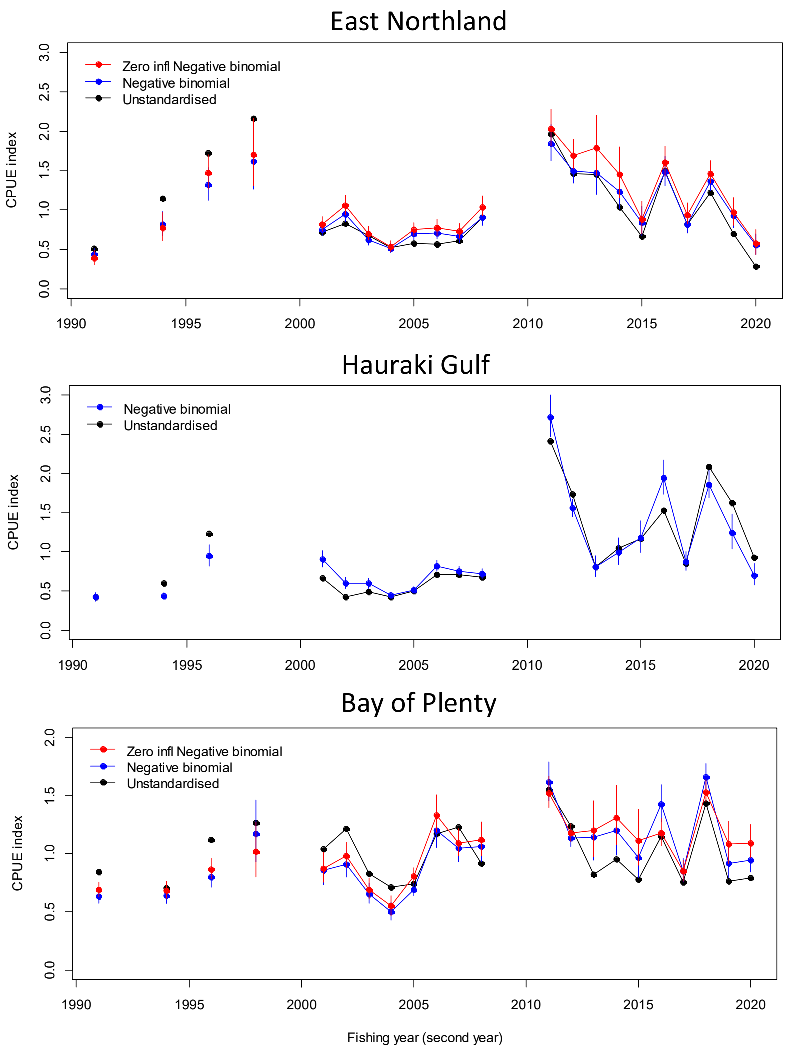


Figure 10: Standardised and unstandardised recreational catch per boat trip CPUE indices for each region of KAH 1. Negative binomial and zero inflated negative binomial standardisations were attempted for all three regions, but the zero inflated negative binomial model for the Hauraki Gulf region did not converge.

5.2 Aerial sightings index of abundance for the Bay of Plenty

Another index of abundance used to inform this assessment was an aerial sightings per unit effort (SPUE) index that was updated for the 2015 assessment (Hartill & Bian 2016). This index was based on spotter plane pilot records of kahawai school sightings and associated tonnage estimates, which were reported by one pilot who had been locating schools of pelagic fish for purse seiners working in the southwest Bay of Plenty since 1975 (Figure 11). Generalised additive modelling (GAM) was used to generate two sightings indices, which were then combined to provide a single abundance index: a log-normal model of positive sightings data, and a binomial model of the proportion of kahawai sightings in each grid square. The methods used to generate these indices are documented by Taylor (2014).

This index was not updated for this assessment because the spotter plane pilot whose data this index was based on had stopped flying, and any data that they had recorded since 2013 were not available in an electronic format. The logistic selectivity ogive estimated for the purse seine fishery was used when fitting the model to this index of abundance.

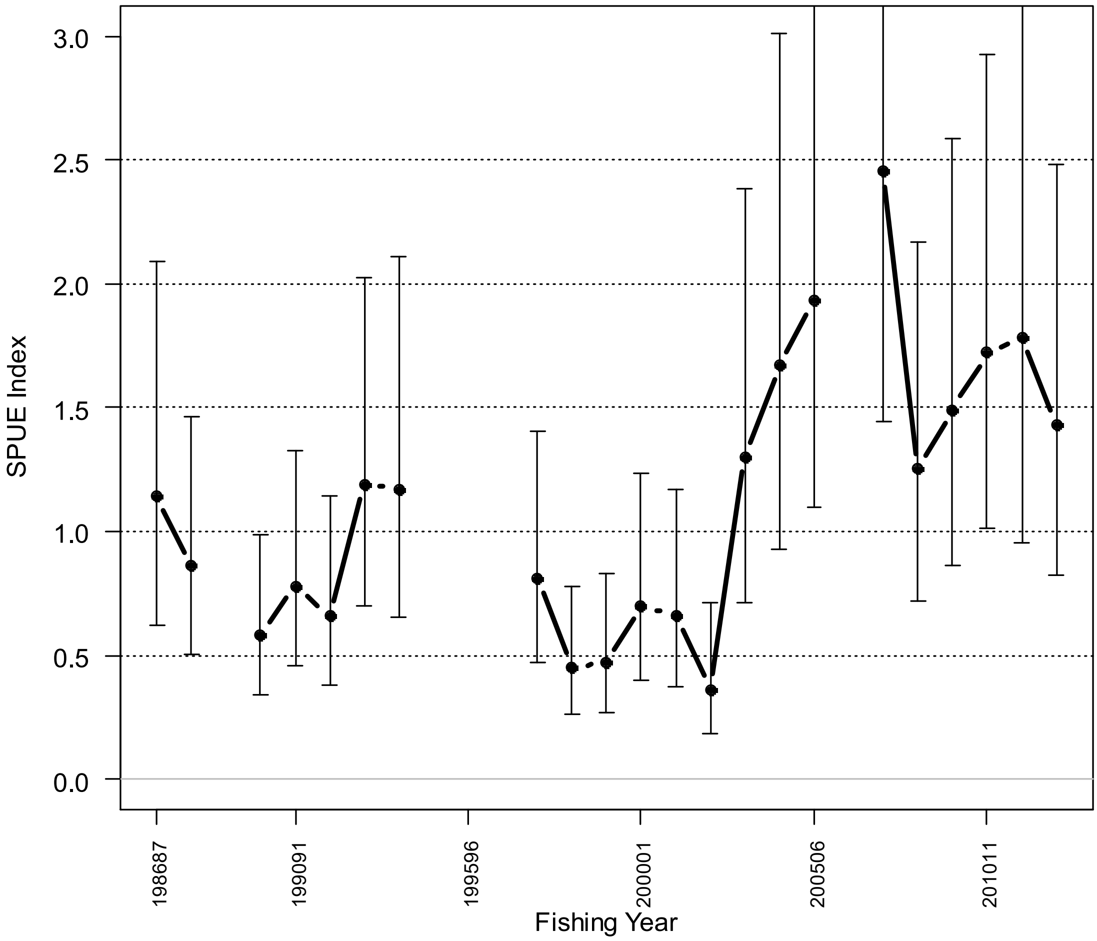


Figure 11: Normalised combined indices of relative abundance (SPUE) for kahawai generated as the combination of the binomial and lognormal regressions; vertical bars are the 95% confidence intervals.

Regional set net CPUE indices used in the previous stock assessments were not incorporated into this assessment, because of concerns about confusion between set net and ring net effort reporting.

5.3 Recreational catch-at-age data

Recreational landings have been sampled regionally for length and age over a 4-month period during most summers since 2001 (January to April), coinciding with the peak season for recreational fishing effort (Figure 12). The recreational catch-at-age time series used in the 2015 assessment (covering the period 2001 to 2012; Armiger et al. 2006, 2014, Hartill et al. 2007a, 2007c, 2008) was updated to include data collected during the summers of 2016, 2017, and 2018 (Armiger et al. 2019).

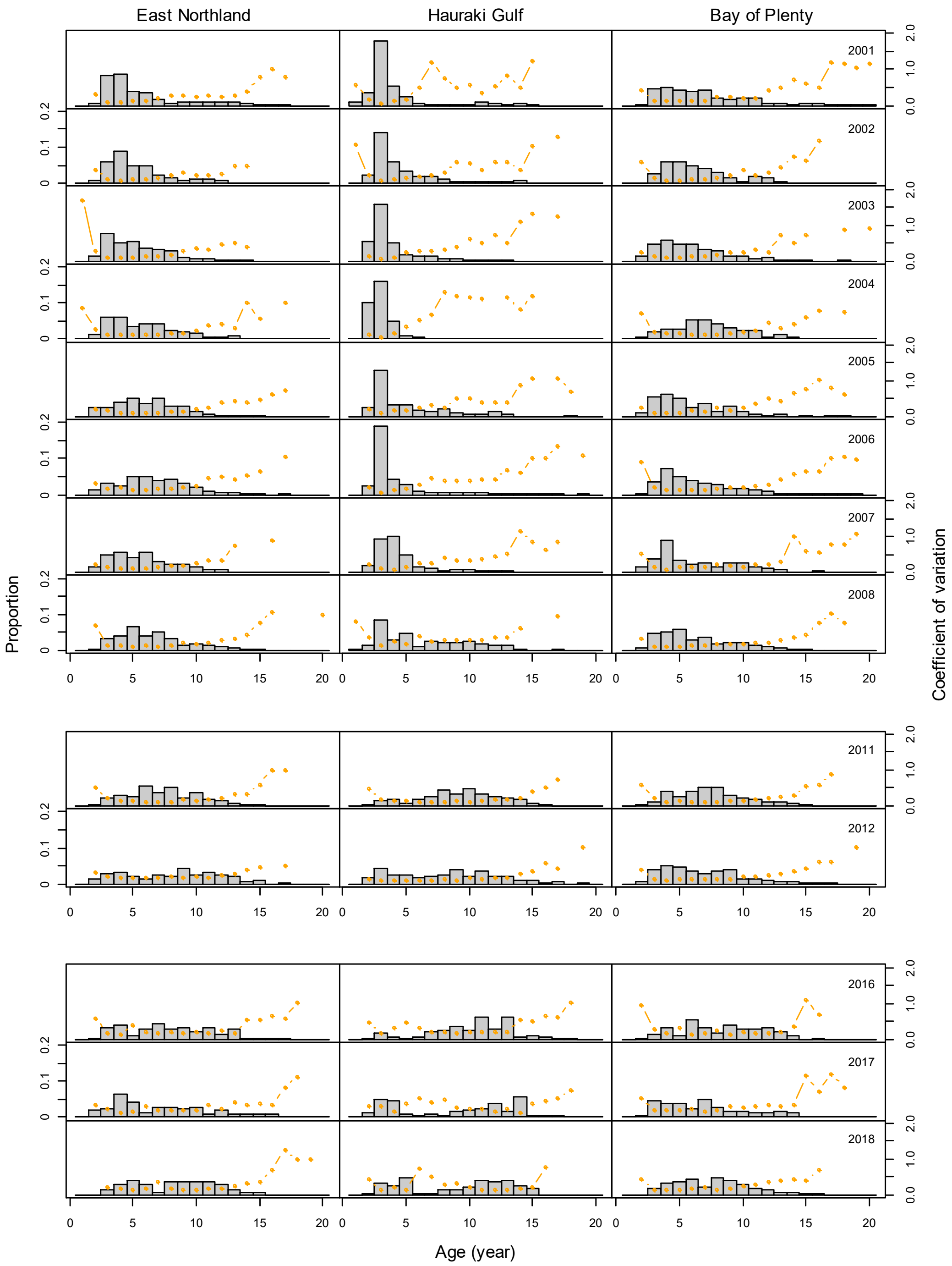


Figure 12: Regional recreational catch-at-age distributions (bars show proportions, points show CV) derived from boat ramp interview surveys conducted between 2001 and 2018. No surveys were conducted in 2009, 2010, or between 2013 and 2015.

The age compositions of recreational landings from East Northland and the Bay of Plenty changed gradually over time, but there was a marked and rapid change in the age composition of kahawai landed from the Hauraki Gulf in the late 2000s. Landings from the gulf during the early to mid 2000s were dominated by 3 and 4 year old fish, but older reproductively mature fish dominated the catch from at least 2011. The rapidly increasing dominance of these older fish in Hauraki Gulf landings did not appear to be the result of the progression of year classes in the same region over time, but rather to be an influx of larger fish from the Bay of Plenty and/or East Northland.

The likely origin of older fish moving into the gulf from elsewhere can be inferred from changes in regional CPUE length class indices during the late 2000s and early 2010s (Figure 13). Catch rates of 50–59 cm kahawai in the Hauraki Gulf increased substantially sometime around 2010, following a period in the early to mid 2000s when there was a higher relative abundance of 40–49 cm kahawai in the Bay of Plenty. There was also a less pronounced increase in catch rates of larger kahawai in East Northland around this time, which suggests that the pronounced change in the age composition of the catch landed from the Hauraki Gulf may be due to emigration from the Bay of Plenty component of the KAH 1 stock.

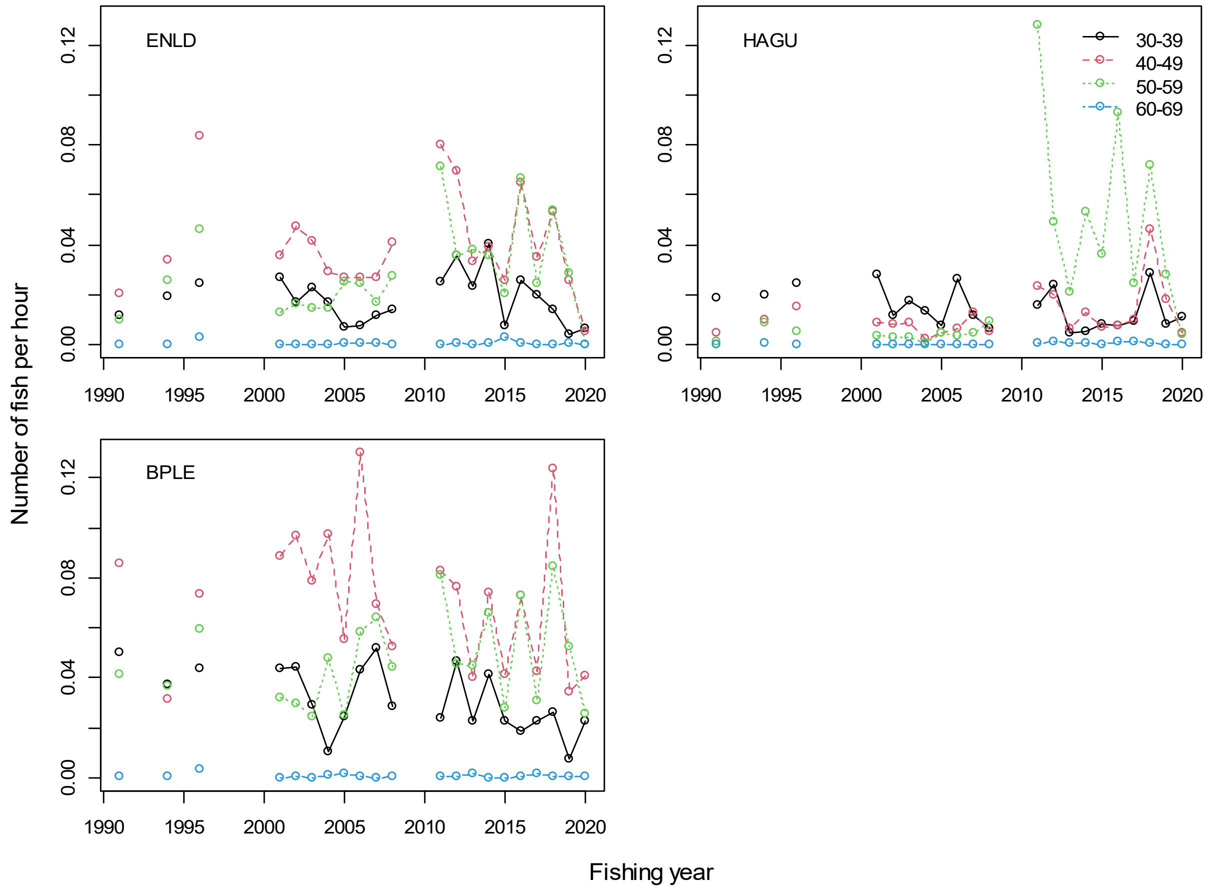


Figure 13: Unstandardised regional recreational catch rate indices for four kahawai size classes.

This interpretation led to the decision to split the Hauraki Gulf catch-at-age compositional time series into two separate fisheries that were fitted in the stock assessment separately: an Early Hauraki Gulf recreational fishery covering the period 1991 to 2008, and a Late Hauraki Gulf recreational fishery, for the period 2009 to 2020.

5.4 Commercial catch-at-age data

The three main commercial fisheries that have landed most of the kahawai from KAH 1 are the purse seine, set net, and bottom trawl fisheries (see Table 2). Most of the purse seine and bottom trawl catch of kahawai has been taken from the Bay of Plenty, whereas most of the set net catch has been taken from the Hauraki Gulf.

Catch-at-age data were available for all three of these fisheries, but for a limited set of years (Figure 14). The age distribution of purse seine landings varied considerably from year to year because kahawai school by size, and sets of as few as about 50 schools are required to take the annual catch landed by this method (Bradford 1999, Devine 2007, Hartill et al. 2013b). The age composition of single trawl landings was broader, but also variable from year to year, with kahawai taken as a bycatch when targeting other species (Bradford 1999). Set net fishers target kahawai that weigh approximately 1 kilogram (3 to 4 year old fish), which maximises the number of whole smoked fish they can sell per tonnage caught (Hartill et al. 2013b).

These catch-at-age data were also used to inform the previous 2015 stock assessment, and there has been no further commercial catch sampling since that assessment, so the data available in 2021 remained the same.

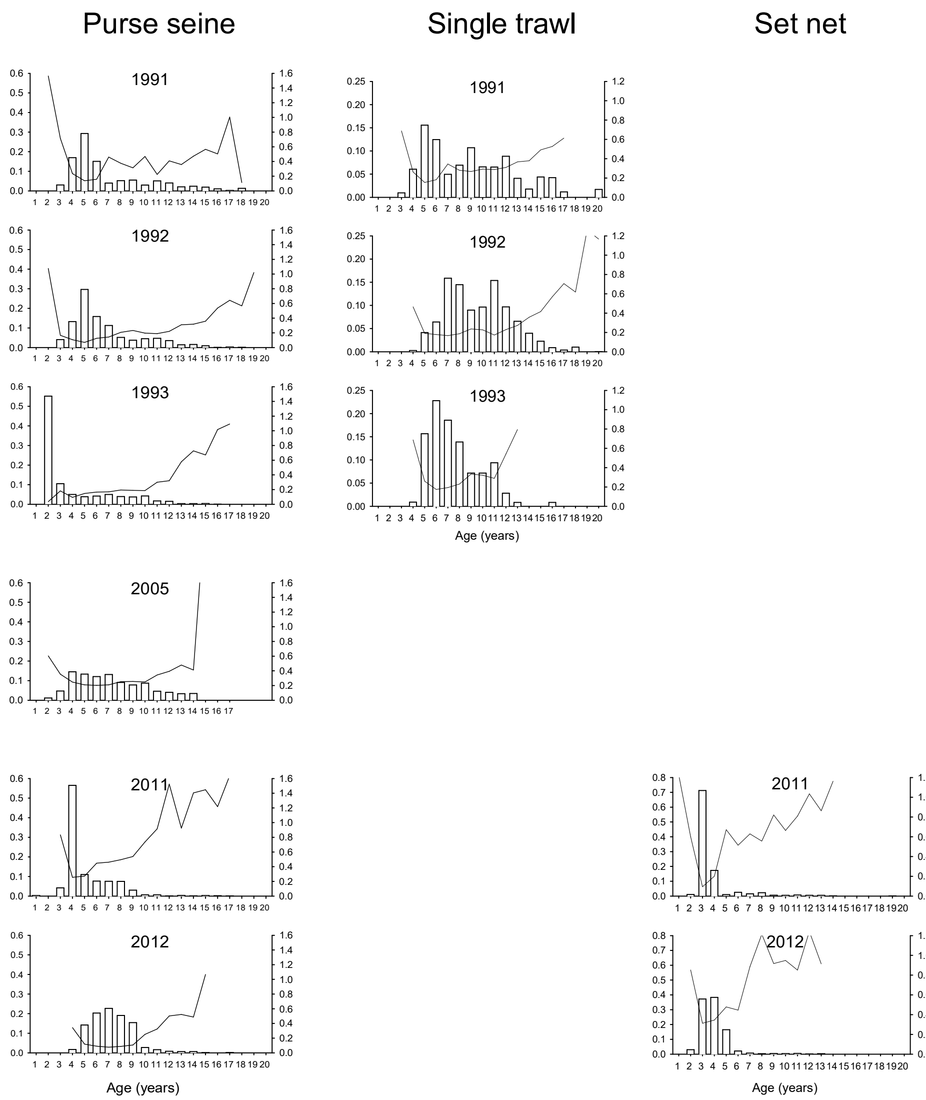


Figure 14: Commercial catch-at-age distributions for the purse seine, single trawl, and set net fisheries.

5.5 Estimating year class strengths and selectivities

The recreational and commercial catch-at-age data used for this assessment were included primarily to estimate relative year class strengths and selectivity ogives. Recruitment deviates were initially estimated for the year classes that were present in three or more consecutive catch-at-age distributions (except for the most recent 2014 year class), for fully selected age classes estimated with reasonable precision (deemed to be 4 to 8 year olds for the purse seine and single trawl fisheries, and 3 to 8 year olds for the recreational fisheries, Table 6). The Working Group concluded, however, that recruitment strengths should only be estimated for the 1994 to 2014 year classes, because of concerns that the selectivity of the purse seine fishery was likely to have varied from year to year, and because there was little evidence of any consistent progression of year classes in the commercial age compositional data collected during the early 1990s.

The 1991, 1992, and 1993 purse seine and single trawl age composition data were retained in the model, however, so that selectivity ogives could be estimated for these fisheries, which have landed most of the cumulative catch taken from KAH 1 since 1930. The commercial compositional data collected in 2004–05, 2010–11, and 2011–12 were heavily down-weighted by having their multinomial effective sample sizes fixed to 1.0, so that the more comprehensive and consistent recreational catch-at-age times series, that had been collected since 2001, had a greater influence on recruitment deviates for the 1994 to 2014 year classes.

Table 6: Criteria used to determine the years for which the model would estimate year class strengths. Recruitment strengths were estimated for year classes that were present in in two or more catch sampling age distributions, for fully selected ages that were sampled with reasonable precision in the age distribution, as indicated by bounding boxes. Purse seine (PS) and single trawl (ST) commercial catch-at-age data from 2005, 2011, and 2012 were heavily down-weighted in the model to minimise their influence on year class estimation.

Fishing	Age class											Fishery
year	1	2	3	4	5	6	7	8	9	10	11	
1990–91	1990	1989	1988	1987	1986	1985	1984	1983	1982	1981	1980	PS & ST
1991–92	1991	1990	1989	1988	1987	1986	1985	1984	1983	1982	1981	PS & ST
1992–93	1992	1991	1990	1989	1988	1987	1986	1985	1984	1983	1982	PS & ST
1993–94	1993	1992	1991	1990	1989	1988	1987	1986	1985	1984	1983	
1994–95	1994	1993	1992	1991	1990	1989	1988	1987	1986	1985	1984	
1995–96	1995	1994	1993	1992	1991	1990	1989	1988	1987	1986	1985	
1996–97	1996	1995	1994	1993	1992	1991	1990	1989	1988	1987	1986	
1997–98	1997	1996	1995	1994	1993	1992	1991	1990	1989	1988	1987	
1998–99	1998	1997	1996	1995	1994	1993	1992	1991	1990	1989	1988	
1999–00	1999	1998	1997	1996	1995	1994	1993	1992	1991	1990	1989	
2000–01	2000	1999	1998	1997	1996	1995	1994	1993	1992	1991	1990	Rec
2001–02	2001	2000	1999	1998	1997	1996	1995	1994	1993	1992	1991	Rec
2002–03	2002	2001	2000	1999	1998	1997	1996	1995	1994	1993	1992	Rec
2003–04	2003	2002	2001	2000	1999	1998	1997	1996	1995	1994	1993	Rec
2004–05	2004	2003	2002	2001	2000	1999	1998	1997	1996	1995	1994	Rec ~~& PS~~
2005–06	2005	2004	2003	2002	2001	2000	1999	1998	1997	1996	1995	Rec
2006–07	2006	2005	2004	2003	2002	2001	2000	1999	1998	1997	1996	Rec
2007–08	2007	2006	2005	2004	2003	2002	2001	2000	1999	1998	1997	Rec
2008–09	2008	2007	2006	2005	2004	2003	2002	2001	2000	1999	1998	
2009–10	2009	2008	2007	2006	2005	2004	2003	2002	2001	2000	1999	
2010–11	2010	2009	2008	2007	2006	2005	2004	2003	2002	2001	2000	Rec, ~~PS & SN~~
2011–12	2011	2010	2009	2008	2007	2006	2005	2004	2003	2002	2001	Rec, ~~PS & SN~~
2012–13	2012	2011	2010	2009	2008	2007	2006	2005	2004	2003	2002	
2013–14	2013	2012	2011	2010	2009	2008	2007	2006	2005	2004	2003	
2014–15	2014	2013	2012	2011	2010	2009	2008	2007	2006	2005	2004	
2015–16	2015	2014	2013	2012	2011	2010	2009	2008	2007	2006	2005	Rec
2016–17	2016	2015	2014	2013	2012	2011	2010	2009	2008	2007	2006	Rec
2017–18	2017	2016	2015	2014	2013	2012	2011	2010	2009	2008	2007	Rec

All available age composition data were initially offered to the model, regardless of whether they were used to inform year class estimation, so that selectivity ogives could be estimated for each fishery. The selectivity ogive choice for each fishery was initially explored by fitting Allvalues selectivity ogives to each fishery (Bull et al. 2012) and visually assessing the shape of the estimated ogive and the resulting fits to each age composition data set.

Four selectivity ogives were estimated for the recreational fisheries, with a double-normal ogive estimated for the Early Hauraki Gulf fishery (1991 to 2008) and logistic selectivities estimated for the Late Hauraki Gulf (2009 to 2020), East Northland, and Bay of Plenty fisheries. For the commercial fisheries, a logistic selectivity ogive was estimated for the purse seine fishery and a double-normal selectivity ogive was estimated for the single trawl fishery. Three parameter Richards' selectivity ogives (asymmetric logistic) were fitted as an alternative to two parameter logistic ogives for the East Northland and Bay of Plenty recreational fisheries, and the commercial purse seine fishery, but similar MPD fits were achieved with either ogive. MCMC traces indicated poor convergence for the Richards' selectivity ogives that were estimated for some fisheries, however, and logistic selectivities were therefore fitted for all three of these fisheries. A double-normal selectivity ogive provided the best fit to the set net compositional data, but parameter values for this ogive were fixed at estimates produced by initial MPD model runs, because the second stage data weighting procedure described in the next section would not converge when the set net catch-at-age data were included in the model. The inability for the model to converge when these data were offered to the model was probably because the progression of year classes, and their relative strengths, cannot be inferred from these two tight monomodal age distributions, which may have conflicted with fits to the better informed regional recreational catch at-age time series data. Heavily down-weighting the set net composition data did not resolve this issue. The MCMC convergence of the 2015 stock assessment model was also poor when attempts were made to estimate a selectivity for the set net fishery as part of that assessment.

5.6 Data weighting

The methods used to provide relative weights for each abundance index and catch-at-age distribution followed an approach recommended by Francis (2011). First stage weights (variance estimates) were initially generated outside the model: a single coefficient of variation (CV) for each abundance index, and effective sample sizes (ESSs) for each catch-at-age distribution.

The variance estimate used for each abundance index was calculated outside the model, by fitting a spline to each index and then calculating a CV from the resulting residuals (Clark & Hare 2006). The smoothness of the spline was determined by a maximum annual rate of population increase, which was assumed to be 10% for KAH 1.

The ESSs for each catch-at-age distribution were initially calculated outside the model, and these were then down-weighted within the model, following the Francis (2011) TA1.8 method. With this second stage weighting process, results from an initial MPD model run were used to inform a down-weighting procedure, and the original ESSs were then replaced by the down-weighted ESSs followed by another MPD run. This process was repeated iteratively up to three times, to balance the down-weighted ESSs calculated for all catch-at-age distributions, given the unadjusted variance estimates calculated for each abundance index.

This compositional data set reweighting procedure was repeated whenever key inputs into the model were added, removed, or changed, to ensure that relative weights were appropriate for each model. This data weighting process therefore placed greater emphasis on the abundance data, because the compositional data sets fitted in this assessment were down-weighted by as much as 98% (for the purse seine age composition data). Down-weighted effective sample sizes estimated for the base case model are given in Appendix 4.

6. MODEL RUNS

6.1 Initial model structure

The single area model structure used for the 2015 assessment was no longer considered appropriate given regional differences in the recreational age composition data (Figure 12), including the change seen in the Hauraki Gulf recreational fishery during the late 2000s. A fleets-as-areas model structure was therefore adopted for this assessment, with separate selectivities estimated for each regional recreational fishery, with a distinction made between the 'Early' and 'Late' phases of the Hauraki Gulf recreational fishery. Several model runs were then undertaken to explore model sensitivities to alternative model input options. A summary of this initial model fishery structure, the observational data used and the selectivities that were estimates and applied to each of these data sets, is given in Table 7.

Table 7: Fleets-as-areas model structure used for the 2021 KAH 1 stock assessment given the observational data used and the selectivities that were estimates and applied to each of these inputs.

Area	Fleet	Catch history	Age composition data	Abundance index	Selectivity
East Northland	Recreational	1930 to 2020	2001 to 2018	1991 to 2020	Rec_EN (logistic)
Hauraki Gulf	Recreational–'Pre'	1930 to 1989	–	–	Rec_BP (logistic)*
	Recreational–'Early'	1990 to 2008	2001 to 2008	1991 to 2008	Rec_early (d-normal)
	Recreational–'Late'	2009 to 2020	2011 to 2018	2011 to 2018**	Rec_late (logistic)
Bay of Plenty	Recreational	1930 to 2020	2001 to 2018	1991 to 2020	Rec_BP (logistic)
All three areas combined	Purse seine	1930 to 2020	6 years (1991 to 2012)	–	PS (logistic)
	Single trawl	1930 to 2020	3 years (1991 to 1993)	–	ST (d-normal)
	Set net	1930 to 2020	2 years (2011 & 2012)	–	SN (fixed d-normal)
	Other methods	1930 to 2020		–	ST (d-normal)
	Aerial-sightings	–	–	1987 to 2013	PS (logistic)

* The Bay of Plenty recreational selectivity was applied to the "pre" recreational catch history for the Hauraki Gulf, which was assumed to be in a relatively unfished state before 1990, because most of the main commercial fishery landing kahawai operated elsewhere at this time.
** The Recreational 'Late' CPUE index was dropped from the final assessment model, for reasons described below.

6.2 Sensitivity to Late Hauraki Gulf observational data inclusion

As discussed above, the rapid change in the age composition of recreational landings from the Hauraki Gulf, and the associated marked increase in CPUE, cannot be explained by the assumed population dynamics within the gulf, and these changes are likely to be at least partially due to kahawai migrating into this region from elsewhere. The observational data for the Hauraki Gulf recreational fishery were therefore split into 'Early' and 'Late' time periods, and MPD model runs were undertaken to assess whether the 'Late' age composition and/or 'Late' CPUE index should be used to inform the assessment, because the influx of large fish into the Gulf may have been a single unrepeated event that did not reflect typical population dynamics.

The model was relatively insensitive to the inclusion of either of the Late Hauraki Gulf recreational fisheries data sets, producing similar biomass trajectories with slightly lower spawning stock biomass indices when included (Figure 15). The working group recommended that Late Hauraki Gulf age composition data should be retained, so that a selectivity could be estimated to account for removals by this fishery, but the CPUE index should be excluded from the model because it may not provide a reliable index of abundance for the wider KAH 1 stock given the assumed episodic migration of fish into Hauraki Gulf in the late 2000s.

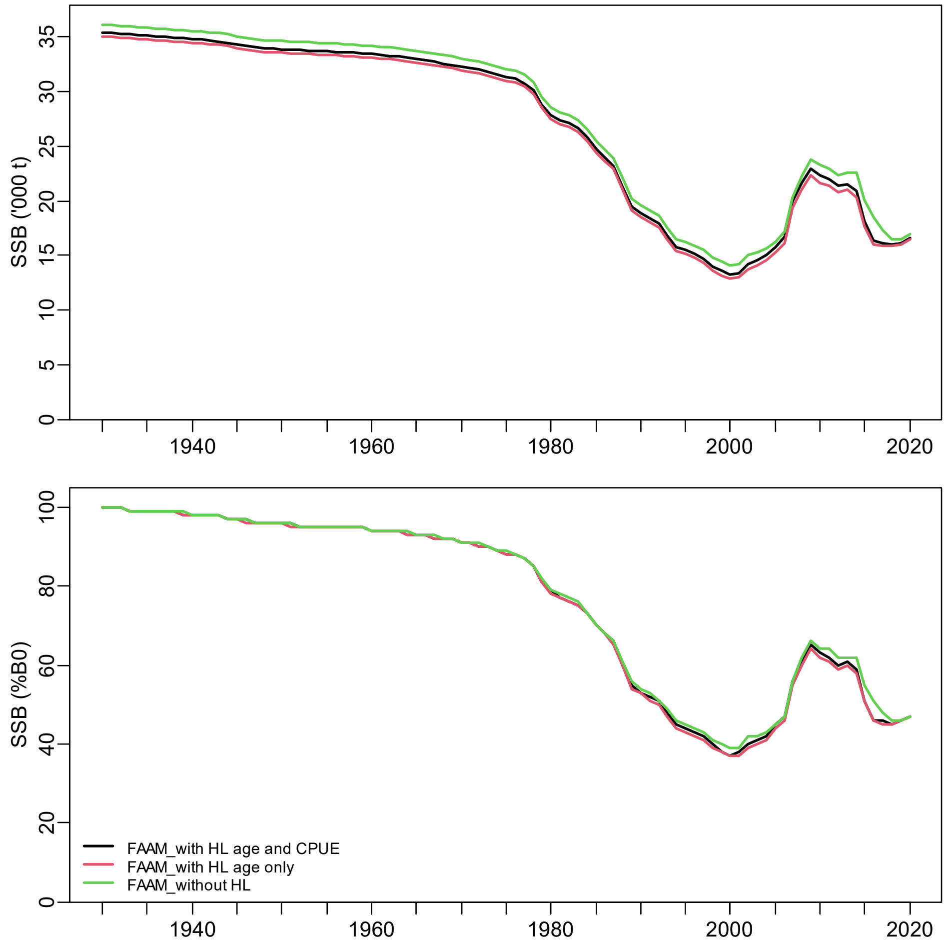


Figure 15: Comparison of MPD biomass trajectories when both the age compositional data and the CPUE index for the late Hauraki Gulf recreational fishery, just the age composition data, and neither data set were offered to the model

6.3 Sensitivity to the inclusion of the SPUE abundance index

The sightings per unit effort (SPUE) abundance index used in the 2015 KAH 1 stock assessment was retained for this assessment, because it extended back as early as the late 1980s when no other observational data were available to inform the model. This abundance index suggested a threefold increase in biomass in the mid to late 2000s, which was far greater than any other abundance index would suggest. This index was therefore again fitted with a CV of 42%, to allow for the observed variability of this index when the maximum annual population growth rate was assumed to be no greater than 10% (Figure 16).

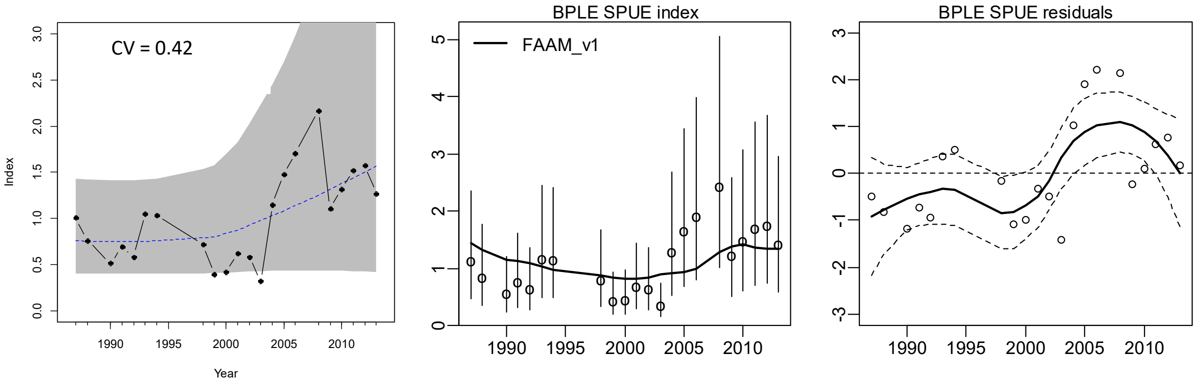


Figure 16: Spline fitted to the SPUE abundance index when a maximum rate of population increase was assumed to be 10%, and the fit of this index by an initial fleets-as-areas model when an index CV of 42% is assumed.

The SPUE index was mostly based on aerial sightings of kahawai schools in the western Bay of Plenty, and the working group questioned whether this index adequately described changes in abundance for the wider KAH 1 stock, especially given the rate at which sightings varied over relatively short time periods. The sensitivity of the model to the inclusion of this index was therefore explored, to see how much influence it had on model fits and the biomass trajectory. Model fits to the other abundance indices, age compositional data, estimates of year class strength, and biomass trajectories were very similar, regardless of whether the SPUE index was offered to the model, which was expected given the high CV associated with this abundance index (Figure 17). The SPUE index was retained for all further model iterations.

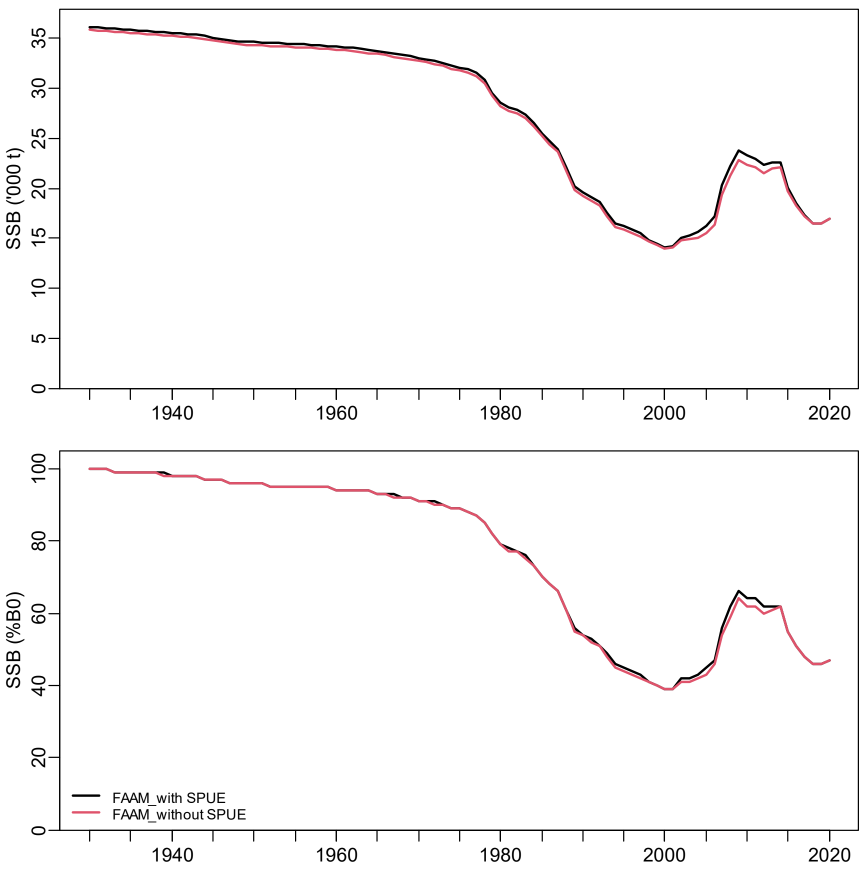


Figure 17: Comparison of MPD biomass trajectories when the SPUE index was included or excluded from the stock assessment model.

6.4 Natural mortality rate likelihood profiling

A key source of uncertainty explored in previous KAH 1 stock assessments was the assumed rate of natural mortality (see Section 3.2). The working group concluded that the assumed base case natural mortality rate should be 0.22, with bracketing sensitivity model runs undertaken where *M* was assumed to be 0.20 and 0.24 y^{-1}. These estimates were higher than those assumed for the 2015 assessment, where the base case rate was assumed to be 0.20 y^{-1} with sensitivity model runs undertaken where *M* was assumed to be 0.18 and 0.23 y^{-1} (Hartill & Bian 2016).

Likelihood profiling was used to further explore a plausible range of natural morality rate estimates. This profiling suggested that the most likely natural mortality rate given all observational data and the model assumptions was 0.233 y^{-1}, which supported the range of estimates proposed by the working group for the base case and final sensitivity model runs undertaken as part of this assessment (Figure 18).

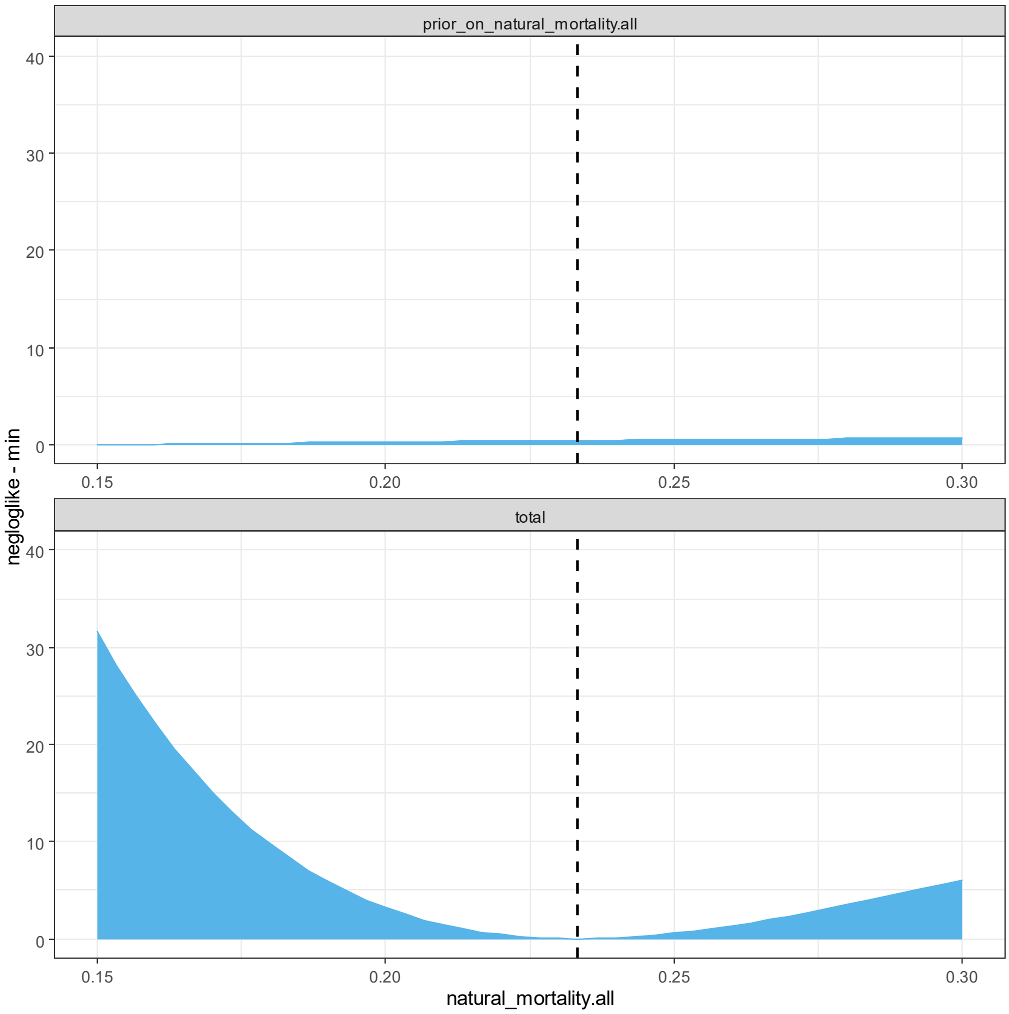


Figure 18: Likelihood profiling of the plausible range of natural mortality values.

7. FINAL BASE CASE AND SENSITIVITY RUNS

7.1 Model structure and MPD runs

The base case model for this assessment was configured as a fleets-as-areas, single time-step model, with processes occurring during each model year in the following order: ageing, recruitment, maturation, growth, natural mortality, and then fishing mortality. The default rate of natural mortality was set to 0.22 y^{-1} as this was considered the most plausible value. The steepness of the Beverton-Holt stock recruitment relationship was set to 0.75, which was also the default value assumed for the 2015 assessment models (Table 8). Wide bounds were set for all priors to not constrain parameter estimation. Year class strengths were only estimated for year classes that appeared at least three times in the available time series of recreational catch-at-age data.

A single selectivity-at-age ogive was estimated for each commercial fishery, and separate selectivities were estimated for each regional fishery fleet (see Table 7), as previously discussed in Section 5.5. Selectivity parameter estimates for the set net fishery were fixed at MPD values. Four abundance indices were used to inform each model: an East Northland recreational CPUE index fitted with a lognormal CV of 0.34; an Early Hauraki Gulf CPUE index (CV = 0.26); a Bay of Plenty CPUE index (CV = 0.20); and a spotter plane pilot-based SPUE index (CV = 0.42). The recreational abundance indices were fitted using the selectivities estimated for each respective fishery, and the purse seine selectivity was used to fit the SPUE index.

Table 8: Parameters used for the base case and sensitivity assessment models. ENLD is East Northland; HAGU is the Hauraki Gulf; BPLE is the Bay of Plenty.

Fixed biological parameters	value		
Natural mortality	M = 0.22(with sensitivities for M = 0.20 & 0.24)		
Steepness (Beverton-Holt)	h = 0.75		
Growth rate (von Bertalanffy)	L_∞ = 54.6		
	K = 0.35		
	t_0 = 0.13		
Length-weight	a = 0.0236		
	b = 2.89		
Age-at-maturity	4 years	(knife edge)	
Estimated biological parameters	**n**	**Priors**	**Bounds**
R_0	1	uniform-log	(10^5, 10^9)
Year class strengths (1994 to 2014)	21	lognormal (mu = 1, cv = 1)	(0.001, 20)
Estimated selectivity parameters			
ENLD recreational selectivity– logistic	2	uniform	(0.3, 25), (0.02, 5)
Early HAGU recreational selectivity – double-normal	3	uniform	(1, 15), (0.02, 15), (0.01, 15)
Late HAGU recreational selectivity– logistic	2	uniform	(0.3, 25), (0.02, 15)
BPLE recreational selectivity – logistic	2	uniform	(0.3, 25), (0.02, 5)
Purse seine selectivity – logistic	2	uniform	(0.3, 25), (0.02, 5)
Single trawl selectivity – double-normal	3	uniform	(1, 15), (0.02, 15), (0.01, 15)
Fixed selectivity parameters	**value**		
Set net selectivity – double-normal (fixed)	A_1 = 3.450		
	S_L = 0.597		
	R_L = 1.095		
Nuisance parameters	**n**	**Priors**	**Bounds**
ENLD recreational CPUE q (nuisance)	1	uniform-log	(1e-9, 1)
Early HAGU recreational CPUE q (nuisance)	1	uniform-log	(1e-9, 1)
BPLE recreational CPUE q (nuisance)	1	uniform-log	(1e-9, 1)
SPUE q (nuisance)	1	uniform-log	(1e-9, 1)

The working group considered the primary source of uncertainty with the base case model was the assumed rate of natural mortality. Sensitivity model runs were therefore requested for alternative assumed values for *M*, which were regarded as plausible lower and upper estimates for this influential parameter, which were 0.20 and 0.24 y^{-1}.

Very similar MPD selectivity ogives were estimated by the base case and higher *M* sensitivity models, but ogives estimated by the lower *M* sensitivity model differed for some fisheries (Figure 19). The East Northland recreational and single trawl selectivity ogives estimated by the lower *M* sensitivity model were less selective for younger fish, with the early Hauraki Gulf recreational ogive selecting fish at a younger age than the other two models.

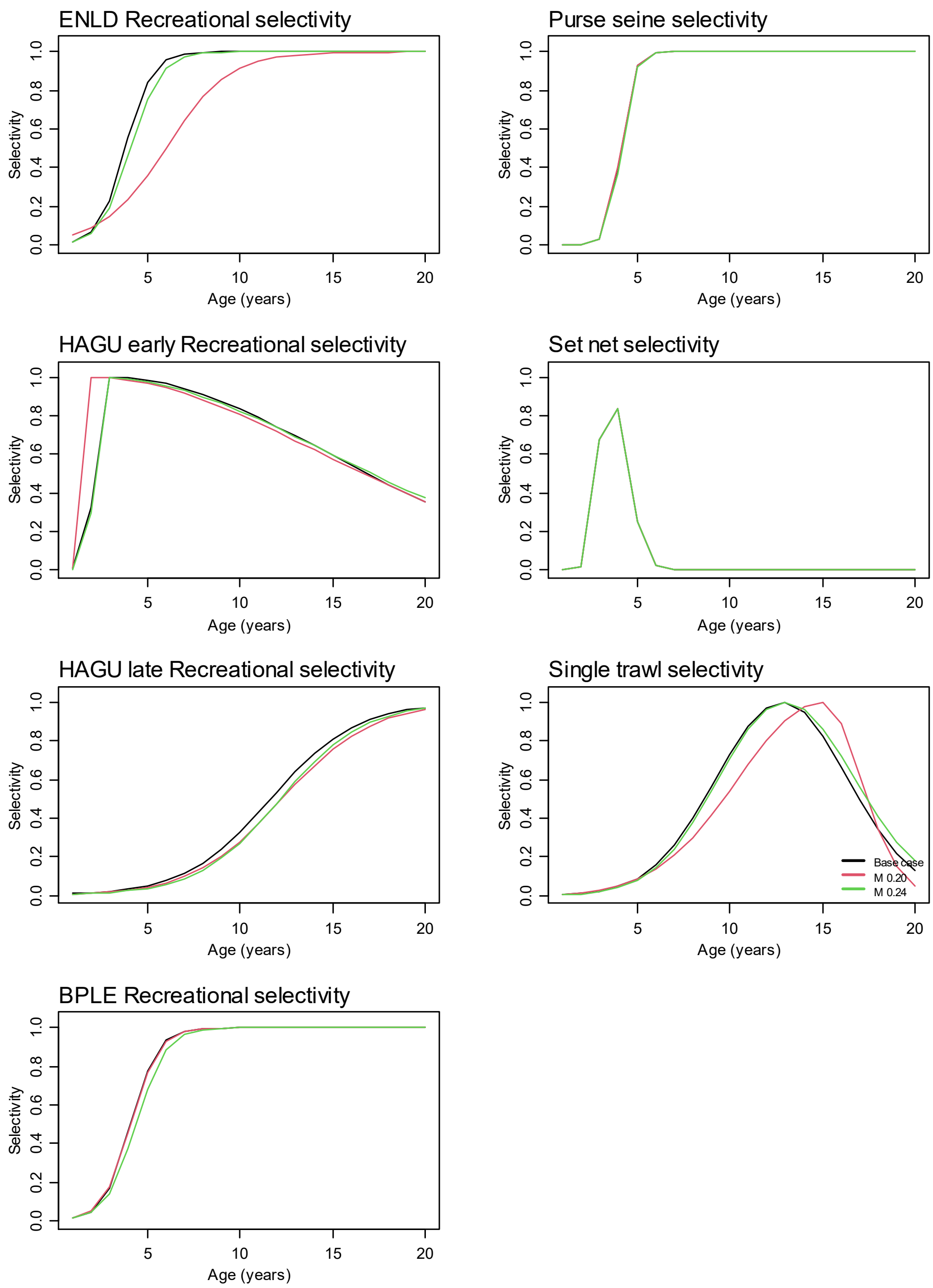


Figure 19: Base case (*M* = 0.22) and sensitivity (*M* = 0.20 & 0.24) model selectivity ogives. Parameter estimates for the set net selectivity ogive were fixed at MPD values provided by preliminary model runs, and the same selectivity was therefore assumed for this fishery for all models.

The two higher *M* models produced marginally better fits to most of the earlier age composition data for the East Northland and Hauraki Gulf recreational fisheries, and the single trawl compositional data from the early 1990s, with the lower *M* model providing marginally better fits to some of the most recent recreational age compositional data, when the younger age classes were less prominent (Figures 20 to 26). The lower *M* sensitivity model predicted marginally stronger year classes during the mid-1990s and weaker year classes since the mid-2000s (Figure 27).

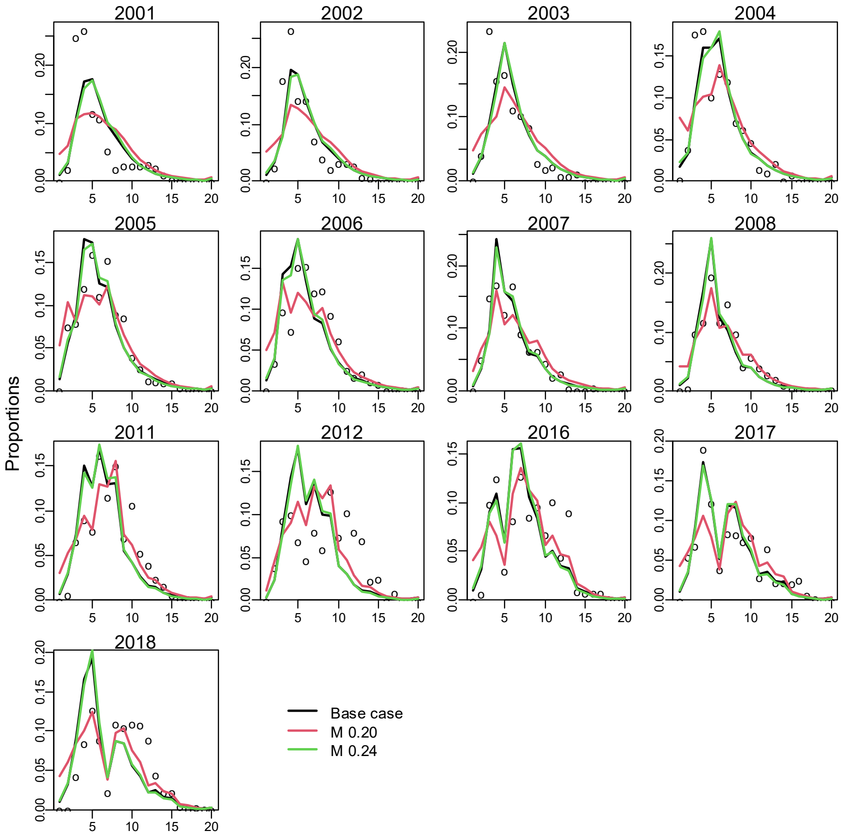


Figure 20: Base case (*M* = 0.22) and sensitivity model fits to the East Northland recreational catch-at-age compositional data.

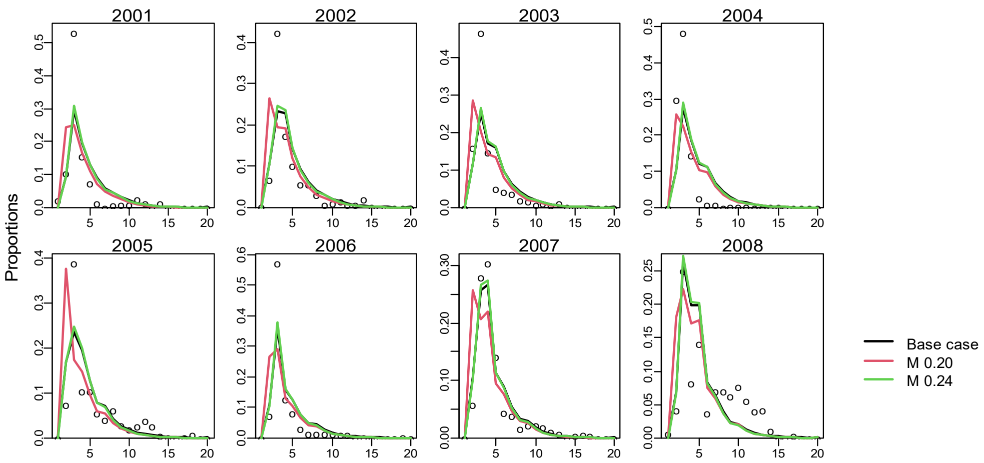


Figure 21: Base case (*M* = 0.22) and sensitivity model fits to the Early Hauraki Gulf recreational catch-at-age compositional data.

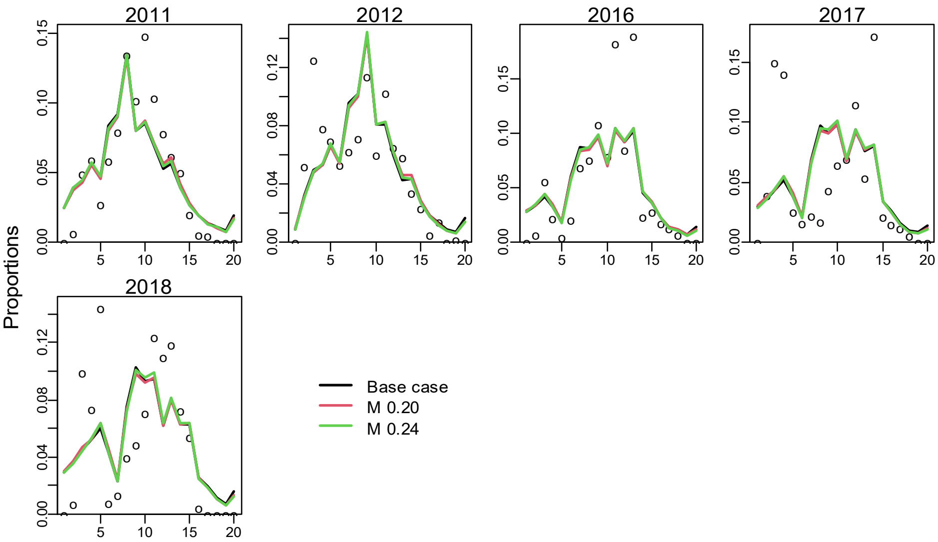


Figure 22: Base case (*M* = 0.22) and sensitivity model fits to the Late Hauraki Gulf recreational catch-at-age compositional data.

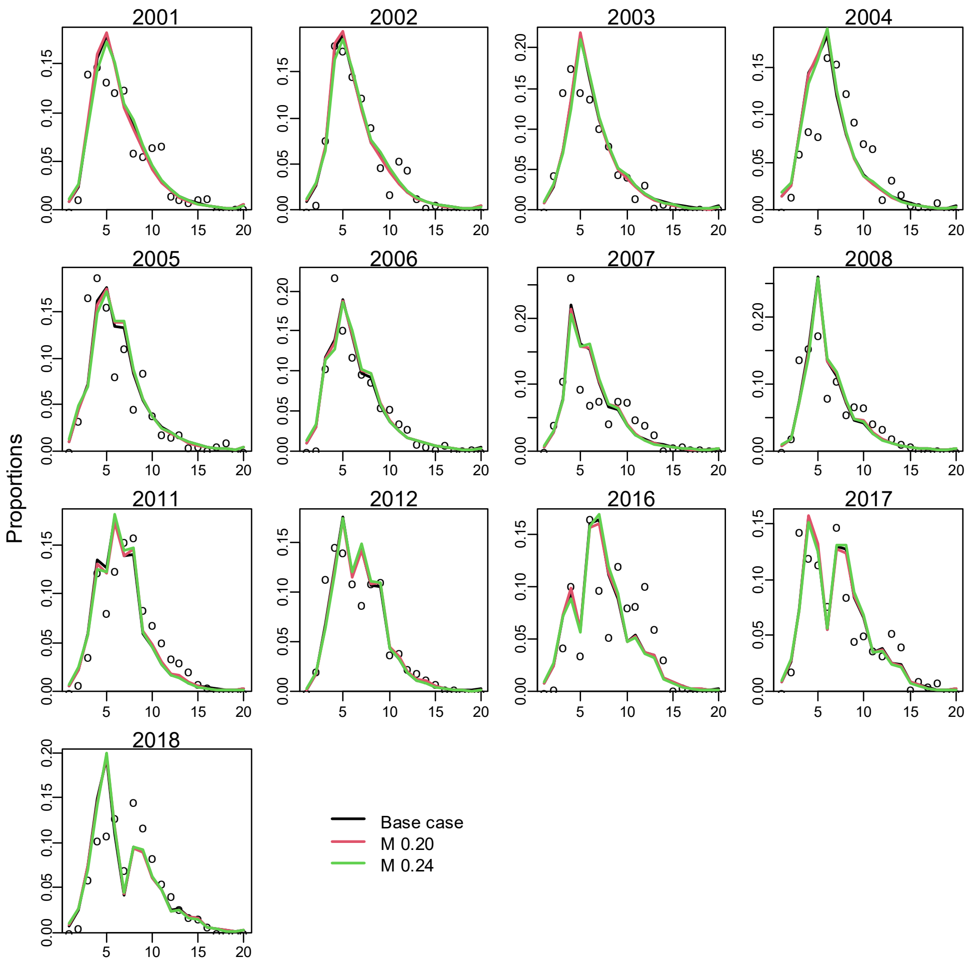


Figure 23: Base case (*M* = 0.22) and sensitivity model fits to the Bay of Plenty recreational catch-at-age compositional data.

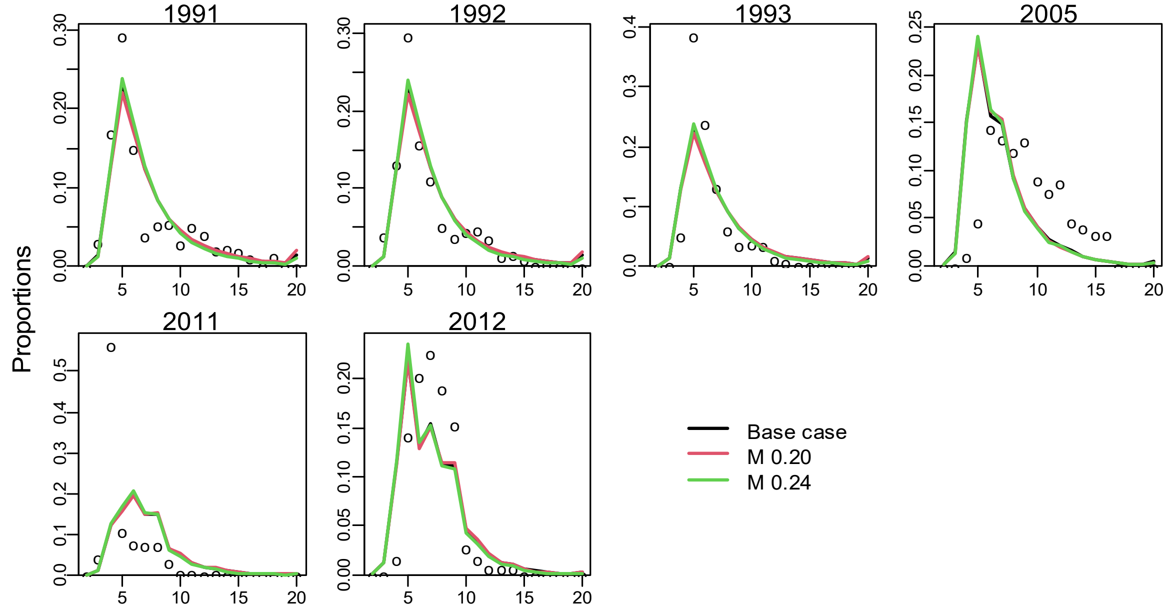


Figure 24: Base case (*M* = 0.22) and sensitivity model fits to the purse seine catch-at-age compositional data.

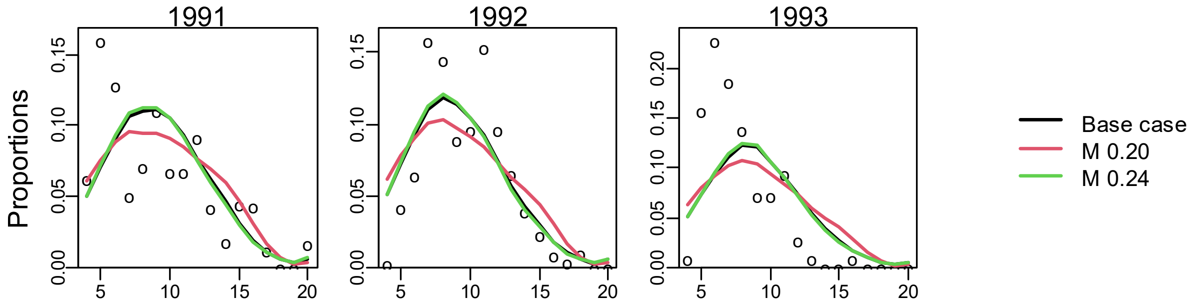


Figure 25: Base case (*M* = 0.22) and sensitivity model fits to the single trawl catch-at-age compositional data.

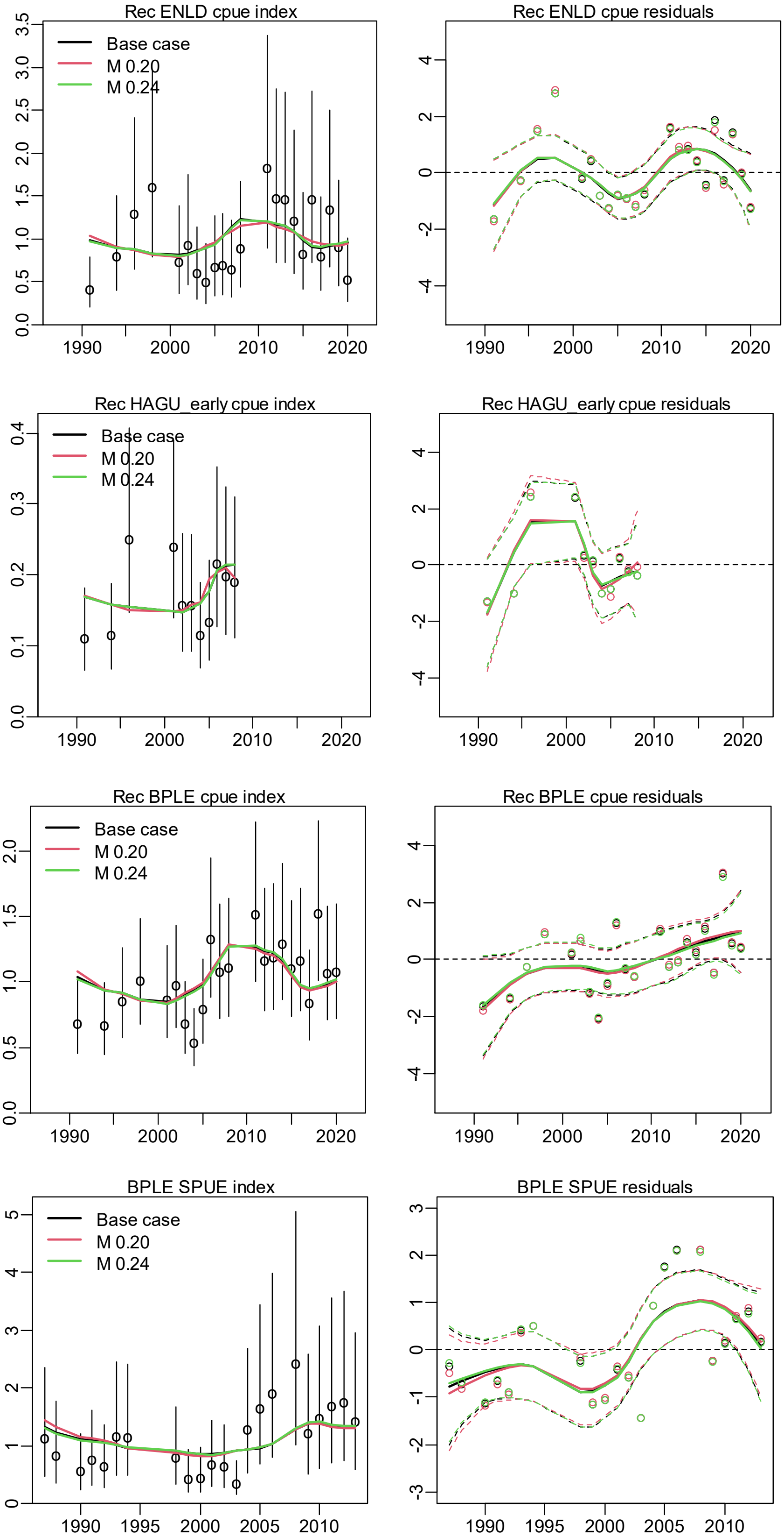


Figure 26: Base case (*M* = 0.22) and sensitivity model fits to three regional CPUE abundance indices and a western Bay of Plenty aerial Sightings Per Unit Effort (SPUE) abundance index. The left panels show the model fits to each index and the right panels show these fits expressed as residuals.

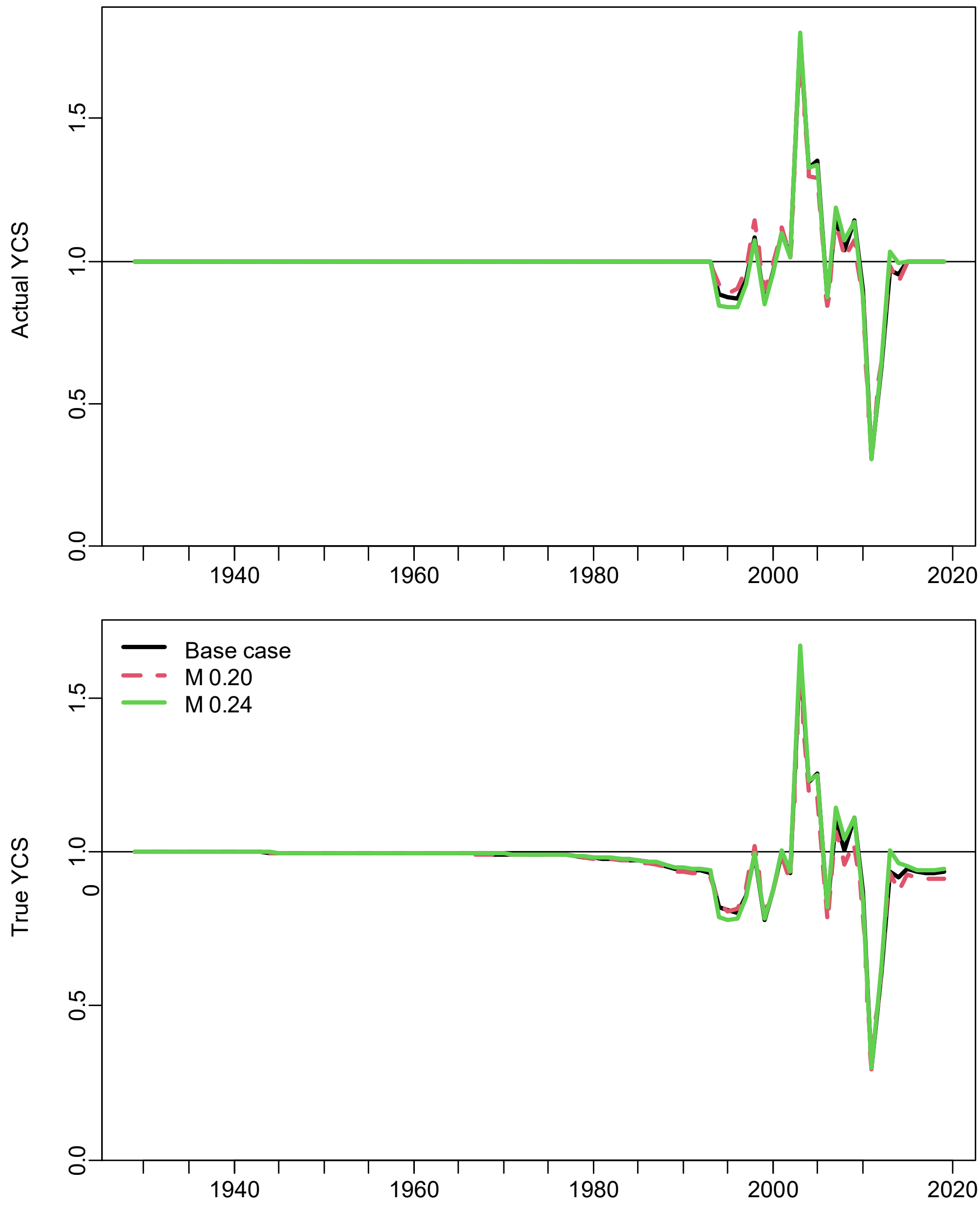


Figure 27: Year class strengths estimated by the base case (*M* = 0.22) and sensitivity models.

While the fits to the abundance indices provided by the three models are very similar, the initially stronger and then subsequently weaker year class strengths predicted by the lower *M* sensitivity model produced a greater reduction in the biomass and status of the KAH 1 stock, than suggested by the base case and higher *M* model (Figure 27 and 28). Regardless, all three models indicated a similar biomass trajectory over time, with a gradual fishing down of the KAH 1 stock during the 1980s and 1990s, followed by a rapid increase in abundance in the late 2000s, that was driven by strong recruitment in the early 2000s, with weaker recruitment resulting in a decline in abundance up until around 2016.

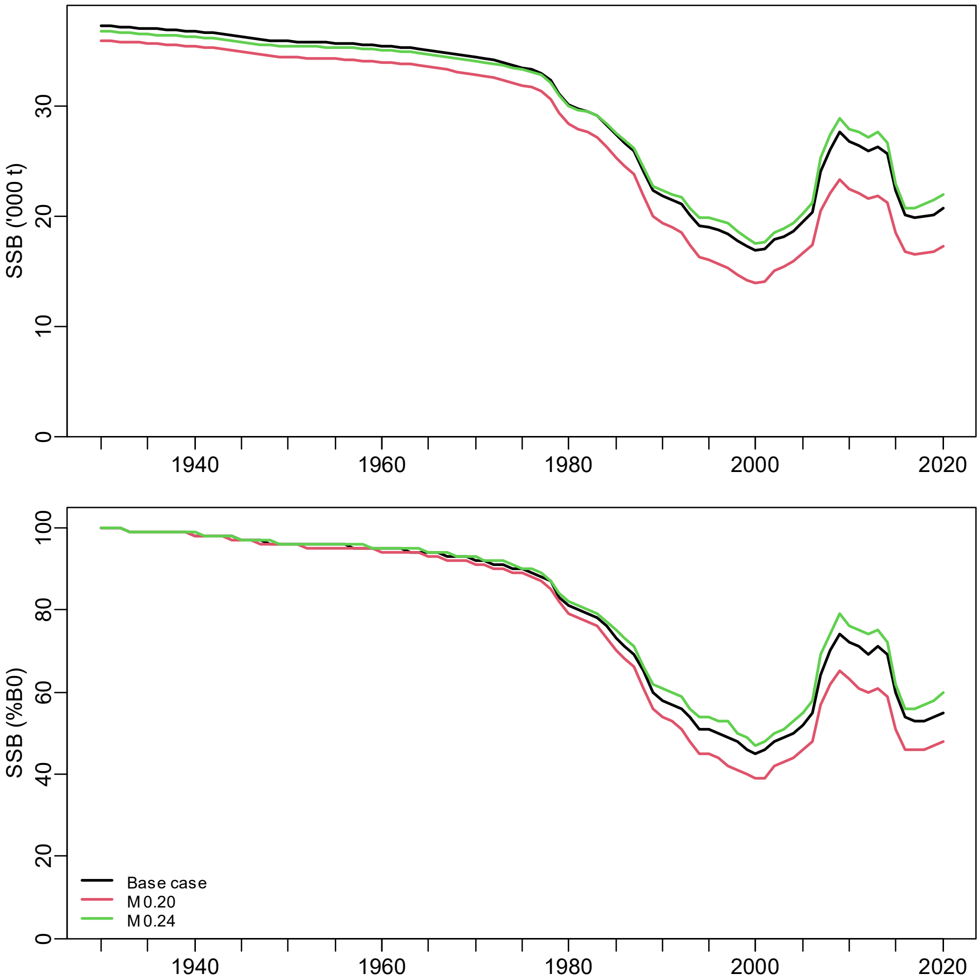


Figure 28: Comparison of biomass trajectories estimated by the base case (*M* = 0.22) and sensitivity models.

7.2 MCMC model runs

Markov chain Monte Carlo (MCMC) chains were subsampled to get final estimates of parameters and their statistical uncertainty for each model. All MCMC chains were started a random step away from the MPD for each model and run for two million iterations, from which every 1000th iteration was sampled after discarding the first 10% of each chain as a burn-in. Three independent MCMC chains were run and samples were concatenated for each model. In initial runs the MCMC traces indicated poor convergence for some of the selectivity parameters, but there was no evidence of non-convergence after the covariance matrix was re-estimated before MCMC chains were restarted for each model. MCMC traces for key outputs provided by each model are shown in Figure 29.

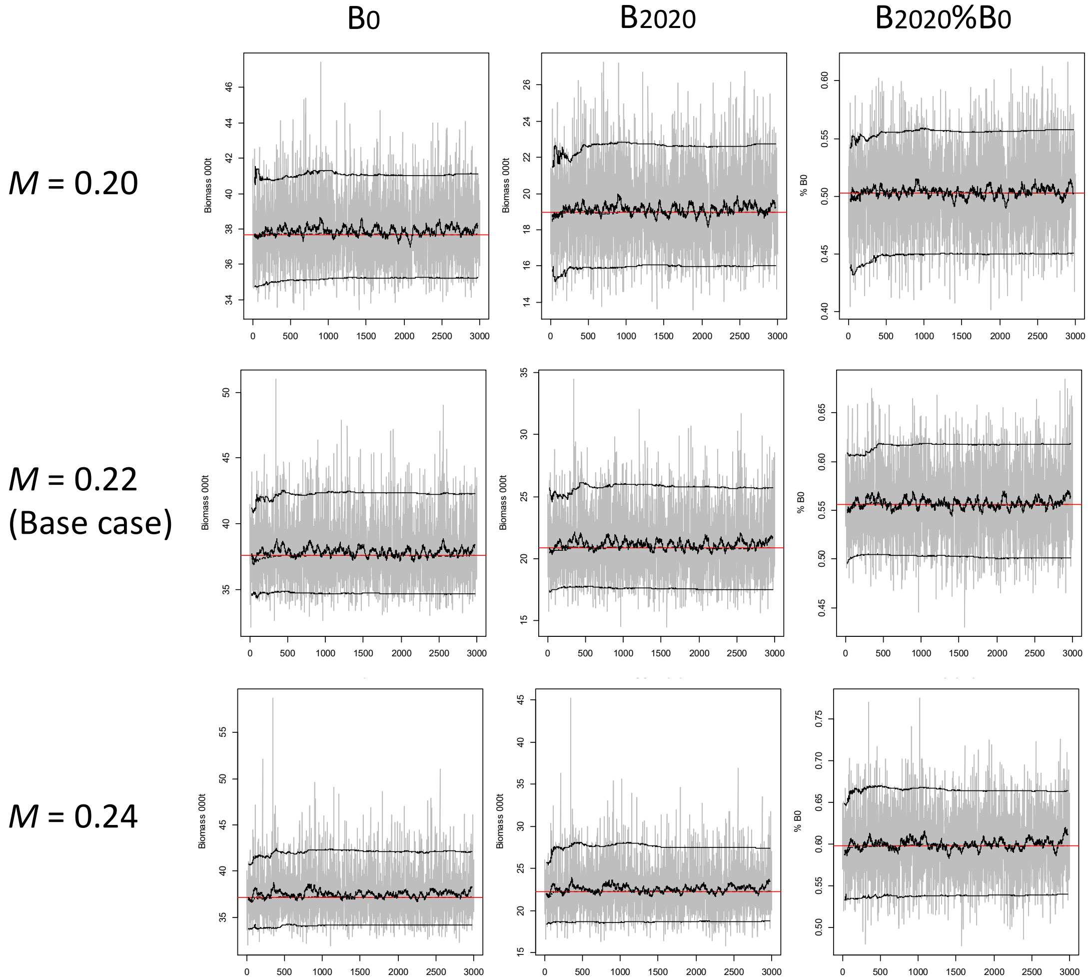


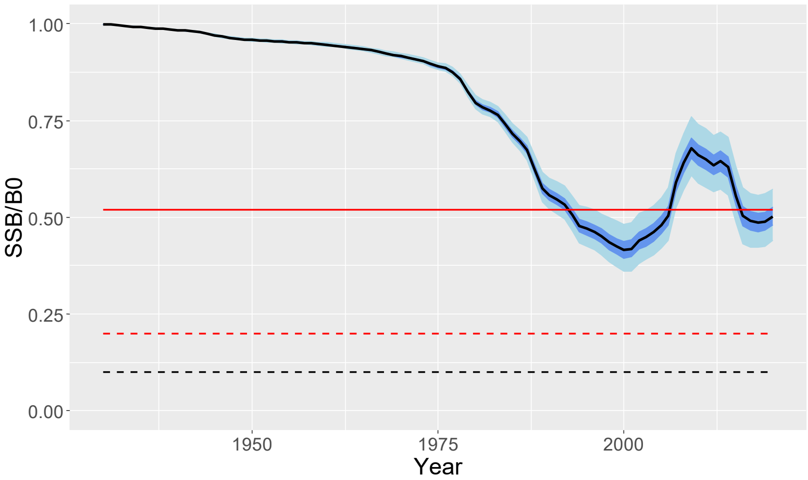
Figure 29: MCMC traces for key outputs produced by the base case and sensitivity models. The horizontal red line denotes the median value for each concatenated MCMC chain, the solid middle black line denotes a moving average of 50 MCMC estimates, and the upper and lower solid black lines depict 95% credibility intervals.

All three models estimated that the biomass of the KAH 1 stock had remained above the 20% soft limit throughout its fishing history and was currently close to or above the 52% B_0 target level (Table 9, Figure 30). The interpretations of stock status held across the range of plausible natural mortality rates evaluated by the sensitivity models.

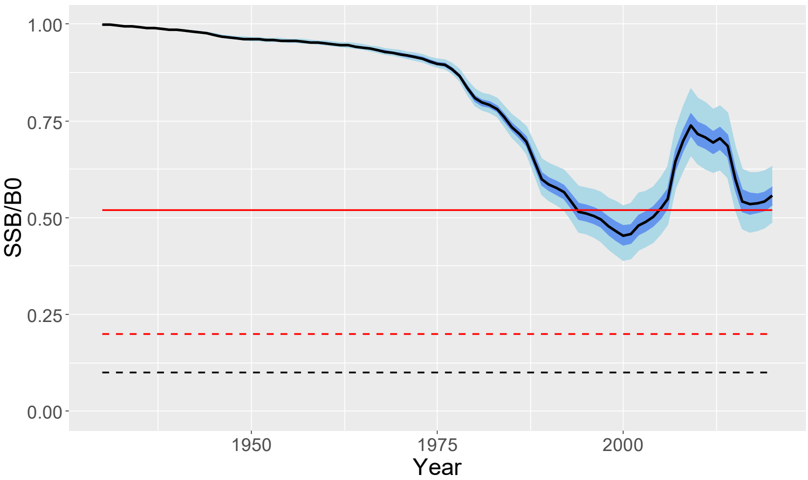
Table 9: Biomass (t) and stock status estimates derived from MCMC runs for the base model (three chains combined) and two sensitivity models (medians with 95% credible intervals in parentheses).

Model	SSB_0	SSB_{2020}	52% SSB	SSB_{2020}/SSB_0	SSB_{2020}/52% SSB
M = 0.20	37 665	18 975	19 586	0.504	0.969
	(34 873–41 824)	(15 533–23 661)	(18 134–21 748)	(0.445–0.566)	(0.857–1.088)
M = 0.22	37 549	20 880	19 524	0.556	1.069
(Base case)	(34 151–43 205)	(17 050–26 796)	(17 759–22 467)	(0.499–0.620)	(0.960–1.193)
M = 0.24	37 131	22 299	19 319	0.600	1.154
	(33 583–43 599)	(18 115–29 016)	(17 463–22 671)	(0.534–0.666)	(1.037–1.278)

M = 0.20



M = 0.22 (Base case)



M = 0.24

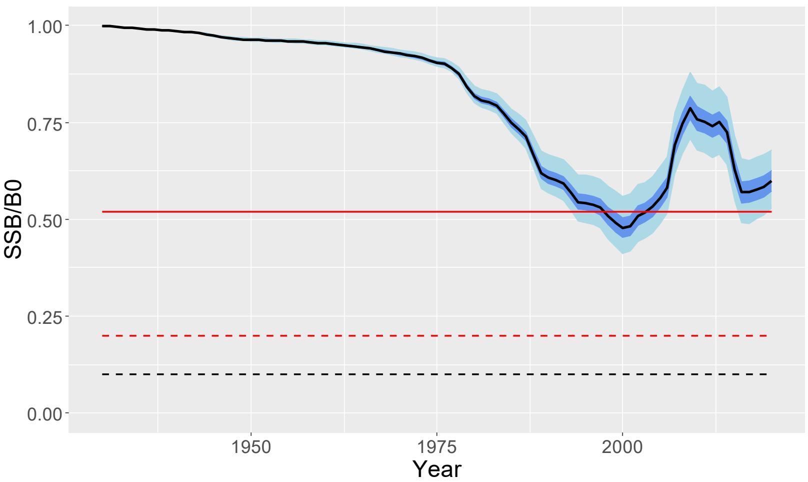


Figure 30: Posterior distributions for estimated stock status (% B_0) trajectories generated by the base case and sensitivity models. Solid lines denote estimated medians, darker blue shaded areas indicate the lower to upper quartile range, and light blue shaded areas indicate 95% credibility intervals. The red horizontal solid lines denote the 52% B_0 target set by the Minister of Fisheries in 2010, the horizontal red dashed lines denotes the 20% B_0 soft limit, and the black dashed horizontal lines denote the hard limit.

7.3 Fishing pressure

The target status for the KAH 1 stock that was set by the Minister of Fisheries in 2010 was 52% B_0, which is well above the Harvest Strategy Standard default target for a medium productivity (35% B_0) species such as kahawai (Ministry of Fisheries 2011). Annual exploitation rate estimates (U), and the level of constant fishing pressure that should result in an equilibrium biomass equivalent to 52% of B_0 ($U_{52\% B0}$), were calculated using the methods described by Cordue (2012). A plot of past annual exploitation rates relative to concurrent stock status estimates suggested that the fishing pressure experienced by the KAH 1 stock exceeded target levels during some years in late 1980s and 1990s, (Figure 31). The KAH 1 stock then rebuilt, following the introduction and further reduction of competitive purse seine catch limits during the early 1990s. The biomass of the KAH 1 stock has been maintained at levels higher than 52% B_0 since that time.

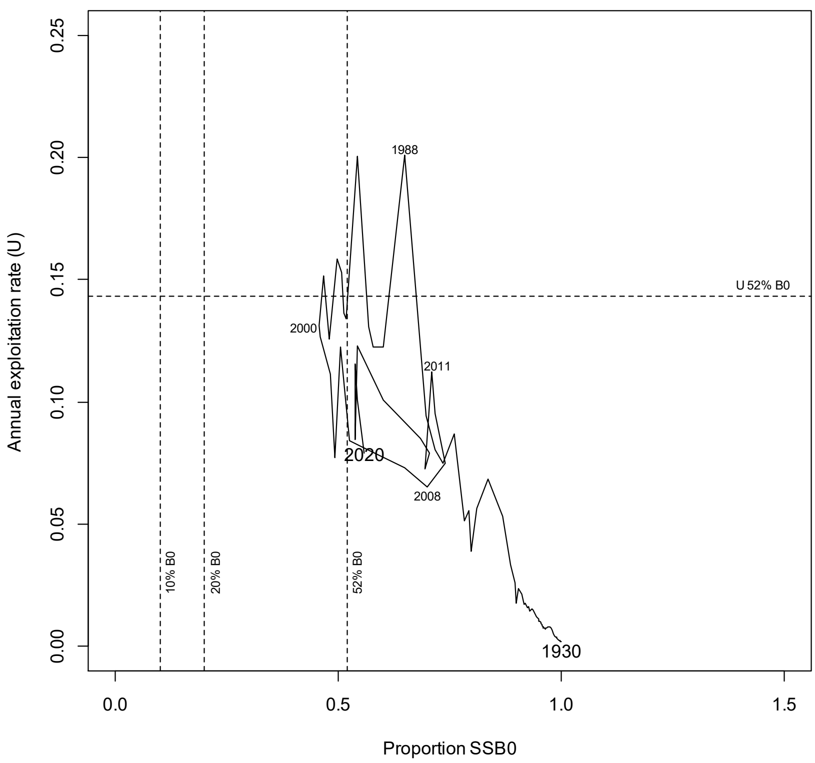


Figure 31: Trajectory of spawning stock biomass relative to B_0 for the base model (M = 0.22) and annual fishing intensity. The 52% B_0 target set by the Minister of Fisheries in 2010 is denoted by a black dashed line and the 20% B_0 soft limit and 10% B_0 hard limit are denoted by the grey dashed lines. Annual exploitation rates were calculated as the total tonnage of all fish 4 years and older divided by the biomass of all fish four years and older in each year.

7.4 Base case model projections

Projections of the base case model were undertaken to estimate the potential status of the KAH 1 stock at the end of the 2025–26 fishing year, with estimated year class strengths being empirically resampled with replacement from two alternative time periods; from the 10 most recent year classes (2005–2014) and from all 21 of the estimated year classes for which strengths were estimated (1994–2014). The assumed annual catch taken over this 5-year projection period was the average annual catch taken by each fishery over the 3-year period from 2017–18 to 2019–20. These projections both suggested that current stock status was likely to gradually improve over the projected period (Table 10, Figure 32). The probability of the stock being at or above 52% B_0 in 2026 was 0.646 when the 10 most recently estimated year classes were resampled and 0.840 when all 21 estimated year classes were resampled.

Table 10: Probability of the KAH 1 stock in 2026 falling below soft and hard limits and being at or above the target reference point in 2026. The target reference point of 52% B_0 was set by the Minister of Fisheries for this stock in 2010. Probabilities are calculated from the distribution of MCMC estimates calculated from each model (three chains combined for the base model).

Model	SSB_{2026}/SSB_0	Pr SSB_{2026}<10% SSB_0	Pr SSB_{2026}<20% SSB_0	Pr SSB_{2026}>52% SSB_0
M = 0.22 (Resampling 21 YCSs)	0.608 (0.460–0.728)	0.000	0.000	0.840
M = 0.22 (Resampling 10 YCSs)	0.556 (0.401–0.682)	0.000	0.987	0.646

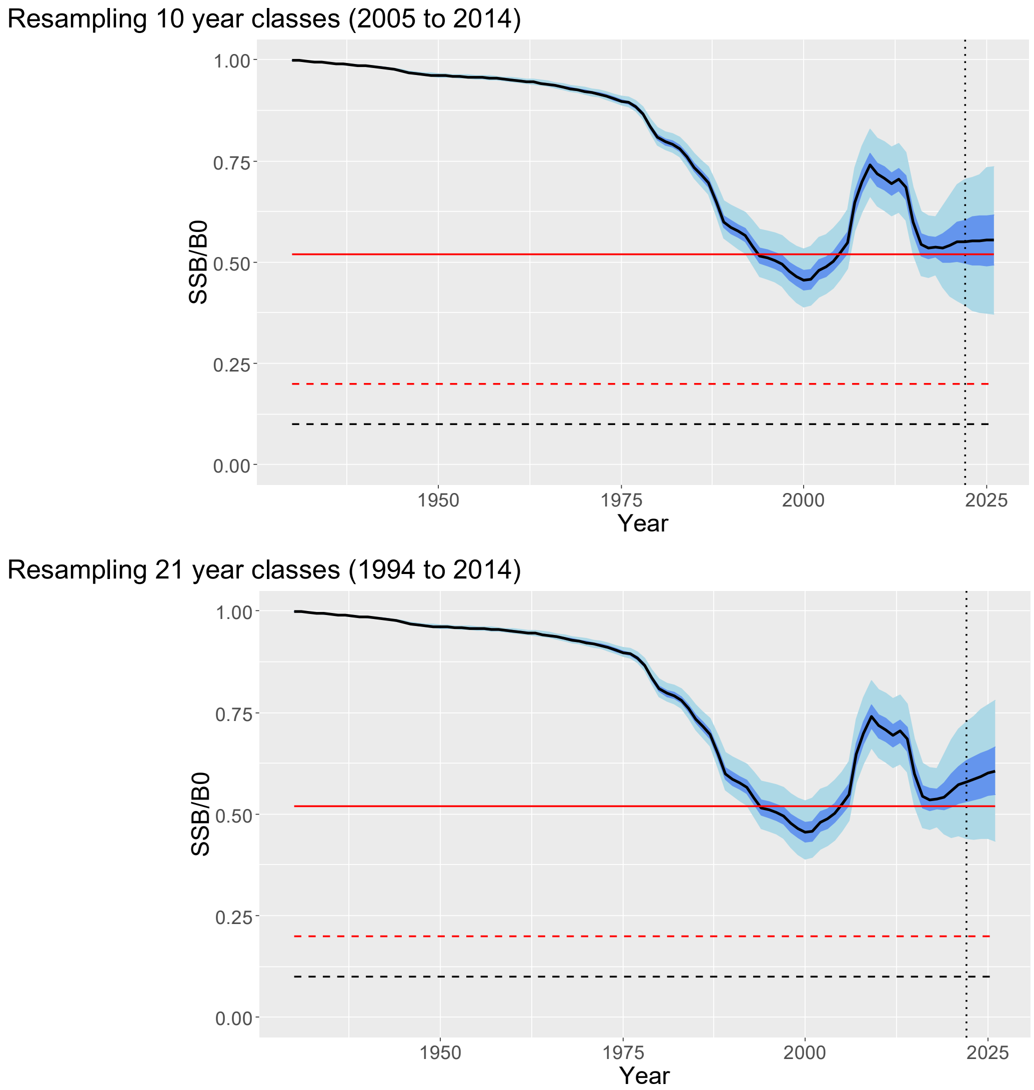


Figure 32: Posterior distributions for estimated stock status (%B_0) trajectories for base case models where 5-year projections were based on empirical resampling of the 10 most recent year class strengths (upper panel) and resampling from the 21 most recent year class strengths (lower panel). Solid lines denote estimated medians, darker blue shaded areas indicate the lower to upper quartile range, and light blue shaded areas indicate 95% credibility intervals. The red horizontal solid lines denote the 52% B_0 target set by the Minister of Fisheries in 2010, the horizontal red dashed lines denote the 20% B_0 soft limit, and the horizontal black dashed lines denote the 10% B_0 hard limit. The vertical black dotted lines denote the first year of the projection period (2021–22).

8. DISCUSSION

The age-based stock assessment described in this report was adapted from the single area CASAL population model developed for the 2015 stock assessment for KAH 1 (Hartill & Bian 2016) which used two abundance indices modelled to represent the whole stock (i.e., not region), one based on BPLE data and another based on combined data from HAGU and ENLD. The latter structure was reviewed and changed (*see* below). All of the biological parameter estimates and observational data used to inform the 2015 assessment were reviewed and, where applicable, updated with most data being sourced from recreational fisheries surveys.

A time series of recreational catch-at-age data was updated to include compositional data collected from the East Northland, the Hauraki Gulf, and the Bay of Plenty fisheries during 2016, 2017, and 2018. Regional recreational age composition data are now available for thirteen years since 2001, and a review of these data led to the reconfiguration of the assessment from a single area to a fleets-as-areas model structure. This was done because there was clear evidence of consistent regional differences in the age compositions of recreational landings, with a hypothesis of an episodic influx of older fish from the Bay of Plenty into the Hauraki Gulf sometime around 2010. The methods used to combine the age composition data from these three regional fisheries into one were no longer considered appropriate, given our limited understanding of the cause and extent of this influx of older fish into the Gulf. A fleets-as-areas model structure, which estimated separate selectivities for pre and post 2010 Hauraki Gulf fisheries and the recreational fisheries operating in East Northland and Bay of Plenty, provided the most tractable means of accommodating the trends seen in these age composition data. Each of the commercial fisheries were treated as a single fleet with its own catch history and selectivity, given the limited observational data available.

The recreational age composition data were given greater emphasis in this assessment, because the commercial age composition data that were available for a limited number of years were heavily down-weighted to minimise their influence on year class strength estimation. Year class strengths should not be inferred from the purse seine, single trawl, and set net fisheries, because: the spatial extent of the landings sampled was limited to one region of KAH 1 in each case; each fishery was only sampled in a very small number of years; and the purse seine fishery interacts with very few schools, in a non-random manner. The down-weighted age composition data sampled from these fisheries were retained in the model, however, so that selectivity ogives could be estimated for each method, to account for the catch removed by these commercial fisheries.

The primary abundance indices used to inform this assessment were based on recreational CPUE data, which have been standardised here for the first time. The recreational CPUE indices used for previous assessments of the KAH 1 stock were unstandardised, because the standardised indices produced by the Poisson and delta-lognormal approaches investigated at that time generated similar indices, with diagnostics indicating poor fits to the data. The rootogram diagnostic plots derived from the negative binomial and zero inflated negative binomial recreational CPUE standardisations support the ongoing use of these methods for future standardisations of recreational CPUE. This development is significant, because this assessment is especially reliant on recreational CPUE indices given the limited utility of the measures of effort reported by the main commercial fisheries operating in KAH 1. The only potentially informative relative abundance index that can be derived from a commercial fishery is the sightings per unit effort (SPUE) index used in this assessment, which was based on sightings of kahawai schools by spotter plane pilots working with the purse seine fleet. This index has limited utility, however, because aerial sightings data are only available from the Bay of Plenty, which were reported by single pilot who is no longer flying, and because of the high degree of interannual variability in abundance suggested by this index. The set net indices used for the 2007 KAH 1 stock assessment (Hartill 2009) are no longer considered reliable, because of the lack of distinction between set net and ring net effort reporting.

A new approach to modelling recreational catch histories was also developed as part of this assessment. Absolute tonnage recreational harvest estimates were only available from large scale aerial-access or

NPS surveys conducted in 2004–05, 2011–12, and 2017–18; the recreational harvest taken in other years was largely unknown. Previous assessments of inshore fish stocks have assumed that changing levels of recreational harvesting can be inferred from changes in recreational CPUE over time, but levels of recreational fishing effort will also change over time, due to prevailing weather conditions, population growth, economic conditions, and in response to perceived likely fishing success. The zero inflated negative binomial modelling of the hourly rate at which kahawai were landed (summed across all boats encountered) therefore provided a more comprehensive measure of changing relative levels of recreational harvesting over time, than previously inferred from CPUE indices that did not account for changing levels of recreational fishing effort over time. Modelling of recreational catches based on this approach or similar is recommended for future inshore stock assessments when non-commercial fisheries account for a significant proportion of the annual landed catch.

The key source of uncertainty investigated in this assessment was the assumed rate of natural mortality (M). The natural mortality rate estimates used for this and previous assessments of the KAH 1 stock have been inferred from age composition data collected during the early to mid-1970s and it is unlikely that further pre-exploitation age composition data will become available. Alternative natural mortality rate estimators could be applied to the existing data, however, to either confirm or revise the range of values assumed for this assessment (Kenchington 2014). The natural mortality rate assumed for the base case of the 2007 assessment was 0.18 y^{-1}, which was revised up to 0.20 y^{-1} for the 2015 assessment base case model. A further review of early exploitation age composition and other data sources from which natural mortality rates could be inferred outside the model, and within model likelihood profiling, suggested a more plausible rate of 0.22 y^{-1}, which was assumed for this assessment's base case model, with sensitivity model runs at 0.20 y^{-1} and 0.24 y^{-1}. All three models in the 2021 assessment indicated a current stock status that was close to or above the target level of 52% B_0, as set by the Minister of Fisheries in 2010.

Other sources of uncertainty considered by the 2006 and 2015 assessments that were investigated in 2021 were: 1) the assumed steepness of the Beverton-Holt stock recruitment relationship; 2) the assumed magnitude of the recreational catch; and 3) choice of abundance index. The 2007 assessment was largely insensitive to the value assumed for steepness, and a default value of 0.75 has been assumed since. Alternative methods have since been used to concurrently estimate and mutually corroborate recreational harvest estimates in 2011–12 (Edwards & Hartill 2015) and 2017–18 (Hartill & Bian 2020), and the model-based estimates provided here give some indication of the likely recreational harvest in each region over at least the past two decades. Finally, the SPUE index was retained for this and the 2015 assessment, although it had relatively little influence on the biomass trajectory estimated for this stock.

Perhaps the most significant source of uncertainty yet to be investigated is structure of the KAH 1 stock and the degree of mixing between regional sub-populations in this area. Aside from, at times, persistent differences between regional recreational catch-at-age compositional data, there was almost no other information available from which we could infer movement rates between areas and the relative contribution of sub-populations to the KAH 1 stock. Agent Based Modelling is currently being used to assess the sensitivity of this stock assessment model to alternative conceptualisations of stock structure, which could be further explored as part of the next assessment of the KAH 1 stock (the first presentation of this work was given to the Inshore Working Group on the 31 August 2022). Further sources of uncertainty that could be explored include: the sensitivity of the model to higher and lower levels of recreational harvesting prior to 1990; the extent to which annual variability in the availability of kahawai to recreational fishers may affect CPUE; and whether the limited age composition data that are available for the purse seine fishery adequately describe removals by this fishery.

9. ACKNOWLEDGEMENTS

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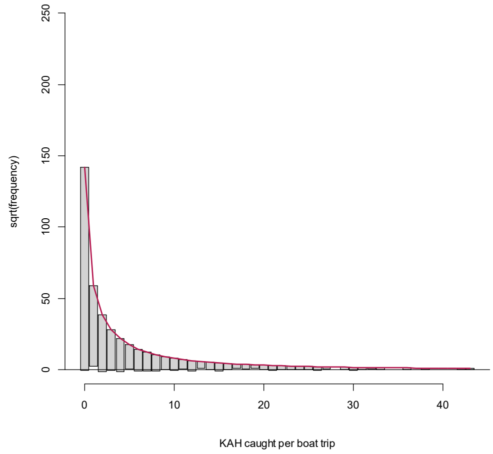
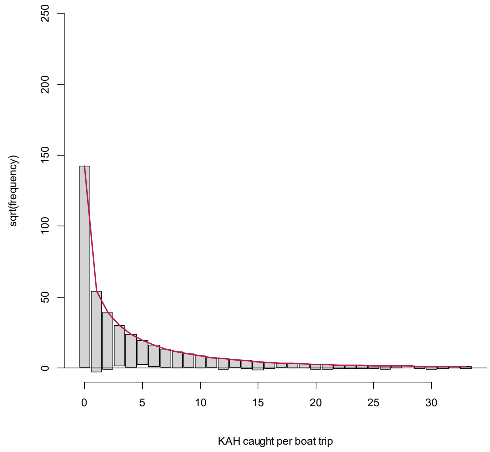
APPENDIX 1: Rootogram diagnostics for regional recreational CPUE standardisations

East Northland

NB

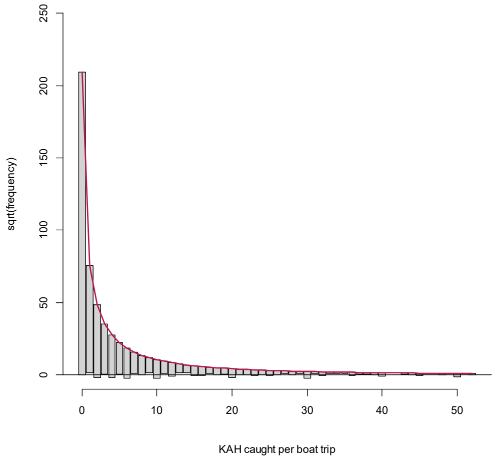


ZINB



Hauraki Gulf

NB



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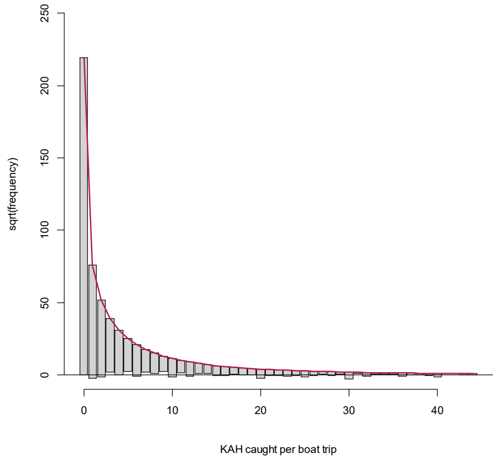
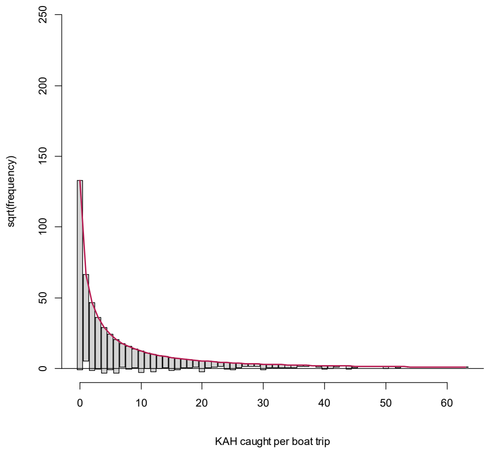


Bay of Plenty

NB



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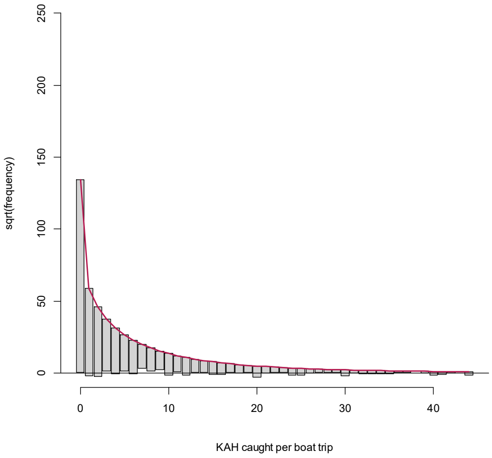
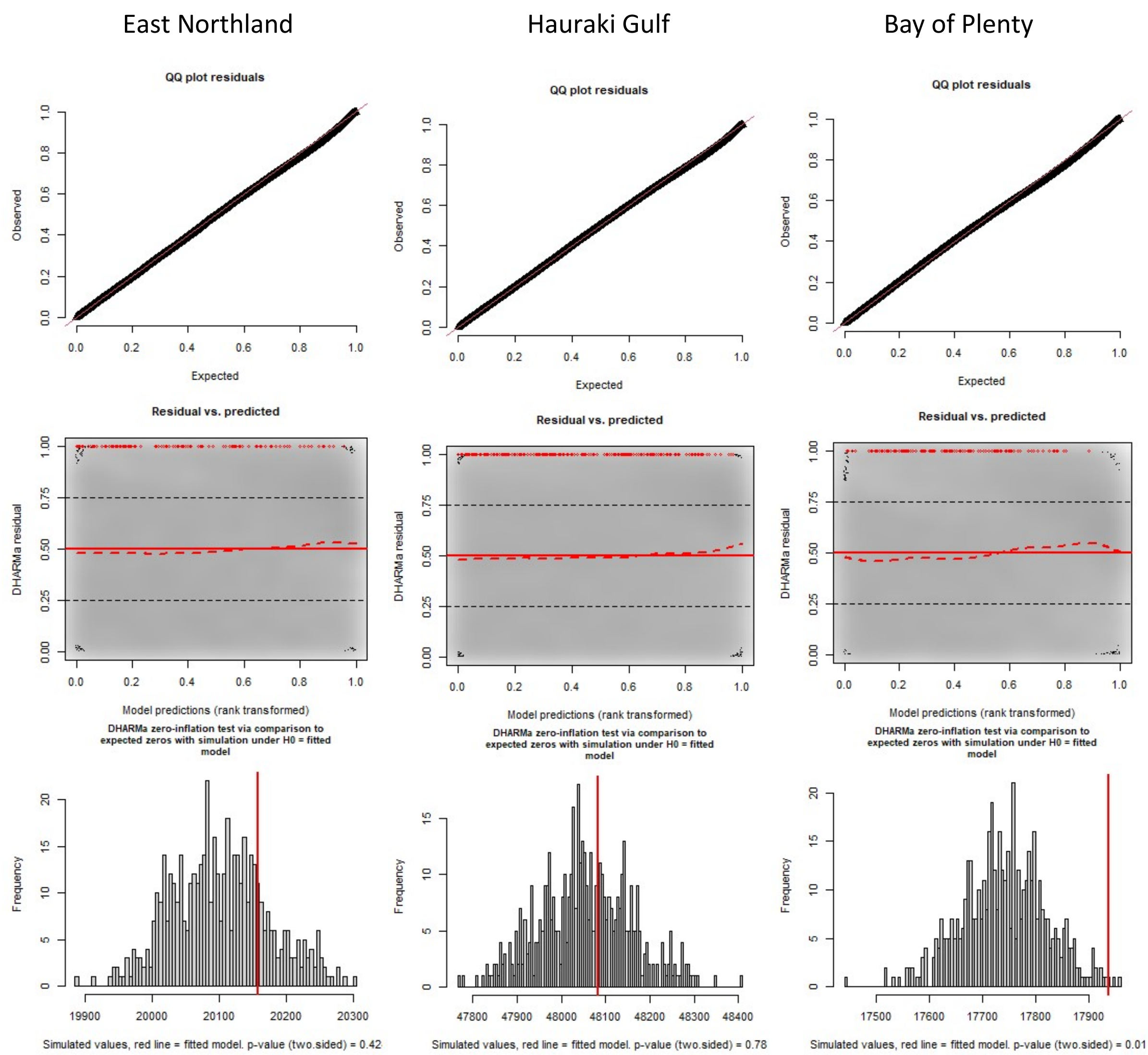


APPENDIX 2: Negative binomial recreational CPUE standardisation diagnostics

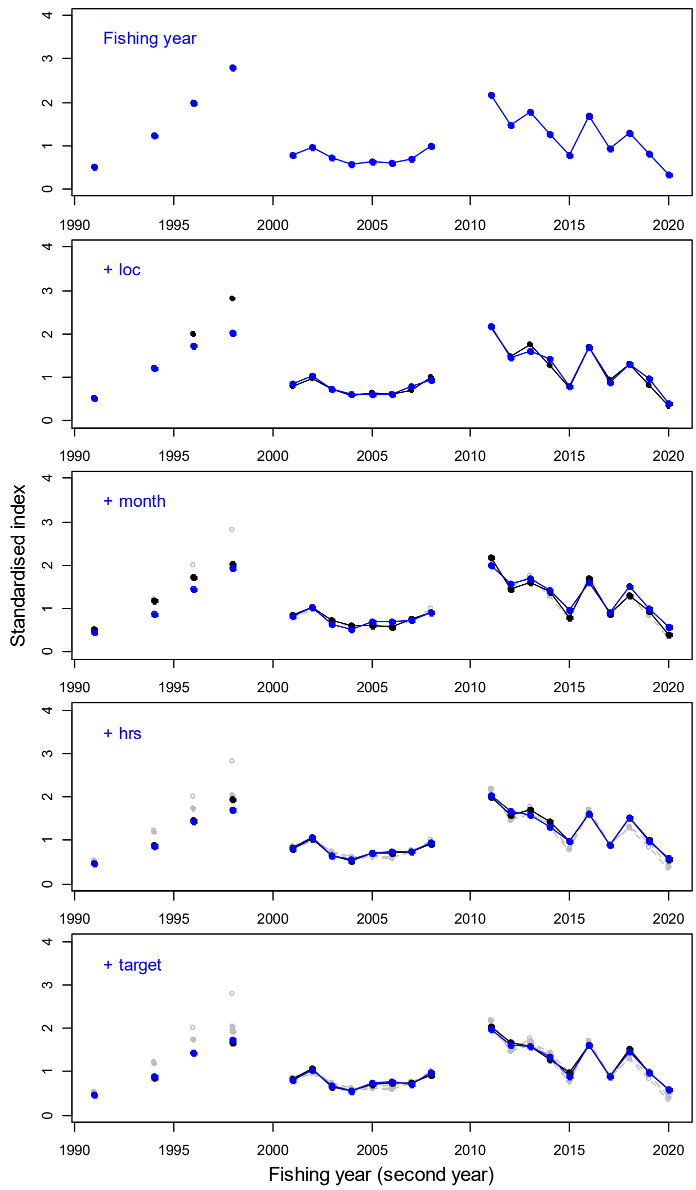


APPENDIX 3: Recreational CPUE variable selection tables and step plots

Order in which predictor variables were selected by a stepwise negative binomial standardisation of the number of kahawai caught per boat fishing trip, and step plots showing the influence that each additional predictor variable had on the East Northland 1 model index.

East Northland

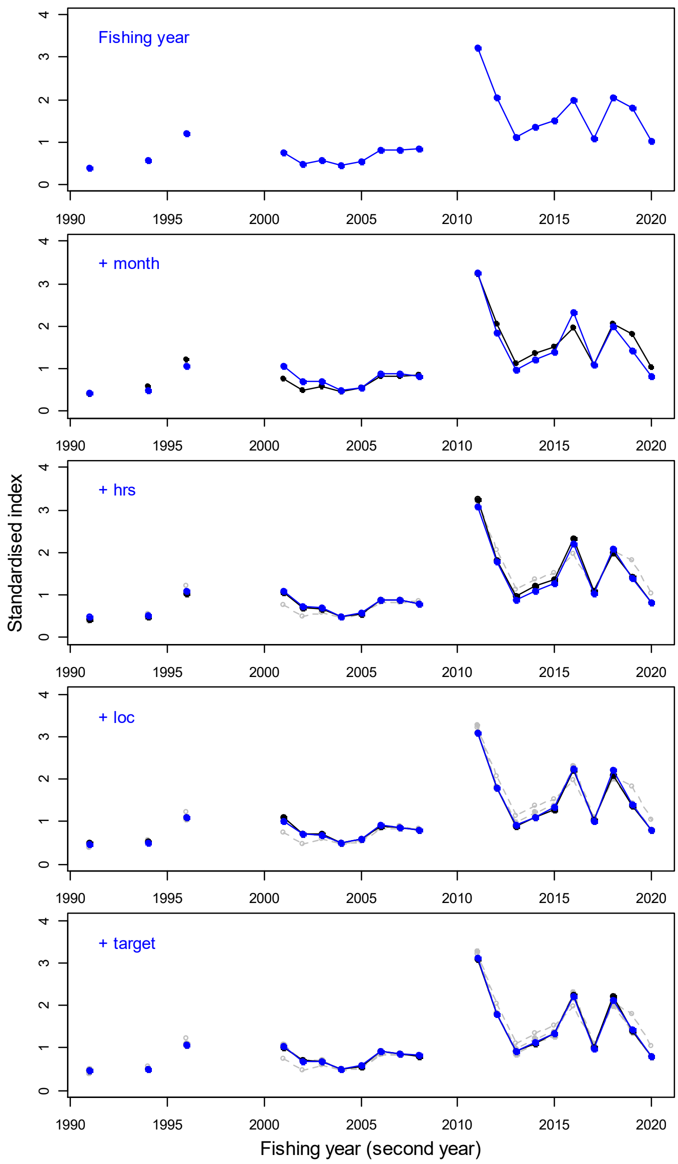
Variable	DoF	Deviance explained	Additional deviance explained (%)
Fishing year	21	1162.1	5.28
Location id	15	1392.1	6.32
Month	11	1157.4	5.26
Hours fished	1	439.8	2.00
Target species	2	370.1	1.68
Total			20.54



Appendix 3 continued: Negative binomial model variable acceptance table and step plot for the Hauraki Gulf model.

Hauraki Gulf

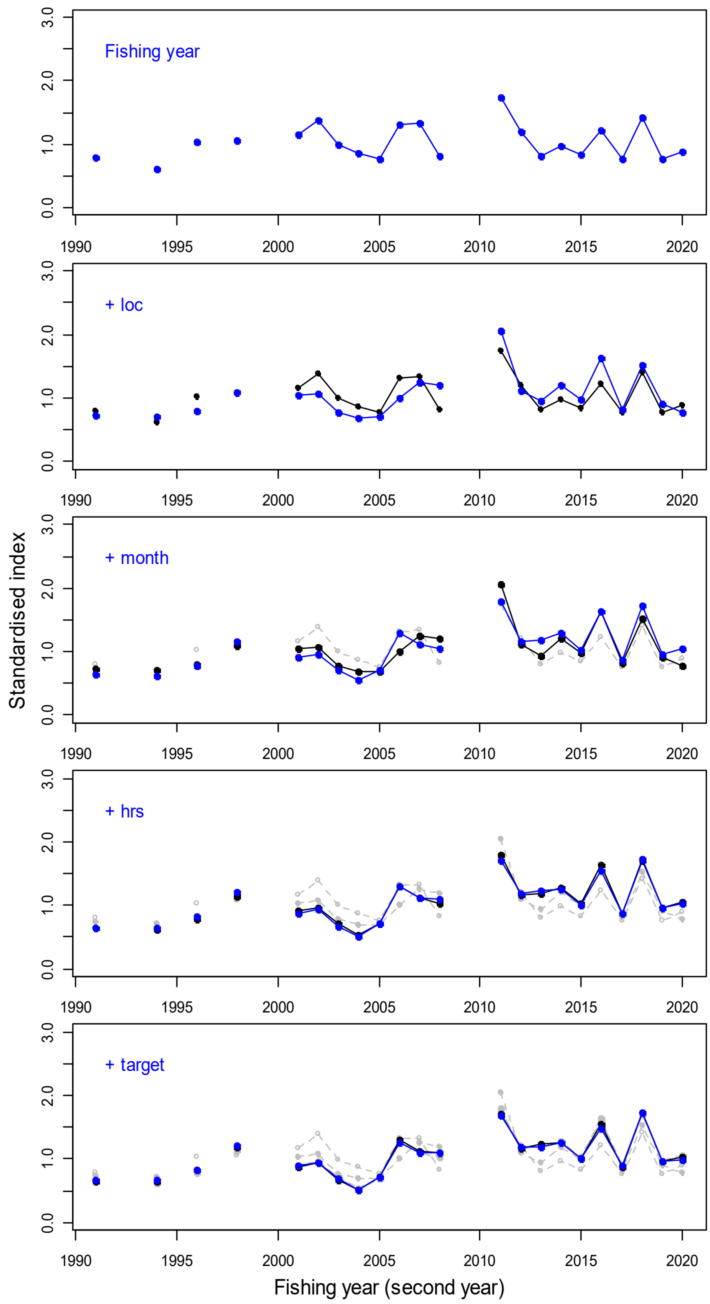
Variable	Dof	Deviance explained	Additional Deviance explained (%)
Fishing year	20	3227.4	8.79
Month	11	1710.1	4.66
Hours fished	1	1264.3	3.44
Location id	15	451.5	1.23
Target species	2	228.2	0.62
Total			18.73



Appendix 3 continued: Negative binomial model variable acceptance table and step plot for the Bay of Plenty model.

Bay of Plenty

Variable	Dof	Deviance explained	Additional Deviance explained (%)
Fishing year	21	662.4	2.29
Location id	18	2518.8	8.70
Month	11	1397.7	4.83
Hours fished	1	619.2	2.14
Target species	2	254.6	0.88
Total			18.83



APPENDIX 4: CASAL input files

POPULATION CSL

```
@initialization

R0  50000000

# PARTITION
@size_based     False
@weightless_model False
@min_age      1
@max_age      20
@plus_group   True
@sex_partition False
@mature_partition False
@n_areas        1
@n_stocks       1
@n_growthpaths   1

# TIME SEQUENCE
@initial    1930
@current    2020
@final      2025
@annual_cycle
   time_steps       1
   spawning_time    1
   spawning_part_mort   0.5
   spawning_areas  1
   spawning_p      1
   aging_time    1
   recruitment_time 1
   recruitment_areas 1
   n_maturations       1
   maturation_times     1
   growth_props  0
   M_props      1
   baranov      False

   midmortality_partition    weighted_sum

   fishery_names   PS    ST    SN    OTHER    REC EN     REC_HG_pre90s     REC_HG_early               REC_HG_late
                   REC_BP
   fishery_times  1      1     1      1        1        1          1          1          1
   fishery_areas   K1     K1     K1     K1       K1            K1         K1         K1         K1


@standardise_YCS  True
@y_enter         1
@recruitment

            YCS_years   1994    1995  1996    1997    1998    1999    2000    2001    2002    2003    2004    2005   2006   2007
            2008   2009   2010   2011   2012   2013   2014   2015   2016   2017  2018  2019

             YCS       1      1       1       1       1       1       1    1       1       1       1       1      1      1      1      1      1      1      1      1
            1     1     1     1       1    1

            n_rinitial     65
            SR        BH
            steepness 0.75
            sigma_r 0.6
            first_free   1994
            last_free    2014
            year_range   1994  2014

@randomisation_method  none
@first_random_year   2024
```

```
@size_weight
  a 2.36e-08
  b 2.89

@size_at_age_type von_Bert
@size_at_age
 k 0.35
 t0 0.13
 Linf 54.6
 cv 0.1
 by_length True

@size_at_age_dist lognormal

@maturity_props
  all knife_edge  4

@natural_mortality
  all     0.22

@fishery PS
        years   1930    1931    1932    1933    1934    1935    1936    1937    1938    1939    1940
        1941    1942    1943    1944    1945    1946    1947    1948    1949    1950    1951    1952
        1953    1954    1955    1956    1957    1958    1959    1960    1961    1962    1963    1964
        1965    1966    1967    1968    1969    1970    1971    1972    1973    1974    1975    1976
        1977    1978    1979    1980    1981    1982    1983    1984    1985    1986    1987    1988
        1989    1990    1991    1992    1993    1994    1995    1996    1997    1998    1999    2000
        2001    2002    2003    2004    2005    2006    2007    2008    2009    2010    2011    2012
        2013    2014    2015    2016    2017    2018    2019    2020
        catches    0    0               0               0               0               0
        0               0               0               0               0               0
        0               0               0               0               0               0
        0               0               0               0               0               0
        0               0               0               0               0               0
        0               0               0               0               0               0
        0               0               0               0               0               0
        0               0               0               38              140             271
        432             875             561             292             440             169
        1445    882     1191    1544    3964    1644    1699    1563    1725    2473    1162    1053
        1098    921     712     1375    1221    1393    957     608     1361    834     535     696
         668    602     555     541     707     707     645     491     717     666     661     640
         682
        selectivity Sel_PS
        U_max 0.7

@fishery ST
        years   1930    1931    1932    1933    1934    1935    1936    1937    1938    1939    1940
        1941    1942    1943    1944    1945    1946    1947    1948    1949    1950    1951    1952
        1953    1954    1955    1956    1957    1958    1959    1960    1961    1962    1963    1964
        1965    1966    1967    1968    1969    1970    1971    1972    1973    1974    1975    1976
        1977    1978    1979    1980    1981    1982    1983    1984    1985    1986    1987    1988
        1989    1990    1991    1992    1993    1994    1995    1996    1997    1998    1999    2000
        2001    2002    2003    2004    2005    2006    2007    2008    2009    2010    2011    2012
        2013    2014    2015    2016    2017    2018    2019    2020
        catches  0      0               0               0               0               0
        0               0               0               0               0               0
        4               12              18              20              19              11
        12              5               7               4               5               3
        4               4               3               5               7               6
        8               8               11              12              15              17
        29              29              21              33              28              37
        34              59              71              19              65              123
        200             380             250             132             202             106
        64              82              53              45              43              68
        42              82              49              176             80              65
        126             113             115             149             106             79
```

59 50 50 47 71 40
57 31 60 58 68 115
133 106 72 87 59 111
80
selectivity Sel_ST
U_max 0.7

@fishery SN
years 1930 1931 1932 1933 1934 1935 1936 1937 1938 1939 1940
1941 1942 1943 1944 1945 1946 1947 1948 1949 1950 1951 1952
1953 1954 1955 1956 1957 1958 1959 1960 1961 1962 1963 1964
1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976
1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988
1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000
2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012
2013 2014 2015 2016 2017 2018 2019 2020
catches 0 0 0 0 0 0
0 1 1 1 1 1
13 35 54 61 56 32
35 14 20 13 16 8
11 12 10 15 20 19
24 24 33 36 45 51
86 88 64 98 84 111
101 177 214 64 148 163
461 228 270 159 357 526
321 411 263 224 212 340
294 333 322 628 596 436
349 691 351 218 243 217
292 237 200 178 216 268
260 274 328 306 186 232
220 211 183 182 161 200
160
selectivity Sel_SN
U_max 0.7

@fishery OTHER
years 1930 1931 1932 1933 1934 1935 1936 1937 1938 1939 1940
1941 1942 1943 1944 1945 1946 1947 1948 1949 1950 1951 1952
1953 1954 1955 1956 1957 1958 1959 1960 1961 1962 1963 1964
1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976
1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988
1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000
2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012
2013 2014 2015 2016 2017 2018 2019 2020
catches 0 0 0 0 0 0
0 0 0 0 0 0
4 12 18 20 19 11
12 5 7 4 5 3
4 4 3 5 7 6
8 8 11 12 15 17
29 29 21 33 28 37
34 59 71 20 48 74
144 159 132 77 135 181
110 141 90 77 73 117
59 62 75 162 138 157
135 106 72 86 43 58
46 37 25 38 82 44
36 48 47 62 84 54
66 198 120 86 100 100
81
selectivity Sel_ST
U_max 0.7

```
@fishery REC_EN
	years	1930	1931	1932	1933	1934	1935	1936	1937	1938	1939	1940
	1941	1942	1943	1944	1945	1946	1947	1948	1949	1950	1951	1952
	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964
	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976
	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
	2013	2014	2015	2016	2017	2018	2019	2020
	catches	15		17		19		21		23		26
	28		30		32		35		37		39
	41		43		46		48		50		52
	55		57		59		61		64		66
	68		70		72		75		77		79
	81		84		86		88		90		93
	95		97		99		101		104		106
	108		110		113		115		117		119
	122		124		126		128		130		133
	135		137		139		142		144		146
	148		151		175		198		221		416
	611		525		438		352		266		179
	227		135		181		162		144		170
	182		260		338		416		168		196
	224		252		280		172		281		256
	230
	selectivity Sel_REC_EN
	U_max 0.7

@fishery REC_HG_pre90s
	years	1930	1931	1932	1933	1934	1935	1936	1937	1938	1939	1940
	1941	1942	1943	1944	1945	1946	1947	1948	1949	1950	1951	1952
	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964
	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976
	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
	2013	2014	2015	2016	2017	2018	2019	2020
	catches	15		16		18		20		22		24
	25		27		29		31		33		35
	36		38		40		42		44		45
	47		49		51		53		55		56
	58		60		62		64		65		67
	69		71		73		75		76		78
	80		82		84		85		87		89
	91		93		95		96		98		100
	102		104		105		107		109		111
	113		115		116		118		120		122
	0		0		0		0		0		0
	0		0		0		0		0		0
	0		0		0		0		0		0
	0		0		0		0		0		0
	0		0		0		0		0		0
	0
	selectivity Sel_REC_BP # as no longer estimating sel for HAGU late
	U_max 0.7

@fishery REC_HG_early
	years	1930	1931	1932	1933	1934	1935	1936	1937	1938	1939	1940
	1941	1942	1943	1944	1945	1946	1947	1948	1949	1950	1951	1952
	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964
	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976
	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
	2013	2014	2015	2016	2017	2018	2019	2020
```

```
        catches 0       0       0       0       0       0
        0       0       0       0       0       0
        0       0       0       0       0       0
        0       0       0       0       0       0
        0       0       0       0       0       0
        0       0       0       0       0       0
        0       0       0       0       0       0
        0       0       0       0       0       0
        0       0       0       0       0       0
        0       0       0       0       0       0
        124     126     131     136     141     181
        222     217     187     158     128     99
        140     91      79      102     200     153
        209     0       0       0       0       0
        0       0       0       0       0       0
        0
        selectivity Sel_REC_HG_early
        U_max 0.7

@fishery REC_HG_late
        years   1930    1931    1932    1933    1934    1935    1936    1937    1938    1939    1940
        1941    1942    1943    1944    1945    1946    1947    1948    1949    1950    1951    1952
        1953    1954    1955    1956    1957    1958    1959    1960    1961    1962    1963    1964
        1965    1966    1967    1968    1969    1970    1971    1972    1973    1974    1975    1976
        1977    1978    1979    1980    1981    1982    1983    1984    1985    1986    1987    1988
        1989    1990    1991    1992    1993    1994    1995    1996    1997    1998    1999    2000
        2001    2002    2003    2004    2005    2006    2007    2008    2009    2010    2011    2012
        2013    2014    2015    2016    2017    2018    2019    2020
        catches 0       0       0       0       0       0
                0       0       0       0       0       0
                0       0       0       0       0       0
                0       0       0       0       0       0
                0       0       0       0       0       0
                0       0       0       0       0       0
                0       0       0       0       0       0
                0       0       0       0       0       0
                0       0       0       0       0       0
                0       0       0       0       0       0
                0       0       0       0       0       0
                0       0       0       0       0       0
                0       0       0       0       0       0
                0       470     732     993     430     493
                556     619     682     289     557     359
                162
        selectivity Sel_REC_HG_late # as no longer estimating sel for HAGU late
        U_max 0.7


@fishery REC_BP
        years   1930    1931    1932    1933    1934    1935    1936    1937    1938    1939    1940
        1941    1942    1943    1944    1945    1946    1947    1948    1949    1950    1951    1952
        1953    1954    1955    1956    1957    1958    1959    1960    1961    1962    1963    1964
        1965    1966    1967    1968    1969    1970    1971    1972    1973    1974    1975    1976
        1977    1978    1979    1980    1981    1982    1983    1984    1985    1986    1987    1988
        1989    1990    1991    1992    1993    1994    1995    1996    1997    1998    1999    2000
        2001    2002    2003    2004    2005    2006    2007    2008    2009    2010    2011    2012
        2013    2014    2015    2016    2017    2018    2019    2020
        catches 30      34      39      43      48      53
        57      62      66      71      76      80
        85      89      94      99      103     108
        112     117     122     126     131     135
        140     145     149     154     158     163
        168     172     177     182     186     191
        195     200     205     209     214     218
        223     228     232     237     241     246
        251     255     260     264     269     274
```

```
    278    283    287    292    297    301
    306    311    283    256    228    278
    327    344    360    284    208    132
    272    247    391    274    415    386
    290    388    485    583    237    284
    332    379    427    195    486    363
    240
    selectivity Sel_REC_BP
    U_max 0.7

@selectivity_names Sel_PS   Sel_ST   Sel_REC_EN   Sel_REC_HG_early   Sel_REC_HG_late   Sel_REC_BP   Sel_SN
Sel_all


@selectivity Sel_REC_EN
  all logistic 3  0.25


@selectivity Sel_REC_HG_early
  all  double_normal 5  3  10


@selectivity Sel_REC_HG_late
  all logistic 8  0.25


@selectivity Sel_REC_BP
  all logistic 3  0.25


@selectivity Sel_PS
  all logistic 4  0.25


@selectivity Sel_ST
   all  double_normal 10 8  8


@selectivity Sel_SN
  all  double_normal 3.450150 0.596666 1.095420  # fixed from 3  0.4 run


 # Fixed selectivities
@selectivity Sel_all
    all size_based knife_edge  1
```

ESTIMATION CSL – following down-weighting of Effective Sample Sizes for the age composition data.

```
@estimator Bayes

@max_iters 10000

@max_evals 10000

@MCMC
start 0
length 4500000
keep 2000
stepsize 0.05
adaptive_stepsize True
adapt_at 20000 40000 60000 80000 100000
proposal_t true
df 4
burn_in 1500

@estimate
parameter initialization.R0
lower_bound 10000.0
upper_bound 100000000.0
prior uniform-log

@profile
parameter initialization.R0
n 50
l 10000.0
u 100000000.0

@estimate
parameter recruitment.YCS
lower_bound 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 1.00
1.00 1.00 1.00 1.00
upper_bound 20.0 20.0 20.0 20.0 20.0 20.0 20.0 20.0 20.0 20.0 20.0 20.0 20.0 20.0 20.0 20.0 20.0 20.0 20.0 20.0 20.0 1.00
1.00 1.00 1.00 1.00
prior lognormal
mu 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
cv 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1

@q_method nuisance

@estimate
parameter q[REC_EN_CPUE].q
lower_bound 1e-9
upper_bound 1
prior uniform-log

@estimate
parameter q[REC_HG_early_CPUE].q
lower_bound 1e-9
upper_bound 1
prior uniform-log

@estimate
parameter q[REC_BP_CPUE].q
lower_bound 1e-9
upper_bound 1
prior uniform-log

@estimate
parameter q[BP_SPUE].q
lower_bound 1e-9
upper_bound 1
prior uniform-log
```

```
@relative_abundance REC_CPUE_EN
area K1
biomass False
ogive Sel_REC_EN
proportion_mortality 0.5
dist lognormal
step 1
q REC_EN_CPUE
years 1991 1994 1996 1998 2001 2002 2003 2004 2005 2006 2007 2008 2011 2012 2013 2014 2015 2016 2017 2018 2019
2020
1991 0.429243972
1994 0.816294429
1996 1.315454257
1998 1.615835418
2001 0.753440222
2002 0.950859297
2003 0.619044618
2004 0.512735175
2005 0.690620402
2006 0.706605727
2007 0.664615814
2008 0.908098686
2011 1.839522832
2012 1.495769665
2013 1.475868969
2014 1.233058627
2015 0.838635552
2016 1.483603789
2017 0.814347609
2018 1.366501848
2019 0.921141821
2020 0.548701268
cv 0.34

@relative_abundance REC_CPUE_HG_early
area K1
biomass False
ogive Sel_REC_HG_early
proportion_mortality 0.5
dist lognormal
step 1
q REC_HG_early_CPUE
years 1991 1994 1996 2001 2002 2003 2004 2005 2006 2007 2008
1991 0.1124
1994 0.1168
1996 0.2525
2001 0.2411
2002 0.1603
2003 0.1589
2004 0.1178
2005 0.1368
2006 0.2181
2007 0.2006
2008 0.1921
cv 0.26

@relative_abundance REC_CPUE_BP
area K1
biomass False
ogive Sel_REC_BP
proportion_mortality 0.5
dist lognormal
step 1
q REC_BP_CPUE
years 1991 1994 1996 1998 2001 2002 2003 2004 2005 2006 2007 2008 2011 2012 2013 2014 2015 2016 2017 2018 2019
2020
1991 0.692739344
```

```
1994 0.68066251
1996 0.863609403
1998 1.019660974
2001 0.873469539
2002 0.982684636
2003 0.690117381
2004 0.547514762
2005 0.807189865
2006 1.333046788
2007 1.09144912
2008 1.120624139
2011 1.520869921
2012 1.176496054
2013 1.197777722
2014 1.30594618
2015 1.113011897
2016 1.176540947
2017 0.850142177
2018 1.530598122
2019 1.083191506
2020 1.09222213
cv 0.20

@relative_abundance BP_SPUE
area K1
biomass True
ogive Sel_PS
proportion_mortality 0.5
dist lognormal
step 1
q BP_SPUE
years 1987 1988 1990 1991 1992 1993 1994 1998 1999 2000 2001 2002 2003 2004 2005 2006 2008 2009 2010 2011 2012
2013
1987 1.14
1988 0.86
1990 0.58
1991 0.78
1992 0.66
1993 1.19
1994 1.17
1998 0.81
1999 0.45
2000 0.47
2001 0.7
2002 0.66
2003 0.36
2004 1.3
2005 1.67
2006 1.93
2008 2.45
2009 1.25
2010 1.49
2011 1.72
2012 1.78
2013 1.43
cv 0.421

@estimate
parameter selectivity[Sel_REC_EN].all
lower_bound 0.3 0.02
upper_bound 25 5
prior uniform

@estimate
parameter selectivity[Sel_REC_HG_early].all
lower_bound 1 0.02 0.01
upper_bound 15 15 15
```

```
prior uniform

@estimate
parameter selectivity[Sel_REC_HG_late].all
lower_bound 0.3 0.02
upper_bound 25 15
prior uniform

@estimate
parameter selectivity[Sel_REC_BP].all
lower_bound 0.3 0.02
upper_bound 25 5
prior uniform

@estimate
parameter selectivity[Sel_PS].all
lower_bound 0.3 0.02
upper_bound 25 5
prior uniform

@estimate
parameter selectivity[Sel_ST].all
lower_bound 1 0.02 0.01
upper_bound 15 10 10
prior uniform

@catch_at REC_EN_AGE
years 2001 2002 2003 2004 2005 2006 2007 2008 2011 2012 2016 2017 2018
fishery REC_EN
at_size False
min_class 1
max_class 20
plus_group False
sum_to_one True
dist multinomial
r 0.0001
2001 0.0000 0.0221 0.2509 0.2624 0.1184 0.1093 0.0538 0.0222 0.0287 0.0279 0.0287 0.0304 0.0233 0.0127 0.0032 0.0013
0.0039 0.0000 0.0000 0.0000
2002 0.0000 0.0241 0.1780 0.2663 0.1430 0.1426 0.0713 0.0410 0.0222 0.0334 0.0327 0.0276 0.0070 0.0063 0.0000 0.0000
0.0000 0.0000 0.0000 0.0000
2003 0.0008 0.0410 0.2347 0.1575 0.1654 0.1114 0.1018 0.0837 0.0279 0.0203 0.0239 0.0094 0.0095 0.0119 0.0000 0.0000
0.0000 0.0000 0.0000 0.0000
2004 0.0032 0.0396 0.1785 0.1823 0.1019 0.1296 0.1210 0.0712 0.0624 0.0478 0.0159 0.0115 0.0223 0.0017 0.0080 0.0000
0.0022 0.0000 0.0000 0.0000
2005 0.0000 0.0752 0.0787 0.1191 0.1576 0.1101 0.1509 0.0896 0.0854 0.0396 0.0263 0.0123 0.0108 0.0102 0.0105 0.0051
0.0035 0.0000 0.0000 0.0000
2006 0.0000 0.0348 0.0972 0.0730 0.1518 0.1534 0.1207 0.1230 0.0936 0.0620 0.0256 0.0174 0.0214 0.0121 0.0091 0.0000
0.0030 0.0000 0.0000 0.0000
2007 0.0000 0.0506 0.1506 0.1700 0.1229 0.1693 0.0911 0.0645 0.0642 0.0461 0.0238 0.0281 0.0036 0.0000 0.0000 0.0057
0.0000 0.0000 0.0000 0.0000
2008 0.0000 0.0050 0.0977 0.1179 0.1966 0.1173 0.1501 0.0986 0.0430 0.0586 0.0413 0.0280 0.0207 0.0114 0.0041 0.0020
0.0000 0.0000 0.0000 0.0020
2011 0.0000 0.0068 0.0659 0.0916 0.0782 0.1637 0.1164 0.1509 0.0702 0.1069 0.0532 0.0407 0.0242 0.0164 0.0063 0.0018
0.0019 0.0000 0.0000 0.0000
2012 0.0000 0.0384 0.0900 0.0970 0.0671 0.0451 0.0776 0.0570 0.1234 0.0714 0.0994 0.0769 0.0675 0.0219 0.0245 0.0000
0.0094 0.0000 0.0000 0.0000
2016 0.0000 0.0070 0.0991 0.1249 0.0307 0.0818 0.1272 0.0857 0.0960 0.0674 0.1012 0.0454 0.0901 0.0099 0.0087 0.0083
0.0084 0.0023 0.0000 0.0000
2017 0.0000 0.0556 0.0687 0.1908 0.1236 0.0388 0.0850 0.0834 0.0751 0.0800 0.0288 0.0657 0.0234 0.0229 0.0222 0.0256
0.0066 0.0021 0.0000 0.0000
2018 0.0000 0.0000 0.0429 0.0845 0.1277 0.0894 0.0233 0.1096 0.1057 0.1096 0.1091 0.0892 0.0454 0.0227 0.0229 0.0049
0.0017 0.0030 0.0025 0.0000
N_2001 16.8892605548785
N_2002 17.9835970919115
N_2003 14.3358086351344
N_2004 14.9194547882188
N_2005 16.8163047857428
```

N_2006 9.22890479564634
N_2007 12.5848701758814
N_2008 16.9986942085817
N_2011 16.4515259400651
N_2012 9.88550671786621
N_2016 10.6880201783572
N_2017 9.921984602434
N_2018 11.5999672925515

@catch_at REC_HG_late_AGE
years 2011 2012 2016 2017 2018
fishery REC_HG_late
at_size False
min_class 1
max_class 20
plus_group False
sum_to_one True
dist multinomial
r 0.0001
2011 0.0000 0.0068 0.0496 0.0597 0.0279 0.0589 0.0799 0.1348 0.1020 0.1492 0.1043 0.0790 0.0622 0.0507 0.0203 0.0059 0.0053 0.0000 0.0000 0.0000
2012 0.0000 0.0526 0.1251 0.0782 0.0700 0.0536 0.0626 0.0714 0.1144 0.0603 0.1026 0.0657 0.0586 0.0339 0.0239 0.0059 0.0140 0.0000 0.0018 0.0000
2016 0.0000 0.0075 0.0556 0.0227 0.0045 0.0214 0.0684 0.0754 0.1077 0.0796 0.1829 0.0848 0.1900 0.0241 0.0277 0.0181 0.0133 0.0071 0.0000 0.0000
2017 0.0000 0.0396 0.1512 0.1416 0.0258 0.0161 0.0228 0.0178 0.0443 0.0653 0.0704 0.1157 0.0543 0.1735 0.0212 0.0147 0.0119 0.0058 0.0000 0.0000
2018 0.0000 0.0072 0.0992 0.0737 0.1451 0.0079 0.0136 0.0404 0.0493 0.0713 0.1246 0.1100 0.1193 0.0730 0.0544 0.0051 0.0000 0.0000 0.0000 0.0000
N_2011 56.8518780870467
N_2012 61.7914674946098
N_2016 19.0127592291108
N_2017 23.7659490363883
N_2018 28.4259390435232

@catch_at REC_HG_early_AGE
years 2001 2002 2003 2004 2005 2006 2007 2008
fishery REC_HG_early
at_size False
min_class 1
max_class 20
plus_group False
sum_to_one True
dist multinomial
r 0.0001
2001 0.0253 0.1040 0.5334 0.1566 0.0762 0.0136 0.0019 0.0069 0.0097 0.0110 0.0262 0.0135 0.0058 0.0144 0.0015 0.0000 0.0000 0.0000 0.0000 0.0000
2002 0.0031 0.0686 0.4247 0.1752 0.1032 0.0592 0.0570 0.0313 0.0077 0.0104 0.0166 0.0085 0.0088 0.0213 0.0027 0.0000 0.0016 0.0000 0.0000 0.0000
2003 0.0000 0.1613 0.4691 0.1496 0.0512 0.0429 0.0396 0.0209 0.0176 0.0096 0.0118 0.0076 0.0113 0.0029 0.0011 0.0000 0.0011 0.0000 0.0000 0.0000
2004 0.0000 0.2995 0.4850 0.1458 0.0276 0.0109 0.0092 0.0019 0.0032 0.0027 0.0029 0.0000 0.0023 0.0049 0.0027 0.0000 0.0000 0.0000 0.0000 0.0000
2005 0.0000 0.0734 0.3856 0.1044 0.1050 0.0541 0.0414 0.0624 0.0290 0.0204 0.0260 0.0391 0.0266 0.0051 0.0033 0.0000 0.0042 0.0084 0.0000 0.0000
2006 0.0000 0.0752 0.5747 0.1292 0.0802 0.0341 0.0142 0.0162 0.0169 0.0156 0.0134 0.0112 0.0050 0.0055 0.0017 0.0017 0.0013 0.0000 0.0030 0.0000
2007 0.0000 0.0588 0.2812 0.3058 0.1423 0.0458 0.0404 0.0176 0.0224 0.0232 0.0185 0.0119 0.0082 0.0032 0.0047 0.0064 0.0052 0.0000 0.0000 0.0000
2008 0.0067 0.0411 0.2476 0.0810 0.1396 0.0363 0.0704 0.0697 0.0616 0.0771 0.0560 0.0404 0.0416 0.0120 0.0000 0.0000 0.0042 0.0000 0.0000 0.0000
N_2001 7.52403757099215
N_2002 9.01798004898698
N_2003 8.74635414389701
N_2004 7.65985052353714
N_2005 5.43251810179939
N_2006 11.1909872897067

N_2007 8.52905341982504
N_2008 4.67196556754747

@catch_at REC_BP_AGE
years 2001 2002 2003 2004 2005 2006 2007 2008 2011 2012 2016 2017 2018
fishery REC_BP
at_size False
min_class 1
max_class 20
plus_group False
sum_to_one True
dist multinomial
r 0.0001
2001 0.0000 0.0117 0.1414 0.1486 0.1332 0.1216 0.1242 0.0596 0.0558 0.0650 0.0668 0.0157 0.0123 0.0098 0.0121 0.0130 0.0015 0.0015 0.0026 0.0027
2002 0.0000 0.0075 0.0768 0.1807 0.1747 0.1464 0.1234 0.0913 0.0482 0.0187 0.0556 0.0448 0.0147 0.0037 0.0074 0.0020 0.0000 0.0000 0.0000 0.0000
2003 0.0000 0.0446 0.1467 0.1761 0.1461 0.1388 0.1019 0.0807 0.0457 0.0420 0.0158 0.0328 0.0046 0.0089 0.0041 0.0000 0.0000 0.0034 0.0000 0.0026
2004 0.0000 0.0151 0.0606 0.0841 0.0792 0.1622 0.1546 0.1241 0.0940 0.0714 0.0655 0.0124 0.0333 0.0188 0.0071 0.0051 0.0000 0.0096 0.0000 0.0000
2005 0.0000 0.0332 0.1660 0.1877 0.1567 0.0813 0.1115 0.0474 0.0851 0.0393 0.0193 0.0165 0.0189 0.0055 0.0064 0.0025 0.0067 0.0107 0.0000 0.0000
2006 0.0000 0.0030 0.1052 0.2179 0.1525 0.1202 0.0980 0.0877 0.0563 0.0537 0.0366 0.0295 0.0111 0.0073 0.0047 0.0091 0.0019 0.0019 0.0034 0.0000
2007 0.0000 0.0413 0.1078 0.2628 0.0966 0.0723 0.0770 0.0437 0.0772 0.0761 0.0492 0.0406 0.0261 0.0020 0.0060 0.0095 0.0043 0.0056 0.0019 0.0000
2008 0.0000 0.0208 0.1390 0.1546 0.1751 0.0811 0.1066 0.0570 0.0682 0.0678 0.0429 0.0353 0.0212 0.0123 0.0097 0.0034 0.0013 0.0030 0.0000 0.0000
2011 0.0000 0.0086 0.0368 0.1229 0.0820 0.1251 0.1544 0.1592 0.0848 0.0698 0.0523 0.0349 0.0317 0.0211 0.0088 0.0047 0.0028 0.0000 0.0000 0.0000
2012 0.0000 0.0209 0.1140 0.1465 0.1413 0.1105 0.0888 0.1103 0.1122 0.0386 0.0403 0.0240 0.0198 0.0133 0.0095 0.0039 0.0043 0.0000 0.0014 0.0000
2016 0.0000 0.0041 0.0428 0.1024 0.0357 0.1666 0.0986 0.0537 0.1213 0.0821 0.0828 0.1020 0.0616 0.0316 0.0026 0.0049 0.0000 0.0000 0.0000 0.0000
2017 0.0000 0.0191 0.1405 0.1182 0.1125 0.0758 0.1453 0.0842 0.0453 0.0498 0.0374 0.0329 0.0521 0.0412 0.0034 0.0105 0.0054 0.0097 0.0000 0.0000
2018 0.0000 0.0060 0.0596 0.1030 0.1095 0.1291 0.0700 0.1473 0.1188 0.0838 0.0555 0.0419 0.0267 0.0177 0.0172 0.0085 0.0000 0.0000 0.0000 0.0000
N_2001 42.6987545728208
N_2002 52.5026982209608
N_2003 51.4707041527355
N_2004 43.730748641046
N_2005 43.0857523484051
N_2006 51.2127056356792
N_2007 51.3417048942072
N_2008 66.1766196249457
N_2011 59.4686581814813
N_2012 65.4026240737767
N_2016 36.6357894219972
N_2017 25.92885096416
N_2018 33.5398072173215

@catch_at PS_AGE
years 1991 1992 1993 2005 2011 2012
fishery PS
at_size False
min_class 2
max_class 20
plus_group False
sum_to_one True
dist multinomial
r 0.0001
1991 0.000071 0.030164 0.169282 0.292800 0.150832 0.039638 0.051941 0.054984 0.029708 0.051028 0.040530 0.020661 0.023582 0.019261 0.010396 0.002110 0.013013 0.000000 0.000000
1992 0.000040 0.040220 0.132110 0.296670 0.158070 0.112560 0.051320 0.037190 0.045100 0.047080 0.035490 0.014020 0.015670 0.008790 0.000830 0.003010 0.001520 0.000140 0.000170

1993 0.00000 0.00049 0.05083 0.38507 0.23970 0.13159 0.06216 0.03435 0.03709 0.03599 0.01188 0.00691 0.00058 0.00097 0.00193 0.00030 0.00017 0.00000 0.00000
2005 0.000000 0.000000 0.011386 0.046834 0.145106 0.133284 0.120896 0.131581 0.090734 0.078104 0.087269 0.045962 0.040422 0.033451 0.034146 0.000171 0.000194 0.000460 0.000000
2011 0.000000 0.042106 0.565011 0.109801 0.076398 0.075281 0.074796 0.030235 0.006322 0.006368 0.000790 0.003490 0.001119 0.002701 0.001604 0.001013 0.000000 0.000000 0.000000
2012 0.000000 0.000000 0.016962 0.141898 0.202956 0.226675 0.190817 0.154101 0.027403 0.016217 0.007686 0.006279 0.006343 0.001129 0.000000 0.001534 0.000000 0.000000 0.000000
N_1991 25.7542484662589
N_1992 91.1839607859442
N_1993 80.1629986044368
N_2005 0.116010128226392
N_2011 0.116010128226392
N_2012 0.116010128226392

@catch_at ST_AGE
years 1991 1992 1993
fishery ST
at_size False
min_class 4
max_class 20
plus_group True
sum_to_one True
dist multinomial
r 0.0001
1991 0.062547 0.160420 0.128413 0.051222 0.071435 0.110257 0.067757 0.067341 0.091328 0.042139 0.018494 0.045147 0.043772 0.012209 0.000000 0.000000 0.017529
1992 0.002727 0.041395 0.064245 0.158760 0.144683 0.089894 0.096387 0.153825 0.096781 0.065627 0.039964 0.022819 0.008790 0.003668 0.010016 0.000178 0.000242
1993 0.008917 0.156546 0.227957 0.185824 0.138776 0.071557 0.071562 0.093856 0.028210 0.008462 0.000000 0.000000 0.008333 0.000000 0.000000 0.000000 0.000000
N_1991 10.9253377991073
N_1992 22.9570389196434
N_1993 8.02113408035734

@catch_at SN_AGE
years 2011 2012
fishery SN
at_size False
min_class 1
max_class 15
plus_group True
sum_to_one True
dist multinomial
r 0.0001
2011 0.00061 0.01470 0.73730 0.15439 0.01231 0.01763 0.01639 0.01402 0.00608 0.00556 0.00535 0.00388 0.00578 0.00334 0.00079
2012 0.00404 0.02626 0.39857 0.37088 0.15559 0.02109 0.00435 0.00289 0.00294 0.00162 0.00531 0.00068 0.00200 0.00000 0.00380
N_2011 1
N_2012 1

@catch_limit_penalty
label CatchMustBeTaken_PS
fishery PS
log_scale true
multiplier 100

@catch_limit_penalty
label CatchMustBeTaken_ST
fishery ST
log_scale true
multiplier 100

@catch_limit_penalty
label CatchMustBeTaken_SN
fishery SN

```
log_scale true
multiplier 100

@catch_limit_penalty
label CatchMustBeTaken_OTHER
fishery OTHER
log_scale true
multiplier 100

@catch_limit_penalty
label CatchMustBeTaken_REC_EN
fishery REC_EN
log_scale true
multiplier 100

@catch_limit_penalty
label CatchMustBeTaken_REC_HG_late
fishery REC_HG_late
log_scale true
multiplier 100

@catch_limit_penalty
label CatchMustBeTaken_REC_HG_early
fishery REC_HG_early
log_scale true
multiplier 100

@catch_limit_penalty
label CatchMustBeTaken_REC_HG_pre90s
fishery REC_HG_pre90s
log_scale true
multiplier 100

@catch_limit_penalty
label CatchMustBeTaken_REC_BP
fishery REC_BP
log_scale true
multiplier 100

@vector_average_penalty
label YCS_mean_1
vector recruitment.YCS
k 1
multiplier 100
```

OUTPUT CSL

```
@print
   fits_every_eval False
   objective_every_eval False
   parameters_every_eval False
   parameter_vector_every_eval False
   fits True
   resids True
   pearson_resids True
   normalised_resids True
   estimation_section True
   # population section stuff
   requests True
   initial_state True
   state_annually False
   state_every_step False
   final_state True
   results True
   #output section stuff
   yields True
   unused_parameters True
   covariance True

@n_projections 1

@quantities
   fishing_pressures True
   nuisance_qs True
   B0 True
   R0 False
   SSBs True
   YCS True
   true_YCS True
   actual_catches True
  ogive_parameters selectivity[Sel_PS].all selectivity[Sel_ST].all selectivity[Sel_SN].all selectivity[Sel_REC_EN].all
  selectivity[Sel_REC_HG_early].all selectivity[Sel_REC_HG_late].all selectivity[Sel_REC_BP].all

@print_sizebased_ogives_at 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34
35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74
75 76 77 78 79 80


@abundance Biom
 biomass True
 all_areas True
 step 1
 proportion_mortality 0.0
 ogive Sel_all
 years 1930 1931 1932 1933 1934 1935 1936 1937 1938 1939 1940 1941
       1942 1943 1944 1945 1946 1947 1948 1949 1950 1951 1952 1953
       1954 1955 1956 1957 1958 1959 1960 1961 1962 1963 1964 1965
       1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978
  1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998
  1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020
  2021 2022 2023 2024 2025
```