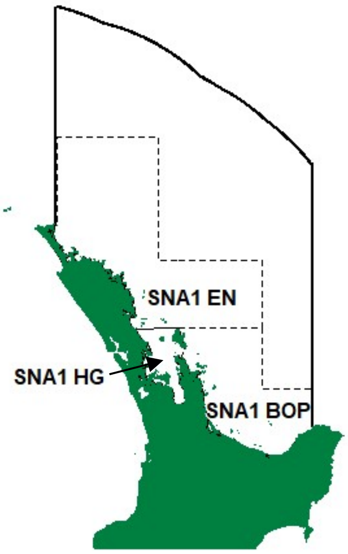
SNAPPER (SNA 1)

(*Chrysophrys auratus*)
Tāmure, Kouarea



1. FISHERIES SUMMARY

1.1 Commercial fisheries

Table 1 and Table 2 provide a summary by fishing year of the reported commercial catches, TACCs, and TACs for SNA 1. Landings and TACCs are plotted in Figure 1.

Table 1: Reported landings (t) of snapper from SNA 1 from 1931 to 1990.

Year	SNA 1	Year	SNA 1
1931–32	3 355	1957	5 129
1932–33	3 415	1958	5 007
1933–34	3 909	1959	5 607
1934–35	4 317	1960	5 889
1935–36	5 387	1961	5 887
1936–37	6 369	1962	6 502
1937–38	5 665	1963	6 967
1938–39	6 145	1964	7 269
1939–40	5 918	1965	7 991
1940–41	5 100	1966	8 762
1941–42	4 791	1967	9 244
1942–43	4 096	1968	10 328
1943–44	4 456	1969	11 318
1944	4 909	1970	12 127
1945	4 786	1971	12 709
1946	5 150	1972	11 291
1947	5 561	1973	10 450
1948	6 469	1974	8 769
1949	5 655	1975	6 774
1950	4 945	1976	7 743
1951	4 173	1977	7 674
1952	3 665	1978	9 926
1953	3 581	1979	10 273
1954	4 180	1980	7 274
1955	4 323	1981	7 714
1956	4 615	1982	7 089

Notes:
1. The 1931–1943 years are April–March but from 1944 onwards are calendar years.
2. SNA 1 landings are approximations derived from port landing subtotals, as follows: SNA 1, Mangonui to Whakatane.
3. Before 1946 the 'QMA' subtotals sum to less than the New Zealand total because data from the complete set of ports are not available.
4. Data for the period 1931 to 1982 are based on reported landings by harbour and are likely to be underestimated as a result of under-reporting and discarding practices. Data include both foreign and domestic landings.

Table 2: Reported landings (t) of snapper from SNA 1 from 1983–84 to present and gazetted and actual TACCs (t) for 1986–87 to present. QMS data from 1986–present.

Fishstock	SNA 1		Fishstock	SNA 1	
FMAs	1		FMAs	1	
	Landings	TACC		Landings	TACC
1983–84†	6 539	–	2002–03	4 487	4 500
1984–85†	6 898	–	2003–04	4 469	4 500
1985–86†	5 876	–	2004–05	4 641	4 500
1986–87	4 016	4 710	2005–06	4 539	4 500
1987–88	5 038	5 098	2006–07	4 429	4 500
1988–89	5 754	5 614	2007–08	4 548	4 500
1989–90	5 826	5 981	2008–09	4 543	4 500
1990–91	5 273	6 002	2009–10	4 465	4 500
1991–92	6 176	6 010	2010–11	4 516	4 500
1992–93	5 427	4 938	2011–12	4 614	4 500
1993–94	4 847	4 938	2012–13	4 457	4 500
1994–95	4 857	4 938	2013–14	4 459	4 500
1995–96	4 938	4 938	2014–15	4 479	4 500
1996–97	5 047	4 938	2015–16	4 408	4 500
1997–98	4 525	4 500	2016–17	4 620	4 500
1998–99	4 412	4 500	2017–18	4 567	4 500
1999–00	4 509	4 500	2018–19	4 437	4 500
2000–01	4 347	4 500	2019–20	4 462	4 500
2001–02	4 374	4 500	2020–21	4 579	4 500

† FSU data. SNA 1 = Statistical Areas 001–010.

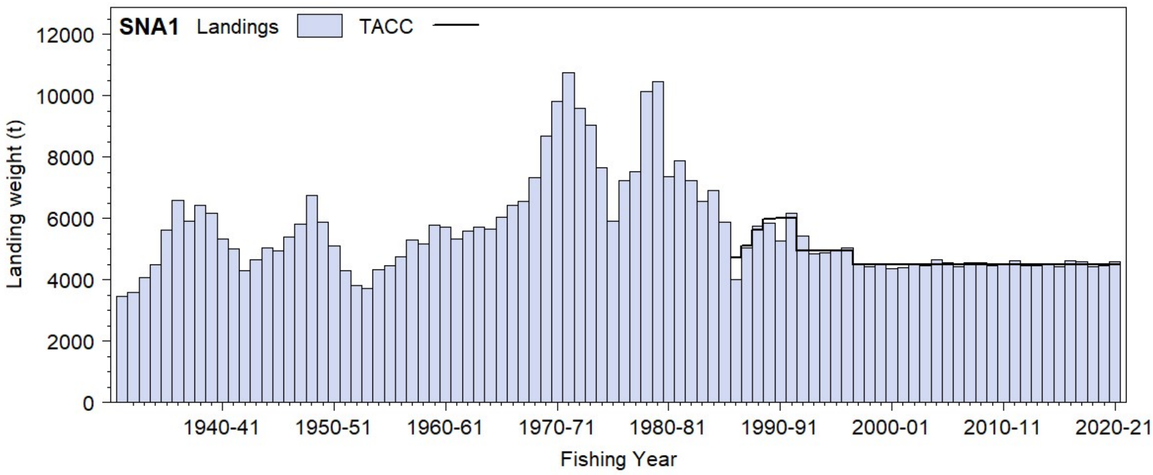


Figure 1: Total reported landings and TACCs for SNA 1.

From 1 October 1997 the TACC for SNA 1 was reduced to 4500 t, within an overall TAC of 7550 t (Table 3). All commercial fisheries have a minimum legal size (MLS) for snapper of 25 cm.

Table 3: TACs, TACCs, and allowances (t) for SNA 1 from 1 October 2021.

Fishstock	TAC	TACC	Customary allowance	Recreational allowance	Other mortality
SNA 1	8 050	4 500	50	3 050	450

Foreign fishing

Japanese catch records and observations made by New Zealand naval vessels indicate that significant quantities of snapper were taken from New Zealand waters by Japanese vessels from the late 1950s until 1977. There are insufficient data to quantify historical Japanese catch tonnages for the respective snapper stocks. However, trawl catches have been reported by area from 1967 to 1977, and longline catches from 1975 to 1977 (Table 4). These data were supplied to the Fisheries Research Division of MAF in the late 1970s; however, the data series is incomplete, particularly for longline catches.

Table 4: Reported landings (t) of snapper, and harvest within SNA 1 from 1967 to 1977 by Japanese trawl and longline fisheries.

Year	(a) Trawl	Trawl catch (all species)	Total snapper trawl catch	SNA 1
1967		3092	30	NA
1968		19 721	562	1
1969		25 997	1 289	–
1970		31 789	676	2
1971		42 212	522	5
1972		49 133	1 444	1
1973		45 601	616	–
1974		52 275	472	–
1975		55 288	922	26
1976		133 400	970	NA
1977		214 900	856	NA
Year	**(b) Longline**		**Total Snapper**	**SNA 1**
1975			1 510	761
1976			2 057	930
1977			2 208	1 104

1.2 Recreational fisheries

The snapper fishery is the largest recreational fishery in New Zealand. It is the major target species on the northeast and northwest coasts of the North Island and is targeted seasonally around the rest of the North Island and the top of the South Island. The current allowance within the SNA 1 TAC is shown in Table 3.

1.2.1 Management controls

The two main methods used to manage recreational harvests of snapper are minimum legal size limits (MLS) and daily bag limits. Both have changed over time (Table 5). The number of hooks permitted on a recreational longline was reduced from 50 to 25 in 1995.

Table 5: Changes to minimum legal size limits (MLS) and daily bag limits used to manage recreational harvesting levels in SNA 1.

Stock	MLS (cm)	Bag limit (no. fish)	Introduced
SNA 1	25	30	01/01/1985
SNA 1	25	20	30/09/1993
SNA 1	27	15	01/10/1994
SNA 1	27	9	13/10/1995
SNA 1	30	7	01/04/2014

1.2.2 Estimates of recreational harvest

A background to the estimation on recreational harvest of snapper is provided in the Introduction – Snapper chapter.

The recreational catch history for SNA 1 is poorly known. Aerial-access survey harvest estimates are available for the Hauraki Gulf in 2003–04 (Hartill et al 2007b) and for all three regions of SNA 1 in 2004–05 (Hartill et al 2007a), in 2011–12 (Hartill et al 2013) and in 2017–18 (Hartill et al 2019). Recreational harvest estimates for all three regions of SNA 1 are also available from national panel surveys undertaken in 2011–12 and 2017–18 (Wynne-Jones et al 2014, 2019), which were of a broadly similar magnitude to those provided by the concurrent aerial-access survey (Table 6).

1.2.3 Monitoring harvest

In addition to estimating absolute harvests, a system to provide relative estimates of harvest over time for key fishstocks has been designed and implemented for some key recreational fisheries. The system uses web cameras to continuously monitor trends in trailer boat traffic at key boat ramps. This monitoring is complemented by creel surveys that provide estimates of the proportion of observed boats that were used for fishing, and of the average harvest of snapper and kahawai per boat trip. These data are combined to provide relative harvest estimates for SNA 1.

Table 6: Recreational catch estimates for SNA 1. Totals for a stock are given in bold. The telephone/diary surveys ran from December to November but are denoted by the January calendar year. Mean fish weights were obtained from boat ramp surveys (for the telephone/diary and panel survey catch estimates). Numbers and mean weights are not calculated in the tag ratio method. Includes charter boat catch and panel survey estimates of s111 catches.

Stock	Year	Method	Number of fish (thousands)	Mean weight (g)	Total weight (t)	CV
East Northland	1985	Tag ratio	–	–	370	–
Hauraki Gulf	1985	Tag ratio	–	–	830	–
Bay of Plenty	1984	Tag ratio	–	–	400	–
Total	1985*	Tag ratio	–	–	**1 600**	–
Total	1994	Telephone/diary	3 804	871	**2 857**	–
East Northland	1996	Telephone/diary	684	1 039	711	–
Hauraki Gulf/BoP	1996	Telephone/diary	1 852	870	1 611	–
Total	1996	Telephone/diary	2 540	915	**2 324**	–
East Northland	2000	Telephone/diary	1 457	1 154	1 681	–
Hauraki Gulf	2000	Telephone/diary	3 173	830	2 632	–
Bay of Plenty	2000	Telephone/diary	2 274	872	1 984	–
Total	2000	Telephone/diary	6 904	904	**6 242**	–
East Northland	2001	Telephone/diary	1 446	–†	1 669	–
Hauraki Gulf	2001	Telephone/diary	4 225	–†	3 507	–
Bay of Plenty	2001	Telephone/diary	1 791	–†	1 562	–
Total	2001	Telephone/diary	7 462	–†	**6 738**	–
Hauraki Gulf	2003–04	Aerial-access	–	–	1 334	0.09
East Northland	2004–05	Aerial-access	–	–	557	0.13
Hauraki Gulf	2004–05	Aerial-access	–	–	1 345	0.10
Bay of Plenty	2004–05	Aerial-access	–	–	516	0.10
Total	2004–05	Aerial-access	–	–	**2 419**	**0.06**
East Northland	2011–12	Aerial-access	–	–	718	0.14
Hauraki Gulf	2011–12	Aerial-access	–	–	2490	0.08
Bay of Plenty	2011–12	Aerial-access	–	–	546	0.12
Total	2011–12	Aerial-access	–	–	**3 754**	**0.06**
East Northland	2011–12	Panel survey	718	1 266	909	0.12
Hauraki Gulf	2011–12	Panel survey	2 350	1 022 / 987‡	2 381	0.11
Bay of Plenty	2011–12	Panel survey	714	956 /1 003‡	691	0.12
Total	2011–12	Panel survey	3 884	1 025	**3 981**	**0.08**
East Northland	2017–18	Aerial-access	–	–	720	0.10
Hauraki Gulf	2017–18	Aerial-access	–	–	2 068	0.07
Bay of Plenty	2017–18	Aerial-access	–	–	680	0.10
Total	2017–18	Aerial-access	–	–	**3 467**	**0.05**
East Northland	2017–18	Panel survey	587	1 351	793	0.10
Hauraki Gulf	2017–18	Panel survey	1 443	1 162/1 189	1 684	0.10
Bay of Plenty	2017–18	Panel survey	571	1 116/1 205	650	0.12
Total	2017–18	Panel survey	2 601	1 202	**3 127**	**0.07**

* The Bay of Plenty programme was carried out in 1984 but is included in the 1985 total estimate.
† The 2000 mean weights were used in the 2001 estimates.
‡ Separate mean weight estimates were used for summer (1 October 2011 to 30 April 2012) and for winter (1 May to 30 September 2012).

Trends inferred from this monitoring programme were initially very similar to that inferred from aerial-access harvest estimates in the Hauraki Gulf in 2004–05, 2006–07, and 2011–12, but the camera/creel snapper harvest estimate for the Hauraki Gulf in 2017–18 is substantially lower than concurrent aerial-access and national panel surveys estimates for the same year (Table 6a cf. Table 6). This difference appears to be due to a recent substantial increase in recreational fishing effort and catch around expanding mussel farms in the Firth of Thames, coinciding with a lesser increase in effort in the north-western Hauraki Gulf. Additional creel survey monitoring has been initiated to monitor changes in the recreational fishery in these areas, which had not been adequately monitored from boat ramps in the Auckland metropolitan area up until 2019–20. These estimates show that the recreational snapper harvest varies substantially more than would be expected if catches were related only to stock abundance; this suggests that changes in localised availability to recreational fishers can also have a marked effect on the recreational harvest. Web camera monitoring is continuing, and the coverage is being progressively extended to other FMAs.

Table 6a: Recreational catch estimates (t) for snapper in different parts of the SNA 1 stock area calculated from web camera and creel monitoring at key ramps and scaled to aerial-access estimates for each area in 2004–05 and 2006–07 (Hauraki Gulf only) and 2011–12 and 2017–18 (all areas within SNA 1).

Year	East Northland	CV	Hauraki Gulf	CV	Bay of Plenty	CV	Total SNA 1	CV
2004–05	612	0.12	1 196	0.10	646	0.11	2 454	0.07
2006–07	–	–	1 272	0.16	–	–	–	–
2011–12	669	0.10	2 818	0.09	544	0.14	4 031	0.07
2012–13	525	0.11	1 232	0.11	241	0.16	1 099	0.08
2013–14	433	0.11	583	0.16	179	0.18	1 196	0.09
2014–15	414	0.12	448	0.14	182	0.25	1 044	0.09
2015–16	519	0.12	375	0.16	133	0.17	1 027	0.09
2016–17	551	0.11	398	0.15	277	0.19	1 227	0.08
2017–18	703	0.12	1 038	0.16	545	0.15	2 286	0.09
2018–19	774	0.10	1 070	0.14	280	0.13	2 125	0.08
2019–20	466	0.13	551	0.18	191	0.19	1 208	0.10
2020–21	667	0.13	498	0.17	297	0.23	1 462	0.10

The boat ramp interview data provided by this monitoring programme, and other previous boat ramp surveys, was used to model reconstructed regional catch histories for updated SNA 1 stock assessment model in 2022, which extended back as far as 1899–1900. The zero-inflated negative binomial (ZINB) generalised linear modelling approach used provides a more comprehensive reconstruction of past recreational catches because it uses data that are available from a far greater number of ramps than those surveyed as part of the web camera/creel survey monitoring programme, as far back as 2001. These ZINB models can be used to predict the number of snapper landed hourly at each surveyed ramp, including those hours when interviewing did not take place. Environmental covariates (wind speed and tidal state) and temporal factors (fishing year, month, and day type) were offered as explanatory variables to separate regional ZINB models. Hourly catch predictions from the ZINB models were then summed across the ramps surveyed in each region, to derive an index of the number of snapper landed annually at each surveyed access point. Annual mean fish weight estimates were then used to convert these annual estimates of the number of snapper landed at the surveyed ramps, into annual tonnage estimates.

Because only a subset of the access points in each region were surveyed, the resulting annual catch weight indices only provided a relative recreational snapper catch index, which was assumed would represent that landed at the other unsurveyed access points in each region. Each regional catch weight index was therefore scaled up to the corresponding geometric mean of the aerial-access estimates of the total harvest landed in each region, in 2004–05, 2011–12, and 2017–18, to account for the harvest tonnage landed throughout the region. Regional harvest back to 1900 from 1999 to 2000 was derived by interpolating from the ZINB model derived 1999–2000 point estimates to 'assumed' 1900 catch levels of 75 t for both East Northland and the Bay of Plenty, and 150 t for the Hauraki Gulf (Figure 2).

1.3 Customary non-commercial fisheries

Snapper form important fisheries for customary non-commercial, but the annual catch is not known. The information on Māori customary harvest under the provisions made for customary fishing is limited and it is likely that Māori customary fishers utilise the provisions under recreational fishing regulations.

1.4 Illegal catch

No new information is available to estimate illegal catch. For modelling SNA 1 an assumption was made that non-reporting of catch was 20% of reported domestic commercial catch prior to 1986 and 10% of reported domestic commercial catch since the QMS was introduced. This was to account for all forms of under-reporting. These proportions were based on the black-market trade in snapper and higher levels of under-reporting (to avoid tax) that existed prior to the introduction of the QMS. The 10% under-reporting post-QMS accounts for the practice of 'weighing light' and the discarding of legal-size snapper.

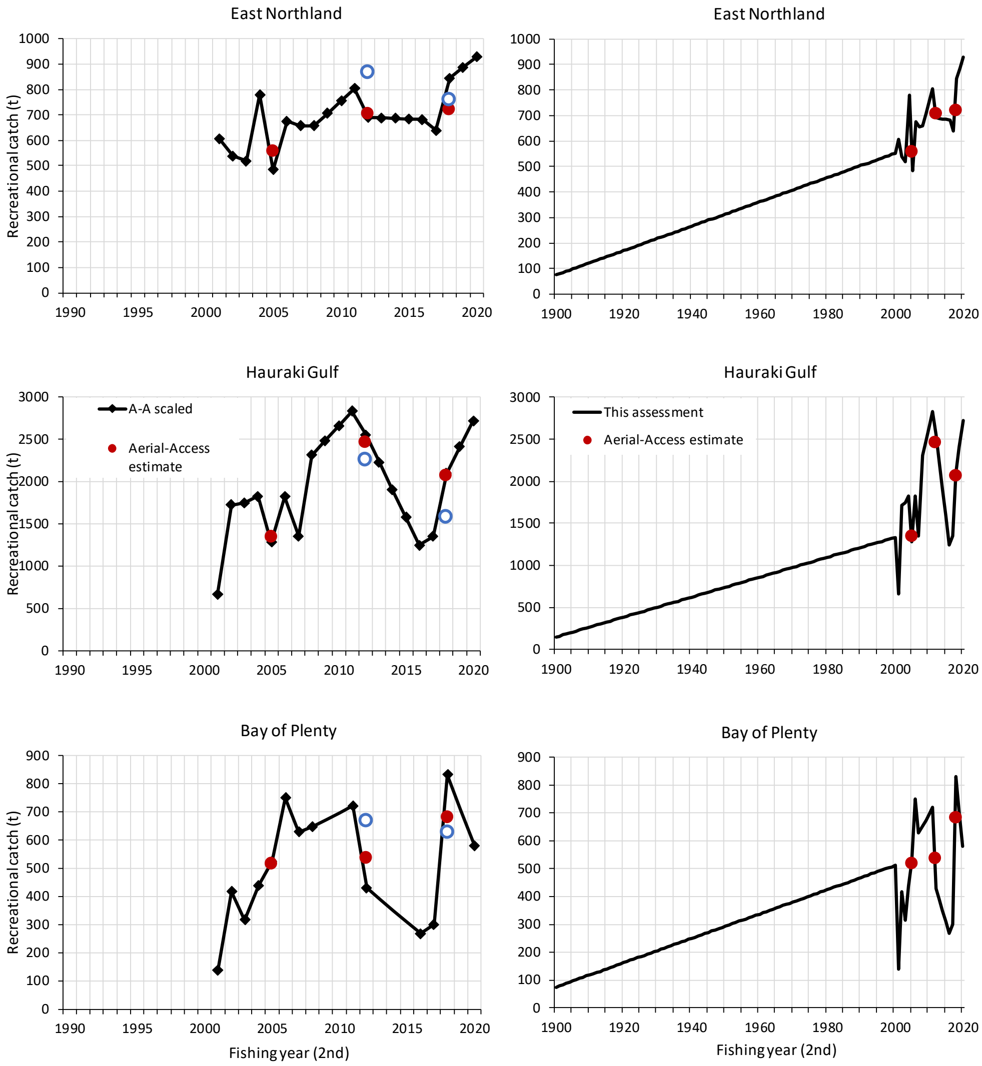


Figure 2: Regional recreational catch histories for SNA 1 based on zero inflated negative binomial modelling of creel survey landings data (snapper landed per complete creel survey hour). The relative harvest indices generated from regional model predictions were scaled up by regional harvest estimates provided by aerial-access surveys of SNA 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 since 2000–01 (left panels). These regional catch histories were then ramped back to nominal assumed recreational catch levels in 1900–01 (right panels).

1.5 Other sources of mortality

No estimates are available regarding the amount of other sources of mortality on snapper stocks; although high-grading of longline fish and discarding of under-sized fish by all methods occurs. An at-sea study of SNA 1 commercial longline fisheries in 1997 (McKenzie 2000) found that 6–10% of snapper caught by number were under 25 cm (MLS). Results from a holding net study indicate that mortality levels amongst lip-hooked snapper caught shallower than 35 m were low.

Estimates for incidental mortality were based on other catch-at-sea data using an age-length structure model for longline, trawl, seine, and recreational fisheries. In SNA 1, estimates of incidental mortality for the year 2000 from longlines were less than 3% and for trawl, seine, and recreational fisheries between 7% and 11% (Millar et al 2001). In SNA 8, estimates of trawl and recreational incidental mortality were lower, mainly because of low numbers of 2- and 3-year old fish estimated in 2000.

In SNA 1, recreational fishers release a high proportion of their snapper catch, most of which was less than 30 cm (recreational MLS). An at-sea study in 2006–07 recorded snapper release rates of 54.2% of the catch by trailer boat fishers and 60.1% of the catch on charter boats (Holdsworth & Boyd 2008). Incidental mortality estimated from condition at release was 2.7% to 8.2% of total catch by weight depending on assumptions used.

With the introduction of Electronic Reporting in 2019, commercial fishers must provide comprehensive reporting of all discards and returns. All fish under the minimum legal size ("sub-MLS fish") must now be returned to the sea; in SNA 1 reported quantities of sub-MLS snapper have been small (~40 t in 2020 and 2021 [i.e., < 1% of total annual commercial SNA 1 landed catch weight]).

2. BIOLOGY

For further information on snapper biology refer to the Introduction – Snapper chapter. A summary of published estimates of biological parameters for SNA 1 is presented in Table 7.

Table 7: Estimates of biological parameters.

Fishstock	Estimate			Source
1. Instantaneous rate of natural mortality (M)				
SNA 1, 2, 7, & 8	0.075			Hilborn & Starr (unpub. analysis)
2. Weight = a(length)^b (Weight in g, length in cm fork length)				
All	a = 0.0447	b = 2.793		Paul (1976)
East Northland	a = 0.0349	b = 2.870		
Hauraki Gulf	a = 0.0494	b = 2.771		Walsh et al (in press)
Bay of Plenty	a = 0.0430	b = 2.813		
3. von Bertalanffy growth parameters				
	Both sexes combined			
	K	t_0	L_∞	
SNA 1	0.102	-1.11	58.8	Gilbert & Sullivan (1994)
4. Age-at-recruitment (years)				
SNA 1*	4 (39%) 5 (100%)			Gilbert et al (2000)

* For years when not estimated.

3. STOCKS AND AREAS

New Zealand snapper are thought to comprise either seven or eight biological stocks based on: the location of spawning and nursery grounds; differences in growth rates, age structure, and recruitment strength; and the results of tagging studies. Three stocks are in SNA 1 (East Northland, Hauraki Gulf, and Bay of Plenty (BoP)), two in SNA 2 (one of which may be associated with the BoP stock), two in SNA 7 (Marlborough Sounds and Tasman Bay/Golden Bay) and one in SNA 8. Tagging studies reveal that limited mixing occurs between the three SNA 1 biological stocks, with greatest exchange between BoP and Hauraki Gulf.

4. STOCK ASSESSMENT

An assessment of SNA 1 was conducted in 2013, following a preliminary assessment undertaken in 2012. Another preliminary stock assessment carried out in 2022 was primarily focused on updating the 2013 assessment, including maintaining its basic structure and most of the assumptions. Although this preliminary assessment still required more work to provide appropriate management advice (see section 4.9 below), it was hoped that this work would provide insight on the progress of the SNA 1 stock since 2013 in terms of its status relative to current management targets.

SNA 1 (Auckland East)

4.1 Model structure

The model used for the 2013 assessment was written using CASAL (Bull et al 2012) and is a development of the three-stock, three-area model used in the 2012 assessment (Francis & McKenzie 2015a). The 2012 assessment was given a quality ranking of '2' due to lack of convergence of

MCMCs and poor estimates of the extent of depletion in 1970. These problems were largely resolved in the 2013 assessment.

The 2013 assessment model covered the time period from 1900 to 2013 (i.e., fishing years 1899–1900 to 2011–12, with two time steps in each year (Table 8).

The assessment explicitly modelled the movement of fish between areas and assumed a Home Fidelity (HF) movement dynamic. Under the HF movement, fish spawn in their home area and some move to other areas at other times of the year where they are subject to fishing. There were two sets of migrations: in time step 1, all fish returned to their home (i.e., spawning) area just before spawning; and in time step 2, some fish moved away from their home area into another area. This second migration may be characterised by a 3 × 3 matrix, in which the *ij*th element, p_{ij}, is the proportion of fish from the *i*th area that migrate to the *j*th area.

The model partitions the modelled population by age (ages 1–20, where the last age was a plus group), stock (three stocks, corresponding to the parts of the population that spawn in each of three subareas of SNA 1), area (the three subareas), and tag status (grouping fish into six categories—one for untagged fish, and one each for each of five tag release episodes). That is, at any point in time, each fish in the modelled population would be associated with one cell in a 20 × 3 × 3 × 6 array, depending on its age, the stock it belonged to, the area it was currently in, and its tag status at that time. To avoid confusion about areas and stocks, two-letter abbreviations (EN, HG, BP) are used for areas, and longer abbreviations (ENLD, HAGU, BOP) to denote stocks. As with previous snapper models (e.g., Gilbert et al 2000), this model did not distinguish fish by sex.

Table 8: Annual model time steps and the processes and observations used in each time step. Note that the home area for a fish is where it spawns (and was recruited). Each year some fish migrate away from their home ground (in step 2) and then return home in step 1 of the following year.

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

* Fishing mortality was applied after half the natural mortality.
† The tagging biomass estimate was assumed to occur immediately before the mortality; all other observations occurred half-way through the mortality.
‡ See Table 9 for more details of all observations.

A total of 168 parameters were estimated in the base model (Table 9). The six migration parameters define the 3 × 3 migration matrix described above (there are only six parameters because the proportions in each row of the matrix must sum to 1). Selectivities were assumed to be age-based and double normal, and to depend on fishing method but not on area. Three selectivities were estimated for commercial fishing (for longline, single trawl, and Danish seine), one for the (single trawl) research surveys, and two for recreational fisheries (for before and after a change in recreation size limit in 1995). All priors on estimated parameters were uninformative except for the usual lognormal prior on year class strengths (with coefficient of variation (CV) of 0.6).

Table 9: Details of parameters that were estimated in the model*.

Type	Description	No. of parameters	Prior
R_0	Mean unfished recruitment for each stock	3	uniform-log
YCS	Year class strengths by year and stock	1 361	lognormal†
Migration	Proportions migrating from home grounds	6	uniform
Selectivity	Proportion selected by age by a survey or fishing method	18	uniform
q	Catchability (for relative biomass observations)	$^{5}/_{168}$	uniform-log

* In the MPD run, YCSs were estimated for years 1966–2007 for ENLD, 1951–2007 for HAGU, and 1971–2001 for BOP; in the MCMC run the most recent years, 2008–2012, were also estimated.
† With mean 1 and coefficient of variation 0.6.

Year class strengths were estimated as free parameters but only for years where there was at least one observation of catch-at-age. The YCS estimation period in the model was also the period over which the R_0 parameter was also estimated. YCS estimation conformed to the Haist parameterisation in which the mean of the YCSs is constrained to 1 (Bull et al 2012). For years where YCS could not be estimated as free parameters, YCS was set to 1.

Some parameters were fixed, either because they were not able to be estimated with the available data (notably natural mortality and stock-recruit steepness were fixed at values determined by the Working Group), or because they were estimated outside the model (Table 10). As in 2012, mean length-at-age was specified by yearly values (rather than a von Bertalanffy curve) because these values showed a strong trend for the older ages. Data were available for 1994–2010 for ENLD, and for 1990–2010 for HAGU and BOP. In each stock, mean lengths for earlier years were set to the average values over these years, and for later years (including projections) to the 2006–2010 average.

Table 10: Details of parameters that were fixed in the model.

Natural mortality	0.075 y^{-1}
Stock-recruit steepness (Beverton & Holt)	0.85
Tag shedding (instantaneous rate, 1985 tagging)	0.486 y^{-1}
Tag detection (1985 and 1994 tagging)	0.85
Proportion mature	0 for ages 1–3, 0.5 for age 4, 1 for ages > 4
Length-weight [mean weight (kg) = a (length (cm))^b]	$a = 4.467 \times 10^{-5}$, $b = 2.793$
Mean length-at-age	provided for years 1990–2010*
Coefficients of variation for length-at-age	0.10 at age 1, 0.20 at age 20
Pair trawl selectivity	$a_1 = 6$ y, $\sigma_L = 1.5$ y, $\sigma_R = 30$ y

* See text for further details.

The most important change from the model used in the 2012 assessment was that the catch history was revised and extended back to 1900, and it was assumed that each stock was at its unfished level (B_0) in 1900. Two other changes of consequence affected the tag-recapture data sets that were 'condensed' (i.e., the number of length classes in each data set was substantially decreased by combining adjacent length classes until each remaining length class contained at least 5 observed recaptures) and iteratively reweighted, together with the composition data sets (for details see Francis & McKenzie 2015b). Other minor changes included dropping small fisheries (prorating their catches over the remaining fisheries in the same area) and removing priors on recreational selectivities.

Five types of observations were used in the base stock assessment (Table 11). These were the same as in the 2012 assessment (Francis & McKenzie 2015a) except for the addition of 2012 data points for each of the CPUE time series and the recreational length compositions.

Table 11: Details of observations used in the stock assessment model. **[Continued on next page]**

Type	Likelihood	Area*	Source	Range of years	No. of years
Absolute biomass	Lognormal	BOP	1983 tagging	1983	1
Relative biomass	Lognormal	BOP	longline	1990–2011	22
		ENLD	longline	1990–2011	22
		HAGU	longline	1990–2011	22
		BOP	single trawl	1996–2011	16
		HAGU	research survey	1983–2001	13
Type	**Likelihood**	**Area***	**Source**	**Range of years**	**No. of years**
Age composition	Multinomial	HAGU	longline	1985–2010	22
		BOP	longline	1990–2010	19
		ENLD	longline	1985–2010	18
		HAGU	Danish seine	1970–1996	11
		HAGU	research survey	1985–2001	10
		HAGU	single trawl	1975–1994	6
		BOP	single trawl	1990–1995	4
		BOP	research survey	1990–1996	3
		ENLD	research survey	1990	1
		BOP	Danish seine	1995	1
Length composition		BOP	recreational fishing	1991–2012†	14
		ENLD	recreational fishing	1991–2012†	14
		HAGU	recreational fishing	1991–2012†	14

Table 11 [continued]

Type	Likelihood	Area tagged*	Year tagged	Areas recaptured*	Years
Tag recapture	Binomials	ENLD	1983	ENLD, HAGU	1984, 1985
		HAGU	1983	ENLD, HAGU	1984, 1985
		ENLD	1993	ENLD, HAGU, BOP	1994, 1995
		HAGU	1993	ENLD, HAGU, BOP	1994, 1995
		BOP	1993	ENLD, HAGU, BOP	1994, 1995

* Areas are East Northland (ENLD), Hauraki Gulf (HAGU), and Bay of Plenty (BOP).
† All length composition data sets were split into pre-1995 (2 years) and post-1995 (11 years) because recreational selectivity was assumed to change in 1995.

Data weighting

The approach to data weighting followed the methods of Francis (2011) except that a new method was used to weight the tag-recapture data (not discussed by Francis 2011) via the dispersion parameter (for details see Francis & McKenzie 2015b). The CVs on the various abundance data sets were defined *a priori* to be consistent with the most 'plausible' fit the model was expected to achieve to the data (as agreed by the Working Group).

4.2 Catch History

Recreational catch

Direct estimates of annual recreational harvest from the three areas of SNA 1(East Northland, Hauraki Gulf, and Bay of Plenty) are available from aerial-access surveys conducted in 2004–05 and 2011–12 (Table 6) (Hartill et al 2007a, Fisheries New Zealand unpublished data).

The recreational catch history used in the previous 2012 stock assessment for SNA 1 was based on commercial longline CPUE indices (1990 to 2011) scaled to the 2004–05 aerial-access estimates for each area of SNA 1. In 2012 the Working Group decided that commercial longline CPUE indices should not be used to inform recreational catch histories because the 2011–12 aerial-access harvest estimates were well above those predicted by the longline CPUE based approach used in 2012, particularly for the Hauraki Gulf. Instead, the Working Group decided that an alternative creel survey based recreational kilogram per trip index provided a more realistic means of interpolating between the 2004–05 and 2011–12 aerial-access harvest estimates, in all three areas of SNA 1. Recreational kilogram per trip data are available for many of the years since 1991, especially since 2001, and these data explicitly take into account the 1995 changes to the recreational MLS and bag limits. These indices are based on creel survey data collected between January and April only. The geometric mean of the recreational kilogram per trip index over the period 2004–05 to 2011–12 was used to scale this index up to the level of the geometric mean of the two aerial-access harvest estimates. Exponential curves fitted to the recreational kilogram per trip index were used to provide interpolated catch estimates for years between 1990 and 2012 where no year index was available (Figure 3). The recreational harvest in 1970 was assumed to be 70% of the 1989–90 estimates in each area, with a linear increase in annual catch across the intervening years (Figure 3).

By choosing to scale recreational catch to the relative CPUE between years and scaling these estimates to the geometric mean of the two aerial surveys, the Working Group implicitly assumed that effort has remained constant throughout the period 1990–2012. Because recreational catch increased more rapidly than the BLL CPUE from 2007, the model estimated an increasing recreational exploitation rate to match the input catches. Increasing exploitation rates with fixed effort can only be resolved if recreational catchability also increased. The Working Group agreed that this was plausible even though relative recreational catchability must have increased by about 50% to account for the increased recreational catch estimates between 2005 and 2012. Projections also require the additional assumption that relative recreational catchability will remain at the values that were associated with the projected exploitation rate. The Working Group agreed to test the sensitivity of the projections to the catchability assumption by projecting forward using high and low recreational exploitation rate estimates: a) from 2013, the final model year, and b) from the average 1995–2005 exploitation rate, a period of relatively constant recreational catch incorporating the 2005 aerial catch estimate.

Recreational catch histories for each area for the period 1900 to 1970 were based on the average of two expert opinions of the harvest in 1900, provided by two regular members of the Marine Amateur

Fisheries Working Group. This averaged estimate was used to generate a linearly increasing recreational catch history for the period 1900 to 1970 (Figure 4).

The customary harvest is not known, and no additional allowance is made beyond the recreational catch.

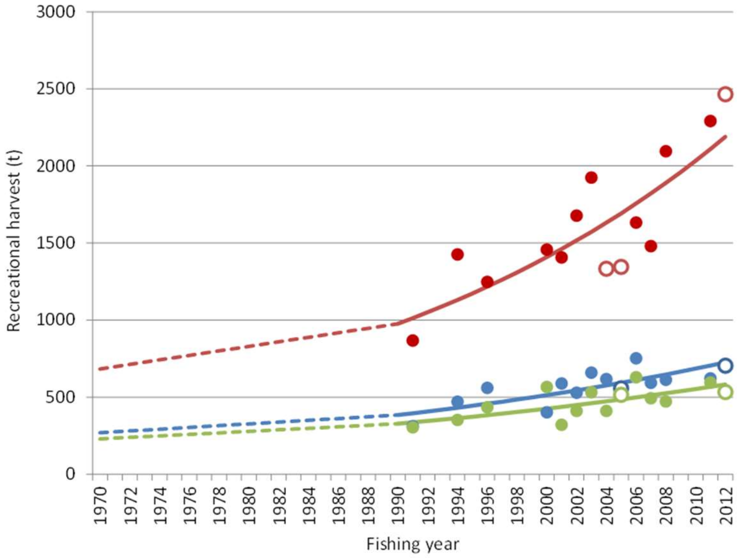


Figure 3: Recreational catch histories for the three areas of SNA 1 (Hauraki Gulf in red, East Northland in blue, and the Bay of Plenty in green). Open circles denote aerial-access survey estimates, closed circles denote recreational kilogram per trip indices scaled to the geometric mean of the aerial-access estimates, solid curved lines denote exponential fits to the scaled kilogram per trip indices which were used to predict harvests for those years for which creel survey data were not available, and dashed lines denote linear interpolations between 1990 and 1970 (when harvests were assumed to be at 70% of that predicted for 1990).

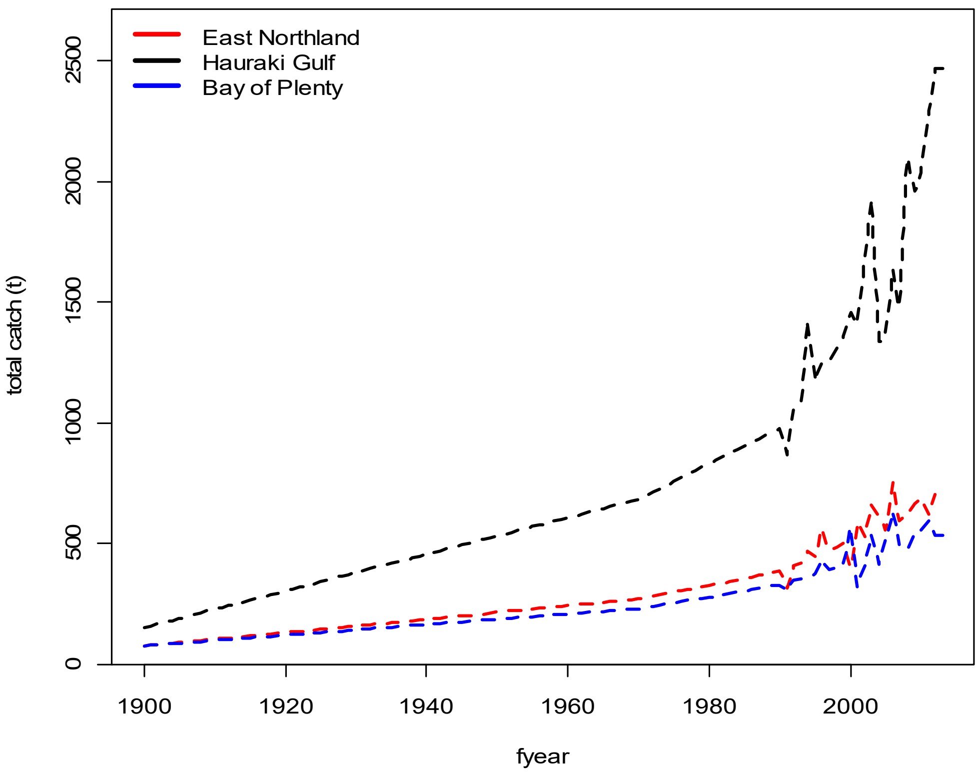


Figure 4: Assumed and derived recreational catch histories for the period 1900 to 2013 that were used in the 2013 SNA 1 assessment model.

Commercial catch

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

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

- 1915–73: Annual Reports on Fisheries, compiled by the Marine Department to 1971 and the Ministry of Agriculture and Fisheries to 1973 as a component of their Annual Reports to Parliament published as Appendices to the Journal of the House of Representatives. From 1931 to 1943 inclusive, data were tabulated by April–March years; these were equated with the main calendar year (e.g., 1931–32 landings are treated as being from 1931). From 1944 onwards, data were tabulated by calendar year.
- 1974–82: Ministry of Agriculture and Fisheries, Fisheries Statistics Unit (FSU) calendar year records published by King (1985). The available data grouped catches for all species comprising less than 1% of the port totals as “Minor species”. An FSU hardcopy printout dated 23 March 1984 held by NIWA was used to provide species-specific catches in these cases (although this had little effect for snapper given that it is typically a major species in SNA 1 ports).

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

The only information available on the spatial distribution of SNA 1 landings before 1983 comes from “The Wetfish Report” (Ritchie et al 1975) in which snapper landings for old statistical areas were provided by year and month for the period 1960–1970. The boundaries of the old Statistical Areas 2, 3, and 4 are similar to those for the East Northland, Hauraki Gulf, and Bay of Plenty sub-stocks. However, Area 4 is smaller than the Bay of Plenty sub-stock, whereas Area 2 is larger than East Northland, and Area 3 is larger than Hauraki Gulf. Nevertheless, the match between old statistical areas and sub-stock boundaries is likely to be close enough to use the catch split from “The Wetfish Report” to apportion SNA 1 landings among sub-stocks. The percentage split by statistical area varied little over the 11-year period 1960–70:

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

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

The historical SNA 1 commercial catch time series was divided into four method fisheries: longline (BLL), single bottom trawl (BT), pair bottom trawl (BPT), and Danish seine (DS). Catches from ‘other’ commercial methods (predominantly set net) were not explicitly modelled but the catch totals were prorated across the fisheries in the same area. Information on specific catching methods becomes increasing less reliable prior to 1973 so the area catch method splits from the early 1970s were applied back to 1900.

As was done for the 2000 and 2012 assessments, commercial catch totals prior to the 1986 QMS year were adjusted upwards to account for an assumed 20% level of under-reporting. Catch totals post QMS were likewise scaled assuming 10% under-reporting (Figures 5 and 6).

Estimation of foreign commercial landings

In the 1997–98 SNA 1 assessment (Davies 1999), the foreign (Japanese longline) catch was assumed to have occurred between 1960 and 1977, with cumulative total removals over the period at three alternative levels: 20 000 t, 30 000 t, and 50 000 t. The assumed pattern of catches increased linearly to a peak in 1968 then declined linearly to 1977; the catch was split evenly between East Northland

and the Hauraki Gulf/Bay of Plenty. For the 2013 assessment, the base case level of total foreign catch for the period between 1960 and 1977 was assumed to be 30 000 t, catch apportioned among the three sub-stocks in the ratio 50% East Northland, 10% Hauraki Gulf, and 40% Bay of Plenty and added to the domestic longline method totals.

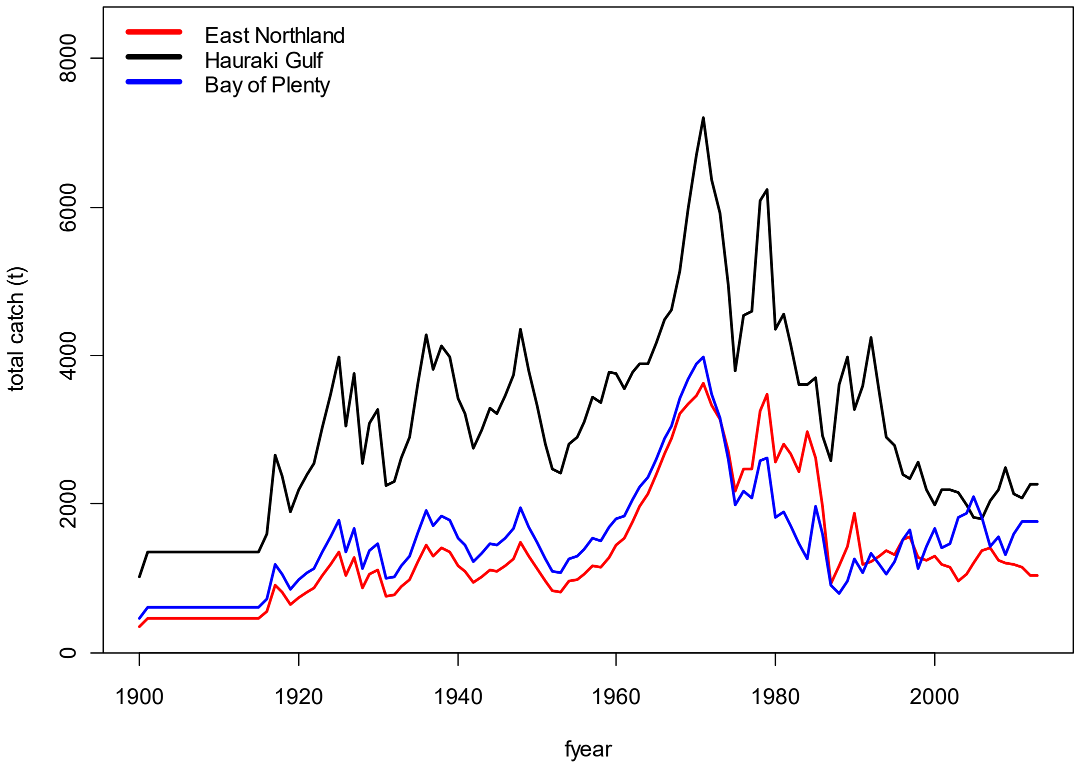


Figure 5: Commercial catch histories by area (adjusted for under-reporting) plus foreign catch used as input to the 2013 SNA 1 assessment model.

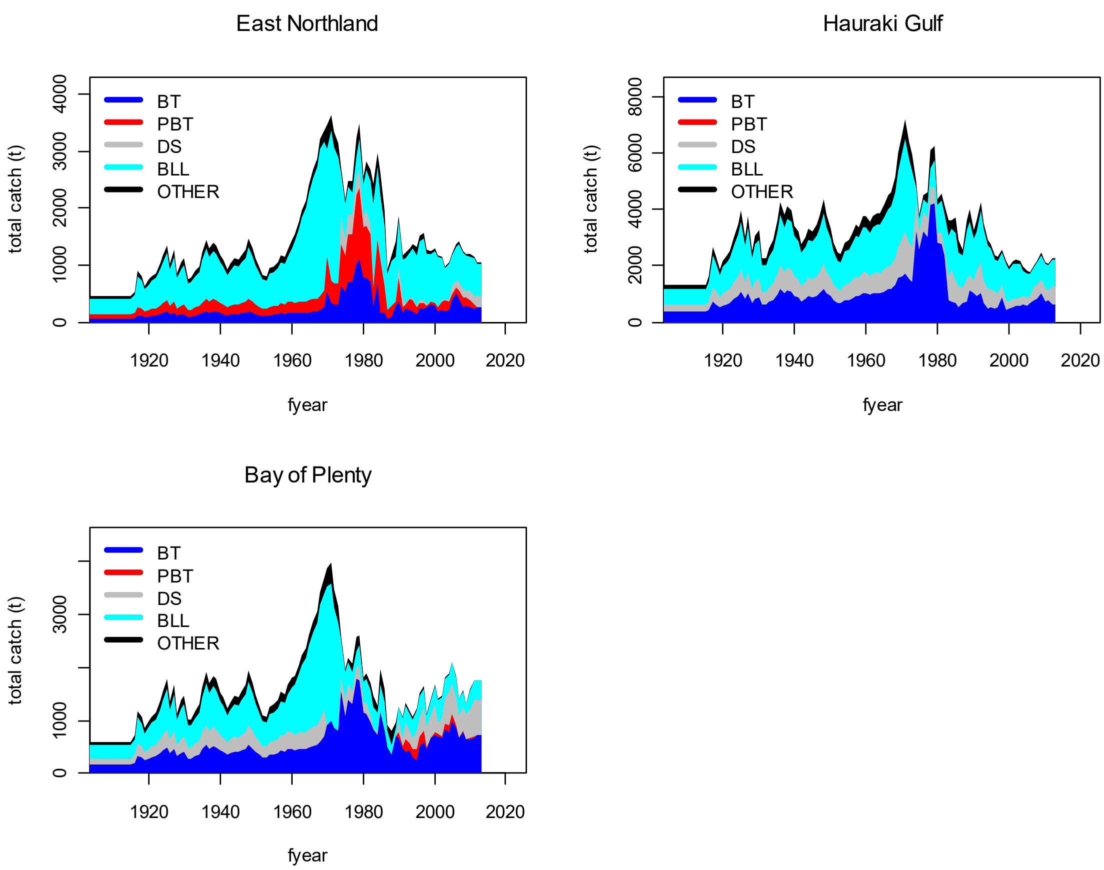


Figure 6: Commercial catch histories by method and area (adjusted for under-reporting) used as input to the 2013 SNA 1 assessment model.

4.3 Abundance indices

Trawl surveys

Trawl surveys were carried out in all three areas between the mid-1980s and 2000. Unfortunately, the only area for which a viable series of abundance estimates exists is the Hauraki Gulf. An index of relative numbers of fish surveyed from the Hauraki Gulf trawl survey series was fitted in the model and was assigned an overall CV of 0.15 (see Table 11).

Longline CPUE

CPUE indices for the fishing years 1989–90 to 2011–12 were derived using data from bottom longline fisheries operating in the East Northland, Hauraki Gulf, and Bay of Plenty areas within SNA 1 (see also McKenzie & Parsons 2012). Data for years prior to 2007–08 were fisher daily amalgamated catch totals, i.e., catch per day. After 1 October 2007 longline fishers were required to report catch and effort on a per set or event basis. To combine the data, the more detailed post 2007 data were aggregated at the daily catch level. The validity of doing this was explored by looking for discontinuities in the annual median number of hooks reported by the core vessels over the form change interval. It was concluded that combining the two data series in a single analysis was appropriate.

Analysis was restricted to a subset of 'core' vessels. The vessel selection process sought to:

- minimise the number of vessels in the analysis;
- maximise the proportion of total longline catch: threshold set at 60%;
- maximise the number of years in the fishery; and
- maximise the average number of trips per year.

Standardised CPUE indices were derived as the coefficient of the year covariate in a log-linear regression model of daily log-catch (kg). Other variables offered to the model were vessel-id, target, month, statistical area, number of hooks, and number of sets (refer McKenzie & Parsons 2012). Parameters selected by the model are given in Table 12.

Alternative analyses were undertaken, using more vessels, to include at least 80% of the total longline catch for the last five years. These analyses produced results consistent with those using fewer vessels and less of the catch suggesting that the derived standardised indices were relatively insensitive to the core vessel selection and the proportion of the total longline catch included.

The pattern in nominal (unstandardised) longline CPUE shows increasing trends in all three areas (Figure 7). Increasing trends in the standardised CPUE indices are also seen in the Hauraki Gulf and Bay of Plenty areas; however, the increase in Hauraki Gulf abundance is less steep than the unstandardised indices (Figure 7). The difference between the standardised and unstandardised longline indices is most pronounced for East Northland with the standardised indices being much flatter (Figure 7).

Table 12: Parameters (covariates) selected in the log-linear model standardisation of daily log-catch from longline (log-catch-per-day) and bottom trawl (log-catch-per-unit-tow) by area along with the proportion of variance explained (model R-squared) by the addition of each successive term (model R-squared).

	Parameter	Fyear	Number of hooks (log)	Vessel	Depth	Month	Target	Stat area
Longline								
East Northland	model R-squared	0.06	0.3	0.35	–	0.39	0.41	–
Hauraki Gulf	model R-squared	0.08	0.34	0.44	–	0.49	–	–
Bay of Plenty	model R-squared	0.07	0.53	0.43	–	–	0.57	–
Bottom Trawl								
Bay of Plenty	model R-squared	0.01	–	0.15	0.17	0.19	0.1	0.21

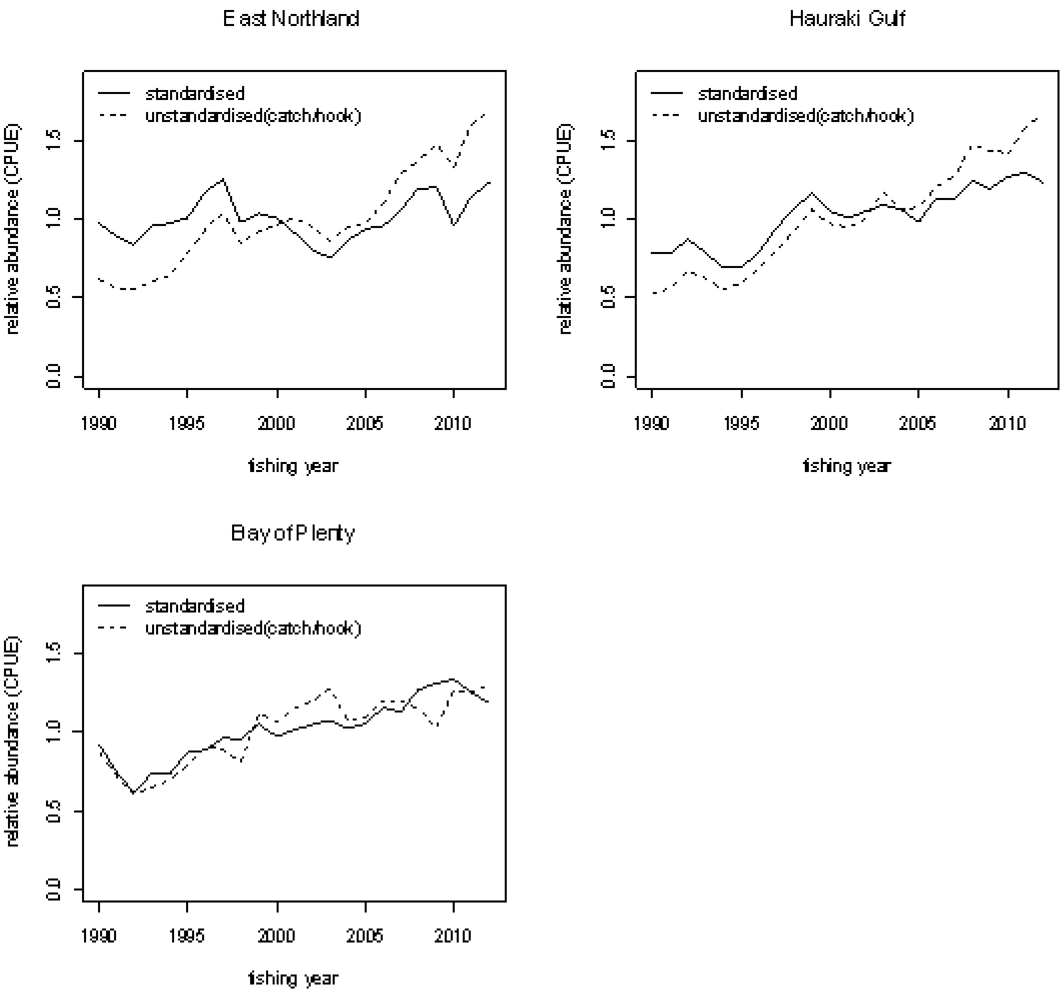


Figure 7: Longline CPUE indices of abundance (standardised and unstandardised) from 1990–2012 for the three component stocks of SNA 1.

The area specific longline CPUE indices were fitted by the 2013 model, with each series assigned an overall CV of 0.15.

Bay of Plenty single trawl CPUE

The Bay of Plenty single trawl CPUE data were available from fishing years 1989–90 to 2011–12 (a 23 year time series). However, three different catch effort form types have been in use during this period, partially limiting the temporal continuity of the series. Prior to the 1995–96 fishing year, most Bay of Plenty trawl fishers used the less detailed daily CELR reporting forms. From 1995–96, however, a significant number of Bay of Plenty trawl fishers (over 70%) were reporting on Trawl Catch Effort Processing Returns (TCEPR) that provide effort details as well as latitude and longitude information for each tow. From the 2007–08 fishing year many Bay of Plenty trawl fishers moved onto the new Trawl Catch Effort Return (TCER) forms. The TCER forms are largely identical to the TCEPR forms but require catch details of the top eight, not five, species to be recorded. It was decided not to include the CELR data in the CPUE standardisations and only to include years where a high proportion of TCEPR and TCER data were available; specifically, the 1995–96 to 2011–12 fishing years (a 17 year time series).

As with the longline analysis both standardised and unstandardised CPUE indices were derived. In the unstandardised analysis CPUE was simply catch per tow, in the standardised analysis CPUE was log catch per tow (positive catches only). The following continuous effort variables were considered in the model selection (standardisation) process: Log (fishing duration); Log (net height); Log (net width); Log (gear depth); Log (engine power); Log (vessel length*depth*breadth). Categorical variables considered were: fishing year (forced); month; season (4); vessel; and statistical area. In the Bay of Plenty trawl fishery 98% of the snapper catch is taken when targeting five main species: SNA, TRE, TAR, GUR, and JDO). Therefore 'target' was included in the standardisation as a six-level categorical variable (five target species plus an 'other' category) (refer McKenzie & Parsons 2012 for details). Parameters chosen by the standardisation procedure are given in Table 16.

The standardised CPUE indices suggest that the Bay of Plenty trawl fishery experienced a slight increase in abundance between 1996 and 2008 and more recently from 2010–11 (Figure 8).

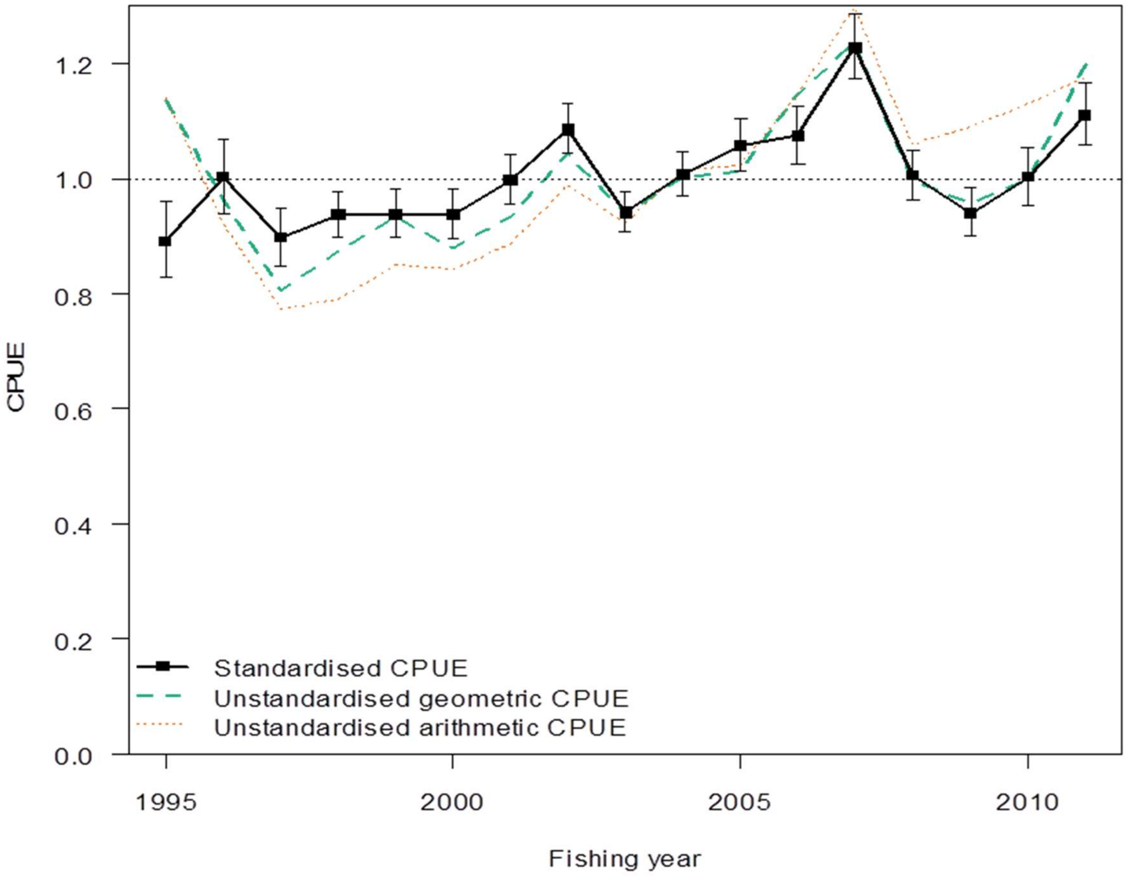


Figure 8: Single trawl CPUE indices of Bay of Plenty area abundance (standardised and unstandardised) from 1996–2012. Note: 1995 is the 1995-96 fishing year in this plot.

The single trawl Bay of Plenty CPUE was fitted with an assigned overall CV of 0.15 (see Table 11).

4.4 Catch at age and length observations

Commercial data

Catch-at-age observations from single trawl, Danish seine, and longline are available from the Bay of Plenty and Hauraki Gulf stocks; longline only for East Northland (see Table 11).

Catch-at-age sampling since 1985 in East Northland shows a greater accumulation of fish older than 20 years than observed in the Hauraki Gulf or Bay of Plenty sub-stocks (Figures 9–11). The Bay of Plenty longline age composition is similar to that for SNA 8, with the fishery largely comprising only 4–6 dominant age classes with few fish older than 20 years present in the catch samples (Figure 11).

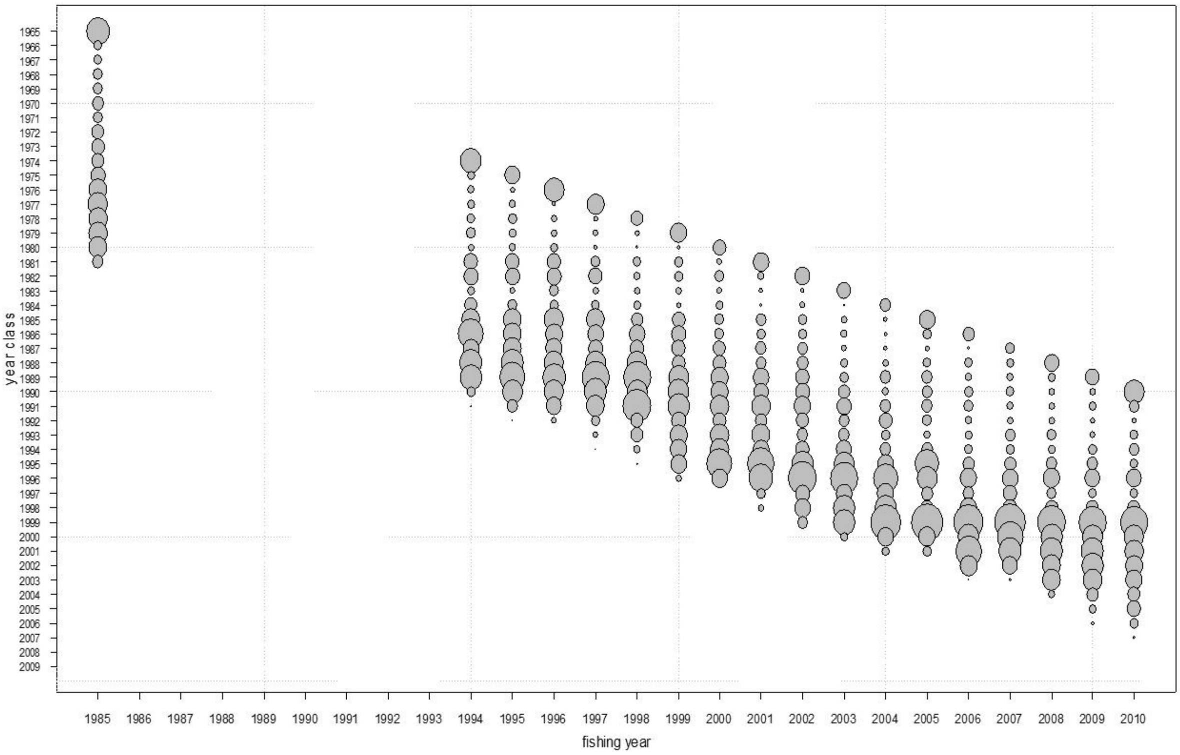


Figure 9: Relative year class strength observed in the East Northland longline fishery 1984–85 to 2009–10. Year on the x-axis refers to the second part of the fishing year. The oldest year class is a 20+ group.

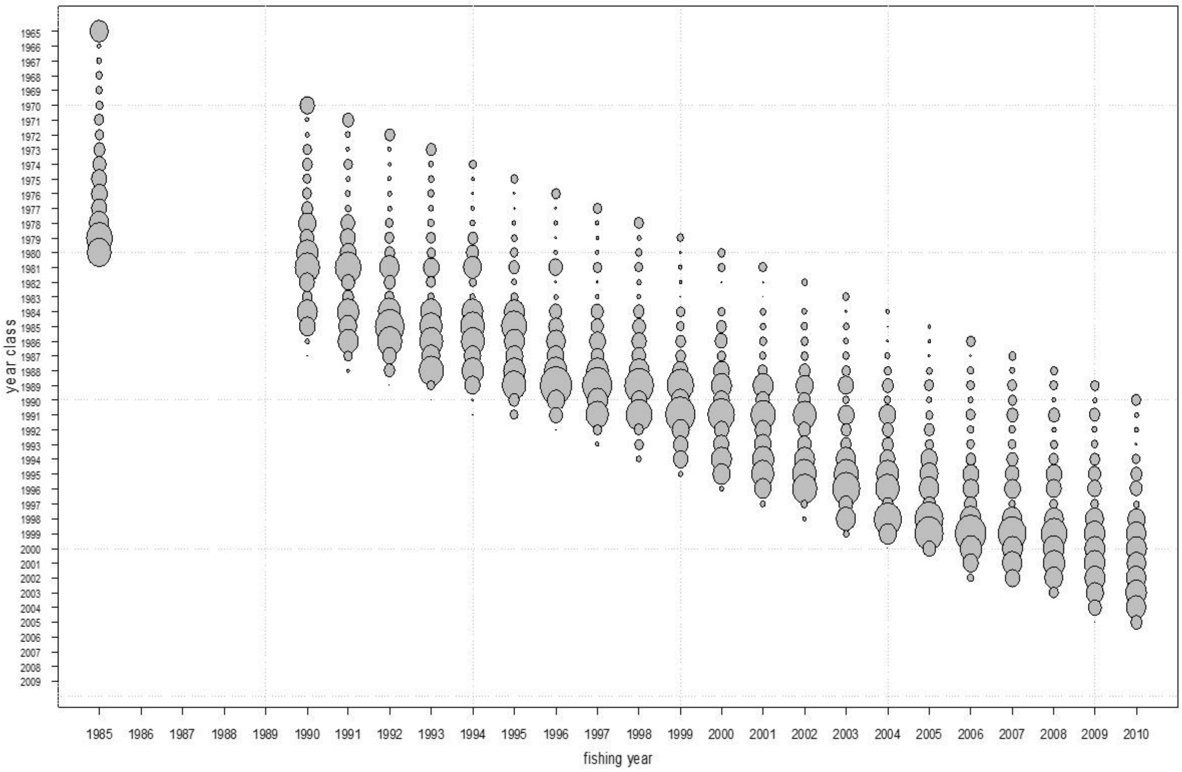


Figure 10: Relative year class strength observed in the Hauraki Gulf longline fishery 1984–85 to 2009–10. Year on the x-axis refers to the second part of the fishing year. The oldest year class is a 20+ group.

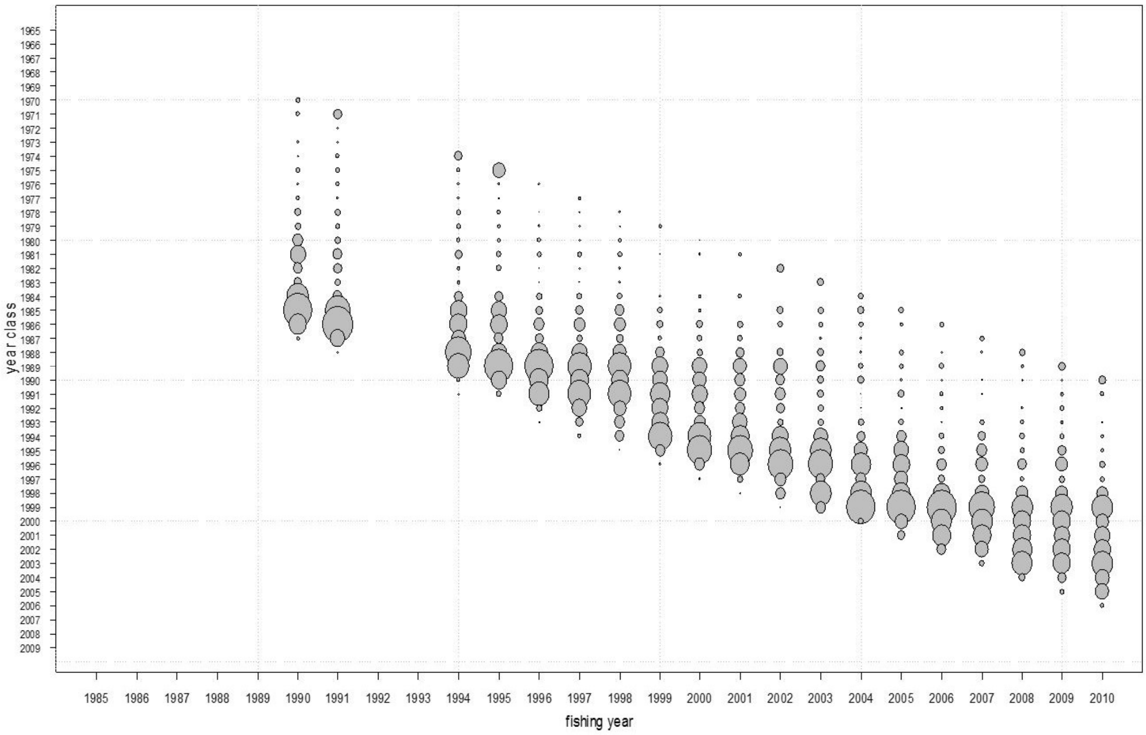


Figure 11: Relative year class strength observed in the Bay of Plenty longline fishery 1990–91 to 2009–10. Year on the x-axis refers to the second part of the fishing year. The oldest year class is a 20+ group.

Recreational data
Observations of recreational catch-at-length are available for most years after 1990, spanning the 1994 change in minimum legal size (see Table 11).

Research trawl data
Catch-at-age observations from research trawl surveys are available for most surveys and fitted in the model for all areas (see Table 11).

4.5 Snapper 1983, 1985, and 1994 tagging programmes

Analysis of past snapper tagging programmes revealed a number of sources of bias that need to be accounted for if these data are to be used for assessment purposes. Data from the 1985 and 1994 tagging programmes were corrected for bias and input directly into the assessment model. Data from the 1983 Bay of Plenty tagging programme were unavailable. The published biomass estimate (6000 t, Sullivan et al 1988) was fitted in the model as a point estimate but given a high CV (0.4) in recognition of the likely inherent but unaccountable biases in the data.

Initial mortality
The release data were adjusted for initial mortality outside the model using methods given by Gilbert & McKenzie (1999).

Tag loss
The effect of tag loss was only an issue for the 1983 and 1985 tagging programmes where external tags were used. A revised estimate of tag loss was derived from a double-tagging experiment in 1985.

Trap avoidance
Trap avoidance was found to occur for both trawl and longline tagged fish (Gilbert & McKenzie 1999); the result of this was that released fish were less likely to be recaptured using the same method. Trawl and longline methods were used to tag fish in both the 1985 and 1994 tagging programmes. The CASAL models used the scaling factors derived by Gilbert & McKenzie (1999) to adjust the tagging data for trap avoidance.

Detection of recaptured tags
Because a fisheries-independent tag recovery process was used in the 1994 programme, a reliable estimate of tag under-detection was obtained. The model was provided this estimate to adjust the 1994 tag recovery data.

The recovery of tags in 1983 and 1984 programmes relied on fishers to voluntarily return tags. Estimates of under-reporting from these programmes are less precisely known but were assumed to be 15% (1988 Snapper Plenary Report).

Differential growth of tagged fish
There is evidence that tagged fish may stop growing for 6 months after tagging (Davies et al 2006). The growth differential between tagged and untagged fish may bias results because the model will expect these fish to be larger than they are. Because it was not possible to incorporate this source of bias in the model, it was assumed that, given that the majority of tags recovered in both programmes came from the first year after release, growth bias would be minimal.

Spatial heterogeneity
A primary objective when tagging fish for biomass estimation is to ensure homogeneous mixing of tags within each spatial stratum so that the probability of recovering a tagged fish is the same in all locations. Spatial heterogeneity impedes realisation of this objective. The potential bias caused by spatial heterogeneity may be high or low because it depends largely on the spatial distribution of recapture effort (i.e., fishing) within the spatial stratum. Heterogeneity was observed in both tagging programmes because mark rates varied amongst statistical areas and methods; and was most apparent in the 1994 Hauraki Gulf Danish seine catches (Gilbert & McKenzie 1999). The results of simulation modelling using Hauraki Gulf data from the 1994 programme showed that under scenarios where the difference in the spatial mark rates was high (up to 4-fold) and catch examination tonnages were spatially disproportionate, the level of bias (positive or negative) in the biomass estimate could be as high as 35% (Davies et al 1999b). However, for scenarios where fishing was more uniform across strata, the expected level of bias was likely to be only 10%. To further investigate potential bias introduced by heterogeneity in the 1994 tagging programme, fish tagged and released by the Hauraki Gulf Danish seine fishery were excluded from the analysis. This increased the 1995 Hauraki Gulf biomass estimate by 15%, from 30 000 t to 34 000 t (Davies et al 1999a). Evidence for spatial heterogeneity in East Northland and the Bay of Plenty was much weaker than for the Hauraki Gulf (Gilbert & McKenzie 1999). For the 2013 stock assessment all tag recovery data are used, including Danish seine recoveries from the Hauraki Gulf.

4.6 Stock Assessment Results

Spawning biomass by stock and by area and for HAGUBOP
Two versions of spawning stock biomass (*SSB*) are presented in the following results. The first, labelled 'by stock', is calculated in the conventional way (in the model time step 1, when spawning occurs and all fish are in their home grounds); the second, labelled 'by area', is calculated half-way through the mortality in time step 2, when some fish are away from their home ground. The former is the usual *SSB*, but the latter is better estimated and may be more relevant for management purposes.

Some *SSB* results are also presented for the Hauraki Gulf and Bay of Plenty combined (labelled HAGUBOP by stock, or HGBP by area) because there is some doubt about the relationship between fish in these two areas.

Base model
The base model MPD achieved good fits to the abundance data and reasonably good fits to the composition data. The fit to the tag-recapture data was negatively affected by a conflict between these data and the age compositions which caused an imbalance in the fits to the tag-recapture data: the observed tag rate (the proportion of fish with tags) was greater than the expected rate in 23 of the 26 data sets. Although the expected rate lay within the 95% confidence bounds in all but three data sets, this result indicates that the model is unable to fit the tagging data well. Issues with the original tagging data and analyses have been identified elsewhere (Gilbert et al 1999, Davies et al 1999b).

All estimated spawning biomass trajectories show substantial reductions up to 1999 (for East Northland) or about 1988 (for other stocks and areas), and then some increase thereafter (Figure 12, upper panels). In terms of current biomass, both the stock BOP and area BP are estimated to be more depleted (3–10% B_0) than the other stocks and areas (15–30% B_0) (Table 13). However, for all stocks and areas, current biomass is 30–68% higher than its minimum value (Table 13). Stock HAGU and area HG are estimated to contain a much greater tonnage of fish than the other stocks and areas, both over the period of the assessment (Figure 12, upper panels) and in their unfished state (Table 13). ENLD/EN and BOP/BP are estimated to have contained broadly similar tonnages (53 000 t to 112 000 t) before the fisheries started—which was estimated to be the larger depends on whether the biomass is considered by stock or by area.

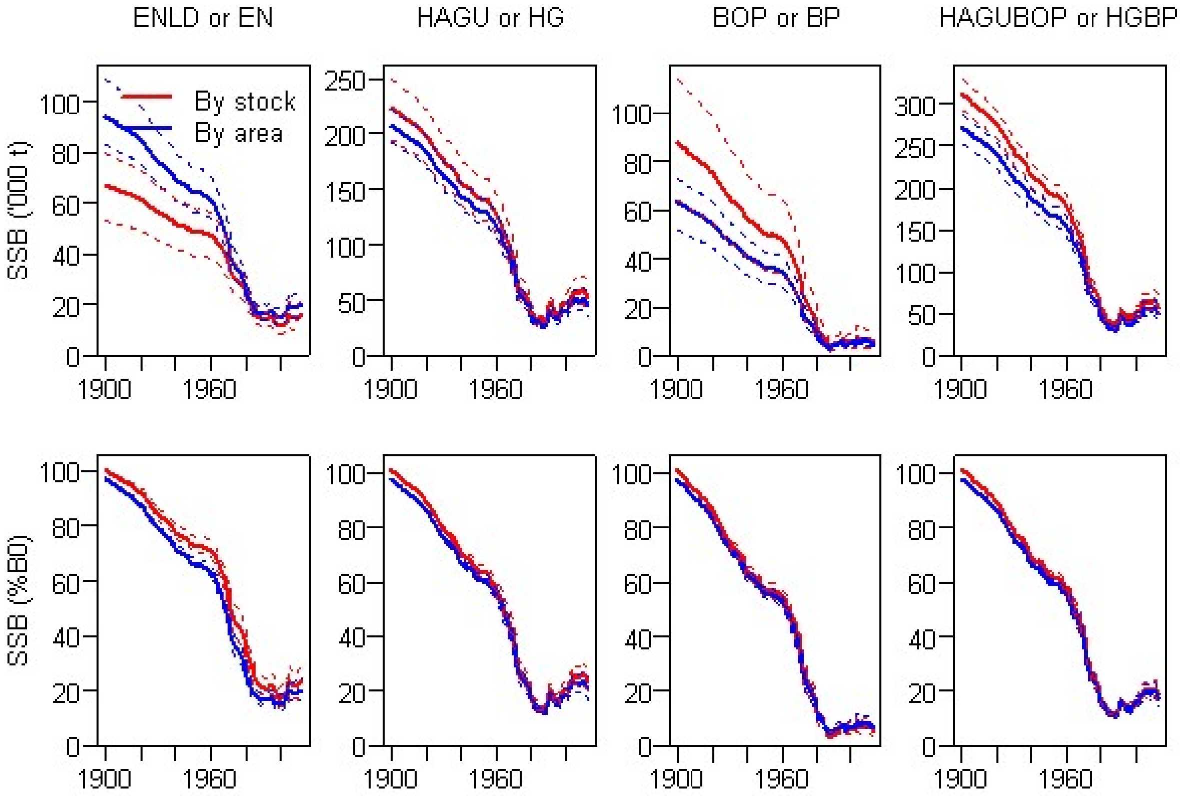


Figure 12: *SSB* trajectories by stock (red lines) and area (blue lines) from the base model. Solid lines are MCMC medians, broken lines are 95% confidence intervals.

Table 13: Base model estimates of unfished biomass (B_0) and current biomass (B_{2013} as % B_0 and % B_{min}) by stock and area. Estimates are MCMC medians with 95% confidence intervals in parentheses.

		B_0 ('000 t)	B_{2013} (% B_0)	B_{2013} (% B_{min})*
By stock	ENLD	66 (53, 79)	24 (18, 30)	137 (108, 176)
	HAGU	220 (192, 246)	24 (19, 29)	168 (137, 206)
	BOP	86 (63, 112)	6 (3, 9)	148 (104, 209)
	HAGUBOP	306 (288, 325)	19 (15, 23)	167 (139, 201)
By area	EN	96 (85, 111)	20 (16, 25)	130 (108, 159)
	HG	211 (197, 227)	21 (17, 26)	167 (136, 204)
	BP	64 (53, 74)	7 (5, 10)	145 (114, 185)
	HGBP	276 (258, 292)	18 (15, 22)	165 (136, 199)

*B_{min} was taken as B_{1999} for ENLD and EN, and as B_{1988} for other stocks and areas.

Most fish do not move away from their home grounds, with migration being most common for BOP fish and least common for ENLD fish (Table 14). Uncertainty in the proportion migrating is greatest for fish from BOP. The estimated proportion migrating from BOP to ENLD appears to be unrealistically high when compared with the observed movements of tagged fish.

Table 14: Base case migration matrix (showing proportions of each stock migrating to each area in time step 2). Estimates are MCMC medians with 95% confidence intervals in parentheses.

Stock	Area EN	Area HG	Area BP
ENLD	0.94 (0.89, 0.97)	0.05 (0.02, 0.10)	0.01 (0.00, 0.04)
HAGU	0.09 (0.05, 0.14)	0.87 (0.82, 0.91)	0.04 (0.02, 0.06)
BOP	0.17 (0.02, 0.36)	0.18 (0.07, 0.34)	0.63 (0.45, 0.83)

In all areas current exploitation rates by method are estimated to be highest for the recreational fisheries (Figure 13). Fishing intensity is estimated to be highest in BOP. For ENLD and HAGU, fishing intensity declined from peaks in the 1980s but has increased in the HAGU since 2007 (Figure 14). The fishing intensity for the HAGUBOP stock rose sharply from the early 1960s and reached a peak in the 1980s. It then declined by approximately 50% to 2007 but has since increased to 86% of the 1985 peak (Figure 14). Estimates of year class strength are precise only for a relatively narrow range of years, particularly for ENLD and BOP, where catch-at-age data are sparser (Figure 15).

No stock or area is at or above the target and none but the Bay of Plenty is below the hard limit. Probabilities of being below the soft limit range from 0.04 to 1.00 (Table 15).

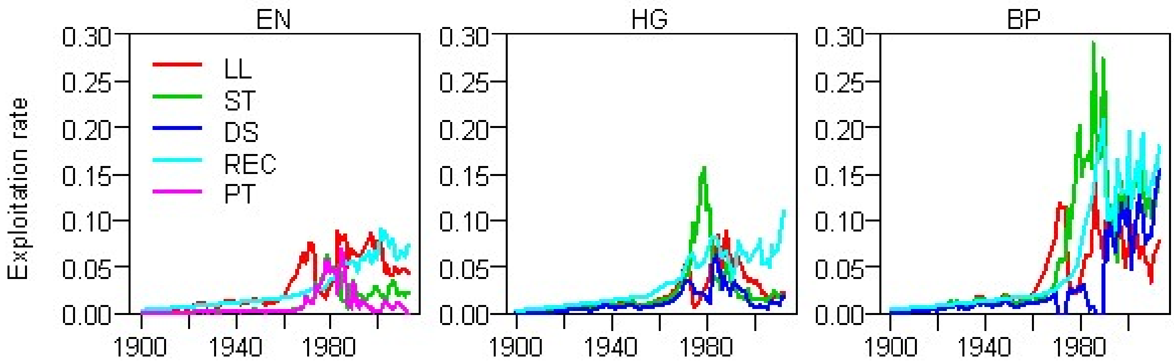


Figure 13: MPD estimates of exploitation rates by fishery and year.

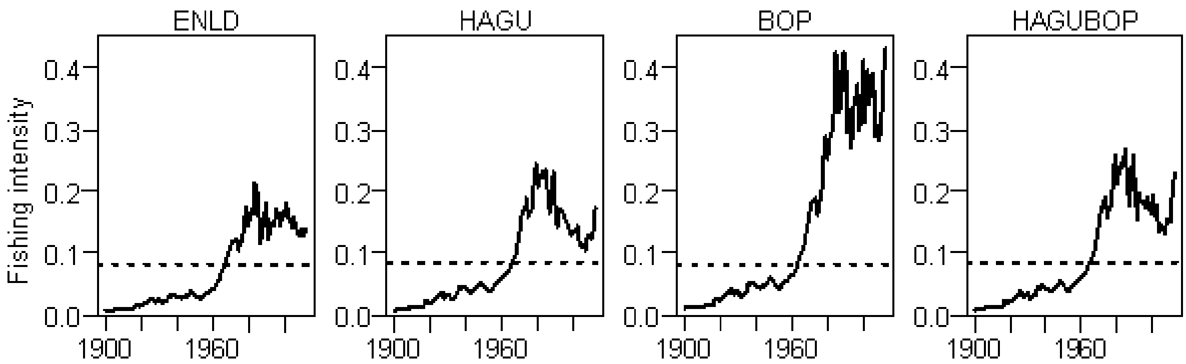


Figure 14: MPD estimates of fishing intensity by year and stock. Dotted lines show the intensity required to maintain the spawning biomass at 40% B_0 ($U_{40\%B_0}$).

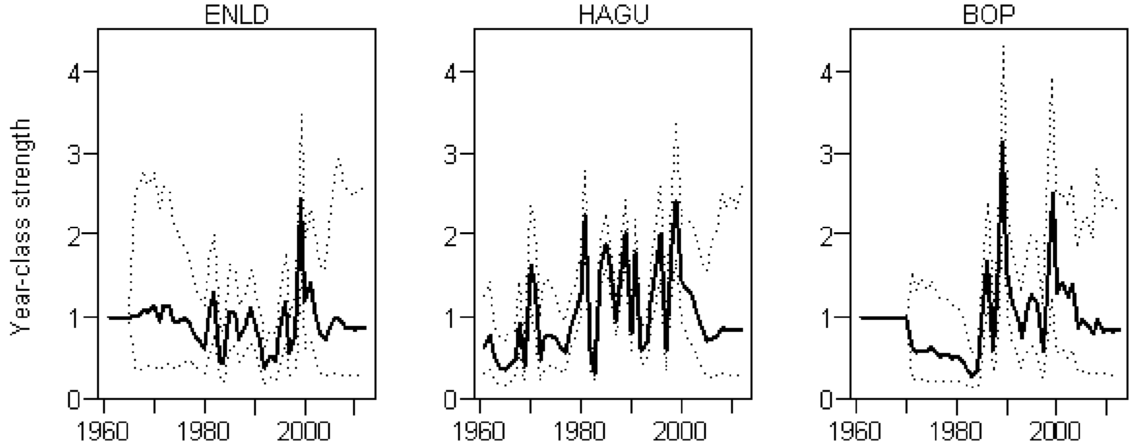


Figure 15: Estimated year class strengths by year and stock (a value of 1 indicates that the year class has the strength predicted by the stock-recruit relationship). Estimates are MCMC medians (solid lines) and 95% confidence intervals (dotted lines).

Table 15: Probabilities, by stock and area, relating current biomass to the target (40% B_0) and limits (soft 20% B_0 and hard 10% B_0).

	ENLD/EN		HAGU/HG		BOP/BP		HAGUBOP/HGBP	
Probability	**by stock**	**by area**	**by stock**	**by area**	**by stock**	**by area**	**by stock**	**by area**
At or above target	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Below soft limit	0.12	0.52	0.04	0.34	1.00	1.00	0.74	0.89
Below hard limit	0.00	0.00	0.00	0.00	0.99	0.99	0.00	0.00

Sensitivity analyses

Many alternative models were constructed and run to determine the sensitivity of the assessment to various model assumptions (Francis & McKenzie 2015b).

Some changes of assumptions had comparatively little effect on stock status. The following changes fall into this category: alternative levels of trap shyness and tag loss; allowing the initial (1900) biomass to differ from B_0; increasing the maximum age in the partition from 20 to 60; dropping tag-recapture data from Statistical Area 008 (the Bay of Plenty area closest to the Hauraki Gulf); and assuming that tagging in area BP occurred before HAGU fish in that area had returned home.

Two other alternative models were useful in demonstrating the sensitivity of the assessment to specific data sets. In one, the longline CPUE indices were replaced by their unstandardised values (which have quite different trends—see Figure 7), and, in the other, the tag-recapture data were strongly down-weighted. In both cases there was a marked change in the estimated biomass trajectories; however, neither of these runs was considered to provide useful information on current stock status.

There are nine alternative models for which some results are presented (Table 16). Most of these alternative models are easily understood, but two merit more detailed description.

Table 16: Brief descriptions of nine alternative models run to determine sensitivity to various model assumptions.

Label	**Description**
catch-lo/hi	Use alternative lower and higher catch histories
sel-by-area*	Assume that fishery selectivity depends on area, as well as fishing method
reweight	Age and tag-recapture data reweighted to reduce imbalance in fit to tag-recapture data
M-lo/hi	Replace the assumed value of natural mortality, $M = 0.075$ y^{-1}, with lower (0.05) and higher (0.10) values
steep-lo/hi	Replace the assumed value of stock-recruit steepness, 0.85, with lower (0.7) and higher (0.95) values
one-stock[1]	Replace the base three-stock (and three-area) model with 3 separate one-stock models: one for each area.

* MCMC runs were done for these sensitivities.

The first, sel-by-area, was motivated by the observation that, for any given fishing method and year, the mean age (or mean length for recreational fisheries) of the catch was almost always lowest in area

BP (Figure 16). In the base model this implied that the biomass was more depleted in BP than in the other areas because of the assumption that the selectivity of each fishing method is the same in all three areas. This assumption was removed in model sel-by-area (so that a separate selectivity curve was estimated for each combination of fishing method and area). Sel-by-area was considered as an alternative base case, but the overall stock status differed little from the base that was chosen when BOP and HG stock status results were combined.

The one-stock models were constructed because of uncertainty about stock structure and fish movement between areas. Although it is clear that fish spawn in all three areas and move between areas (as assumed in the base model), the complexity of this structure and movement is unlikely to be well represented in the base model. For example, the proportion of fish migrating between areas in the relatively few years of the tag-recapture data may not be representative of what happened in other years. Also, the assumptions that (a) all fish were in their home area at the time of tagging, and (b) all recaptures occurred during the period that migrating fish were away from home, are likely to be only approximately true. The one-stock models offer an alternative, and much simpler, way of analysing the available data. Each of these models may be thought of as being constructed from the base model in the obvious way, by removing the stock and area structures (and the associated migrations), and also the observations and fisheries that were associated with other areas. The only complicated part in this construction concerned the tag release and recapture observations (for details see Francis & McKenzie 2015b).

Results of the sensitivity analyses are presented in terms of their effects on current status (Figure 17). Regardless of whether current status was measured by stock or by area, all models estimated the Bay of Plenty spawning biomass to be the most depleted, and most models estimated that the Hauraki Gulf was least depleted. The greatest sensitivity was shown with model sel-by-area, which estimated much less depletion for the Bay of Plenty (current biomass was 14% B_0, compared with 6–7% B_0 in the base model), and model re-weight, which estimated more depletion for the other areas. Estimates from sel-by-area were broadly similar to those from the one-stock models. Changes in both M and steepness had predictable effects (the same for all stocks and areas): lower values, which imply lower productivity, led to more depletion, and higher values to less depletion. Current status estimates were not very sensitive to alternative catch histories. Stock status was always slightly worse by stock than by area for Bay of Plenty, with the reverse being true for East Northland and Hauraki Gulf. Due to uncertainty about the relationship between BOP and HGU, stock status is also presented for the two stocks combined.

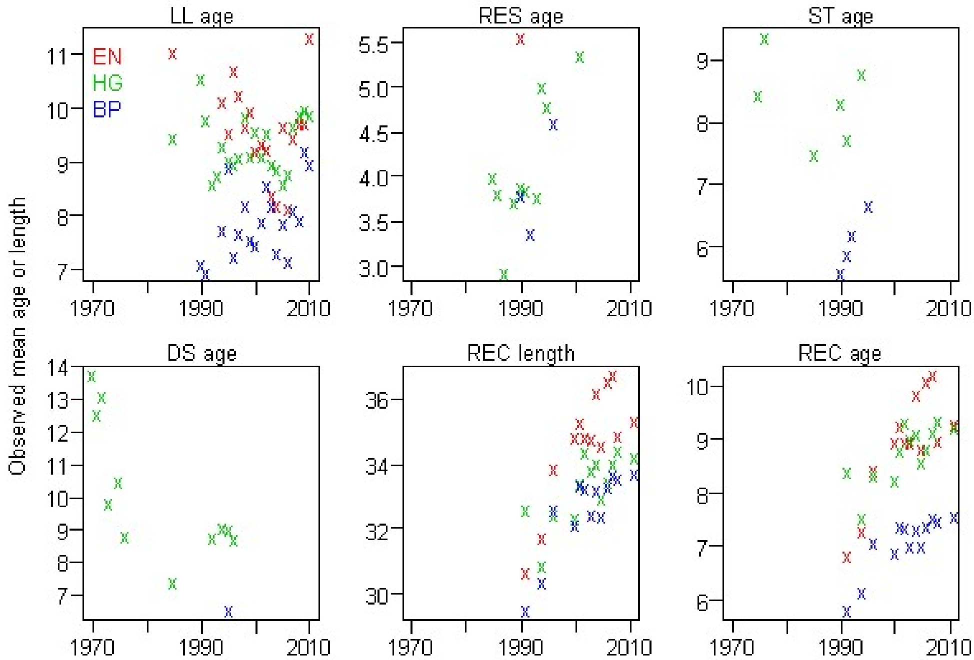


Figure 16: Observed mean age (for commercial fisheries and research surveys) or length (for recreational fisheries) by fishing method and area. In the bottom right-hand panel, the observed recreational mean lengths have been converted to ages using the mean length-at-age relationship (averaged over years 1994–2010) for each area.

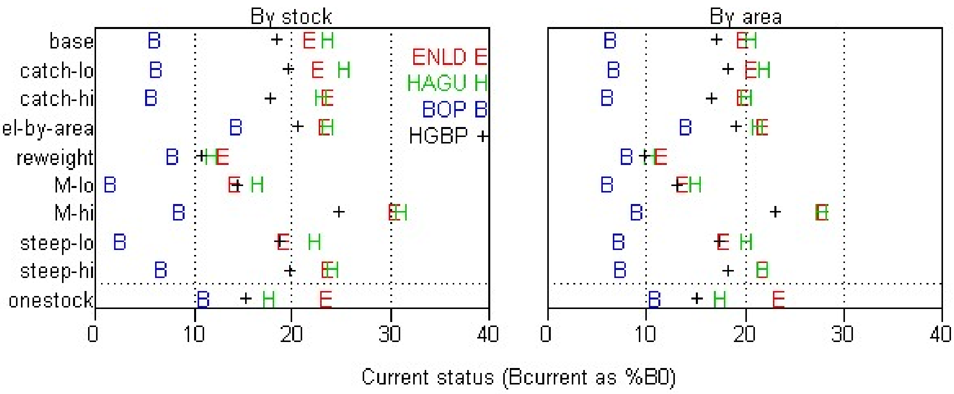


Figure 17: MPD estimates of current status (B_{2013} as % B_0), by stock and area, for the base model and some sensitivity analyses. The horizontal broken line separates the one-stock estimates from the others as a reminder that there is no distinction between spawning biomass by stock and by area for these models.

4.7 Yield estimates and projections

Five-year projections of the base case were carried out under 'status quo' conditions, which were taken to mean constant catches (equal to the 2012 and 2013 catches) for the commercial fisheries and constant exploitation rate (equal to the average of the 2008–2012 rates) for the recreational fisheries. In these projections, simulated year class strengths were resampled from the 10 most recent reliably estimated YCSs (deemed to be 1995–2004). The simulated YCSs included both the recent YCSs that were not estimated (due to the lack of recent age composition data) in the MPD (2008–2012) as well as the five 'future' YCSs (2013–2017).

With status quo catches the biomass is likely to continue to increase for all stocks and areas (Figure 18). These results changed only slightly when the future exploitation rate for the recreational fishery in HG was changed from 0.0779 (the average of the 2008–2012 rates) to 0.0648 (the average for 1995–2005) or 0.1089 (the rate for 2013). Projections from the one-stock and sel-by-area sensitivity models predicted increasing or near-stable biomass for all stocks and areas.

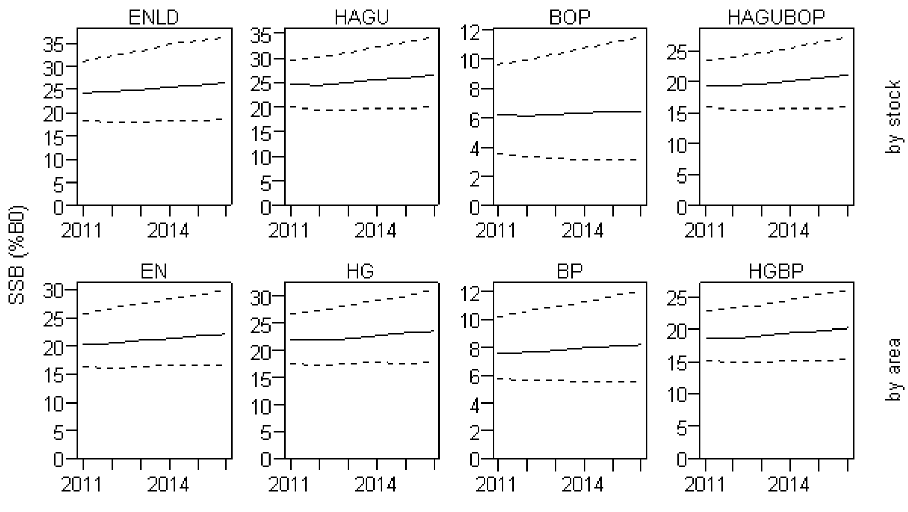


Figure 18: Projected spawning stock biomass (*SSB*) by stock and by area. Estimates are MCMC medians (solid lines) and 95% confidence intervals (broken lines).

Deterministic B_{MSY}

Deterministic B_{MSY} was calculated as 25–26% B_0 for all individual stocks and areas and 30% for the combined Hauraki Gulf/Bay of Plenty. There are several reasons why B_{MSY}, as calculated in this way, is not a suitable target for management of the SNA 1 fisheries. First, it assumes a harvest strategy that is unrealistic in that it involves perfect knowledge including perfect catch and biological information and perfect stock assessments (because current biomass must be known exactly in order to calculate target catch), a constant-exploitation management strategy with annual changes in TACs (which are unlikely to happen in New Zealand and not desirable for most stakeholders), and perfect management implementation of the TAC and catch splits with no under-runs or overruns. Second, it assumes perfect knowledge of the stock-recruit relationship, which is actually very poorly known. Third, it would be very difficult with such a low biomass target to avoid the biomass occasionally falling below 20% B_0, the default soft limit according to the Harvest Strategy Standard. Thus, the actual target needs to be above this theoretical optimum; but the extent to which it needs to be above has not been determined.

Results from the deterministic B_{MSY} calculations were used to determine the level of fishing that would maintain the spawning biomass at the interim target level of 40% B_0. This ranged from 19% to 59% of the 2013 level (Table 17).

Table 17: Estimated levels of fishing—expressed as multiples of 2013 exploitation rates—that would be required to maintain spawning biomass at 40% B_0.

	ENLD	HAGU	BOP	HAGUBOP
by stock	0.59	0.50	0.19	0.38
by area	0.55	0.46	0.21	0.38

4.8 Qualifying comments

1. Uncertainty associated with some of the tagging assumptions is not explicitly incorporated into the model. Examples include confidence intervals on trap shyness, the duration of the mixing period, and clumping of recaptures (for example, higher recovery rates in 1994 Danish seine Hauraki Gulf catches).
2. A lack of recent catch-at-age data means that recent relative year class strengths were not available for projections of stock size. SNA 1 is currently only sampled for catch-at-age every three years.

4.9 Preliminary 2022 model description and results

The above described 2013 assessment model was structurally updated in 2022 in line with future research recommendations documented in the 2013 Plenary chapter, and to accommodate new abundance and compositional data series available since 2013. The key differences between the 2013 and 2022 SNA 1 stock assessment models are as follows:

- Increase in the number of age classes specifically modelled (i.e., increase from 1–20+ to 1–30+ age classes).
- Fit all recreational compositional data as catch-at-age (fitted as catch-at-length in 2013 model).
- Estimation of specific area-method selectivities rather than assuming method selectivities are the same in all areas as per the 2013 model.
- Addition of separate post 2015 Modular Harvest System (MHS) fisheries in each area in recognition that the selectivity of these new fisheries likely differs from those of standard bottom trawl gear.
- Addition of post 2015 recreational fisheries in each area also in recognition that the post 2015 recreational harvest selectivities likely changed because of 2015 MLS and bag limit changes.
- Replacement of the 1900–2021 recreational catch histories with those derived pursuant to the ZINB methods as described in section 1.2.3 above.
- Inclusion of Bay of Plenty research trawl abundance and compositional model likelihoods.
- Fitting the Hauraki Gulf and Bay of Plenty research abundance data as five separate series, i.e., one series each for ages 1 to 4 and a 5+ amalgamated abundance series expressed as relative weight, not numbers.
- Dropping the Hauraki Gulf and Bay of Plenty longline CPUE abundance series from the final 'base' model, a change based on Fishing Industry anecdotal evidence that suggests longline fishing practices had changed over the 30-year series period, meaning these series were likely to be hyper-stable.
- Changing the relative weight of the tagging data to reflect the additional data added since 2013.

The basecase and various sensitivity MPD model runs did not predict that the East Northland stock and the Hauraki Gulf/Bay of Plenty stock complex was at or above the target 40% B_0 in 2020–21.

However, most MPD model sensitivity runs predicted the two SNA 1 stock regions as being above the 20% B_0 soft limit in 2020–21 and that abundance had increased since 2013.

The basecase model MCMC generated biomass posteriors were consistent with MPD model results, with a 100% probability that the spawning stock biomass for each of the two SNA 1 stock areas was greater than 20% B_0 but less than 40% B_0 in 2021. The basecase model median posterior biomass trajectories for both SNA 1 stock areas showed increasing trends in biomass between 2012–13 to 2020–21, a prediction consistent with anecdotal stakeholder experience.

4.9.1 Qualifying Comments

The 2022 May Plenary, although acknowledging the 2022 assessment model was an improvement over the 2013 model, deemed the 2022 base model was unsuitable for providing management advice due to unresolved data conflicts and poor model diagnostics. The Plenary made further model developmental recommendations to be undertaken prior to the 2022 November Plenary when the final SNA 1 assessment is due to be presented.

4.10 Future research considerations

- Investigate options for fisheries-independent abundance estimates, such as a new tagging study or fishery independent longline surveys in areas not amenable to trawl, e.g., East Northland. This is necessary because there is uncertainty in the relationship between standardised CPUE and abundance,
- Investigate the utility of longline CPUE as an index of abundance and include possible changes in selectivity, by comparing the series used for the stock assessment with alternative series modelled using finer-scale information collected since the introduction of new statutory forms (LCER) in 2007.
- Improve the understanding of stock boundaries and movement dynamics in East Northland, Bay of Plenty, the Hauraki Gulf, and SNA 2 before these areas may be reliably modelled as separate. A new tagging study is likely to be the best option for understanding SNA 1 stock structure and mixing.
- Evaluate the optimal frequency of catch-at-age monitoring. The current three-year cycle constitutes a two thirds reduction in the number of independent observations available for any given year class over annual sampling (i.e., is a loss of precision) and also may delay, by up to three years, our first awareness of extreme recruitment events. If both SNA 1 stock assessments and catch-at-age sampling are to be conducted on a three-year cycle, it is important that the assessment be timed for the year following the latest catch-at-age study. This would provide for more reliable projections. The WG recommended changing the frequency of catch sampling to be 2 consecutive years in every 5 instead of every 3rd year.
- Develop alternative bottom trawl and or recreational CPUE indices for East Northland.
- Investigate and correct for possible adult and/or juvenile snapper catchability changes in the Hauraki Gulf and Bay of Plenty trawl survey series. This study should include an investigation of environmental covariates and spatial expansion of the stock.
- Explore utility of the trawl survey as an index of abundance for adult and juvenile snapper.
- Further develop the recreational catch model, including models with all three areas combined and an area factor and testing the addition of interaction parameters.

Recommendations for the 2022 assessment

- Investigate alternative commercial catch histories with all catches coming from bottom trawl up to 1963.
- Investigate model sensitivity to the previous recreational harvest estimate history.
- Investigate the addition of incidental mortality.
- Compare estimates of biomass and movement obtained through stock assessment with those obtained externally (e.g., Petersen analysis).
- Investigate options to simplify the model structure:
  - Stand-alone ENLD model, BPLE / HAGU model, or three separate models;
  - Explore sensitivities with alternative movement hypotheses, including no movement;
  - Fix movement parameters (at estimated values or at externally derived estimates);
  - Fit to the tag abundance estimates rather than trying to fit the individual observations.

- Reinvestigate fitting the 5+ survey abundance series as numbers not weight.
- Explore alternative selectivity ogives for fitting the 5+ survey age composition data.
- Investigate estimating *q* as free parameters.
- Explore sensitivities to increasing U_{max} for BPLE to avoid catch penalties,
- Further investigate models starting in the 1970s in an exploited state.
- Further investigate model YCS estimation drivers, specifically, investigate the sensitivity of the YCS pattern estimated by the model including the survey data to different YCS assumptions (e.g., 3-look rule, bounding values on YCS, etc.).
- Further investigate alternative growth hypotheses, with models in particular expanding back and forward rather than using mean weight-at-age for those time periods (including predictions).

5. STATUS OF THE STOCKS

Stock Structure Assumptions

New Zealand snapper are thought to comprise either seven or eight biological stocks based on the location of spawning and nursery grounds, differences in growth rates, age structure, and recruitment strength, and the results of tagging studies. Three stocks are assumed in SNA 1 (East Northland, Hauraki Gulf, and Bay of Plenty), two in SNA 2 (one of which may be associated with the Bay of Plenty stock), two in SNA 7 (Marlborough Sounds and Tasman Bay/Golden Bay), and one in SNA 8. Tagging studies reveal that limited mixing occurs between the three SNA 1 biological stocks, with the greatest exchange between the Bay of Plenty and Hauraki Gulf.

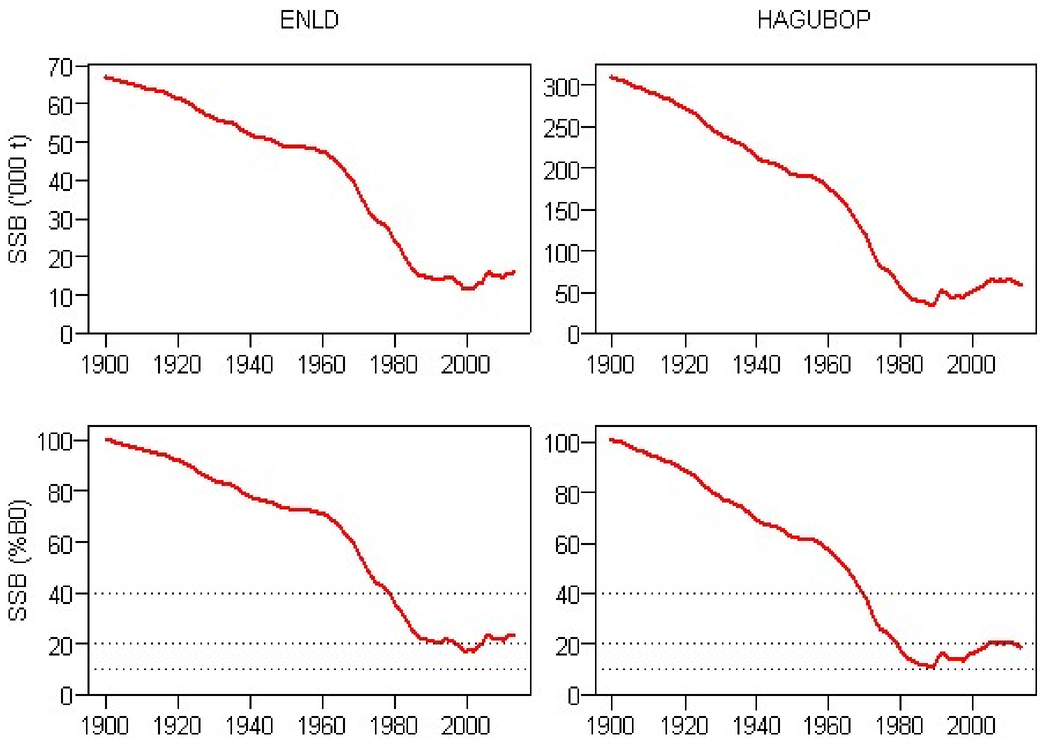
- **SNA 1**

Both the 2013 and 2022 assessments were based on three stocks: East Northland, Hauraki Gulf, and Bay of Plenty; however, assessment results for Hauraki Gulf and the Bay of Plenty are combined in the summaries below due to uncertainties about movement of the two stocks between the two areas.

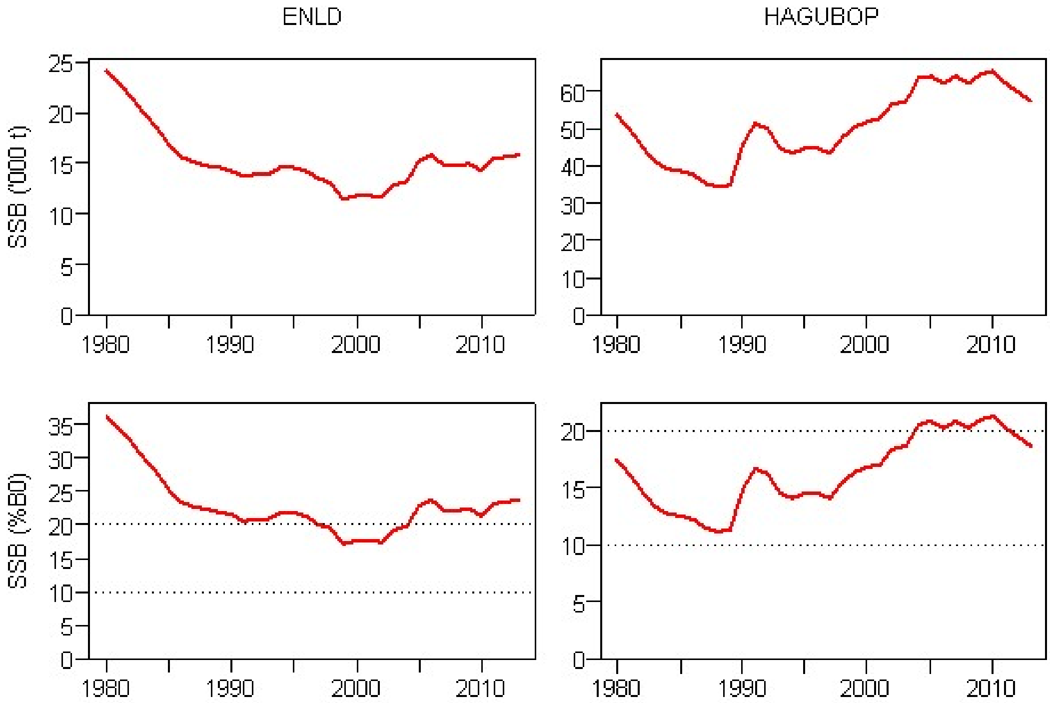
Stock Status	
Year of Most Recent Assessment	2013; Preliminary results 2022
Assessment Runs Presented	2013; Base case models for East Northland and the Hauraki Gulf and Bay of Plenty to 2013 2022: Preliminary base case to 2021
Reference Points	Interim target: 40% B_0 Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold: $U_{40\%B0}$
Status in relation to Target	East Northland B_{2013} was estimated to be 24% B_0; Very Unlikely (< 10%) to be at or above the target Preliminary estimate of B_{2021} may have slightly increased from B_{2013}: Very Unlikely (< 10%) to be at or above the target Hauraki Gulf + Bay of Plenty B_{2013} was estimated to be 19% B_0; Very Unlikely (< 10%) to be at or above the target Preliminary estimate of B_{2021} may have slightly increased from B_{2013}; Very Unlikely (< 10%) to be at or above the target
Status in relation to Limits	East Northland B_{2013} was About as Likely as Not (40–60%) to be below the soft limit

	B_{2013} was Very Unlikely (< 10%) to be below the hard limit Preliminary estimate of B_{2021} is Unknown in relation to the soft limit Preliminary estimate of B_{2021} is Very Unlikely (< 10%) to be below the hard limit <u>Hauraki Gulf + Bay of Plenty</u> B_{2013} was About as Likely as Not (40–60%) to be below the soft limit B_{2013} was Very Unlikely (< 10%) to be below the hard limit Preliminary estimate of B_{2021} is Unknown in relation to the soft limit Preliminary estimate of B_{2021} is Very Unlikely (< 10%) to be below the hard limit
Status in relation to Overfishing	<u>East Northland</u> 2013: Overfishing was Likely (> 60%) to be occurring 2022: Unknown <u>Hauraki Gulf+Bay of Plenty</u> 2013: Overfishing was Likely (> 60%) to be occurring 2022: Unknown

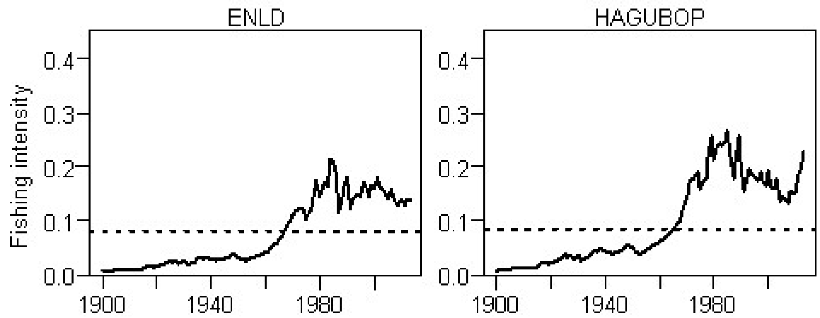
Historical Stock Status Trajectory and Current Status



MCMC base model *SSB* and status trajectories by stock (dotted lines indicate target (40% B_0), soft limit (20% B_0), and hard limit (10%B_0)).



MCMC base model *SSB* and status trajectories by stock, for the period since 1980 (dotted lines indicate soft limit (20% B_0) and hard limit (10% B_0)).

Fisheries and Stock Trends	
Recent Trend in Biomass or Proxy	<u>East Northland</u> 2013: Stock biomass was estimated to have experienced a long steep decline from about 1960 to 1985 and had fluctuated without trend since then. 2022: Stock biomass may have increased slightly since 2013. <u>Hauraki Gulf+Bay of Plenty</u> 2013: Stock biomass was estimated to have experienced a long steep decline from about 1960 to about 1988, after which it gradually increased to 2010 and then declined slightly. 2022: Stock biomass may have increased slightly since 2013.
Recent Trend in Fishing Intensity or Proxy	 <u>East Northland</u> 2013: The fishing intensity for this stock rose sharply from the early 1960s, reached a peak in the early 1980s, and then since declined slightly. 2022: Unknown <u>Hauraki Gulf + Bay of Plenty</u> 2013: The fishing intensity for this stock rose sharply from the early 1960s and

	reached a peak in the 1980s. It then declined by approximately 50% to 2007 but then increased to 86% of the 1985 peak. 2022: Unknown
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	-

Projections and Prognosis	
Stock Projections or Prognosis	N/A
Probability of Current Catch or TACC causing Biomass to remain below, or to decline below, Limits (5 years)	Unknown
Probability of Current Catch or TAC causing Overfishing to continue or to commence	Unknown

Assessment Methodology and Evaluation		
Assessment Type	Level 1 – Full Quantitative Stock Assessment	
Assessment Method	Spatially-disaggregated, 3-stock, age-structured, single-sex model undertaken in CASAL	
Assessment Dates	Latest assessment: 2013	Next assessment: November 2022
Overall assessment quality rank	1 - High Quality	
Main data inputs (rank)	- Proportions-at-age from the commercial fisheries and historic trawl surveys	1 – High Quality
	- Proportions-at-length from the recreational fishery	1 – High Quality
	- Estimates of biological parameters (e.g., growth, age-at-maturity, and length/weight)	1 – High Quality
	- Standardised longline CPUE indices	1 – High Quality
	- Standardised single trawl for the BoP	1 – High Quality
	- Estimates of recreational harvest	1 – High Quality
	- Commercial catch	1 – High Quality
	- Tag-based biomass estimates (BoP - 1983)	2 – Medium or Mixed Quality: data no longer available
	- Data from tagging experiments in 1985 (HG, EN) - Data from tagging in 1994 (all areas)	1 – High Quality 1 – High Quality
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	- Catch history extended back to 1900 and stocks assumed to be at B_0 in 1900 - Tag-recapture data sets condensed and reweighted	

Major Sources of Uncertainty	- Stock structure and degree of exchange between BoP and HG - Conflict between catch-at-age and tagging data - Relationship between standardised longline CPUE and abundance, because the methodology may not account for perceived changes in fishing behaviour - Temporal trends in growth rate

Qualifying Comments
Working Group and Plenary members had difficulty reaching consensus on the reliability of the 2013 assessment (with many of the issues remaining for the 2022 assessment). Some members felt the 2013 assessment was robust to uncertainties, whereas others were concerned that alternative assumptions could affect outcomes about stock status.

Fisheries Interactions
Main QMS bycatch species are trevally, red gurnard, John dory, and tarakihi. Incidental captures of sea turtles and seabirds occur in the bottom longline fisheries, including black petrel, which are ranked very high risk in the Seabird Risk Assessment (Richard et al 2020).

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