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A total catch history model for SNA 1

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1 EXECUTIVE SUMMARY

An alternative model of the SNA 1 stock to that used in recent years' stock assessments was developed. Instead of modelling the stock starting at the 1985 tag recapture estimate of stock size and age structure, the whole history of the fishery from 1850 was modelled. It was assumed that the underlying population parameters had been constant over the whole period. The catch history before 1931 was unknown and had to be assumed.

This alternative model gave results very close to the 1992 and 1994 assessments and did not show the extreme sensitivity to the 1983 to 1991 recruitment indices and to the catch per unit effort indices which lead to the uncertainty in the 1993 stock assessment. Several other sources of uncertainty were also examined.

The model proved to be remarkably insensitive to the level of catch before 1931. A very wide range of assumed catch was tested and found to have very little effect on the estimates. Lack of catch data for this period was shown to be unimportant in the modelling of this stock.

On the other hand, the model proved to be very sensitive to the recruitment assumptions. With recruitment varying according to temperature, and temperature fluctuating between decades, the stock estimates were considerably influenced by which historic period was chosen to correspond to "mean" recruitment. This is not a special weakness of this particular model, as the same problem is implicit in the assumption that the mean recruitment from 1985 to the present corresponds to "mean" recruitment in the 1992 to 1994 stock assessments. The difficulty is inherent in all stock assessments because we are essentially trying to make statements about future recruitment (sustainable yield) based on past recruitment.

2 INTRODUCTION

This paper describes an alternative model of the SNA 1 stock to that used in the 1992, 1993 and 1994 snapper stock assessments (Annala 1993, Annala 1994, Gilbert & Sullivan 1994). The norm in the modelling of New Zealand fish stocks has been to start at a virgin state and to model the whole catch history of the stock (Francis 1990, Francis & Robertson 1991). This has the advantage of reducing the number of parameters to be estimated, because the virgin stock biomass is at the same time a parameter and an initial condition. A virgin stock has conventionally been assumed to have been in equilibrium, so that a virgin stock biomass corresponds to a particular value of mean recruitment (the mean recruitment parameter). The conventional model also implicitly assumes that future mean recruitment (as modified by any stock recruitment relationship and any recruitment indices) will be the same as virgin mean recruitment.

The model used in the 1992 stock assessment did not model the stock from a virgin state. The history for SNA 1 is much longer than that for other New Zealand stocks, and catches in the 19th century were undoubtedly substantial. Not only has the catch during the early years not been recorded, but it is a strong assumption that underlying population parameters (natural mortality, growth, and mean recruitment) have remained stable over such a long period. Most of the Snapper Working Group members were not willing to accept this assumption.

The model described by Gilbert & Sullivan (1994) took a given initial condition (numbers at age) in 1985 and modelled the stock from that year onwards. It ignored the information contained in the landings before 1985 and the potential to obtain an annual recruitment index from the established relationship between recruitment and temperature for the period 1910 to 1984. More importantly, by using the information contained in the 1985 tag recapture data to obtain the initial numbers at age, it could not be used to estimate mean recruitment. Thus, the estimation of the mean recruitment parameter and hence the estimation of the virgin stock biomass was solely dependent on the commercial catch per unit effort (CPUE) relative biomass index. The estimate of mean recruitment proved to be highly sensitive to changes in the CPUE index and to changes in the temperature recruitment index (Annala 1993). This is undesirable from an estimation perspective.

Here I have used the more conventional approach, taking a starting point at 1850 and assuming that the stock was then in its virgin state. It was necessary to assume that the underlying population parameters remained constant throughout the period and to assume a time series of landings for the period before 1931, where there is no record of snapper landings. I assumed that recruitment was independent of stock size. Instead I have used the relationship between water temperature and recruitment established by Francis (1993).

3 MODEL ASSUMPTIONS AND DATA

3.1 Biological and fishery parameters

The biological and fishery parameters used in the model are the same as those used by Gilbert & Sullivan (1994) except that no method selectivity by age was assumed. Gilbert & Sullivan's model was extremely insensitive to selectivity by age (K.J. Sullivan pers. comm.). The parameters are given in Table 1.

3.2 Stock indices

The model was fitted to the 1985 tag recapture biomass estimate (53 369 t) and to a longline CPUE stock index calculated as the mean of the monthly median catch per hook by those longline vessels which had recorded catch in at least 50 months or in at least 8 years (Annala 1993). Virgin biomass and catchability (for the CPUE index) were estimated by the method of maximum likelihood described by Francis (1990) using the modification described by Francis *et al.* (1992: appendix 2). In this modification the stock biomass indices are assumed to be normally distributed with known coefficients of variation.

Table 1: Model parameters and relationships for SNA 1 from Gilbert & Sullivan (1994)

Parameter or process	**Estimate or formula**
Natural mortality (yr^{-1})	$M = 0.06$
Length-weight relationship (g, cm)	$w = 0.04467 \times l^{2.793}$
von Bertalanffy growth relationship (cm, yr)	$l = 58.8 \times (1 - e^{-0.102 \times (t + 1.11)})$
Age at recruitment, knife edge (yr)	4
Maximum age, 100% mortality assumed (yr)	50
Fishing and natural mortality occur concurrently	$C = \dfrac{F \times (1 - e^{-(F + M)}) \times B_{beg}}{F + M}$

There were two slight differences between this model and that of Gilbert & Sullivan (1994). The 1985 start of year biomass in this alternative model was not conditioned to be exactly equal to the tag recapture estimate, but was fitted to both this estimate and the CPUE indices, assuming a normal error structure with known coefficients of variation (0.10 for the 1985 biomass and 0.20 for each of the CPUE indices). The model did not include catch by method and assumed that each year a single fishing mortality rate applied to all age classes.

3.3 Catch

It is certain that combined annual catches of all species of several thousand tonnes were taken in the first decades of the century (Paul 1977), but official records of snapper catch do not begin until 1931. Maori exploitation of this stock undoubtedly goes back a considerable time, but at what level, is unknown. I have assumed that catch was negligible before 1850. Cumulative commercial plus non-commercial catch for the period 1851 to 1930 was assumed to follow a gradually increasing trend and to total 150 000 t. For the period 1931 to 1982, catch was based on port of landing. From 1983 onwards it was based on area of catch. Table 2 gives the calendar year catches from SNA 1 since 1931.

Table 2: Commercial catch (t) for SNA 1 by calendar year

Year	1931	1932	1933	1934	1935	1936	1937	1938	1939	1940
Catch	3464	3542	4060	4482	5603	6652	5980	6366	6180	5343
Year	1941	1942	1943	1944	1945	1946	1947	1948	1949	1950
Catch	5003	4278	4643	5108	4999	5381	5815	6744	5866	5107
Year	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960
Catch	4301	3795	3703	4315	4441	4743	5284	5153	5777	5696
Year	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970
Catch	5323	5583	5702	5643	6038	6428	6556	7333	8674	9791
Year	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
Catch	10 736	9574	9036	7635	5894	7217	7514	10 127	10 459	7369
Year	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Catch	7861	6266	6158	7094	6617	5969	4544	5126	5823	5719
Year	1991	1992	1993	1994	1995	1996				
Catch	5737	5741	4900†	4900†	4900†	4900†				

† assumed value = TACC

It was also assumed that the non-commercial catch was a known proportion of the commercial catch each year (Table 3), rather than the result of the constant fishing mortality by method and age class assumed by Gilbert & Sullivan (1994). The only available estimate of non-commercial catch is that obtained from the tagging experiment in 1985. The assumption by Gilbert & Sullivan that the non-commercial fishing mortality remained constant from 1985 onwards gave relatively stable non-commercial catches during a period of relatively stable stock biomass. If applied to the substantially larger stock biomasses estimated here at the early stages of the fishery, this fishing mortality would generate completely unbelievable non-commercial catches. Instead, it was assumed here that non-commercial catch was more or less constant since 1931. Smaller human population sizes and less sophisticated gear would have been balanced by the higher catch rates from a larger stock. The approximately constant catch was generated by applying arbitrary percentages to the commercial catch data.

Table 3: Assumed non-commercial catch (t) for SNA 1 by calendar year (1985 is based on the tag recapture experiment). Non-commercial catches before 1931 were assumed to be 25% of commercial catches

Year	1931	1932	1933	1934	1935	1936	1937	1938	1939	1940
% of commercial	25	25	25	25	25	25	25	25	25	25
Catch	866	885	1015	1120	1401	1663	1495	1591	1545	1336
Year	1941	1942	1943	1944	1945	1946	1947	1948	1949	1950
% of commercial	25	25	25	25	25	25	25	25	25	25
Catch	1251	1069	1161	1277	1250	1345	1454	1686	1466	1277
Year	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960
% of commercial	25	25	25	25	25	25	25	25	25	25
Catch	1075	949	926	1079	1110	1186	1321	1288	1444	1424
Year	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970
% of commercial	21	21	21	21	21	21	21	16	14	12
Catch	1118	1172	1197	1185	1268	1350	1377	1173	1214	1175
Year	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
% of commercial	12	13	14	16	21	21	17	12	12	18
Catch	1288	1245	1265	1222	1238	1516	1277	1215	1255	1326
Year	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
% of commercial	16	21	21	21	21	23	31	27	23	23
Catch	1258	1316	1293	1490	1390	1373	1409	1384	1339	1315
Year	1991	1992	1993	1994	1995	1996				
% of commercial	23	23	28	28	28	28				
Catch	1319	1320	1372	1372	1372	1372				

3.4 Recruitment

The relationship between water temperature and recruitment given by Gilbert & Sullivan (1994) was based on work by Francis (1993). M.P. Francis (MAF Fisheries, pers. comm.) has updated the analysis on which this was based (with another year's data) and derived an equivalent relationship,

$$\ln(\mathbf{R}) = -23.663 + 1.333\mathbf{w} \qquad (1)$$

where **R** is the number of 1-year-olds and **w** is the mean February to June sea surface temperature measured at Leigh. The coefficient of determination, R^2, for this regression was 0.75.

Water temperature data were not available before 1967, so to extend the time series of recruitment indices back to 1910, air temperature in Auckland was used. The correlation coefficient between water and air temperature at a 1 month lag is 0.95. The following relationship was obtained by linear regression over the period 1967 to 1992,

$$\mathbf{w} = 0.6496 + 0.9857\mathbf{a} \qquad (2)$$

where **a** is the mean January to May Auckland air temperature (Albert Park and Owairaka Meteorological Stations). The coefficient of determination, R^2, for this regression was 0.81. Snapper recruit to the stock at age 4, on average, and it is assumed that the number of fish surviving to age 4 is proportional to the number at age 1. Recruitment indices (Table 4) were therefore obtained by substituting equation 2 into equation 1.

Annual recruitment is obtained in the model by multiplying the mean recruitment parameter by the index for the year. An index value of 1.0 for a year thus implies mean recruitment for that year. The indices have been scaled so that their mean is 1.0 for the period 1931 to 1991. The baseline estimates are thus based on the assumption that the mean recruitment corresponding to the 1850 virgin stock and that the **future** mean recruitment are both equal to the mean recruitment for 1931 to 1991. Between 1851 and 1909 a constant mean index of one was assumed, i.e., mean recruitment for this period. These assumptions are not secure, because there was considerable variation in temperature between decades. For example the mean recruitment index between 1910 and 1930 was only 0.40.

For the years 1983 to 1989 and 1991, the observed indices were used instead of the predicted indices, as in Annala (1993). These were scaled so that their mean equalled that of the predicted indices for these years (apart from a small error). These observed values are also given in Table 4.

4 BASELINE RESULTS

Estimates under the baseline assumptions are given in Table 5. The trajectory of the modelled stock biomass is shown in Figure 1, together with the tag recapture and CPUE stock indices. The estimate of mean recruitment ($\mathbf{R_0}$) was 10.1 million 4-year-olds. This corresponds to a virgin stock biomass of 323 000 t. The 1994 biomass was estimated to be 52 000 t. The annual yield that would maintain the stock in equilibrium at this biomass (assuming mean recruitment) is called the current surplus production (**CSP**) and was estimated to be 7300 t. Maximum sustainable yield (**MSY**), the maximum **CSP**, was estimated to occur at a stock biomass of 84 000 t and to be 7600 t.

Table 4: Predicted recruitment indices for SNA 1 based on Leigh water temperature (1967 to 1992) and Auckland air temperature (1910 to 1966) and observed indices (1983 to 1989 and 1991)

											Decade mean
Year	1910	1911	1912	1913	1914	1915	1916	1917	1918	1919	
Predicted index	0.80	0.63	0.06	0.07	0.18	0.09	0.76	0.36	0.51	0.08	0.35
Year	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	
Predicted index	0.11	0.12	0.37	0.09	1.38	0.20	0.16	0.21	1.28	0.45	0.44
Year	1930	1931	1932	1933	1934	1935	1936	1937	1938	1939	
Predicted index	0.13	0.09	0.23	0.74	0.15	1.31	0.19	0.13	6.53	0.17	0.97
Year	1940	1941	1942	1943	1944	1945	1946	1947	1948	1949	
Predicted index	0.08	0.40	0.25	0.25	0.50	0.14	0.61	0.17	0.66	0.15	0.32
Year	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	
Predicted index	0.61	0.45	0.29	0.34	0.82	3.05	2.16	1.54	0.61	0.36	1.02
Year	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	
Predicted index	0.41	0.34	2.11	0.51	0.26	0.29	0.82	0.54	0.67	0.21	0.61
Year	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	
Predicted index	2.54	3.41	0.75	1.53	3.90	1.21	0.41	0.59	2.48	0.97	1.78
Year	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	
Predicted index	0.39	3.69	0.73	0.14	0.59	1.12	1.55	0.39	0.81	2.19	1.16
Year	1990	1991	1992	1993							
Predicted index	1.59	0.45	0.16	0.29							
Year	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	
Observed index	-	-	-	0.11	0.55	0.69	0.83	0.26	1.11	3.04	
Year	1990	1991	1992	1993							
Observed index	-	1.07	-	-							

5 SENSITIVITY ANALYSES

Several sources of uncertainty were examined by varying parameters or input data (each separately) from those applied in the baseline case. The ranges of values of parameters and the variations to the input data assumed for sensitivity testing, in my opinion, probably cover the true values. Results for the various sources of uncertainty, shown in Tables 5 to 10, are dealt with from least to greatest sensitivity. The baseline estimates are given in each set for comparison. An ad hoc sensitivity indicator has been calculated for each model estimate to indicate the degree to which the estimate is sensitive to the particular source of uncertainty. This is defined as the maximum value minus the minimum value divided by the baseline value, expressed as a percentage.

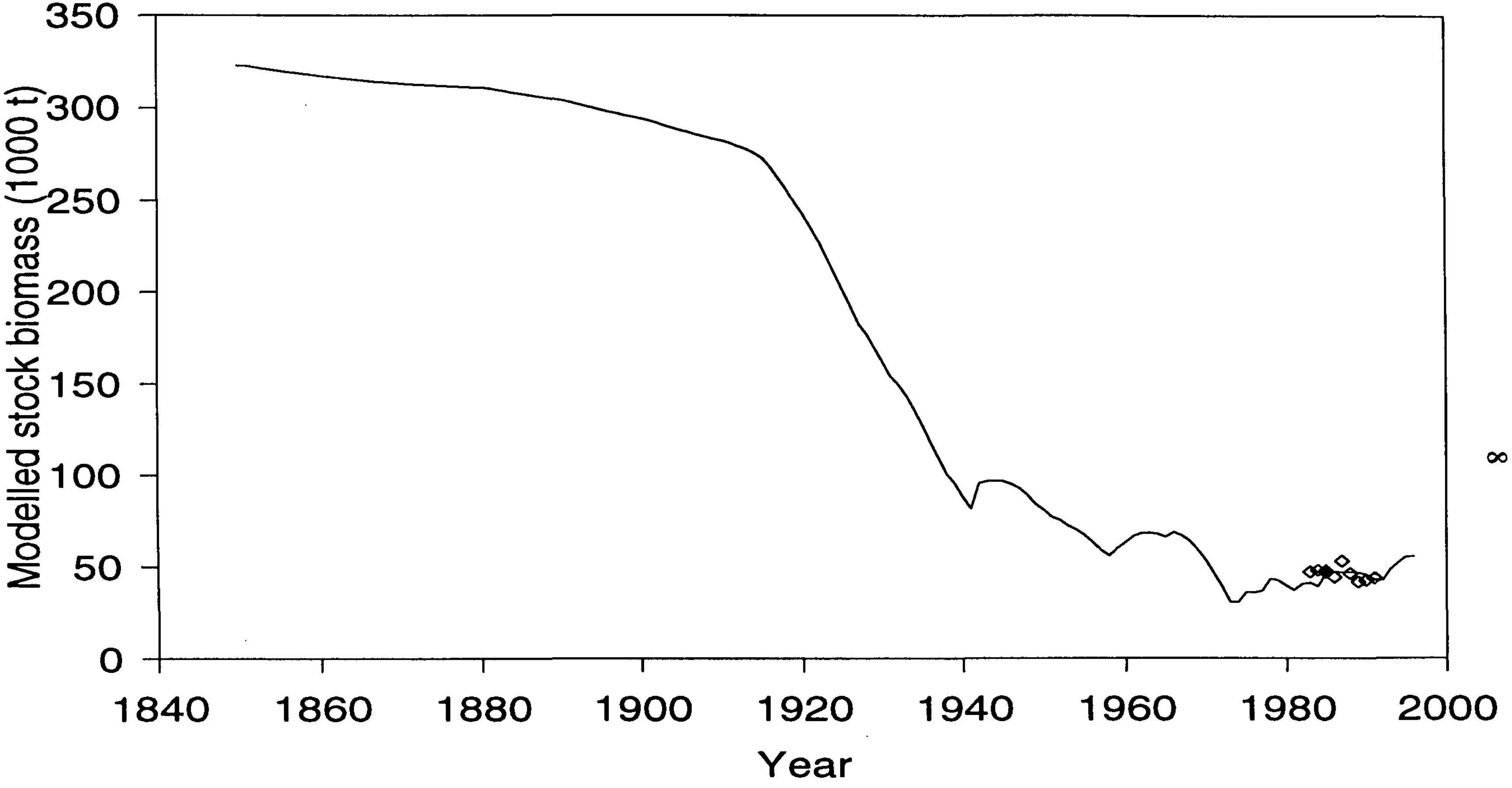

Figure 1: The modelled trajectory of the SNA 1 stock biomass starting from an assumed virgin stock size in 1850 and fitted to absolute tag recapture estimate (♦) and relative CPUE indices (◊) (baseline case). Jumps in the trajectory correspond to exceptionally strong year classes.

The following estimates are tabulated. $\mathbf{R_0}$ is the mean annual number of 4-year-old recruits. $\mathbf{B_0}$ is the mean virgin stock biomass, $\mathbf{B_{MSY}}$ is the stock biomass at which the **MSY** occurs, $\mathbf{B_{94}}$ is the predicted mid-year biomass for 1994. **CSP@**$\mathbf{B_{94}}$ is the equilibrium surplus production assuming mean recruitment when mid-year biomass equals $\mathbf{B_{94}}$. Actual surplus production depends on the age structure of the population in 1994 and on recruitment, and has not been tabulated. In all scenarios, actual surplus production is close to, or exceeds, **CSP@**$\mathbf{B_{94}}$, when this is calculated assuming mean recruitment (values are not tabulated here). $\mathbf{C_{94}}$**/CSP@**$\mathbf{B_{94}}$ is the ratio of the predicted 1994 catch (TACC, 4900 t, plus assumed non-commercial catch, 1372 t) to **CSP@**$\mathbf{B_{94}}$. **MSY Comm + NC** are the commercial and non-commercial catches at the maximum sustainable yield. The commercial catch is what remains from the **MSY** after an assumed non-commercial catch has been deducted. This non-commercial catch is calculated differently from the historical non-commercial catch. It is assumed to be a constant proportion of the stock biomass (3.0%).

5.1 CPUE stock indices

The model estimates are almost completely insensitive to the CPUE stock index decline (*see* Table 5). This is primarily because the tag recapture estimate of stock biomass is an absolute index whereas the CPUE indices are relative indices. The CPUE indices also have a higher coefficient of variation. The insensitivity to the CPUE indices here contrasts sharply with the results of Annala (1993) where $\mathbf{R_0}$ is highly sensitive to these indices.

Table 5: Sensitivity of SNA 1 model results to the decline in the CPUE stock index between 1983-84 and 1991-92. *See* p. 9 for definition of terms

Model estimates

	CPUE stock index decline	$\mathbf{R_0}$	$\mathbf{B_0}$	$\mathbf{B_{MSY}}$	$\mathbf{B_{94}}$	$\mathbf{\frac{B_{94}}{B_{MSY}}}$	**CSP@**$\mathbf{B_{94}}$	$\mathbf{\frac{C_{94}}{CSP@B_{94}}}$	**MSY Comm +**	**NC**
	%	10^6	kt	kt	kt	%	kt	%	kt	kt
	0	10.2	323	84	53	63	7.3	86	5.1	+ 2.5
Baseline:	**7**	**10.1**	**323**	**84**	**52**	**62**	**7.3**	**86**	**5.1**	**+ 2.5**
	14	10.1	323	84	51	61	7.3	86	5.1	+ 2.5
Sensitivity indicator (%)		1	0	0	3	3	0	0	0	0

5.2 Historical catch (1851 - 1930)

The most surprising result from this analysis is the insensitivity of the estimates to the aggregate historical catch between 1851 and 1930. For aggregate values between 51 000 t and 364 000 t (*see* Figure 2) the estimates change by only a few percent (*see* Table 6). It is an important result that accurate knowledge of historical catch in the distant past is not always necessary to the modelling of a stock.

Table 6: Sensitivity of SNA 1 model results to the aggregate commercial plus non-commercial historical catch for the period 1851 to 1930. *See* text for definition of terms

Model estimates

Aggregate catch (1851-1930)	R_0	B_0	B_{MSY}	B_{94}	$\frac{B_{94}}{B_{MSY}}$	CSP@B_{94}	$\frac{C_{94}}{CSP@B_{94}}$	MSY Comm +	NC
kt	10^6	kt	kt	kt	%	kt	%	kt	kt
51	9.8	316	82	51	62	7.1	88	5.0	+ 2.5
Baseline: 150	**10.1**	**323**	**84**	**52**	**62**	**7.3**	**86**	**5.1**	**+ 2.5**
364	10.5	336	87	55	63	7.6	83	5.3	+ 2.6
Sensitivity indicator (%)	6	6	6	8	2	6	6	6	6

5.3 Non-commercial catch

The model estimates are not sensitive to the level of non-commercial catch (except for the estimate of non-commercial catch at MSY) (*see* Table 7). An increase in the level of non-commercial catch results in a reduction in the commercial catch at MSY. There is a partially compensating effect in that MSY increases slightly.

Table 7: Sensitivity of SNA 1 model results to the level of non-commercial catch. *See* p. 9 for definition of terms

Model estimates

Non-commercial catch (% of baseline)	R_0	B_0	B_{MSY}	B_{94}	$\frac{B_{94}}{B_{MSY}}$	CSP@B_{94}	$\frac{C_{94}}{CSP@B_{94}}$	MSY Comm +	NC
	10^6	kt	kt	kt	%	kt	%	kt	kt
80	9.8	312	81	53	66	7.1	84	5.4	+ 2.0
Baseline: 100	**10.1**	**323**	**84**	**52**	**62**	**7.3**	**86**	**5.1**	**+ 2.5**
120	10.5	326	88	51	58	7.4	88	4.7	+ 3.1
Sensitivity indicator (%)	7	4	8	5	13	5	5	13	47

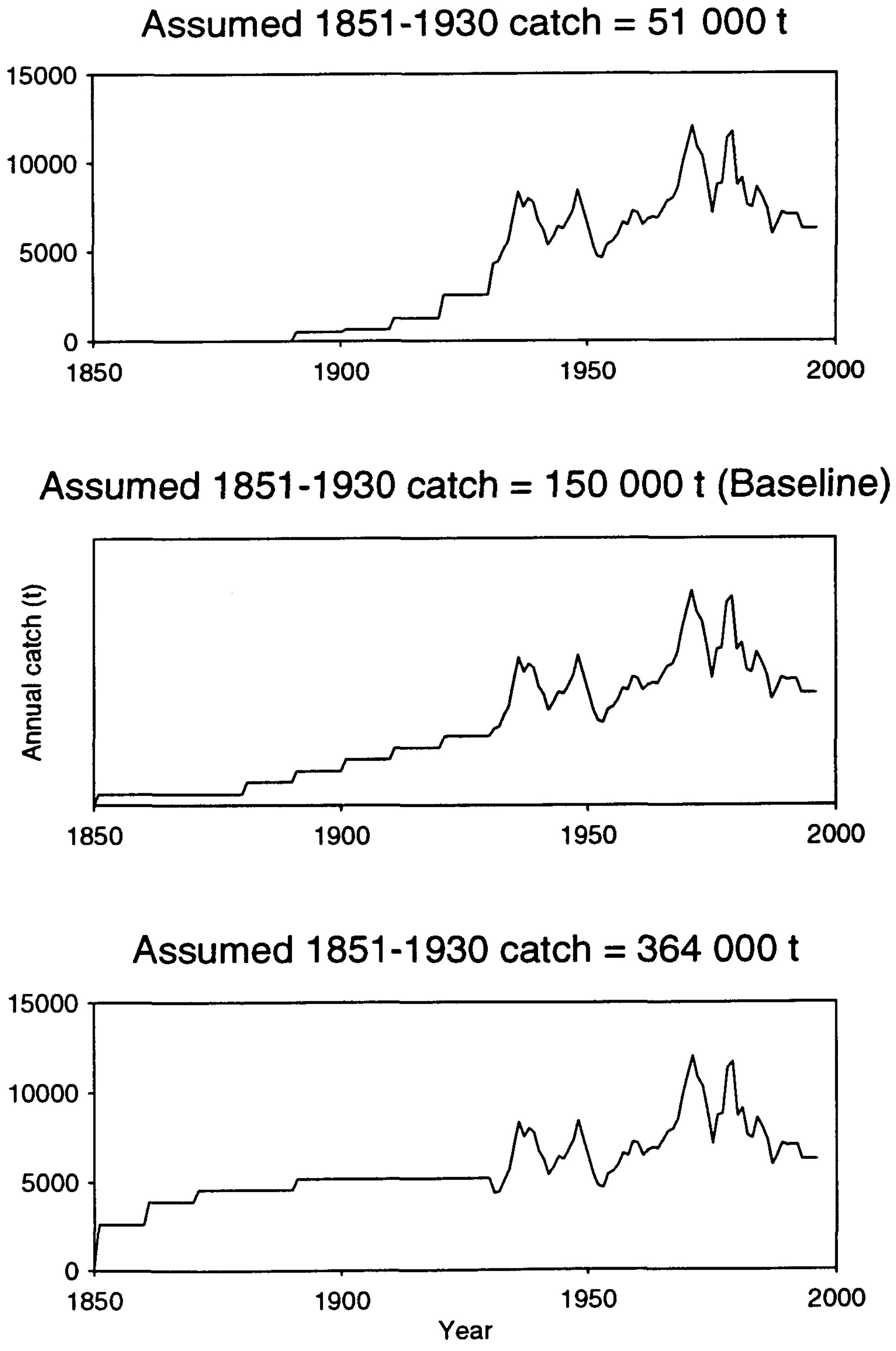

Figure 2: The time series of annual catches used in the sensitivity analysis of the SNA 1 stock model. Three different time series of catch are assumed for the period 1851 to 1930.

5.4 Tag recapture estimate of 1985 biomass

Error in the 1985 tag recapture estimate of stock biomass has a slight effect on the estimated present level of surplus production, but almost no effect on the estimate of MSY (*see* Table 8). Its main effect is, not surprisingly, on the estimate of present stock biomass. A lower 1985 biomass estimate would mean that the stock was further away from its optimum size.

Table 8: Sensitivity of SNA 1 model results to the tag recapture estimate of biomass (1985). A 20% variation around the baseline is assumed. *See* p. 9 for definition of terms

Model estimates

1985 estimate of biomass	**R_0**	**B_0**	**B_{MSY}**	**B_{94}**	**$\frac{B_{94}}{B_{MSY}}$**	**CSP@B_{94}**	**$\frac{C_{94}}{CSP@B_{94}}$**	**MSY Comm +**	**NC**
kt	10^6	kt	kt	kt	%	kt	%	kt	kt
43	10.1	320	83	37	44	6.8	93	5.0	+ 2.5
Baseline: 53	**10.1**	**323**	**84**	**52**	**62**	**7.3**	**86**	**5.1**	**+ 2.5**
64	10.3	326	86	68	79	7.6	83	5.1	+ 2.6
Sensitivity indicator (%)	2	2	4	59	56	11	12	2	2

5.5 Natural mortality rate

The effects of uncertainty in the natural mortality rate are considerable (*see* Table 9). A higher natural mortality rate would mean that the stock was more productive, but that the virgin stock (and therefore B_{MSY}) was smaller. These effects would balance to produce an almost unchanged MSY, although the allocation between non-commercial and commercial would change. A higher natural mortality rate would mean that the present stock size was closer to B_{MSY} and that the commercial catch would be a greater proportion of the MSY in a rebuilt stock.

Table 9: Sensitivity of SNA 1 model results to natural mortality rate. *See* p. 9 for definition of terms

Model estimates

Natural mortality rate	**R_0**	**B_0**	**B_{MSY}**	**B_{94}**	**$\frac{B_{94}}{B_{MSY}}$**	**CSP@B_{94}**	**$\frac{C_{94}}{CSP@B_{94}}$**	**MSY Comm +**	**NC**
y^{-1}	10^6	kt	kt	kt	%	kt	%	kt	kt
0.05	8.9	348	93	49	53	7.0	90	4.7	+ 2.8
Baseline: 0.06	**10.1**	**323**	**84**	**52**	**62**	**7.3**	**86**	**5.1**	**+ 2.5**
0.08	12.6	279	68	57	84	7.7	81	5.7	+ 2.0
Sensitivity indicator (%)	37	21	30	15	50	11	10	21	30

5.6 Recruitment

Uncertainty in the relative recruitment index time series has a large effect on all the estimates and is the most important source of uncertainty in the model (*see* Table 10). The recruitment index time series used in the baseline case shows a general upward trend between 1910 and 1993 (*see* Figure 3 and the decade means in Table 4), corresponding to the upward trend in the temperatures over this period. The relationship between year class strength and temperature was established for the years 1983 to 1989 and 1991. The assumption made here is that the same relationship has applied since 1910 and that recruitment varied around the mean with no trend in the century before that. It would be difficult to establish that this pattern of recruitment was true. There is also uncertainty as to what period should be taken to represent mean recruitment. If the period 1910 to 1991 were taken to correspond to the mean, then the mean of the index over this period would be scaled to 1.0 and the estimates of virgin biomass, current surplus production, and MSY would all be lower. If the period 1967 to 1991 were taken as corresponding to the mean, then all these estimates would be substantially higher. Other assumptions, not modelled here, have the 1850 stock or the period 1850 to 1910 corresponding to values different from mean recruitment.

Table 10: Sensitivity of SNA 1 model to the recruitment index. The recruitment assumption labelled "Constant" means that recruitment equals the mean recruitment parameter, R_0, in all years, "Mean 1910-91" means that Francis' (1993) recruitment index (*see* text) is scaled so that R_0 corresponds to the period 1910-91, "Baseline" means that Francis' recruitment index is scaled so that R_0 corresponds to the period 1931-91, "1981 reduced" means that the baseline recruitment index is used except that the 1981 recruitment index is reduced from 3.69 to 1.5, "1983-91 predicted" means that the baseline recruitment index is used except that the 1983-91 recruitment indices (observed values) are replaced by the Francis' predicted values, "Mean 1967-91" means that Francis' recruitment index is scaled so that R_0 corresponds to the period 1967-91. *See* p. 9 for definition of other terms

Model estimates

Recruitment	R_0	B_0	B_{MSY}	B_{94}	$\frac{B_{94}}{B_{MSY}}$	CSP@B_{94}	$\frac{C_{94}}{CSP@B_{94}}$	**MSY** **Comm +**	**NC**
	10^6	kt	kt	kt	%	kt	%	kt	kt
Constant	8.5	271	71	38	54	6.0	105	4.3 +	2.1
Mean 1910-91	8.7	278	73	54	74	6.4	98	4.4 +	2.2
Baseline	**10.1**	**323**	**84**	**52**	**62**	**7.3**	**86**	**5.1 +**	**2.5**
1981 reduced	10.2	326	86	46	54	7.2	87	5.1 +	2.6
1983-91 predicted	10.1	323	85	56	66	7.4	85	5.1 +	2.5
Mean 1967-91	13.0	415	108	50	46	8.8	71	6.5 +	3.3
Sensitivity indicator (%)	45	45	44	34	45	40	40	45	45

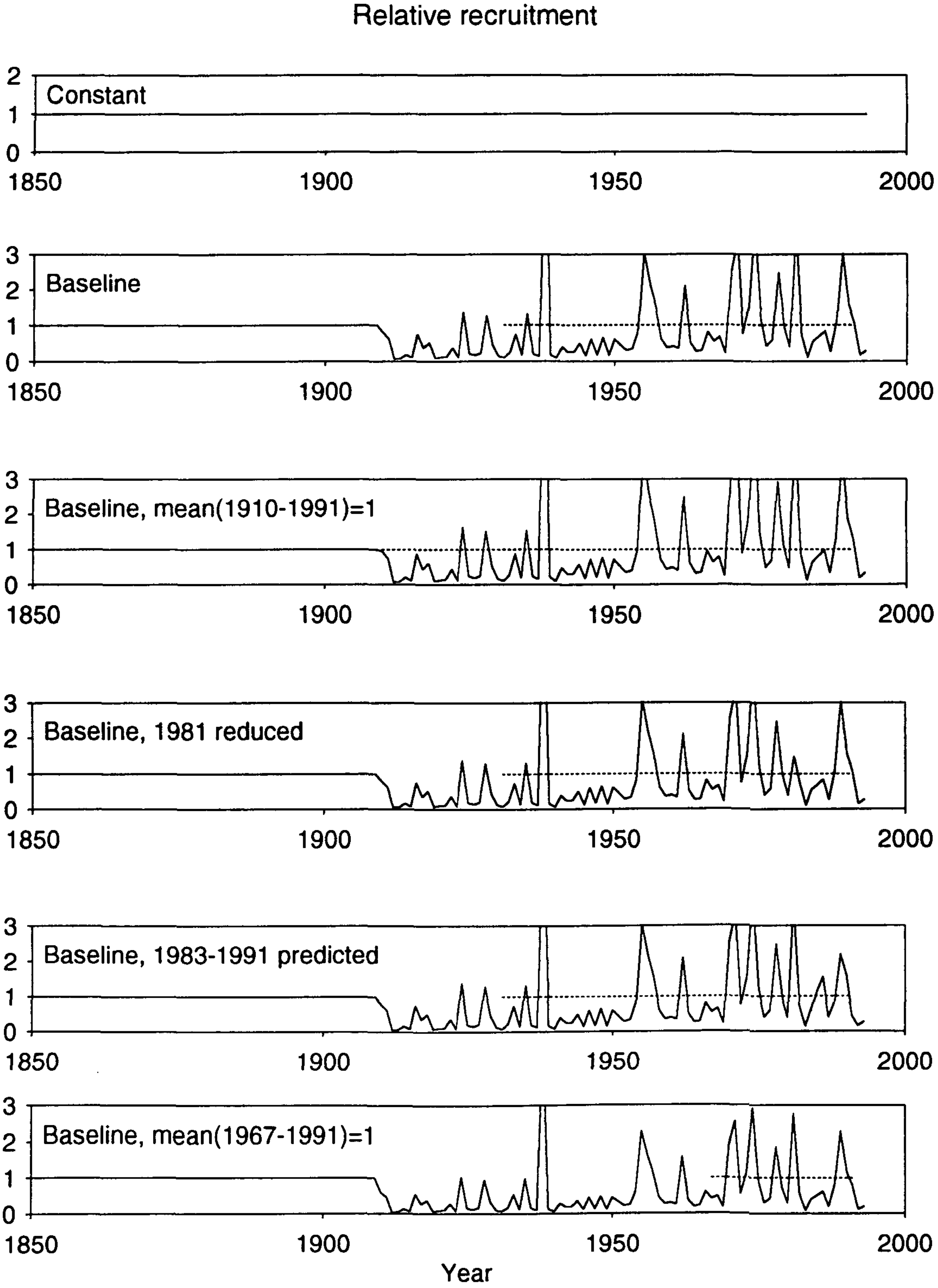

Figure 3: The alternative relative recruitment indices assumed for the sensitivity analysis of the SNA 1 model. The period assumed to correspond to mean recruitment is marked by the dashed line. *See* caption to Table 10 for an explanation of the 6 alternative assumptions.

6 CONCLUSIONS

The approach described here, which involved modelling the history of the fishery from 1850, gave results very similar to the 1992 and 1994 stock assessments. It did not exhibit the extreme sensitivity to the 1983 to 1991 recruitment indices and to the catch per unit effort indices which lead to the uncertainty in the 1993 stock assessment. The results given here add weight to the 1992 and 1994 assessments.

Several overall observations can be drawn from these results. Over the scenarios modelled, $\mathbf{R_0}$ is estimated to be between 8.5 and 13.0 million (virgin biomass 271 000 t to 415 000 t). This range is similar to that assumed in Annala (1993), 8.5 to 14.0 million. $\mathbf{B_{94}/B_{MSY}}$ is estimated to be between 44% and 84%. There is therefore considerable confidence that the 1994 stock biomass is well below $\mathbf{B_{MSY}}$. The **MSY** exceeds $\mathbf{C_{94}}$ under all scenarios, although if stock biomass reached equilibrium at **BMSY**, the increase in yield would, in some cases, be small. Because of the proportional way the non-commercial catch is modelled, an increase in the stock biomass from $\mathbf{B_{94}}$ to $\mathbf{B_{MSY}}$ may cause an increase in the non-commercial catch which exceeds the increased production. It is therefore possible that an increase in stock biomass to $\mathbf{B_{MSY}}$ may cause a reduction in commercial catch. Whether this modelling assumption is true is arguable.

In all scenarios, actual surplus production is close to, or exceeds, $\mathbf{CSP@B_{94}}$ when this is calculated assuming mean recruitment. $\mathbf{C_{94}/CSP@B_{94}}$ lies between 71% and 105%. This means that under almost all scenarios the present TACC (4900 t) would lead to an increase in stock size over time.

In view of the lesser sensitivity of the total catch history model to CPUE and recent recruitment data, I believe that this approach is preferable to the approach accepted by the Snapper Working Group in which the stock was modelled over a short time period starting from an estimated initial state. The approach described here is the conventional one used for most New Zealand fish stocks, except that here recruitment is not assumed to be dependent on stock biomass.

The sensitivity of the model to several sources of uncertainty was examined. The model proved to be remarkably insensitive to the level of catch before 1931. A very wide range of assumed catch was tested and found to have very little effect on the estimates. Lack of catch data for this period is therefore unimportant in the modelling of this stock. The circumstances under which this lack of sensitivity to catch data would hold have not been established here. I hypothesise that two factors are important. One is that the stock biomass was fitted to an **absolute** estimate in the recent past. This strongly constrains the model. The second is that the catches to which the model is not sensitive occurred sufficiently far in the past that, had these particular fish not been caught, they would have mostly died naturally before the date of the first stock biomass index. Further work is required to prove this hypothesis.

The model proved to be rather sensitive to the natural mortality rate. This is hardly surprising as productivity is closely related to natural mortality. Some compensation occurs in the model fitting in that at higher natural mortality the estimates of stock biomass tend to be lower.

The model proved to be very sensitive to the recruitment assumptions. With recruitment varying according to temperature, and temperature fluctuating between decades, the estimates are considerably influenced by the choice of **which** historic period is to be used to obtain the mean recruitment parameter. One approach would be to use the longest available time series of recruitment. This assumes a long term stability. Another approach would be to assume that future recruitment would be best estimated by the mean of the most recent few years. Under this assumption the mean recruitment corresponding to the initial ("virgin") stock would not necessarily equal mean recruitment in the near future.

The difficulty in estimating the mean recruitment parameter is inherent in modelling for stock assessment purposes because we are essentially trying to make statements about future recruitment (sustainable yield) based on past recruitment. Future recruitment is dependent on unpredictable exogenous variables. Therefore there will always remain an irreducible uncertainty in the estimates important to stock assessment.

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