New Zealand Fisheries Assessment Research Document 99/34

Assessment of the NSN and NSS stocks of red rock lobster (*Jasus edwardsii*) for 1998

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This series documents the scientific basis for stock assessments and fisheries management advice in New Zealand. It addresses the issues of the day in the current legislative context and in the time frames required. The documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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1. Executive summary

A new size-based model for assessing New Zealand rock lobster stocks is described, evaluated, and applied to two of the existing New Zealand rock lobster stocks: Northland/Bay of Plenty (NSN) and Otago/Stewart Island/Fiordland (NSS). The results for the NSN stock indicate that it is well above the B_{MSY} reference point and that MSY is likely to be larger than the current removals. The current observed increase in CPUE is thought to be a product of higher than average recruitment in the mid to late 1980s. The results for the NSS stock assessment indicate that this stock is well below the B_{MSY} reference point and that MSY is larger than the current removals. The failure of the stock to respond to substantial cuts in total removals since 1990 is thought to be due to lower than average recruitment in recent years. Although the size-based model introduced for this assessment differs from the previous age-based models in a number of aspects, the results obtained are largely consistent with the results from previous assessments.

2. Introduction

The New Zealand rock lobster fishery is its most valuable inshore fishery. The red rock lobster (*Jasus edwardsii*) makes up most of the catch, although small amounts of packhorse lobster (*Jasus verreauxi*) are taken in the north of the North Island. Most of the catch is taken by commercial potting, although recreational diving activities are significant in some areas.

Before 1990, the fishery was primarily managed by “input control” methods. These included setting minimum legal size limits, recreational bag limits, prohibitions on the taking of ovigerous females and soft-shelled lobsters, and some local area closures. In 1990, the fishery was brought into the Quota Management System which uses maximum allowable catch levels as “output controls”. However, the “input control” regulations were kept as well. Ten Quota Management Areas (QMAs), each with a separate Total Allowable Commercial Catch (TACC), were put in place in 1990.

The Fisheries Act 1996 requires that fish stocks be maintained at or above B_{MSY}, the biomass that will maintain the maximum sustainable yield. To achieve this target, TACCs are adjusted where necessary by the Minister of Fisheries based on advice from the Ministry of Fisheries. The Ministry bases its advice on the results of stock assessments. This report describes the assessment of two NSI substocks carried out in 1998 by the Science Group of the New Zealand Seafood Industry Council.

3. Description of the assessment model

A sex- and size-structured model of the New Zealand rock lobster fishery was developed. Much of the model structure and dynamics are based on a similar model for the rock lobster fishery in Tasmania (Punt & Kennedy 1998). For each sex the number of individuals in each tail width size class is updated each year according to natural and fishing mortality, growth, and recruitment. Size-specific vulnerabilities and weights are used to calculate exploitation rates from catch data and to apply these to individual size classes.

The model is constrained to match the existing catch history and conforms to the existing minimum legal size limits by discarding (with accompanying handling mortality) those lobster which are smaller than the size limit. The model has a number of parameters that can be estimated, including average recruitment over the period of simulation, annual relative recruitment strengths, the rate of natural mortality, and steepness of the stock recruitment relationship (see Table 15 in Appendix I). The model has been implemented to allow priors to be placed on parameters that are estimated so that Bayesian posterior distributions can be generated for the performance indicators. The mode of the joint posterior distribution is used as an estimate of the model parameters (PME-Posterior Mode Estimate). These estimates include information from data, by fitting the model to catch size frequencies and biomass indices using likelihoods, and from information contained in the priors (e.g. the log-normal prior on annual recruitment variation). The PME is used in the same manner as a maximum likelihood estimate (MLE). The parameter estimates are used to calculate B_{MSY} and other fishery performance indicators through forward projections using Bayesian procedures.

3.1 Dynamics

3.1.1 Time step and initial conditions

The model has an annual time step and in the initial year the population is assumed to be in equilibrium under average recruitment and no fishing mortality (Eq 7).

Recruitment

At the beginning of each year, equal numbers of males and females recruit into the smaller size classes. Total annual recruitment is determined by an average recruitment parameter, the steepness of the Beverton-Holt stock-recruitment relationship, and by annual recruitment deviations (Eq 8). Annual egg production is determined from the number of mature females in each size class and a size-to-egg relationship (Eq 13). The proportion of recruits entering each size class is modelled as a normal distribution with a specified mean and standard deviation and truncated at the smallest size class (Eq 14).

Growth

Growth is modelled using the Schnute growth model (Schnute 1981, Francis 1995) and applied through a transition matrix that specifies the probability of an individual remaining in the same size class or of growing into each of the larger size classes. Lobsters are assumed not to shrink and accumulate in the largest size class. Along with recruitment, the transition matrix is used to update the number of individuals in each size class for each sex before fishing and natural mortality in the following year (Eq 22).

Vulnerability

Fishing mortality is applied through size- and sex-specific vulnerability. These vulnerability schedules are used to calculate the biomass of lobsters available to the legal and illegal fisheries.

The shape of the vulnerability curve is assumed to be a compound normal distribution specified with separate variance parameters for each side of the distribution mode (Eq 23). This results in a distribution which has increasing vulnerability from the initial length class to an estimated maximum, followed by decreasing or flat vulnerability, depending on the value estimated for the right hand variance parameter (Eq 23). The curve is specified by three parameters for each sex: two of the parameters are the variances of the ascending and descending limbs and the value of the length at which vulnerability is at its maximum. The third parameter estimates the relative maximum vulnerability between males and females to allow for differential exploitation rates on each sex.

The ascending limb variance was assumed to change between the 1992 and 1993 assessment years because a change in escape gap regulations caused a change in the proportion of smaller fish retained in the commercial pots. The use of a single variance parameter for the right-hand (descending) selectivity over the entire period assumes that there have been no changes in the relative selectivity for large lobster over the period of assessment.

Maturity

The proportion of females that are berried or spent in each size class is estimated by a logistic curve varied by a scaling parameter. A scaling parameter allows the proportion of females caught in each size class which are berried or spent to be less than the proportion that are mature. This is expected to occur because most females are released alive during the egg bearing season (Eq 25).

Mortality

The model includes four sources of mortality; natural mortality, legal removals (including commercial and recreational), handling mortality associated with the legal fishery, and illegal removals. Natural mortality is assumed to be constant and independent of sex and age.

The annual exploitation rate of legal fishing is calculated as the ratio of legal catch to the legal biomass (Eq 26). Legal biomass is defined as the mass of males and females in the size classes above their respective minimum legal size limits, adjusted for their relative vulnerability. For females, legal biomass is also determined by the proportion of individuals that are berried or spent in each size class (Eq 27).

The annual rate of illegal fishing mortality is calculated similarly (Eq 28). The illegal fishery is assumed to have the same vulnerability as the legal fishery but disregards regulations on size limits and the condition of females. Illegal biomass is therefore defined as the mass of males and females in each size classes adjusted for their relative vulnerability (Eq 29).

All sources of mortality are applied simultaneously at the end of each year (Eqs 31 & 32). The handling mortality rate is a fixed proportion of all lobsters that are released and is thus proportional to legal fishing mortality.

3.2 Parameter estimation

Parameters are estimated by maximising a likelihood function which is the product of five likelihood components: (i) model fits to observed catch at size; (ii) model fits to observed biomass indices; (iii) parameter prior likelihoods (iv) a recruitment residuals penalty; and (v) a penalty for estimated exploitation rates which exceed a specified maximum (75%).

Model predictions are made for the proportion of females-non-berried, females-berried, and males of each size class in the legal fishery catch (Eqs 33\34\35). These predictions are fitted to observed proportions using a robust normal likelihood function (Eq 36) (Fournier *et al.* 1990). The robust likelihood eliminates the influence of observed outliers that have either high or low predicted probability. The predicted biomass index is calculated from the predicted legal biomass and an analytically estimated catchability constant (Eq 37). This is fitted to observed CPUE indices using a robust log-normal likelihood function (Eq 39). Annual recruitment residuals are penalised using a log-normal likelihood function assuming a mean of zero and a fixed standard deviation (Eq 40). The parameter estimates from the mode of the joint posterior distributions (PME-Posterior Mode Estimate) were found by minimising the total negative log likelihood using quasi-Newton minimisation (AD Model Builder™, Otter Research Ltd.).

3.3 Model Outputs

Bayesian estimation procedures were employed to estimate uncertainty in model estimates of biomass, yield, and future projections. This procedure is conducted in the following steps.

1. Model parameters were estimated using maximum likelihood and the prior probabilities. Co-variance matrices for the parameters were calculated;
2. Samples of the joint posterior distribution of parameters were generated using the Markov Chain Monte Carlo procedure (MCMC);
3. The posterior distribution was estimated for each quantity of interest by integrating the product of the likelihood and the priors over all model parameters and the mean, median, and 90% confidence intervals of the distribution of the parameters of interest were estimated;
4. For each sample of the posterior, 5-year projections (encompassing the 1998–99 to 2003–04 assessment years) were generated by assuming a catch trajectory. Future annual recruitment was randomly sampled from a lognormal distribution with mean and variance taken from the estimates of historical recruitment. This step, in conjunction with (3), was used to calculate the fishery performance indicators.

Table 1: Performance indicators used to assess the status of the fishery being modelled

$\mathrm{E}\left(\frac{B_{99}}{B_{MSY}}\right)$	Expected value of $B_{1998\text{–}99}$ as a proportion of B_{MSY}
$\mathrm{E}\left(\frac{B_{04}}{B_{MSY}}\right)$	Expected value of $B_{2003\text{–}04}$ as a proportion of B_{MSY}
$\mathrm{E}\left(\frac{B_{04}}{B_{99}}\right)$	Expected value of $\mathrm{B}_{2003\text{–}04}$ as a proportion of $\mathrm{B}_{1998\text{–}99}$
$\mathrm{E}(MSY)$	Expected value of MSY
$\mathrm{E}(B_{MSY})$	Expected value of B_{MSY}
$\mathrm{E}\left(\frac{Catch_{98}}{B_{98}}\right)$	Expected value of catch to biomass ratio in 1997–98 (=U_{98})
$\mathrm{P}(B_{04} > B_{MSY})$	Probability that $B_{2003\text{–}04}$ is greater than B_{MSY}
$\mathrm{P}(B_{04} > B_{99})$	Probability that $B_{2003\text{–}04}$ is greater than $B_{1998\text{–}99}$

The Working Group agreed to use the performance indicators listed in Table 1 as measures of the current status and future risk for each stock assessed. These performance indicators were calculated for each management scenario investigated.

4. Assessment model testing

Two procedures were used to test the assessment model described in the previous section. Firstly, the translation of the model equations into computer code and the operation of the minimisation procedure were validated. Once the proper operation of the model implementation was confirmed, an analysis was done of the sensitivity of the model to observation errors in the data being fitted.

4.1 Validation of programming

Given the complexity of modern fishery models, errors can arise in translating the model equations into the computer code needed to implement them. The programming can be validated by simulating a set of observations using the assessment model, a set of known parameters, and a known catch history. The simulated data are then used by the model program and the resulting parameter estimates compared to their known values. However, it is easy for errors in interpretation and of model misspecification to be duplicated in both the simulation and assessment code. An alternative approach is to simulate the model dynamics with a different model structure and then to evaluate the output with the assessment model. In addition to being a more robust method to test computer code, this also provides a means to test the specifications of the assessment model.

Here we describe an individual-based data simulator which was used to generate the catch history, the biomass indices, and the size frequency data which were then used to validate the code and the minimisation procedures of the assessment model.

An additional validation of the basic model occurred because the initial testing of the equations and model structure was made in Excel, a commercially available "spreadsheet" software programme. Because Excel differs substantially from a normal procedural programming language, coding the basic model into this format essentially provided an additional test of the validity of the basic model structure as common errors between these two dissimilar formats are less likely.

4.1.1 Methods

The model equations in the previous section describe the aggregate dynamics of a rock lobster population. The same dynamics can be represented in probabilistic rather than aggregate terms by simulating the lives of individual lobster. The various components of the model equations can be expressed as random Bernoulli trials. For example, rather than calculating the number of lobsters that survive natural mortality by,

Eq 1 $$N_{t+1} = N_t e^{-M}$$

where M is the instantaneous rate of natural mortality, we simulate natural mortality acting on N_t individual lobsters,

Eq 2 $$\textbf{for 1 to } N_t\textbf{: if } U(0,1) \le 1 - e^{-M} \textbf{ then } N_{t+1} = N_t - 1$$

where $U(0,1)$ is a uniformly distributed random number between 0 and 1.

An individual-based data simulator was developed to simulate the life of each lobster in a population subject to the fishery. The data generated by the simulator were based on a set of population dynamics parameters and a specified catch history. The unexploited size structure of males and females was generated by simulating the unexploited dynamics of the population over 200 years. An initial population of 30 000 individuals was generated by randomly selecting sex in equal probability and with size frequency chosen in proportion to the initial size structure. The maturity status of female lobsters (i.e., mature or not) was randomly selected for each size class in proportion to the specification of the maturity ogive.

Each year, a certain number of recruits are added to the population as determined by the parameters of the stock recruitment relationship. The size of recruits is randomly chosen from a normal distribution with a specified mean and standard deviation and truncated to the smallest size. Book keeping is done by examining each individual and adding it to the legal biomass and egg production where appropriate. The exploitation rate is calculated as the proportion of the catch of the legal biomass.

Each year, each lobster has a probability of being caught in the fishery, dying of natural mortality, growing, and maturing (Figure 1). When a lobster is caught in the fishery, its sex and size are recorded to generate catch and size-frequency data. Catch per unit effort for the fishery is generated as a constant proportion of the total weight of legal lobsters in the population. Illegal catch is assumed to be zero.

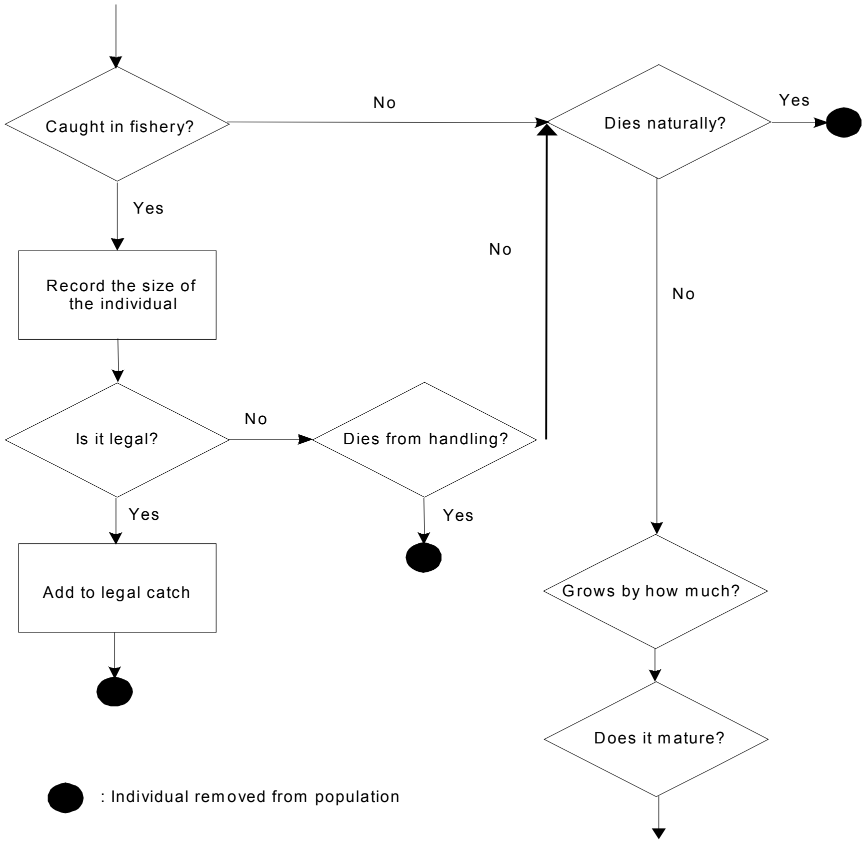

Figure 1: Schematic diagram of the year in the life of each lobster simulated. Final arrow on lower right indicates that the lobster exits from the year alive and enters the next simulated year in the upper left of the schematic diagram.

No observation or process errors are included in the simulation and the only error that arises is a result of the sampling error associated with the simulated Bernoulli trials. The data simulated by the individual-based data simulator are analysed by the assessment model.

4.1.2 Results

Initial tests were done with only R_0 estimated. There was an average bias of about 2% in the estimate of R_0. Fixing R_0 in the assessment model implementation produced a biomass trajectory as simulated, which suggested that the bias arose from a fault in the estimation procedure. Further examination suggested that the bias came from using the predicted proportions to estimate the variance in the catch-at-size component of the likelihood (Eq 36). The observed proportions at size were used instead and the bias in the estimate of R_0 was removed. Further simulations confirmed that the assessment model was correctly implemented.

4.2 Sensitivity

Validation of computer code does not ensure that the model and its estimation procedure perform well. In particular, the parameter estimates produced by the assessment model may be affected by observation errors in the data. We evaluated the bias and robustness of the assessment model by simulating data under various levels of observation error and fitting the model to these data.

4.2.1 Methods

To ensure that the variation in the simulated data arose only from the applied observation error and not from process error, data were simulated using the assessment model equations described in Appendix I rather than the individual-based data simulator described above because these data include process error associated with each of the random trials in the life of a lobster.

Each simulation included stochastic observation error on either CPUE or size frequency data as determined by a coefficient of variation (Table 2). Five levels of each observation error *c.v.* were tested (0.1, 0.2, 0.3, 0.4, 0.5) with thirty replicate simulations. Data were simulated based on the existing NSS catch trajectory and parameters estimates were made as described below. Recruitment error was not simulated.

Table 2: Types of observation error used in simulation data sets

Term	Description	Definition
σ_I	CPUE observation variation	$\tilde{I}_y = I_y e^{N(1,\sigma_I)-\sigma_I^2/2}$
σ_s	Size frequency observation variation	$\tilde{p}^s_{l,y} = p^s_{l,y} e^{N(1,\sigma_s)-\sigma_s^2/2}$

Only the main assessment model parameters were estimated using uniform priors: R_0, *h,* and *M*. Recruitment residuals were not estimated as recruitment error was not simulated. The other parameters were fixed to their input simulated values. If informative priors were used when estimating the parameters, the sensitivity tests would reflect the accuracy of the prior, not the level of sensitivity to the observation error. However, using uninformative priors in the sensitivity analysis may give an overly pessimistic indication of the performance of the actual assessment.

The accuracy of the resulting parameter set was assessed by comparing the simulated and estimated values of the ratio of the current biomass to the biomass that would produce the maximum sustainable yield, B_{CUR}/B_{MSY}. The proportional error (E_r) for each simulation set is,

Eq 3 $$E_r = \frac{\tilde{J}_r - J_r}{J_r}$$

where $\tilde{J}_r$ and J_r are respectively the estimated and simulated values of B_{CUR}/B_{MSY}. The accuracy and precision of the replicate model results were summarised using the mean proportional bias,

Eq 4 $$bias = \frac{\sum_{r=1}^{n} E_r}{n}$$

and the mean proportional imprecision

Eq 5 $$imprecision = \frac{\sum_{r=1}^{n} |E_r|}{n}$$

where n is the number of replicate simulations.

4.2.2 Results

For both CPUE and size frequency observation errors, imprecision increased as the coefficient of variation increased (Figures 2 and 3). Precision was more affected by CPUE observation error than by size frequency observation error. This is likely to be a result of the way in which the two types of error were applied in the model. The size frequency observation error was applied to each of the individual size-sex classes. Thus over the entire size-sex composition for a year, these errors may be cancelled out to some degree. In contrast, there are relatively few CPUE indices and the relative impact of the coefficient of variation may be higher. Imprecision was as high as 25% for high levels of CPUE observation error (Figure 2).

Bias was unaffected by size frequency observation error (Figure 3). However, for the highest levels of CPUE observation error, there was appreciable bias. This appears to have arisen because the simulated value of steepness was not in the centre of the bounds placed on its uniform prior. There was a strong positive correlation between the proportional error of each run and the estimate of steepness. Because the simulated steepness estimate was closer to the lower bound, there were more estimates of steepness that resulted in a positive error than in a negative error as the observation error increased (Figure 4). Since the imprecision caused by size frequency observation error was lower, this effect was not as important when observation error was put into this data set (Figure 5).

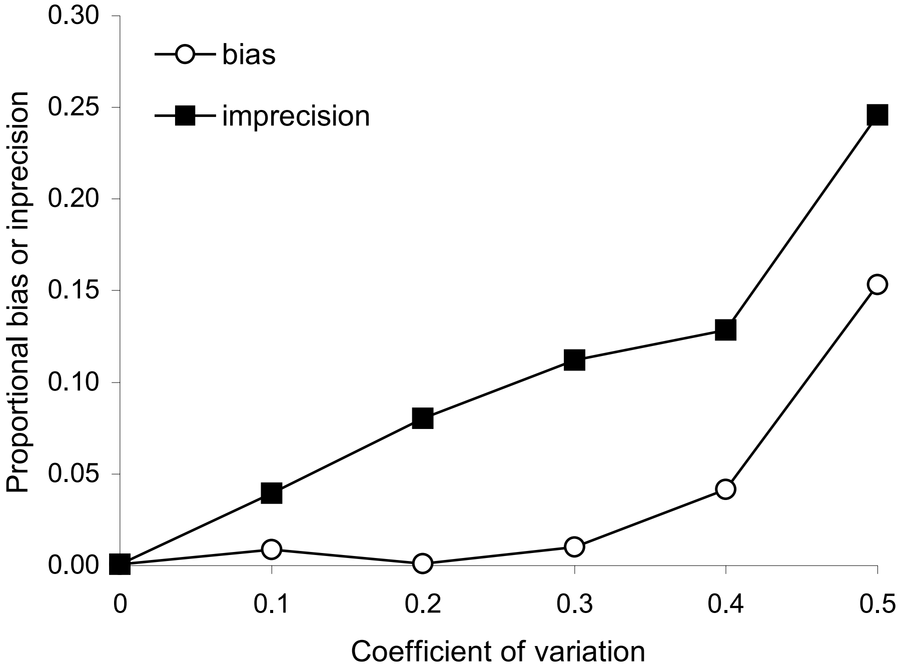

Figure 2: Trends in bias and imprecision with increasing coefficient of variation of CPUE observation error.

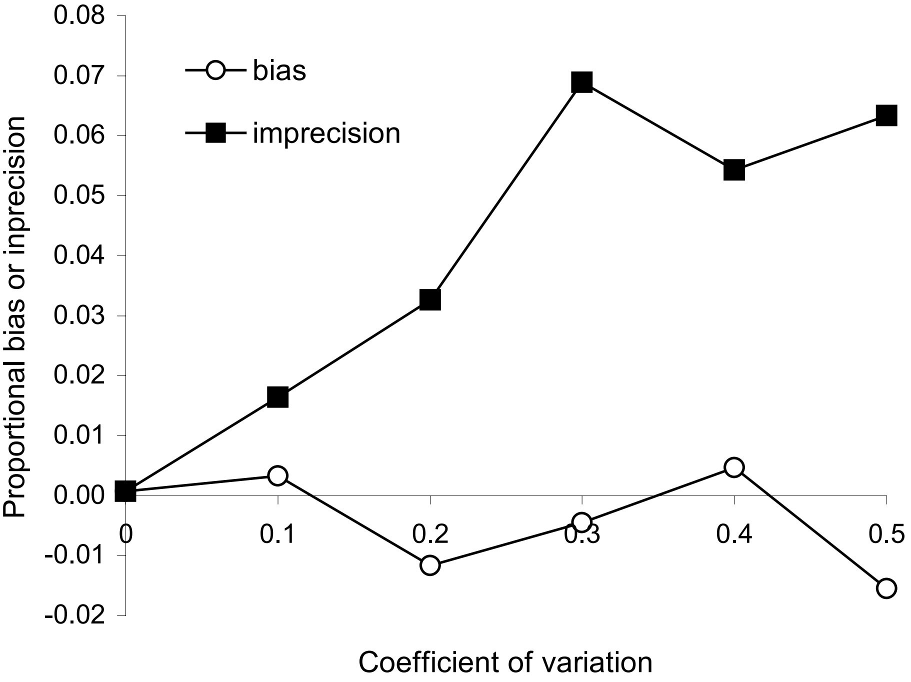

Figure 3: Trends in bias and imprecision with increasing coefficient of variation of size frequency observation error.

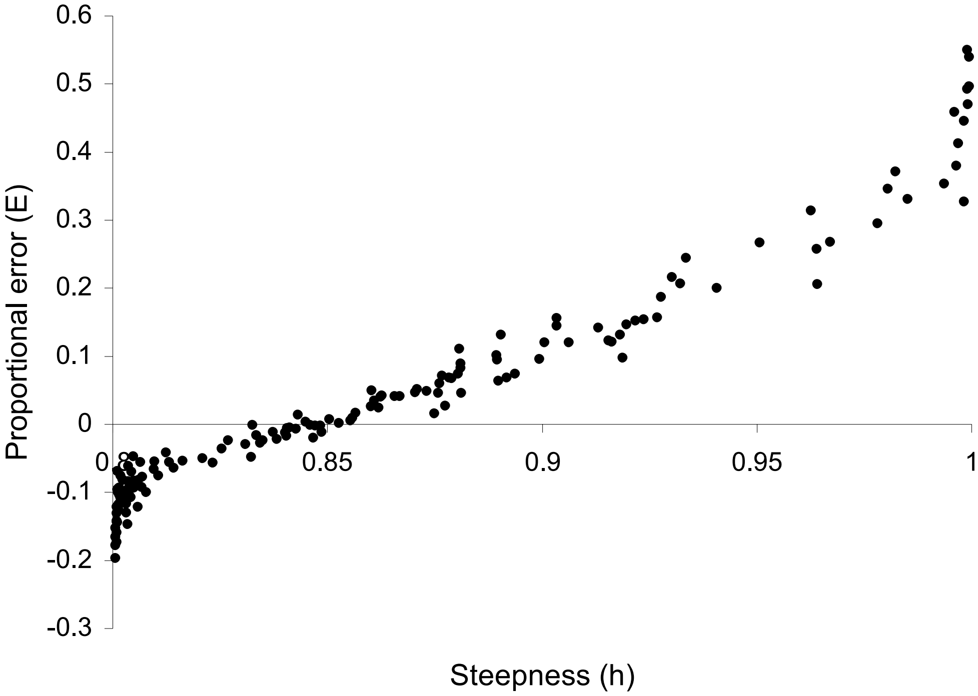

Figure 4: The relationship between proportional estimation error and steepness for the CPUE observation error simulations with *c.v.*s from 0.1 to 0.5.

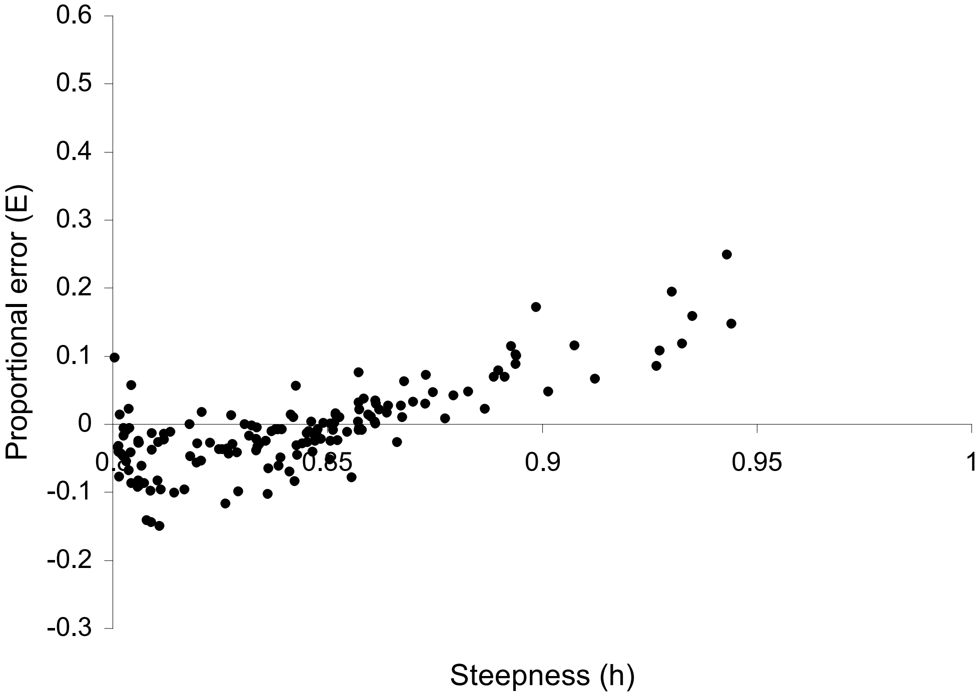

Figure 5: The relationship between proportional estimation error and steepness for the size frequency observation error simulations with *c.v.*s from 0.1 to 0.5.

5. Stocks assessed

The fishery for *Jasus edwardsii* occurs around the whole of New Zealand. Evidence for separate stocks based on genetics, morphology, movement, population parameters, catch per unit effort trends, larval distribution, and parasites has been reviewed (Booth & Breen 1992). Based on this work, in 1994 the Working Group agreed to define four stocks for assessment purposes from eight of the nine quota management areas:

NSN: CRA 1 & CRA 2

NSC: CRA 3, CRA 4 & CRA 5

NSS: CRA 7 & CRA 8

CHI: CRA 6

As yet, the CRA 9 Quota Management Area has not been assigned to a stock.

This document describes assessments for the NSN and NSS stocks.

6. Assessment model inputs

This section describes the data and parameter inputs used for the NSN and NSS assessments. These inputs include the period over which the model was run, catch data, catch rate indices, annual size frequencies, and the priors and point values used for estimated and fixed parameters respectively.

The NSN stock has similar catch size frequencies over all statistical areas. However, the NSS stock has quite different size frequencies between CRA 7 and CRA 8. Even within CRA 8, size frequencies suggest that there is a different exploitation rate in the Stewart Island (Area 924) fishery than in Fiordland (Areas 926 to 928). In the NSS stock, updated estimates of growth are available only for Fiordland. Thus, to maintain consistency within the model, the Working Group agreed that size frequencies, catch rate indices and maturity parameter priors for Fiordland only should be used. Thus, for the NSS assessment the model is fitted to Fiordland data but is scaled up to the NSS as a whole by using catch data for the entire stock. Future work will address the issue of how best to incorporate the Stewart Island information into the stock assessment.

6.1 Period included in the model and definition of assessment year

The model simulation begins in 1945, the first year for which catch data are available. Until 1979, catch data are collated by calendar year. After that date, catch, catch rate, and size frequency data are summarised by an assessment year spanning a period chosen by the Working Group (1 September to 31 August). Assessment years are labelled in Appendix II using the last calendar year in each pair (for example, the 1996–97 assessment year which covers the period 1 September 1996 to 31 August 1997 is labelled as ‘1997’).

6.2 Structure of size frequency data

Tail width size frequency data from research sampling and from voluntary logbook programmes were binned into 2 mm size classes from 30 to 90 mm. These limits spanned the size range of most lobsters caught in the catch. Two millimetre size classes were considered small enough to provide enough resolution in the model without being too small to be affected by measurement error.

6.3 Control variables

The catch data and the CPUE abundance indices used in the NSN and NSS stock assessments are provided in Appendix II.

6.3.1 Catches

The assessment model requires annual values of legal and illegal catch. Legal catch is defined as the total weight of lobsters taken in accordance with existing regulations on the minimum legal size limit and the maturity state of females (i.e., berried or non-berried). Illegal catch is taken without regard to these regulations and includes lobsters both above and below the size limit and females in berry and unberried. Three types of catches are considered when collating annual legal and illegal catch totals.

Commercial reported

From 1945 to 1987, reported commercial catches were obtained from Breen & Kendrick (1998). From 1988 to 1998, monthly catch totals for each Fishstock obtained from Quota Management Returns (QMRs) were summed by the appropriate QMAs to form the substock being assessed (Section 5 provides the QMAs which form each substock) to obtain totals for each assessment year.

Commercial unreported

Estimates of unrecorded commercial catch have been made for the calendar years 1974 to 1980 by comparing recorded catches with export weights of lobster and assigning the discrepancy to stocks in proportion to the recorded commercial catch (Breen 1991).

Recreational

The Rock Lobster Fishery Assessment Working Group agreed to assume that in 1945 recreational catches were 20% of current levels and that they increased at a constant rate until 1980. After that year, it was assumed that catches have remained constant at current levels. Current levels of recreational catch are estimated as the mean of all recreational catch estimates made since 1980, 189.5 t for the NSN stock and 34 t for the NSS stock (Table 3).

Table 3: Estimates of the recreational rock lobster harvest (t) from telephone and diary surveys in 1992 (for CRA 7 and CRA 8), in 1994 (for CRA 1 and CRA 2) and in 1996 (all four QMAs, - = not available). Two estimates of catch in tonnes are presented for the 1994 estimates for CRA 1 and CRA 2 which are based on two sources of mean weight information: one from the diary survey and the other from the Industry Logbook Programme for CRA 2 (Bradford 1997). Mean weights used in the other QMAs are based either on weights reported in the diaries or from boat ramp surveys (Teirney *et al.* 1997)

	1992 or 1994 survey			1996 survey		
Fishstock	Estimated number of lobsters	Mean weight (gm)	Estimate (t)	Estimated number of lobsters	Mean weight (gm)	Estimate (t)
CRA 1	56 000	871[1] or 674[2]	48 or 38	74 000	686	51
CRA 2	142 000	871[1] or 674[2]	123 or 95	223 000	618	138
CRA 7	6 000	-	1 – 6	3 000	-	-
CRA 8	32 000	-	15 – 60	22 000	700[1]	16

[1] diary estimate of mean weight

[2] logbook estimate of mean weight

Legal catch

Legal catch in the model is defined as the sum of the commercial reported, the commercial unreported, and the recreational catch.

Illegal catch

There are two categories of illegal catch: one is the catch which is taken without regard to the existing regulations but may eventually be included in the legal catch totals. For instance, this category includes holding berried females in pots until they release their eggs. The other category of illegal catch includes lobster which never enter into the catch reporting system. It is necessary to separate these categories as the former category needs to be subtracted from the reported legal catch to avoid double counting of catch. In the model, it is assumed that both categories of illegal catch have the same size and female maturity distributions as the legal catch, but that all lobster are retained. Estimates of illegal catches have been obtained from the Ministry of Fisheries Compliance Section for the 1990–91 to 1997–98 fishing years (Table 4). However, estimates were partitioned between "reported" and "unreported" illegal catch only for the 1996–97 fishing year. These proportions were applied to all previous years with illegal catch. It was assumed that no illegal catch was taken before 1979 and interpolation was used to fill the years without illegal catch estimates. Illegal catches were assumed to be the same in the final assessment year (1997–98) as in the 1996–97 fishing year.

Table 4: Estimates of illegal rock lobster catches (t) for the NSN and NSS stocks. These estimates have been made by the Ministry of Fisheries Compliance Section (P. Breen, NIWA Ltd, *in litt*. 4/8/98). Note that estimates are not available for all years

Calendar/ Fishing Year	NSN	NSS
1979	10	11
1987	48	55
1990–91	108	74
1992–93	48	104
1994–95	85	90
1995–96	75	60
1996–97	104	68

6.3.2 Minimum legal size limits

While there have been some changes in the size limit regulations over the model period, it was not possible to adequately address the possible effects of these changes given the available time and the lack of historical size frequency data. The Working Group agreed to use the current minimum legal size limits (Table 5) over the entire model period.

Table 5: Minimum legal size limits (mm tail width) for the NSN and NSS stocks

Stock	Males	Females
NSN	54	57
NSS	54	60

6.4 State variables

6.4.1 Biomass indices

The catch of legal lobsters per potlift is used as an index of legal biomass. Annual relative indices of catch rates are generated by standardising for month and statistical area (Maunder & Starr 1995, Breen & Kendrick 1998). These indices are made relative to a base year which is defined as the year with the absolute index with the lowest standard deviation. The raw mean catch per potlift is then used to adjust all the indices into absolute terms.

Detailed catch and effort data prior to the 1979–80 assessment year (the first complete assessment year from the FSU system) are not available and could not used to fit the model. The last year of data available from the Ministry of Fisheries Catch Effort Landing Returns (1997–98 assessment year) also could not be used as the returns were clearly incomplete.

For NSS, the standardised abundance indices were estimated from catch per unit effort data from Fiordland only (statistical areas 926 to 928). For NSN, all statistical areas in CRA 1 and CRA 2 were used (statistical areas 939 and 901–908).

6.4.2 Size frequencies

Data on the size of lobsters entering pots in the legal catch were available from research sampling on commercial vessels and from voluntary logbook programmes in CRA 2, CRA 5 and CRA 8. Estimates of the annual length frequency were obtained by using length frequency data that had been summarised by area/month strata and weighted by the commercial catch taken in that stratum. When there were more than one source of size frequency data available within a single stratum, the length data were summed between methods. It was assumed that the length frequency data used were representative of the commercial catch. For NSS, size frequencies were generated from data derived from Fiordland only (statistical areas 926 to 928).

An estimate of the effective sample size is required to calculate the variance in the catch-at-size likelihood equation. Using the absolute number of lobsters measured is likely to underestimate the variance because there is sampling variation in addition to multinomial sampling error. A sample which has fewer lobsters measured over more months and areas within the fishery is likely to be more representative of the fishery than one that has many lobsters but is concentrated in a few months and areas. Thus an index of effective sample size was calculated for each year that was proportional to the number of month-area combinations sampled within the stock,

Eq 6
$$\kappa_y = 100 \frac{O_y}{\sum_{y=1}^{n_y} O_y} n_y$$

where, O_y is the number of area-month combinations sampled in year y and n_y is the number of years for which size frequency data are available.

6.5 Parameter priors

For all parameters estimated, priors were set after discussions in the Working Group (Table 6). The basis for these priors are outlined below.

Table 6: Parameters estimated in the model and their prior distributions. Prior types: U, uniform; N, normal; L, lognormal; TW, tail width

			Prior				
	Description	Dimension	Type	Lower Bound	Upper Bound	Mean	*c.v.*
M	Instantaneous rate of natural mortality	yr^{-1}	U	0.05	0.15	-	-
H	Steepness of the Beverton-Holt stock-recruitment relationship	-	U	0.8	1	-	-
R_0	Average recruitment in unexploited population	Thousand recruits	U	1	50000	-	-
m_{50}	Size-at-50%-maturity for females	mm TW	N	30	90	NSN: 53.76 NSS: 57.16	0.03
m_{95}	Size-at-95%-maturity for females	mm TW	N	30	90	NSN: 63.07 NSS: 65.11	0.03
$m_{\max}$	Maximum proportion of females berried or spent	-	U	0.25	1	-	-
L^s_{full}	Size at full selectivity for sex s	mm TW	U	40	70	-	-
R	Relative vulnerability of males	-	U	0.2	2	-	-
V^s_L	Variance of the left hand limb of the selectivity curve	mm TW	L	10	500	40	1
V^s_R	Variance of the right hand limb of the selectivity curve	mm TW	L	100	10000	1000	1
g^{50}_f	Growth rate of 50 mm female	mm TW yr^{-1}	L	0.1	20	NSN: 2.80 NSS: 2.97	0.15
g^{80}_f	Growth rate of 80 mm female	mm TW yr^{-1}	L	0.1	10	NSN: 1.25 NSS: 0.94	0.3
g^{50}_m	Growth rate of 50 mm male	mm TW yr^{-1}	L	0.1	20	NSN: 2.66 NSS: 5.67	0.15
g^{80}_m	Growth rate of 80 mm male	mm TW yr^{-1}	L	0.1	10	NSN: 1.26 NSS: 2.19	0.3

6.5.1 Natural mortality, average recruitment, steepness

Insufficient information was available to put informative priors on any of these parameters. Bounds were set by the Working Group to restrict estimates within a plausible and agreed range (Table 6).

6.5.2 Female maturity

The two size at maturity parameters, m_{50} and m_{95}, were estimated outside of the assessment model for the NSN and for Fiordland using the maximum likelihood method described in Appendix III. The coefficients of variation associated with these estimates were less than 0.01. To allow for a degree of flexibility when fitting these parameters in the model, the *c.v.*s for the priors of the maturity parameters were set to 0.03 (Table 6).

6.5.3 Vulnerability

Seven parameters associated with vulnerability for males and females were estimated in the model. There was no information available to set an informative prior for the relative vulnerability (to the female vulnerability) of males. Bounds were set to contain the vulnerability of males within 0.2 to 2 times that of females. There was also little basis for setting an informative prior for the size at full selectivity of each sex. Therefore, a uniform prior was set from 40 to 70 mm tail width for each sex.

The Working Group felt that the parameters determining the shape of the ascending and descending limbs of the selectivity curve, v_L^s and v_R^s, should have informative priors, but with wide coefficients of variation. The priors for these parameters were set after examining the effect of alternative values on the shape of the selectivity curve.

6.5.4 Growth rates

For the assessment of the NSS stock, growth parameters were fixed at the values estimated directly from Fiordland tagging data (Table 7). The choice to estimate these growth parameters external to the model was made because these growth rate estimates were based on the analysis of nearly 2000 tag recoveries in Fiordland made in the early 1980s. Because the assessment model was not structured to incorporate the information from these tag recoveries, the only information in the model to estimate growth rates would come from the length frequency distributions derived from logbook data. Such information is at best only an indirect measure of growth and it was felt that the tag recovery data provided more reliable estimates of growth rates.

For the NSN stock, von Bertalanffy growth parameter estimates are available from much more limited tagging work done in statistical areas 905 and 906. These were converted to parameters of the Schnute growth function with the shape parameter set to correspond to the von Bertalanffy function ($c_g = 1$) and growth variability (φ_g) was assumed to be the same as estimated for Fiordland lobsters (Table 7). These parameter estimates were mainly used as informative priors in most of the NSN model runs or else were fixed in some sensitivity runs.

Table 7: Parameters of the von-Bertalanffy growth function and the derived values of the Schnute growth function. Italics for the NSN Schnute growth parameters indicate that they have been derived from the von-Bertalanffy equation

	NSS		NSN	
	Females	Males	Females	Males
Von-Bertalanffy				
k	-	-	0.055	0.048
L_∞	-	-	103.8	106.5
Schnute				
g_g^{50}	2.97	5.67	2.80	2.66
g_g^{80}	0.94	2.19	1.25	1.26
c_g	1.26	0.58	*1*	*1*
φ_g	1.55	1.87	*1.55*	*1.87*

6.6 Fixed parameters

6.6.1 Size of recruits

The parameters governing the size distribution of recruits were fixed at $\phi_g = 40$ mm and $\gamma_g =$ 4 mm for both assessments and these parameters were applied as indicated in Eq. 14 (Appendix I).

6.6.2 Recruitment variation

The Working Group agreed to set the coefficient of variation for recruitment at 0.4. Recruitment residuals were estimated only for those years where information would exist in the size frequency data. Therefore, the age of 80 mm tail width lobsters was estimated and taken from the first year for which size frequency data were available. Recruitment residuals were estimated from 1973 for the NSN and from 1975 for NSS.

6.6.3 Recruitment age

For both assessments the age of recruitment to the fishery was set to two, the approximate age of 40 mm tail width lobsters.

6.6.4 Handling mortality

Handling mortality was assumed to be 10% of all lobsters that were discarded.

6.6.5 Size-weight relationship

The parameters of the size to weight relationship were fixed at values estimated from catch sampling data (Table 8) and these parameters were applied as indicated in Eq. 30 (Appendix I).

Table 8: Parameters of the size to weight relationship for the NSN and NSS stocks (Breen & Kendrick 1998)

		Females		Males	
Stock	Statistical Area	a	b	a	b
NSN	912	-1.7545	1.9031	-3.3972	2.4227
NSS	927 & 928	-2.7355	2.1766	-5.8321	3.0048

6.6.6 Fecundity

Parameters of the size to fecundity relationship were fixed at values used in previous assessments (Table 9) and these parameters were applied as indicated in Eq. 13 (Appendix I)

Table 9: Parameters of the size to fecundity relationship for the NSN and NSS stocks (Breen & Kendrick 1998)

Stock	ψ	ξ
NSN	0.21	2.95
NSS	0.06	3.18

7. Assessment results

7.1 Catches used for projections

Various catch trajectories were used for projections (*see* Section 3.3 for description of how the projections were done) used to estimate the probability of achieving management goals(Table 10).

Table 10: Catches used in the five year projections by stock. "*status quo*" implies that the projected catches are based on the current TACC and the current estimates of recreational and illegal catches

Population modelled	Commercial catch (t)	Recreational catch (t)	Illegal catch (t)
NSN– *status quo*	366	190	155
NSS – *status quo*	955 [1]	34	33 [2]
NSS – decreased TACC	777 [3]	34	33 [4]

[1] Consists of 67 t for CRA 7 (=average catch for 1993–94 to 1997–98 assessment years) and the CRA 8 TACC (888 t)

[2] Unreported illegal. Reported illegal was modelled as 5% of the CRA 8 TACC (= 45 t)

[3] Consists of 67 t for CRA 7 (=average catch for 1993–94 to 1997–98 assessment years) and 80% of the CRA 8 TACC (710 t)

[4] Unreported illegal. Reported illegal was modelled as 5% of the CRA 8 TACC (= 36 t)

7.2 NSN stock

The assessment of this stock was made difficult by the confounding of several of the key parameters of the model. Therefore, initial runs were made to test the sensitivity of the model parameter estimates and to settle on a "base case" run which would be credible given the available data (Table 11). Note that the growth rate parameters were chosen to be estimated in this model (unlike for the NSS stock), although the parameter estimates provided in Table 7 were used to construct informative priors and as starting estimates in the parameter estimation procedure. This choice was made due to the paucity of tagging data from which the historical von-Bertalanffy curves were estimated.

The following paragraphs summarise the process followed to complete the NSN stock assessment. Various combinations of estimated parameters were tried before settling on a single "base case" assessment. Following that, runs to test the sensitivity to model assumptions were made using maximum likelihood methods. The generation of the Bayesian posteriors and the calculation of the probabilistic projections were only done for the "base case" assessment.

1. The initial run (*M estimated* – Table 11), which was made with all the major parameters estimated, resulted in a high estimate for M and a high estimate for R_0 compared to values of R_0 from assessments in other areas (particularly NSS). Examination of the parameter correlation matrix revealed a high positive correlation between M and R_0 and it appeared that the fit favoured high values of both parameters. This confounding probably results from the low level of contrast in the time series of CPUE and size frequency data. This initial fit produced a biomass trajectory and values of MSY and B_{CUR}/B_{MSY} that the Working Group considered to be unlikely. The Working Group also considered that it was extremely unlikely that the underlying population for this stock

was considerably larger than the NSS because of the demonstrated higher yields from the latter stock.

2. Given the high positive correlation between R_0 and M, an upper bound was placed on R_0 at 2000 (*Upper bound on* $R_0 = 2000$ – Table 11). This resulted in an assessment that appeared to be more realistic but was felt by the Working Group to be unreasonably arbitrary.

3. As an alternative, M was fixed at 0.1 (*Base case* – Table 11). This value was chosen because it is the fixed parameter value that has been used in all recent age structured lobster stock assessments (e.g. Breen & Kendrick 1998). Breen & Anderson (1993) reviewed the available literature for natural mortality in lobster and concluded that "M is likely to be low for temperate lobster of legal size". This run estimates a lower value for R_0 and lower estimates for MSY and B_{CUR}/B_{MSY} compared to the run when M was estimated. This run was chosen by the Working Group to be the base case.

4. To investigate whether the estimation of growth parameters was having an appreciable effect on the model estimates, the g_g^{50} and g_g^{80} growth parameters for both sexes were fixed using the values taken from the von-Bertalanffy curve used in the previous age-structured stock assessment (Breen & Kendrick 1998) for both males and females (*Growth fixed* – Table 11). Model results changed little relative to the base case indicating that, given the other parameter estimates, the fixed growth rates were consistent with the observed length frequencies from the fishery.

5. The base case model estimates for v_g^r were low, particularly for females (Table 11), indicating the presence of a cryptic population which is not vulnerable to fishing. Because the existence of such a population would considerably reduce the risk of fishing, the Working Group required further investigation into the causes of this result. One sensitivity run was done with v_g^r fixed at a value of 10 000 (v_g^r *fixed* – Table 11), a value which produces full selectivity at all lengths above η_g, and is therefore similar to the selectivity schedule used in previous assessments (which assumed that selectivity was 100% after the fish recruited to the fishery). The g_g^{80} growth parameter estimate for females was reduced to nearly 0, implying that female growth at larger size intervals was not consistent with the observed size frequencies in the fishery if larger lobster were fully vulnerable to the fishery. Therefore, the low estimate for the female v_g^r in the base case (and hence the existence of the large cryptic biomass) is a function of the interaction of the growth parameter estimates and the observed fishery length frequencies.

6. To test this conclusion, a sensitivity run was made with v_g^r and the growth parameters fixed (v_g^r *fixed and growth fixed* – Table 11). This run resulted in a considerably poorer fit to the observed length frequency data, particularly for females. It also resulted in a reduction in the estimate of B_{MSY} relative to the run with only v_g^r fixed. Even with these pessimistic assumptions the estimate of B_{CUR}/B_{MSY} was still well above the B_{MSY} target.

7. To test the sensitivity of the assessment to the CPUE data, a run was made which omitted the CPUE data (*Not fitted to CPUE* – Table 11). This produced results that were similar to the base case, suggesting that the CPUE and length frequency data give similar biomass signals.

8. The base case was run without the estimation of recruitment residuals (*Recruit. residuals not fitted* – Table 11). This sensitivity run estimated a much higher R_0, presumably to improve the fit to the increasing CPUE in recent years. The larger estimate for R_0 results in a larger estimate for *MSY*. Note again that the estimate of stock status is still well above B_{MSY}.

Table 11: Model likelihoods, stock indicator estimates and PME parameter estimates for different runs in the NSN assessment

		Run							
		Base case	*M estimated*	*Upper bound on R_0 = 2000*	*Growth fixed*	v_g^r *fixed*	v_g^r *fixed and growth fixed*	*Not fitted to CPUE*	*Recruit. Residuals not fitted*
Likelihoods	CPUE	9.1	9.2	8.8	9.0	7.1	5.1	**0**	15.1
	Size Freq.	-1 444.9	-1 445.3	-1 444.8	-1 444.0	-1 440.5	-1 414.1	-1 444.4	-1 433.3
	Priors	9.4	8.7	9.74	9.8	12.2	6.2	9.7	9.2
	Rec.Resid.	5.1	4.1	5.5	5.7	8.7	16.6	3.0	**0**
	Total	-1 421.3	-1 423.4	-1 417.7	-1 419.6	-1 412.5	-1 386.3	-1 431.8	-1 409.1
Indicators	*MSY*	780	1251	712	744	626	570	778	1035
	B_{MSY}	1 133	1 375	1 069	1 097	1 333	1 151	1 144	1 403
	B_{CUR}/B_{MSY}	572%	631%	547%	580%	405%	453%	475%	414.1
Average recruitment	R_0	2 280	5 285	2 000	2 311	1 810	1 623	2 325	3 152
Natural mortality	M	**0.1**	0.149	0.097	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**
Stock-recruit steepness	h	0.993	0.991	.995	0.993	0.998	0.999	0.981	.985
Female maturity status	m_{50}	53.3	53.3	53.3	53.3	52.7	52.1	53.3	53.0
	m_{95}	65.5	65.5	65.4	65.5	64.3	62.7	65.5	65.6
	$m_{\max}$	0.800	0.800	0.797	0.799	0.762	0.698	0.800	.801
Size at full selectivity	η_{femle}	61.4	62.2	61.4	61.5	63.4	62.5	61.3	60.8
	η_{male}	54.8	55.0	54.8	55.0	54.6	54.8	54.7	55.3
Relative male vuln.	r	1.16	1.04	1.19	1.20	1.16	1.09	1.16	1.11
Ascending limb of selectivity curve	v^l_{female}	66.8	67.4	66.8	67.0	80.8	83.2	63.4	46.5
	v^l_{male}	25.7	25.0	25.8	26.2	24.3	26.2	24.9	25.1
Descending limb of selectivity curve	v^r_{female}	236	320	234	239	**10 000**	**10 000**	216	193.4
	v^r_{male}	2 277	1 898	2 757	2 773	**10 000**	**10 000**	2 350	460.3
Female growth	g^{50}_{female}	2.94	2.95	2.97	**2.80**	2.37	**2.80**	2.91	2.65
	g^{80}_{female}	1.12	1.11	1.11	**1.25**	0.06	**1.25**	1.17	1.32
	c_{female}	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
	φ_{female}	**1.55**	**1.55**	**1.55**	**1.55**	**1.55**	**1.55**	**1.55**	**1.55**
Male growth	g^{50}_{male}	2.82	2.84	2.94	**2.66**	2.93	**2.66**	2.76	2.77
	g^{80}_{male}	0.97	1.14	1.12	**1.26**	1.44	**1.26**	0.83	1.04
	c_{male}	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
	φ_{male}	**1.87**	**1.87**	**1.87**	**1.87**	**1.87**	**1.87**	**1.87**	**1.87**

Bold type indicates that the parameter was fixed at that value.

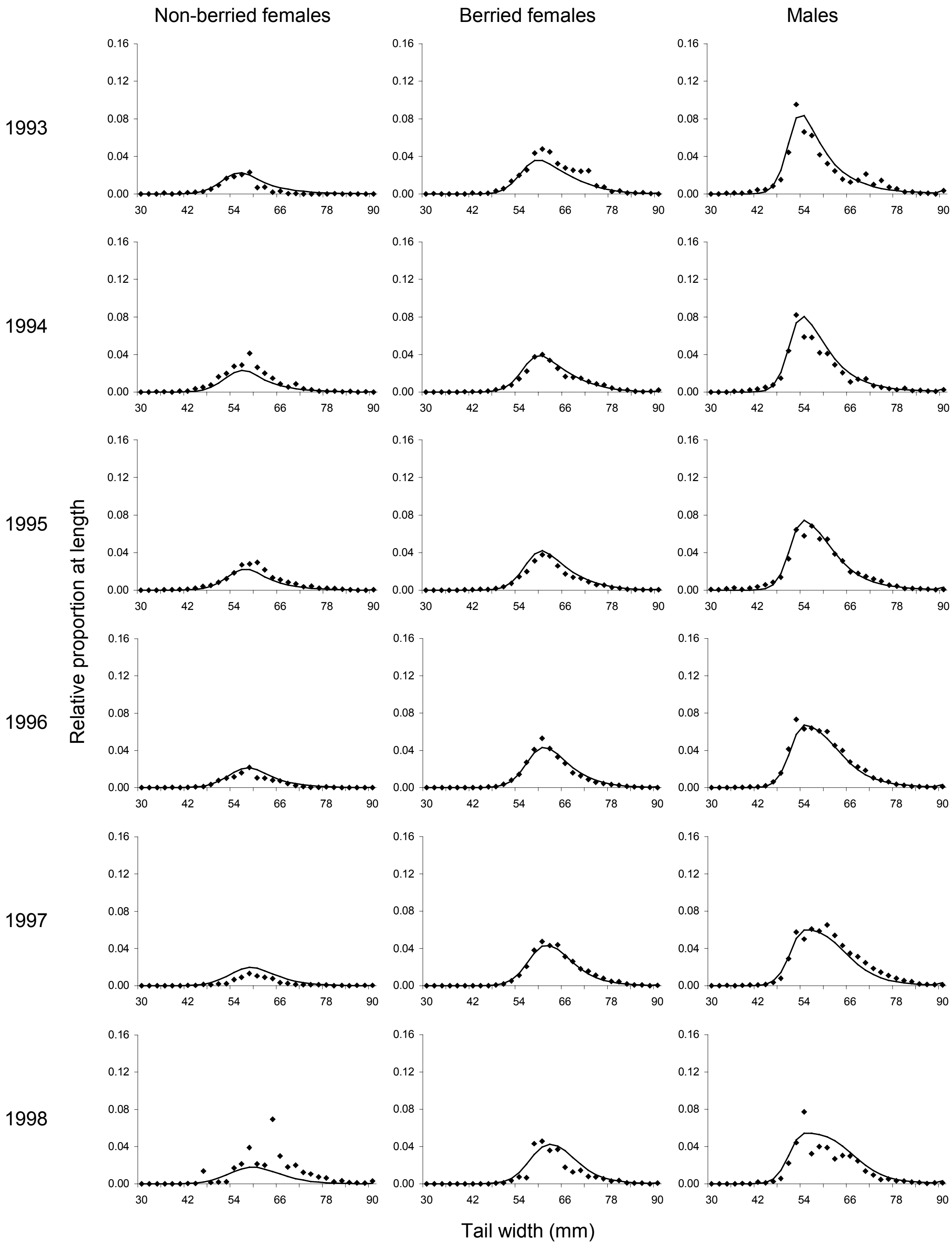

Figure 6. The PME base case assessment fit to the fisheries size distributions by sex class (non-berried females, berried and spent females, and males) by assessment year for the NSN stock. These data are derived from the industry logbook sampling programme for the indicated years.

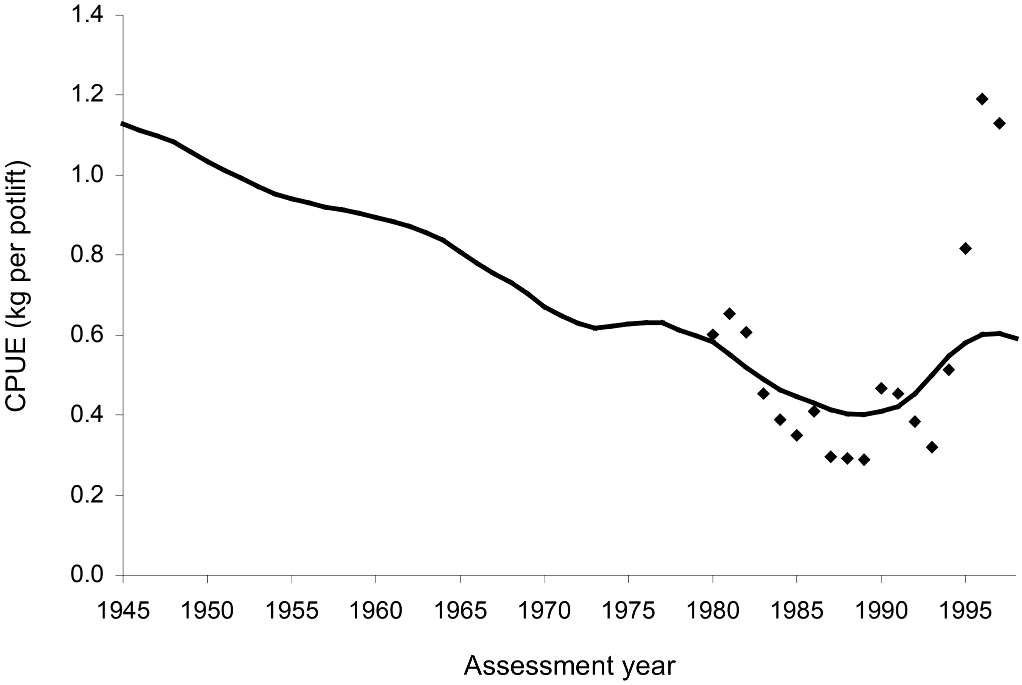

Figure 7. Biomass trajectory for the NSN stock from the PME base case assessment, expressed as kg per potlift. Fitted CPUE data points are indicated as points, beginning with the 1979–80 assessment year.

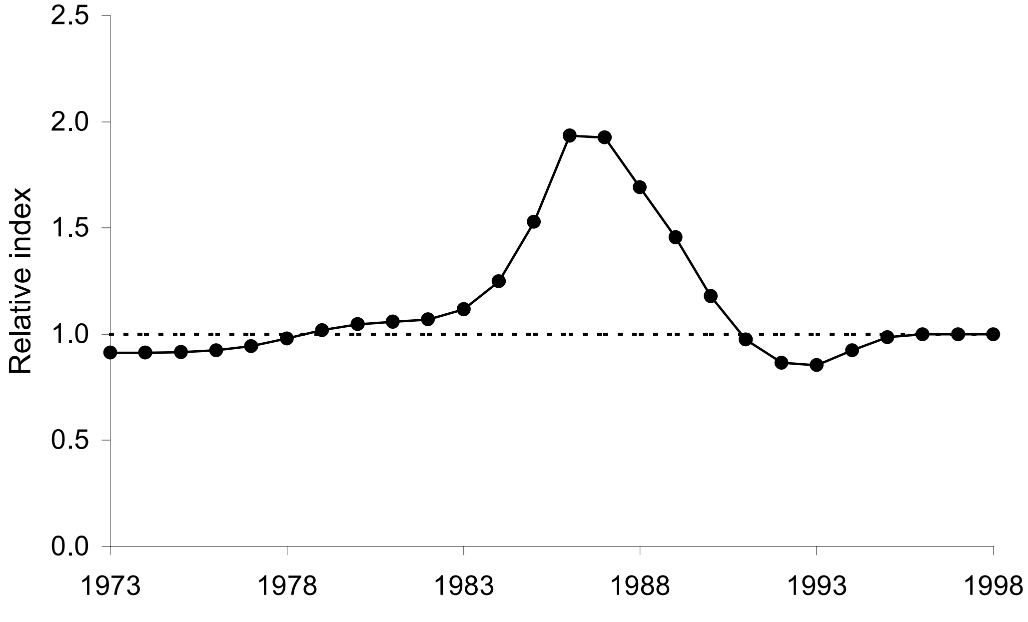

Figure 8. Estimates of the annual recruitment multipliers from the PME base case assessment for the NSN stock.

The fit to the size frequency data by the base case assessment is generally satisfactory (Figure 6), with the poorest fit in the most recent assessment year. This is probably due to incomplete data as this assessment year would have little data in it at the time of the assessment (this fishery is now mainly a winter fishery which extends from July to mid September and the logbook data were current only up to end of May 1998).

The results from the base case assessment indicate that, given the fixed M at 0.1, the stock had gradually declined over time as the biomass was fished down (Figure 7), but the assessment estimated that the stock is still presently well above B_{MSY} (Table 12). This assessment also explains the recent increase in abundance (CPUE) as resulting from above average recruitment in the late 1980s (Figure 8). However, the model dynamics do not allow the biomass to increase as rapidly, nor to such a high level, as the observed CPUE increase (Figure 7).

Posterior distributions for the performance indicators were generated for the "base case" run only (Table 12). Model projections to the year 2003–04 (using *status quo* catch levels as given in Table 10) indicate that the stock is expected to remain well above B_{MSY} but is also expected to decline about 15% relative to the current biomass (Table 12). The estimated yield at MSY is higher than the current removals (about 900 t, ranging from 600 t to 1500 t – Table 12), indicating that long term yields could be higher at lower biomass levels.

Table 12: Performance indicators for the base case NSN assessment. Expected value results are the mean, median, and 5% and 95% percentiles from the Bayesian posteriors. Probability results are the count of the indicated test divided by the number of posterior samples

	Mean	Median	Lower 5%	Upper 95%
$E(B_{99}/B_{MSY})$	557%	518%	355%	934%
$E(B_{04}/B_{MSY})$	471%	438%	282%	777%
$E(B_{04}/B_{99})$	84%	84%	72%	98%
$E(MSY)$	892	794	637	1 496
$E(B_{MSY})$	1 602	1 517	879	2 703
$E(U_{98})$	7.2%	7.1%	3.9%	10.7%
$P(B_{04} > B_{MSY})$	100%			
$P(B_{04} > B_{99})$	3.1%			

7.3 NSS stock

The NSS stock was modelled using CPUE, length-frequency data, and growth rates derived from Fiordland only. Catch data were scaled up to represent the entire NSS stock so that estimates of B_{MSY} and other indicators could be applied to the entire stock.

The following paragraphs summarise the base case and sensitivity runs made to complete the NSS stock assessment. The generation of the Bayesian posteriors and the calculation of the probabilistic projections were only done for the "base case" assessment.

1. The chosen "base case" run estimated all the parameters listed in Table 6 except the four (two male and two female) growth parameters (*Base case* – Table 13). Parameter estimates from this run appeared to be consistent with results from previous age-structured stock assessments, particularly for the estimate of MSY (1655 t compared to the previous 1600 t) and for stock status (for instance, B_{CUR} is estimated to be about 20% of B_{MSY} compared to the previous estimate of 30% (Breen & Kendrick 1998)).

2. To test the sensitivity of the model to the fixed growth rate parameters, a sensitivity run which estimated these growth parameters was run (*Growth estimated* – Table 13). The estimated values for the g_g^{50} growth parameter (growth at 50 mm tail width) were higher for females and were lower for males than the externally estimated values. For the g_g^{80} growth parameter (growth at 80 mm tail width), the female value was unchanged while the male value was higher relative to the externally estimated values. The estimated value for r was close to 1.0 compared to the value of 1.67 estimated in the base case, indicating that there is an interaction between growth rates and the relative vulnerability between the sexes. *MSY* and stock status are similar to the base case assessment, while the estimate for B_{MSY} is considerably reduced and the R_0 estimate is much larger than the base case assessment.
3. To investigate the influence of the CPUE data on the assessment, a sensitivity run was made without using the CPUE indices (*Not fitted to CPUE* – Table 13). Model results did not change appreciably, indicating that the length frequency data and the CPUE data gave similar biomass signals.
4. To test the sensitivity of the model results to the descending limb of the selectivity curve, v_g^r was fixed to 10 000 to eliminate any cryptic adult population (v_g^r *fixed* – Table 13). When this was done, B_{MSY} increased, stock status decreased slightly, and *MSY* remained the same. Other parameter estimates were similar to the base case. However, the overall conclusions regarding this stock remained similar to the base case.
5. To further test the sensitivity of the model results to the descending limb of the selectivity curve, another sensitivity run was done with v_g^r again fixed to 10 000 along with the estimation of the male and female g_g^{50} and g_g^{80} growth parameters (v_g^r *fixed, growth estimated* – Table 13). Relative to the previous sensitivity run (v_g^r *fixed*), the estimate of B_{MSY} was lower, the stock status was slightly higher, and *MSY* was unchanged. These differences are probably attributable to the differences in the growth rate estimates from the base case, as these parameters estimates are similar to those which were obtained when g_g^{50} and g_g^{80} were estimated along with v_g^r.

The fit to the size frequency data by the base case assessment is generally good for berried and non-berried females (Figure 9). However, the model was not able to fit the large mode in the observed male size frequencies around the minimum legal size (Figure 9). The reason for this poor fit to the data is probably more complex than a simple adjustment to the male growth rates. When the model estimated the growth parameters on the basis of the size frequency data, the male g_g^{50} parameter is reduced and the male g_g^{80} parameter is increased relative to the tagging estimates. This implies that the male growth rates based on tagging are too high at smaller sizes and possibly too low at the larger sizes. However, the fit to the males size frequencies produced with these alternative growth parameter values also misses the mode near the male minimum legal size.

Table 13: Model likelihoods, stock indicator estimates and PME parameter estimates for different runs in the NSS assessment

						Run
		Base case	*Growth estimated*	*Not fitted to CPUE*	v^r_g *fixed*	v^r_g *fixed, growth estimated*
Likelihoods	CPUE	1.1	1.6	**0.0**	1.2	1.9
	Size Frequency	-1 994.2	-2 009.7	-1 994.7	-1 991.2	-2 009.0
	Priors	12.0	18.4	12.2	9.6	16.8
	Recruitment	2.5	1.7	1.8	3.2	1.7
	Total	-1 978.6	-1 988.1	-1 980.7	-1 977.2	-1 988.5
Indicators	MSY	1 655	1 669	1 625	1 642	1 667
	B_{MSY}	9 654	8 202	9 964	15 644	11 283
	B_{CUR}/B_{MSY}	17.7%	20.9%	14.7%	11.0%	15.4%
Average recruitment	R_0	2 673	3 671	2 609	2 268	3 460
Natural mortality	M	0.069	0.081	0.069	0.069	0.084
Stock-recruit steepness	h	0.843	0.801	0.827	0.875	0.801
Female maturity status	m_{50}	57.9	57.8	57.8	58.0	57.9
	m_{95}	63.8	63.7	63.5	64.0	64.0
	$m_{\max}$	0.586	0.582	0.581	0.594	0.595
Size at full selectivity	η_{femle}	56.7	56.8	57.1	56.6	56.8
	η_{male}	52.8	53.2	52.8	52.8	53.2
Relative male vuln.	r	1.67	1.10	1.53	1.68	1.08
Ascending limb of selectivity curve	$v^l_{<=1992,female}$	78.2	72.4	79.7	77.3	71.6
	$v^l_{>1992,female}$	64.5	52.7	64.9	65.2	52.9
	$v^l_{<=1992,male}$	18.2	20.1	19.9	17.8	19.9
	$v^l_{>1992,male}$	10.0	10.0	10.0	10.0	10.1
Descending limb of selectivity curve	v^r_{female}	2 678	2 116	3 203	**10 000**	**10 000**
	v^r_{male}	734	822	864	**10 000**	**10 000**
Female growth	g^{50}_{female}	**2.97**	3.28	**2.97**	**2.97**	3.23
	g^{80}_{female}	**0.94**	0.92	**0.94**	**0.94**	0.96
	c_{female}	**1.26**	**1.26**	**1.26**	**1.26**	**1.26**
	φ_{female}	**1.55**	**1.55**	**1.55**	**1.55**	**1.55**
Male growth	g^{50}_{male}	**5.67**	3.72	**5.67**	**5.67**	3.60
	g^{80}_{male}	**2.19**	2.58	**2.19**	**2.19**	2.60
	c_{male}	**0.58**	**0.58**	**0.58**	**0.58**	**0.58**
	φ_{male}	**1.87**	**1.87**	**1.87**	**1.87**	**1.87**

Bold type indicates that the parameter was fixed at that value.

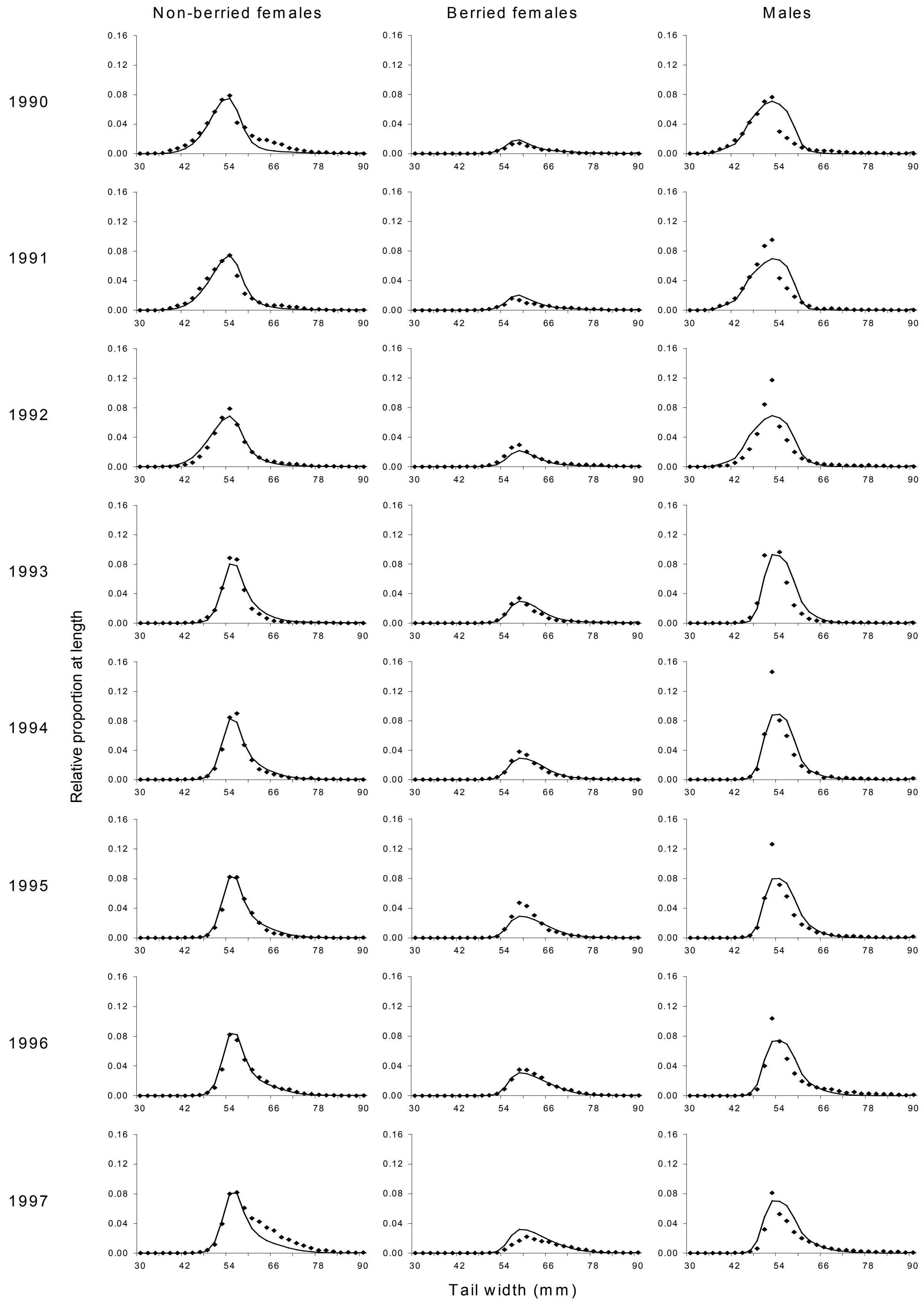

Figure 9: The PME fit of the base case assessment to fisheries size distributions by sex class (non-berried females, berried and spent females, and males) by assessment year for the NSS stock. These data are derived from the industry logbook and from the research sampling programmes for the indicated years.

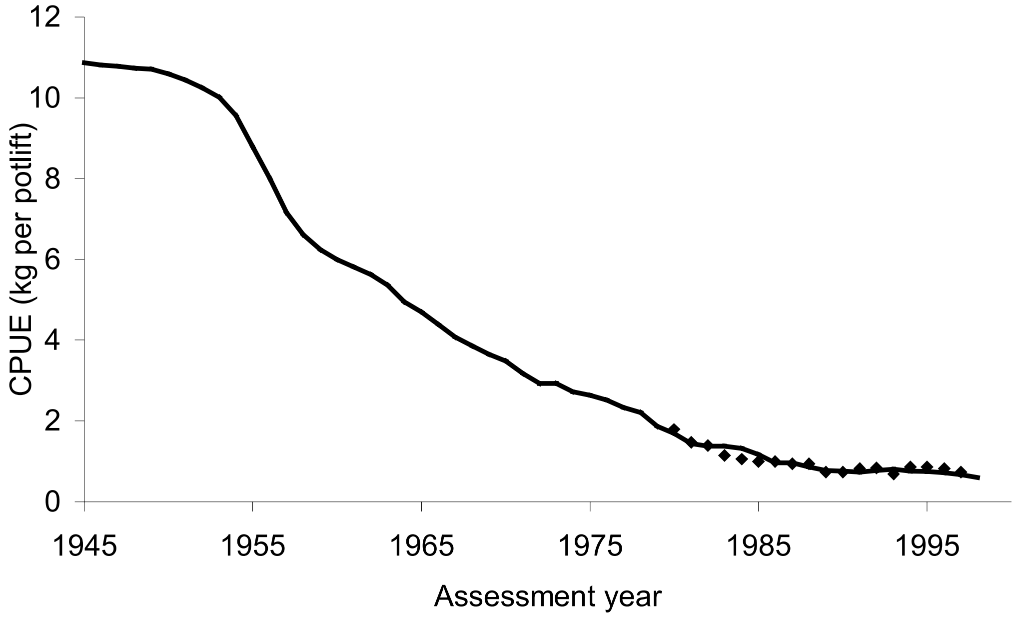

Figure 10. Biomass trajectory for the NSS stock from the PME base case assessment, expressed as kg per potlift. Fitted CPUE data points are indicated as points, beginning with the 1979–80 assessment year.

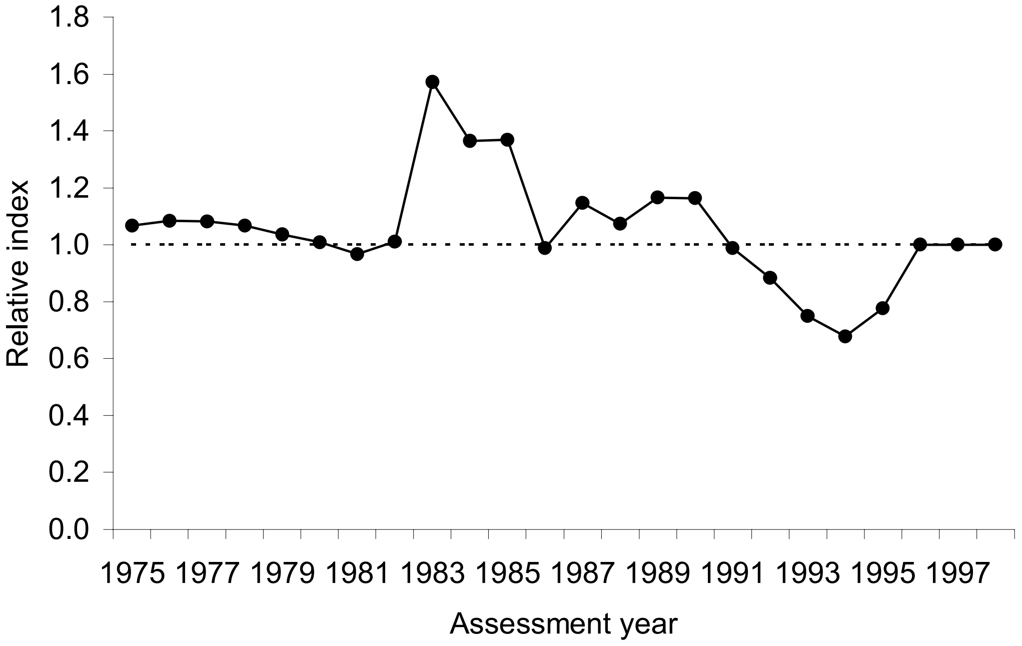

Figure 11. Estimates of the annual recruitment multipliers from the PME fit of the base case assessment for the NSS stock.

The results from the base case assessment indicate that this stock has declined steadily since fishing began in earnest in the mid 1960s (Figure 10). The relative recruitment multipliers are all below average since 1990, which may account for the lack of a biomass increase from the TACC cuts which have been made since 1990 (Figure 11).

Posterior distributions for the performance indicators were generated for the "base case" run only (Table 14). Current exploitable biomass is estimated to be low relative to the B_{MSY} reference point (about 20%, ranging from 12% to 28% – Table 14). Average long term yields at the B_{MSY} reference point are estimated to be higher than current catches (about 1600 t, ranging from 1500 t to 1800 t). Model projections to 2003–04 (using *status quo* catch levels as given in Table 10) indicate that the stock is expected to stay at about the same level under the current catches (Table 14). However, there is a strong likelihood of starting a rebuild if the TACC is cut by the required 20% under the present NSS "decision rule" (the probability of the stock size increasing rises to about 75% – Table 14).

Table 14: Performance indicator results for base case NSS assessment. Expected value results are the mean, median, and 5% and 95% percentiles from the Bayesian posteriors. Probability results are the count of the indicated test divided by the number of posterior samples

	Status Quo TACC				Decreased TACC by 20%			
	Mean	Median	Lower 5%	Upper 95%	Mean	Median	Lower 5%	Upper 95%
E(B_{99}/B_{MSY})	19%	19%	12%	28%				
E(B_{04}/B_{MSY})	21%	17%	8%	48%	28%	26%	9%	58%
E(B_{04}/B_{99})	106%	94%	52%	196%	143%	135%	65%	247%
E(MSY)	1 624	1 619	1 483	1 781				
E(B_{MSY})	10 044	10 004	8 496	11 799				
E(U_{98})	43.6%	43.0%	32.6%	57.1%				
P($B_{04} > B_{MSY}$)	0.1%				0.1%			
P($B_{04} > B_{99}$)	45%				74%			

8. Discussion

8.1 NSN Stock

The assessment for the NSN stock did not yield credible results when both R_0 (mean recruitment) and M were estimated simultaneously. Examination of the parameter correlation matrix indicated that these two parameters were highly correlated. The resulting estimate of stock size substantially exceeded the estimate for the NSS stock, which is thought to be the largest of the New Zealand stocks given its long catch history and higher catch rates. Because of this implausible result, M was fixed at 0.1, the value used in previous rock lobster stock assessments.

Growth parameters were estimated within the model as the tagging information available to estimate growth for this stock is extremely limited. Model estimates of growth were similar to the growth estimates used in previous assessments. This is partly because these values were used to construct informative priors for these parameters and as starting values in the fitting procedure. However, the sensitivity run which estimated the growth rate parameters while fixing the selectivity function suggest that there may be a relationship between growth and the parameters used to determine this function (see below)-.

B_{MSY} for this stock is small relative to the initial biomass. This may in part be due to the large cryptic population, particularly for females, estimated by the model which requires a decreasing descending (right-hand) limb for the female selectivity curve. Sensitivity runs suggested that there is correlation between the right-hand limb parameter of the selectivity curve and the growth parameters. When the right-hand limb was forced to be horizontal (i.e., no cryptic population), the parameter estimate for the second female growth parameter ($\boldsymbol{g^{80}_{female}}$) was nearly zero. This indicates that the existence of a cryptic population of females is needed to fit the observed length frequencies while still allowing for growth in larger lobster. Other possible explanations for the lack of large females in the catch is that they migrate away from the fishing areas or that there is a high natural mortality. However, the population at B_{MSY} is only slightly larger when v^r_g is fixed, indicating that the low B_{MSY}/B_0 ratio is probably also due to the underlying dynamics of the model and the accompanying parameter estimates.

Sensitivity runs performed for this stock included (a) estimating R_0 and M simultaneously; (b) fixing the growth rate parameters; (c & d) forcing the right-hand limb of the selectivity curve to be horizontal (i.e., no cryptic population) – with fixed and variable growth parameters; (e) dropping the CPUE data; and (f) not estimating the recruitment residuals. Runs (b) to (e) gave similar estimates of stock status and *MSY* as the base case. Run (f) estimated a higher R_0 when the recruitment residuals were not estimated and the model dynamics did not fit the observed increase in CPUE. All sensitivity runs indicated that this stock is well above B_{MSY}.

Comparison of the results from this new model with those from previous assessments indicated that the NSN assessment has not changed markedly: B_0 was previously estimated to be about 12 000 t and this assessment estimated a similar value. *MSY* is now estimated to be around 900 t which is higher than the previously estimated 600 t. The 1996 Fishery Assessment Plenary agreed that the biomass was likely to be above B_{MSY} but the 1998 assessment is more definite on this conclusion.

8.2 NSS Stock

This assessment concludes that the NSS stock has been gradually fished down over the 30 year existence of the fishery and that the stock is well below the B_{MSY} reference point. Therefore, the available yield for harvest can only come from recruitment, which is subject to annual variation. Finally, the stock assessment concludes that recent recruitment has been below average which may account for the lack of response in stock rebuild in spite of substantial reductions in total catch from this population since 1990.

The conclusions for this stock from this assessment are similar to those presented in the 1997 stock assessment. B_0 was previously estimated at 43000 t while this assessment estimated a value closer to 30000 t for the vulnerable biomass. *MSY* was estimated by both assessments to be about 1600 t. Both assessments indicated that this stock is well below B_{MSY}, with the 1997 assessment estimating that the current status was about 30% of B_{MSY} while the present assessment estimated this value to be closer to 20% of B_{MSY} (*see* Table 14).

Sensitivity runs performed for this stock included (a) estimating the growth rate parameters; (b & c) forcing the right-hand limb of the selectivity curve to be horizontal (i.e., no cryptic population) – with fixed and variable growth parameters; and (d) dropping the CPUE data. These sensitivity runs did not alter the conclusions from the base case run with respect to the level of *MSY* and to the current stock status relative to B_{MSY}.

Two 5-year projections ending in the 2003–04 assessment year were run for this stock using catches as indicated in Table 13. The "status quo" projection using the current CRA 8 TACC estimated that the probability of exceeding B_{MSY} at the end of the period was less than 1% and that the probability of the biomass being larger at the end of the period was less than 50% (Table 14). Because the NSS "decision rule" has been invoked in this assessment (Annala & Sullivan 1998), a 20% cut in the CRA 8 TACC was also simulated. For this projection, the probability of exceeding B_{MSY} remained low (less than 1%), but the probability of the vulnerable biomass in 2003–04 exceeding the 1998–99 biomass increased to nearly 75% (Table 14).

8.3 Model Evaluation

The performance of this new size-based stock assessment model has been satisfactory, especially considering that this is the first application of this model. Results for both stocks have been credible, considering the limitations of the data, and consistent with previous stock assessments for the same rock lobster stocks.

A size-based approach which explicitly incorporates stochasticity into the model dynamics should be superior to the previous deterministic age-based approach. However, the consistency in results suggest that the previous age-based approach did not introduce serious biases into the assessment when performing the conversion from mean length at age to age. It is not possible to directly compare the results from the size-based and age-based assessment models as other innovations were added to this model, such as allowing for variation in annual recruitment strength, the addition of Bayesian priors, and the estimation of additional parameters.

It is suggested that the approach adopted by this new stock assessment model be continued, in spite of the added complexity of the model, including using Bayesian methods to estimate the uncertainty in the stock projections.

9. Acknowledgments

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Appendix I. ASSESSMENT MODEL

The variables and parameters in the model can be divided into:

- **Structural parameters** that are fixed and influence the structure of the model.
- **Control variables** that are known and influence the history of the fishery in the model.
- **Dynamic parameters** that influence the dynamics of the stock and the fishery and can be estimated or fixed at assumed values.
- **State variables** that describe the modelled state of the stock and can be used to derive model predictions.
- **Likelihood variables** that are used in calculating the model likelihood from model predictions.

The major variables and parameters of the model, and variables derived from them, are described in Table 15.

Table 15: Major variables and parameters of the assessment model

Structural parameters	
$\bar{S}_{s_{\min}}$	Smallest size modelled
δ	Width of each size class (mm tail width)
$s_{\max}$	Number of size classes modelled
$\bar{S}_s$	Size of an individual in size class *s* (mid point of the size class bounds)
Control variables	
C_y^{legal}	Legal catch weight in year *y*
$C_y^{illegal}$	Illegal catch weight in year *y*
l_g	Minimum legal size limit for sex *g*
$L_{s,g}$	Legal status flag (zero or one) for individuals of sex *g* and size *s*
Dynamic parameters	
R_0	Average recruitment in an unexploited population
M	Instantaneous rate of natural mortality
d	Proportion of discarded animals that die
h	Steepness of the Beverton-Holt stock recruitment relationship.
ϕ_g	Mean of the size distribution of recruits of sex *g*
γ_g	Standard deviation of the size distribution of recruits of sex *g*
r	Relative vulnerability of males to females
η_g	Size of maximum vulnerability of sex *g*
v_g^l	Variance of the left hand limb of the vulnerability curve for sex *g*
v_g^r	Variance of the right hand limb of the vulnerability curve for sex *g*
g_g^{50}	Annual growth rate at 50 mm tail width of sex *g*
g_g^{80}	Annual growth rate at 80 mm tail width of sex *g*

Continued

Dynamic parameters (cont.)

c_g	Shape of growth curve of sex *g*
φ_g	Variability of the growth of sex *g*
m_{50}	Size-at-50%-maturity for females
m_{95}	Size-at-95%-maturity for females
$m_{\max}$	Maximum proportion of females that are caught berried or spent in a year
a_g	Scalar of the size-weight relationship for sex *g*
b_g	Exponent of the size- weight for sex *g*
ψ	Scalar of the size-egg relationship
ξ	Exponent of the size-egg relationship

Derived variables

$\mathbf{R}_0^g$	Vector of recruitment at size for sex *g* based on average recruitment in an unexploited population
$\mathbf{N}_0^g$	Vector of numbers at size for sex *g* in an unexploited population
$\mathbf{I}$	Identity matrix
$\mathbf{X}^g$	Growth transition matrix for sex *g*
$X_{s,s'}^g$	Proportion of individuals of sex *g* that move from size-class *s* to size-class *s*' in 1 year
P_0	Annual egg production in an unexploited population
$V_{s,g}$	Vulnerability of an individual of sex *g* and size *s*
Q_s	Proportion of females of size *s* that are berried or spent
$W_{s,g}$	Weight of an individual of sex *g* and size *s*
E_s	Number of eggs produced by a female of size *s*

State variables

$N_y^{s,g}$	Numbers of sex *g* and size *s* at the start of year *y*
$\dot{N}_y^{s,g}$	Numbers of sex *g* and size *s* after fishing and natural mortality during year *y*
P_y	Egg production in year *y*
R_y	Total recruitment in year *y*
$R_y^{s,g}$	Recruitment to sex *g* and size *s* in year *y*
B_y^{legal}	Biomass vulnerable to legal fishing in year *y*
$B_y^{illegal}$	Biomass vulnerable to illegal fishing in year *y*
u_y^{legal}	Legal exploitation rate in year *y*
$u_y^{illegal}$	Illegal exploitation rate in year *y*

Likelihoods

ε_y	Recruitment residual in year *y*
σ^{ε}	Standard deviation of recruitment residuals
σ^{s}	Standard deviation of proportional catches at size and sex
q	Catchability coefficient.
σ^{I}	Standard deviation of annual biomass indices

I.1 Initial size structure

The population is assumed to be at equilibrium in an unexploited state at the start of the period being modelled. The number of each sex, in each size class, is the equilibrium function of the growth transition matrix, recruitment and natural mortality,

Eq 7
$$\mathbf{N}_0^g = \mathbf{R}_0^g\left(\mathbf{I} - \mathbf{X}^g e^{-M}\right)'$$

where $\mathbf{R}_0^g$ is derived from the multiplication of R_0 and equilibrium recruitment proportions calculated as in Eq 14.

I.2 Recruitment

Total annual recruitment is log-normally distributed with a mean equal to the expected deterministic value from the Beverton-Holt stock-recruitment relationship,

Eq 8
$$\boldsymbol{R}_y = 0.5\frac{\boldsymbol{P}_y}{\boldsymbol{\alpha} + \boldsymbol{\beta}\,\boldsymbol{P}_y}\exp\left[\boldsymbol{\varepsilon}_y - \frac{(\boldsymbol{\sigma}^{\boldsymbol{\varepsilon}})^2}{2}\right]$$

where, ε_y is normally distributed with mean zero and standard deviation σ^{ε}. The term $-\frac{(\sigma^{\varepsilon})^2}{2}$ corrects for the log-normal bias associated with different values of σ^{ε}. The year index is lagged by 2 years, thus assuming that lobster are 2 years old when they are first found in pots at around 40 mm (see Section 6.6.1 and Eq 14).

Values for the stock-recruitment parameters α and β are calculated from two parameters, the average unexploited recruitment (R_0) and the steepness of the stock-recruit relationship (*h*), and from the annual egg production in an unexploited population (P_0). The value of *h* is the fraction of R_0 to be expected (in the absence of recruitment variability) when egg production is reduced to 20% of its pristine level,

Eq 9
$$\alpha = P_0\frac{1-h}{4hR_0}$$

Eq 10
$$\beta = \frac{5h-1}{4hR_0}$$

Eq 11
$$P_0 = \sum_s N_0^{s,f} Q_s E_s$$

Annual egg production is determined from the number of berried females in each size class,

Eq 12
$$P_y = \sum_s N_y^{s,f} Q_s E_s$$

and the size-egg relationship,

Eq 13
$$E_s = \psi\left(\bar{S}_s\right)^{\xi}$$

Recruitment is dispersed over the size-classes following a normal distribution that is truncated at the smallest size class,

Eq 14
$$R_y^{s,g} = \frac{\exp\left({-(\bar{S}_s - \phi_g)^2} \Big/ {\left(\gamma_g\right)^2} \right)}{\sum_s \exp\left({-(\bar{S}_s - \phi_g)^2} \Big/ {\left(\gamma_g\right)^2} \right)} R_y$$

I.3 Growth

Growth is modelled for each sex using the Schnute growth model (Schnute 1981, Francis 1995) where the size of an individual in the following year is a function of its current size plus some random variation,

Eq 15
$$S_{y+1} = \left[\rho\,(S_y)^{\varsigma} + \varsigma\,(1-\rho)\right]^{1/c} + \varepsilon$$

where,

Eq 16
$$\rho = \frac{\left(S_2^c - S_1^c\right)}{\left(\lambda_2^c - \lambda_1^c\right)}$$

Eq 17
$$\varsigma = \frac{\left(S_2^c \lambda_1^c - S_1^c \lambda_2^c\right)}{\left(\lambda_1^c - S_1^c + S_2^c - \lambda_2^c\right)}$$

Eq 18
$$\lambda_1 = S_1 + g_1$$
$$\lambda_2 = S_2 + g_2$$

Variability in growth was assumed to be normally distributed as used in the estimation of the growth parameters,

Eq 19
$$\varepsilon \sim N(0, \varphi)$$

From this growth model the transition matrix is generated as follows. The expected size of an individual of size *s* in the following year is

Eq 20
$$\hat{S}_s = \left[\rho\,(\bar{S}_s)^{\varsigma} + \varsigma\,(1-\rho)\right]^{1/c}$$

However, due to the variability in growth, not all individuals move into the size class to which $\hat{S}_s$ belongs. Some individuals move into size classes above and below this size depending upon the magnitude of φ. For each size class, *s*, the probability of an individual growing into each of the other size classes, s', in 1 year is calculated by integrating over a normal distribution with mean, $\hat{S}_s$ and standard deviation, φ. It is assumed that no shrinkage occurs (which means that estimated negative growth is truncated to zero), so transition matrix elements below the diagonal are set to zero and the diagonal elements are calculated by integrating from $-\infty$ to the largest size in the size class, $\overrightarrow{S}_{s'}$. The largest size group is cumulative, that is no animals grow out of this group, so the integration is done from the smallest size in that size class, $\overleftarrow{S}_{s'}$ to ∞.

Eq 21
$$X_{s,s'} = \begin{cases} 0 & \text{if } s' < s \\ \displaystyle\int_{-\infty}^{\overrightarrow{S}_{s'}} \frac{1}{\sqrt{2\pi}\varphi} \exp\left(-\frac{\left(S - \hat{S}_s\right)^2}{2\varphi^2} \right) dS & \text{if } s' = s \\ \displaystyle\int_{\overleftarrow{S}_{s'}}^{\overrightarrow{S}_{s'}} \frac{1}{\sqrt{2\pi}\varphi} \exp\left(-\frac{\left(S - \hat{S}_s\right)^2}{2\varphi^2} \right) dS & \text{if } s < s' < s_{\max} \\ \displaystyle\int_{\overleftarrow{S}_{s'}}^{\infty} \frac{1}{\sqrt{2\pi}\varphi} \exp\left(-\frac{\left(S - \hat{S}_s\right)^2}{2\varphi^2} \right) dS & \text{if } s' = s_{\max} \end{cases}$$

The growth transition matrix is applied to the numbers of lobster remaining in each size class after fishing. Along with the addition of recruitment this updates numbers in each size class prior to fishing in the following year.

Eq 22
$$N_{y+1}^{s',g} = \sum_s \left(X_{s,s'}^{g} \dot{N}_y^{s,g} \right) + R_{y+1}^{s',g}$$

I.4 Vulnerability

The ascending and descending limbs of the vulnerability curve are modelled using normal curves with common means but different variances. A logistic selectivity curve can be approximated by setting the variance for the right hand limb to a large number. The relative vulnerability of each sex is determined by the parameter r.

Eq 23
$$V_{s,f} = \begin{cases} \exp\left\{ \dfrac{-\left(S_s - \eta_f\right)^2}{v_f^l} \right\} & \text{for} \quad S_s \le \eta_f \\ \exp\left\{ \dfrac{-\left(S_s - \eta_f\right)^2}{v_f^r} \right\} & \text{for} \quad S_s > \eta_f \end{cases}$$

Eq 24 $$V_{s,m} = r\begin{cases} \exp\left\{\dfrac{-\left(S_s - \eta_m\right)^2}{v_m^l}\right\} & \text{for } S_s \le \eta_m \\ \exp\left\{\dfrac{-\left(S_s - \eta_m\right)^2}{v_m^r}\right\} & \text{for } S_s > \eta_m \end{cases}$$

I.5 Maturity

Maturity follows a logistic curve scaled by the maximum, over all size classes, of the proportion of females caught that are berried or spent,

Eq 25 $$Q_s = \frac{1}{1 + \exp\left[{-\ln(19)(\bar{S}_s - m_{50})}\big/{\left(m_{95} - m_{50}\right)}\right]} m_{\max}$$

I.6 Exploitation rates

The annual exploitation rates for the legal and illegal fisheries are calculated as the ratio of the catch to the available biomass. The available biomass for each fishery is the sum across all size classes of the product of the number of individuals, their weight and the proportion that are vulnerable. For the legal fishery this is further adjusted for whether the size class is above the size limit for that sex and for females by the proportion that are berried or spent and therefore prohibited for capture. Note that these equations assume that the vulnerabilities are the same for legal and illegal catches and that the only difference between these two categories is the type of lobster retained.

Eq 26 $$u_y^{legal} = \frac{C_y^{legal}}{B_y^{legal}}$$

Eq 27 $$B_y^{legal} = \sum_s N_y^{s,f} W_{s,f} V_{s,f} L_{s,f} (1 - Q_s) + N_y^{s,m} W_{s,m} V_{s,m} L_{s,m}$$

Eq 28 $$u_y^{illegal} = \frac{C_y^{illegal}}{B_y^{illegal}}$$

Eq 29 $$B_y^{illegal} = \sum_{s,g} N_y^{s,g} W_{s,g} V_{s,g}$$

The weight of individuals in each size class is determined by

Eq 30 $$W_{s,g} = a_g \left(\bar{S}_s\right)^{b_g}$$

I.7 Mortality

Fishing, natural, and handling mortality are applied simultaneously. Due to the regulations that prohibit the taking of berried or spent females, legal fishing mortality is applied differently to males and females. For females, an additional term is used to account for the proportion of females that are mature in each size class. Handling (discard – *d*) mortality is applied in proportion to the rate of legal fishing mortality.

Eq 31

$$\dot{N}_{y+1}^{s,f} = N_y^{s,f} e^{-M}\left[1-U_y^{legal}V_{s,f}\left(L_{s,f}\left((1-Q_s)+Q_s d\right)+(1-L_{s,f})d\right)\right]\left[1-U_y^{illegal}V_{s,f}\right]$$

Eq 32

$$\dot{N}_{y+1}^{s,m} = N_y^{s,m} e^{-M}\left[1-U_y^{legal}V_{s,m}\left(L_{s,m}+(1-L_{s,m})d\right)\right]\left[1-U_y^{illegal}V_{s,m}\right]$$

I.8 Catch-at-size likelihood

The observed relative catch-at-size ($p_y^{s,g}$) for males (*m*), non-berried-females (*fnb*) and berried-females (*fb*) are fitted separately but not independently as the proportions for all three categories sum to one. The model predictions for the relative frequencies of each of these categories are,

Eq 33
$$\hat{p}_y^{s,m} = \frac{V_{s,m}N_y^{s,m}}{\sum_{s,g} V_{s,g}N_y^{s,g}}$$

Eq 34
$$\hat{p}_y^{s,fnb} = \frac{V_{s,f}N_y^{s,f}(1-Q_s)}{\sum_{s,g} V_{s,g}N_y^{s,g}}$$

Eq 35
$$\hat{p}_y^{s,fb} = \frac{V_{s,f}N_y^{s,f}Q_s}{\sum_{s,g} V_{s,g}N_y^{s,g}}$$

We adopt the robust normal likelihood formulation proposed by Fournier *et al.* (1990) for fitting the model predictions to the observed catch compositions. The variance is assumed to be multinomial and is weighted by the effective sample size used to determine the proportional catch-at-size (κ_y), Eq 36

$$L(\hat{p}_y^{s,g} \mid \theta) = \frac{1}{\sqrt{2\pi p_y^{s,g}(1-p_y^{s,g}) + 0.1/\Omega}} \exp\left(\frac{-\kappa_y (\hat{p}_y^{s,g} - p_y^{s,g})^2}{2(p_y^{s,g}(1-p_y^{s,g}) + 0.1/\Omega)} \right) + 0.01$$

where Ω is the number of proportions observed in the catch-at-size data. The robust likelihood eliminates the influence of observed outliers that have either high or low predicted probability. The 0.01 term in the second part of the likelihood equation reduces the influence for observations more than three standard deviations from the predicted eliminating the influence of outliers. The $0.1/\Omega$ term prevents the variance from tending to zero as the predicted value tends to zero avoiding influence of observed outliers with small predicted probability (Fournier *et al.* 1990).

I.9 Biomass indices likelihood

A predicted biomass index is calculated as a proportion of legal biomass,

Eq 37 $$\hat{I}_y = qB_y^{legal}$$

where the catchability coefficient is calculated analytically,

Eq 38 $$q = \exp\left[\frac{\sum_y^{n_y} \log\left(\frac{\hat{I}_y}{B_y^{legal}} \right)}{n_y} \right]$$

where n_y is the number of years for which an observed biomass index is available.

A robust log-normal likelihood function is used to compare predicted ($\hat{I}_y$) and observed (I_y) biomass indices,

Eq 39 $$L(\hat{I}_y \mid \theta) = \frac{1}{\sigma^I \sqrt{2\pi}} \exp\left[\frac{-(\ln(I_y) - \ln(\hat{I}_y))^2}{2(\sigma^I)^2} \right] + 0.01$$

where the variance σ^I is assumed and is constant for all observations. As with the catch-at-size data, the 0.01 term in the likelihood equation reduces the influence for observations more than three standard deviations from the predicted eliminating the influence of outliers (Fournier *et al.* 1990).

I.10 Recruitment residuals likelihood

Annual recruitment residuals are penalised using a normal likelihood function,

Eq 40 $$L(\varepsilon_y \mid \theta) = \frac{1}{\sigma^{\varepsilon}\sqrt{2\pi}} \exp\left[\frac{-(\varepsilon_y)^2}{2(\sigma^{\varepsilon})^2}\right]$$

This penalty essentially makes the model fitting Bayesian, with a prior distribution on the recruitment residuals of $N(0, \sigma^{\varepsilon})$. The model maximum likelihood estimates represent the mode of the joint posterior distributions of the parameters and recruitment residuals.

Appendix II. TABLES OF INPUT DATA USED IN ASSESSMENTS

Table 16: Legal and illegal catch data and CPUE biomass indices used for the NSN assessment. All catches are in kilograms and the CPUE indices are in kg per potlift. Catches are reported by calendar year up to 1978. From 1979 onwards, catches are reported by 'assessment year', 1 September to 31 August

Assessment year[1]	Commercial reported[2]	Commercial unreported[3]	Recreational legal[4]	Reported illegal[5]	Unreported illegal[6]	CPUE indices[7]
1945	158 862	0	37 900	0	0	
1946	139 657	0	42 231	0	0	
1947	169 682	0	46 563	0	0	
1948	302 990	0	50 894	0	0	
1949	302 431	0	55 226	0	0	
1950	301 517	0	59 557	0	0	
1951	276 217	0	63 889	0	0	
1952	312 542	0	68 220	0	0	
1953	322 143	0	72 551	0	0	
1954	221 908	0	76 883	0	0	
1955	219 113	0	81 214	0	0	
1956	235 168	0	85 546	0	0	
1957	186 678	0	89 877	0	0	
1958	217 031	0	94 209	0	0	
1959	254 575	0	98 540	0	0	
1960	242 147	0	102 871	0	0	
1961	279 875	0	107 203	0	0	
1962	338 706	0	111 534	0	0	
1963	359 000	0	115 866	0	0	
1964	519 000	0	120 197	0	0	
1965	539 000	0	124 529	0	0	
1966	491 000	0	128 860	0	0	
1967	493 000	0	133 191	0	0	
1968	574 000	0	137 523	0	0	
1969	652 000	0	141 854	0	0	
1970	550 000	0	146 186	0	0	
1971	530 000	0	150 517	0	0	
1972	442 000	0	154 849	0	0	
1973	261 000	0	159 180	0	0	
1974	200 000	26 337	163 511	0	0	
1975	216 000	53 884	167 843	0	0	
1976	243 000	48 506	172 174	0	0	
1977	381 000	100 681	176 506	0	0	
1978	321 000	100 510	180 837	0	0	
1979	354 216	32 113	185 169	313	9 688	

Continues

Assessment year[1]	Commercial reported[2]	Commercial unreported[3]	Recreational legal[4]	Reported illegal[5]	Unreported illegal[6]	CPUE indices[7]
1980	485 557	65 090	189 500	461	14 289	0.60
1981	587 949	0	189 500	609	18 891	0.65
1982	569 641	0	189 500	758	23 492	0.61
1983	551 617	0	189 500	906	28 094	0.45
1984	486 829	0	189 500	1 055	32 695	0.39
1985	499 878	0	189 500	1 203	37 297	0.35
1986	548 338	0	189 500	1 352	41 898	0.41
1987	492 769	0	189 500	1 500	46 500	0.30
1988	430 721	0	189 500	2 125	65 875	0.29
1989	389 549	0	189 500	2 750	85 250	0.29
1990	439 913	0	189 500	3 375	104 625	0.47
1991	372 684	0	189 500	2 438	75 563	0.45
1992	340 316	0	189 500	1 500	46 500	0.38
1993	324 129	0	189 500	2 078	64 422	0.32
1994	376 053	0	189 500	2 656	82 344	0.51
1995	380 039	0	189 500	2 344	72 656	0.82
1996	382 610	0	189 500	3 250	100 750	1.19
1997	371 206	0	189 500	5 000	155 000	1.13
1998	392 774[8]	0	189 500	5 000	155 000	[9]

[1] An assessment year is defined from 1 September to the following 31 August.

[2] This is the total reported commercial catch from catch statistics.

[3] The estimate for unreported commercial catch is calculated from a comparison of total reported commercial catch with published export statistics (Breen 1991).

[4] Recreational catch has been set to 20% of the current estimate in 1945. This value is then increased linearly to 100% which is reached in 1980. The current recreational catch estimate is the mean of all available recreational catch estimates. The recreational catch estimate is combined with the reported and the unreported commercial catch less the “reported” illegal catch to give the total legal catch.

[5] This is the fraction of illegal catch which is thought to have been processed through normal legal channels by the Ministry of Fisheries Compliance Unit. This value is subtracted from the total reported commercial catch when calculating the total legal catch in order to avoid double counting of catch. This value has only been estimated in the most recent years (1996) and this fraction has been applied retrospectively to the period of illegal catch estimates.

[6] This is the remaining fraction of illegal catch which is thought to have been processed through other channels by the Ministry of Fisheries Compliance Unit. The total illegal catch is the sum of these two illegal components.

[7] These CPUE indices are the standardised CPUE indices scaled to the 1980 unstandardised index to preserve the units of kg per potlift. CPUE indices were not fitted prior to 1 September 1979 as the earlier data were considered to be too unreliable.

[8] Commercial catches for the 1997–98 assessment year were estimated from the relative ratios of the most recent fishing year because the QMR catches appeared to be incomplete in the more recent months.

[9] The CPUE index corresponding to the 1998 assessment year (1 September 1997 to 31 August 1998) was not used due to what appeared to be bias in the data available from the Ministry of Fisheries.

Table 17: Legal and illegal catch data and CPUE biomass indices used for the NSS assessment. All catches are in kilograms and the CPUE indices are in kg per potlift. Catches are reported by calendar year up to 1978. From 1979 onwards, catches are reported by 'assessment year', 1 September to 31 August

Assessment year[1]	Commercial reported[2]	Commercial unreported[3]	Recreational legal[4]	Reported illegal[5]	Unreported illegal[6]	CPUE indices[7]
1945	202 298	0	6 800	0	0	
1946	171 765	0	7 577	0	0	
1947	169 632	0	8 354	0	0	
1948	193 306	0	9 131	0	0	
1949	525 610	0	9 909	0	0	
1950	743 708	0	10 686	0	0	
1951	947 125	0	11 463	0	0	
1952	1 285 574	0	12 240	0	0	
1953	2 281 673	0	13 017	0	0	
1954	3 750 242	0	13 794	0	0	
1955	4 290 330	0	14 571	0	0	
1956	4 772 859	0	15 349	0	0	
1957	3 784 432	0	16 126	0	0	
1958	3 243 632	0	16 903	0	0	
1959	2 792 144	0	17 680	0	0	
1960	2 537 172	0	18 457	0	0	
1961	2 547 120	0	19 234	0	0	
1962	2 827 046	0	20 011	0	0	
1963	3 405 000	0	20 789	0	0	
1964	2 866 000	0	21 566	0	0	
1965	3 024 000	0	22 343	0	0	
1966	3 081 000	0	23 120	0	0	
1967	2 761 000	0	23 897	0	0	
1968	2 729 000	0	24 674	0	0	
1969	2 549 000	0	25 451	0	0	
1970	2 952 000	0	26 229	0	0	
1971	2 806 000	0	27 006	0	0	
1972	1 993 000	0	27 783	0	0	
1973	2 528 000	0	28 560	0	0	
1974	1 924 000	253 359	29 337	0	0	
1975	1 741 000	434 319	30 114	0	0	
1976	1 942 000	387 647	30 891	0	0	
1977	1 738 000	459 275	31 669	0	0	
1978	2 057 000	644 077	32 446	0	0	
1979	2 136 753	139 716	33 223	6 346	4 654	1.80
1980	2 185 371	237 730	34 000	9 519	6 981	1.79
1981	1 810 828	0	34 000	12 692	9 308	1.48

Continues

Assessment year[1]	Commercial reported[2]	Commercial unreported[3]	Recreational legal[4]	Reported illegal[5]	Unreported illegal[6]	CPUE indices[7]
1982	1 606 668	0	34 000	15 865	11 635	1.40
1983	1 617 402	0	34 000	19 038	13 962	1.16
1984	1 768 390	0	34 000	22 212	16 288	1.05
1985	2 117 200	0	34 000	25 385	18 615	1.01
1986	1 868 414	0	34 000	28 558	20 942	1.00
1987	2 068 300	0	34 000	31 731	23 269	0.94
1988	1 770 599	0	34 000	35 385	25 949	0.94
1989	1 264 186	0	34 000	39 038	28 628	0.74
1990	1 294 124	0	34 000	42 692	31 308	0.73
1991	1 086 489	0	34 000	51 346	37 654	0.83
1992	1 051 920	0	34 000	60 000	44 000	0.83
1993	1 164 790	0	34 000	55 962	41 038	0.70
1994	952 250	0	34 000	51 923	38 077	0.86
1995	933 732	0	34 000	34 615	25 385	0.86
1996	872 240	0	34 000	39 231	28 769	0.82
1997	882 304	0	34 000	45 000	33 000	0.74
1998	777 744	0	34 000	45 000	33 000	[9]

[1] An assessment year is defined from 1 September to the following 31 August.

[2] This is the total reported commercial catch from catch statistics.

[3] The estimate for unreported commercial catch is calculated from a comparison of total reported commercial catch with published export statistics (Breen 1991).

[4] Recreational catch has been set to 20% of the current estimate in 1945. This value is then increased linearly to 100% which is reached in 1980. The current recreational catch estimate is the mean of all available recreational catch estimates. The recreational catch estimate is combined with the reported and the unreported commercial catch less the “reported” illegal catch to give the total legal catch.

[5] This is the fraction of illegal catch which is thought to have been processed through normal legal channels by the Ministry of Fisheries Compliance Unit. This value is subtracted from the total reported commercial catch when calculating the total legal catch in order to avoid double counting of catch. This value has only been estimated in the most recent years (1996) and this fraction has been applied retrospectively to the period of illegal catch estimates.

[6] This is the remaining fraction of illegal catch which is thought to have been processed through other channels by the Ministry of Fisheries Compliance Unit. The total illegal catch is the sum of these two illegal components.

[7] These CPUE indices are the standardised CPUE indices scaled to the 1980 unstandardised index to preserve the units of kg per potlift. CPUE indices were not fitted prior to 1 September 1979 as the earlier data were considered to be too unreliable.

[8] Commercial catches for the 1997–98 assessment year were estimated from the relative ratios of the most recent fishing year because the QMR catches appeared to be incomplete in the more recent months.

[9] The CPUE index corresponding to the 1998 assessment year (1 September 1997 to 31 August 1998) was not used due to what appeared to be bias in the data available from the Ministry of Fisheries.

Appendix III. MAXIMUM LIKELIHOOD METHOD FOR ESTIMATING SIZE AT MATURITY

Information on the size of maturity of female lobsters is obtained from the relative proportion of females which are mature and not mature from the size frequency data described in Sections 6.2 and 6.4.2. A logistic model of maturity was used to estimate the sizes at which 50% (m_{50}) and 95% (m_{95}) of females are mature

Eq 41
$$p_i = \frac{1}{1 + e^{-\log 19\left(\frac{m_i - m_{50}}{m_{95} - m_{50}}\right)}}$$

where for size class i of mean size m_i, p_i is the proportion of females mature. This model was fitted by maximising the binomial likelihood, where for size class i, p_i is the predicted proportion mature, n_i is the number of individuals that were staged, j_i is the number that were mature and q is the number of size classes.

Eq 42
$$L(P|\theta, N, J) = \prod_{i=1}^{q} \binom{n_i}{j_i} p_i^{n_i} (1 - p_i)^{n_i - j_i}$$

Parameters and their standard errors were estimated using quasi-Newton minimisation (ADModel Builder™, Otter Research Ltd).